SEWAGE WORKS JOURNAL

Vol. XVIII JULY, 1946 No. 4

Special Features

Sulfide Control—Pomeroy and Bowlus

Oxidation-Clarification—Hood

Trickling Filters—Dreier

Nineteenth Annual Meeting—October 7–9, 1946

Royal York Hotel, Toronto, Ont., Canada

OFFICIAL PUBLICATION OF THE

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

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of the

Federation of Sewage Works Associations

in conjunction with

The Canadian Institute on Sewage and Sanitation

Hotel Royal York

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October 7-9, 1946

Federation of Sewage Works Associations

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FEDERATION OF SEWAGE WORKS ASSOCIATIONS

SEWAGE WORKS JOURNAL

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A Bimonthly Journal devoted to the advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes, and the design, construction, operation and management of sewage works.

Publication Office: Prince and Lemon Sts., Lancaster, Pa.

Subscription Price:

Members of Local Sewage Works Associations affiliated with the Federation, $3.00 per year.

Non-members: U. S. and Canada, $5.00 per year; other countries, $6.00.

Foreign Subscriptions must be accompanied by International Money Order.

Single copies: United States, $1.00 each; Foreign, $1.25 each.

Manuscript and advertising copy may be sent to the Editor, W. H. Wisely, 325–26 Illinois Bldg., Champaign, Ill., for acceptance or rejection subject to the provisions of the Federation Constitution.

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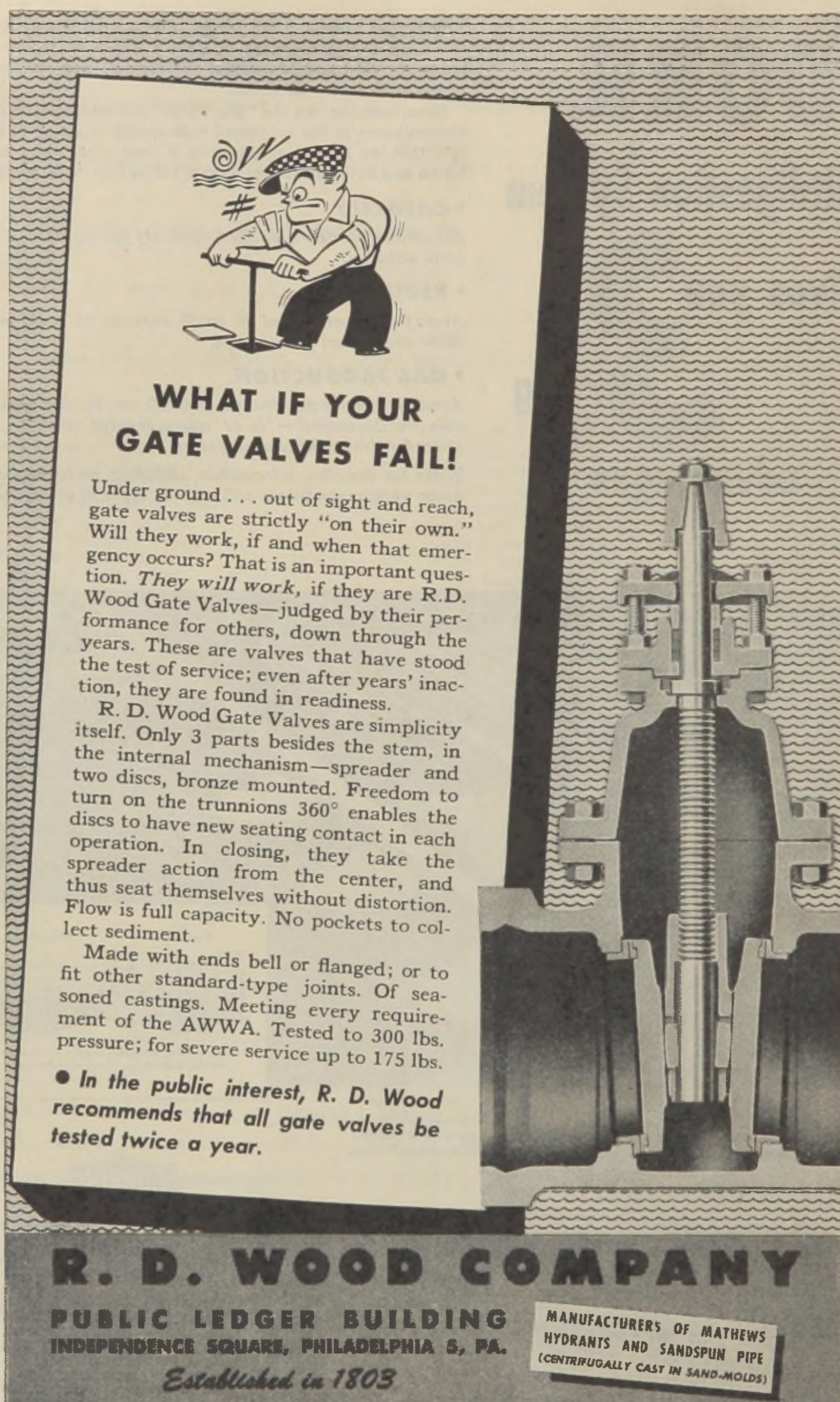
Entered as second-class matter, May 7, 1934, at the post office at Lancaster, Pa., under the Act of March 3, 1879. Accepted for mailing at the special rate of postage provided for in the Act of February 28, 1925, embodied in part 4, Section 538, P. L. & R., authorized October 4, 1945.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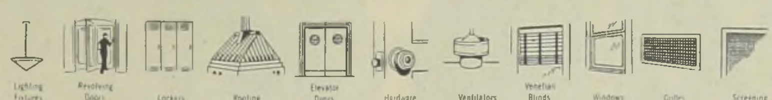

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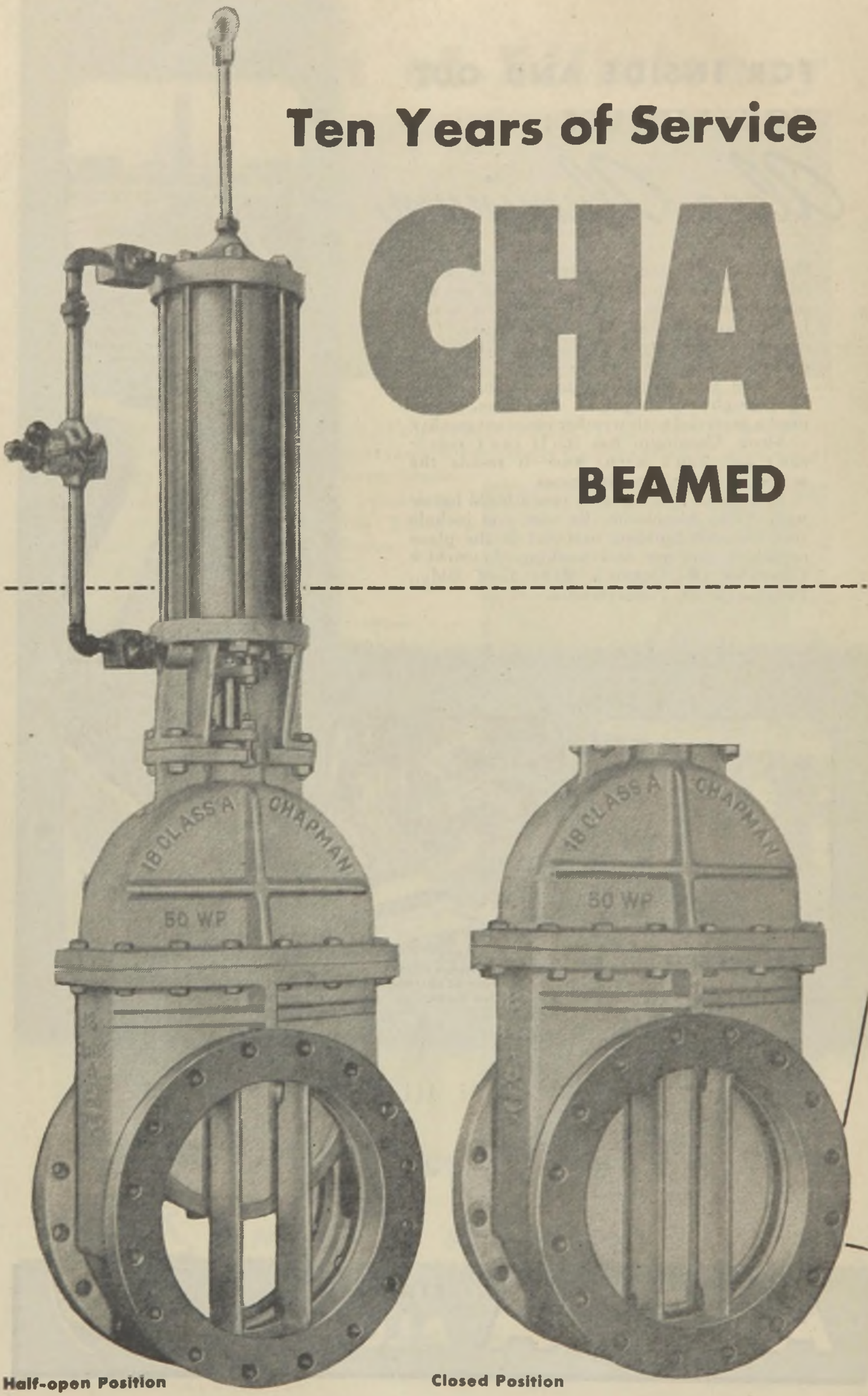
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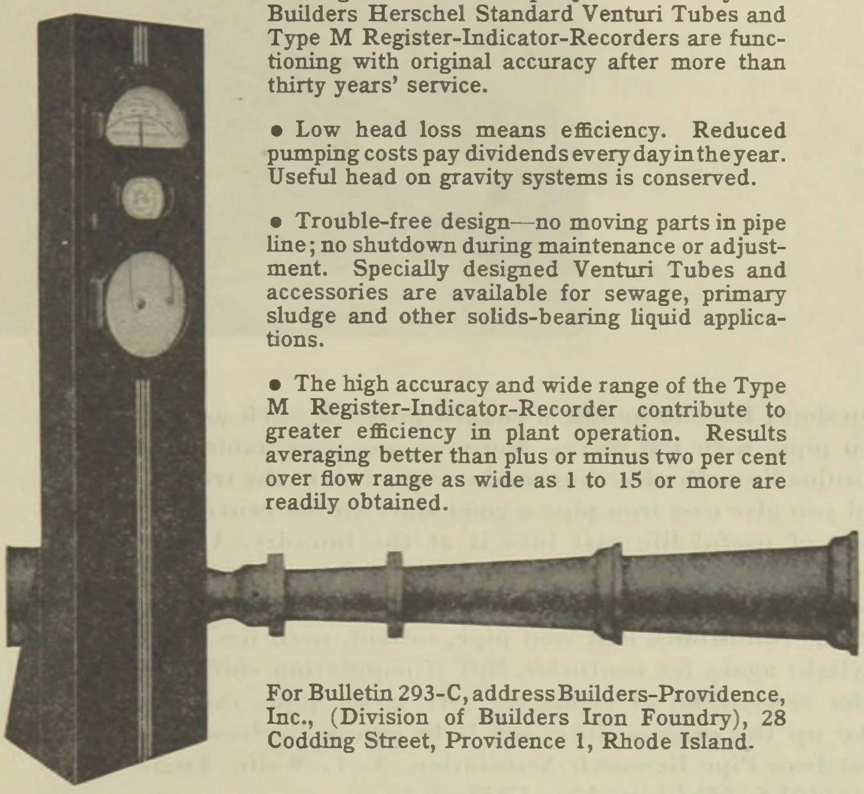
Aqua Ammonia NH_4OH plus Water (*Ammonia Water*)	Colorless Liquid	26°Be. (29.4% NH_3)	Steel Drums Carboys	Used with chlorine to form chloramines for water and main disinfection.
Ammonium Aluminum Sulfate $Al_2(SO_4)_3 \cdot (NH_4)_2SO_4 \cdot 24H_2O$ (*Ammonia Alum*) (*Crystal Alum*)	Lump Nut Granular Powdered	11.2% Al_2O_3	Bags Fibre Drums	Coagulant for water. Advantageous for pressure filters. Supplies ammonia for chloramine formation. 1% Sol. pH 3.5.
Sodium Bisulfite, Anhydrous $Na_2S_2O_5$ (*ABS*) (*Sodium Metabisulfite*)	Powdered	97.5% $Na_2S_2O_5$ (Equiv. 65.5% SO_2)	Fibre Drums	Antichlor. Remove iron and manganese deposits from filter sand. 1% Sol. pH 4.6.
Sodium Silicate $Na_2O \cdot X(SiO_2)$ plus H_2O (*Water Glass*) (*Silicate of Soda*)	Viscous Liquid	38° to 52°Be. Various ratios of $Na_2O \cdot SiO_2$	Drums Tank Cars Tank Trucks	1. Aid in floc formation. 2. Prevent red water in distribution lines. 1% Sol. pH 12.7.
Sodium Thiosulfate $Na_2S_2O_3 \cdot 5H_2O$ (*Hypo*) (*Sodium Hyposulfite*)	Crystals: Prismatic Rice Selected Universal • Granular	99.75% $Na_2S_2O_3 \cdot 5H_2O$	Bags Barrels Fibre Drums	Antichlor. Water solution is neutral.
Sulfuric Acid H_2SO_4 plus H_2O (*Oil of Vitriol*)	Corrosive, oily liquid Various strengths	66°Be. (93.19% H_2SO_4)	Bottles Carboys Drums Tank Trucks Tank Cars	1. Reduce pH and alkalinity. 2. Regenerate carbaceous zeolites and ion exchangers.
Potassium Aluminum Sulfate $Al_2(SO_4)_3 \cdot K_2SO_4 \cdot 24H_2O$ (*Potash Alum*)	Lump Nut Granular Powdered	10.7% Al_2O_3	Bags Fibre Drums	Coagulant for water. Slow, even rate of solubility desirable for solution pots. 1% Sol. pH 3.52.
Sodium Sulfite, Anhydrous Na_2SO_3 (*"Sulfite"*)	Granular Powdered	98.5% Na_2SO_3	Bags Fibre Drums	Weak solutions absorb oxygen readily. 1% Sol. pH 9.8.



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Sewage Works Journal

Published by

Federation of Sewage Works Associations

Lancaster, Pa.

Vol. XVIII | **July, 1946** | **No. 4**

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PROGRESS REPORT ON SULFIDE CONTROL RESEARCH

By Richard Pomeroy and Fred D. Bowlus

Partner, Montgomery and Pomeroy, Pasadena, Calif., and Office Engineer, Los Angeles County Sanitation Districts, Los Angeles, Calif., Respectively

The Los Angeles County Sanitation Districts began treatment of sewage in 1928 following an intensive two-year construction program. The Districts now serve an area of nearly 400 sq. mi. lying largely east and south of Los Angeles city. Thirty-one cities and many unincorporated communities are served (Figure 1). The 225 miles of trunk line sewers built by the Districts collect wastes from 1,500 miles of lateral sewer lines.

The Districts' Joint disposal plant near Wilmington, built in 1928, was operated as an activated sludge plant until 1937, with effluent disposal into a slough entering San Pedro Harbor. In 1937, upon completion of a 6-mile outfall tunnel under the San Pedro Hills and an ocean outfall, the plant was converted to plain sedimentation and separate sludge digestion, with effluent disposal one mile off shore near White Point in 110 ft. depth of ocean water.

Sewage flow into the disposal plant has increased from 2 to 50 m.g.d. since 1928, and when connections are completed from Districts 3, 15, 16, and 17 within the next three years, the flow will exceed 80 m.g.d. With sewage temperatures varying from 20° to 25° C., sluggish velocities throughout the system due to the low ratio of flow to design capacity, and the large proportion of high strength industrial waste, hydrogen sulfide generation began promptly. A curve showing total sulfides at the Joint disposal plant is presented in Figure 2.

In 1931 the Districts' staff started a systematic survey of sulfides throughout the trunk sewer system. In 1932 Bowlus and Banta (1) published results of investigations made up to that time. Chlorination, which was the most reliable and generally applicable method of sulfide control then known, was found to be highly beneficial, not only in reducing sulfides, but also in improving operation of the activated sludge plant. During the 7-year period from 1932 to 1938, the Districts used an average of 96 lb. of chlorine per m.g. of sewage. A program of timely trunk sewer cleaning was inaugurated in 1932 as was also a detailed study of trade wastes. As may be noted from Figure 2 sulfides were brought under fair control by the end of that year.

Beginning in March, 1939, the Districts undertook an even more fundamental and far-reaching study of the problem. The magnitude of the research which has been done may be judged by the fact that the number of sulfide analyses made since that time has totaled over sixty thousand. This work has been greatly facilitated by the use of the sensitive and rapid methylene blue method (2).

During the years since 1940 a considerable amount of sulfide research has also been done by the Orange County sewer system, the Santa Fe Springs Waste Water Disposal Company, the city of Los Angeles, the city of Long Beach, and the city of Anaheim. All of these organizations have graciously permitted information from their experiments to be included in this report.

The research has gone into many ramifications, and the further it has progressed, the more unexplored frontiers have been encountered. The present report, which gleans the significant conclusions from the mass of accumulated data, frequently must leave important questions unanswered.

It is regretted that time has not been available for an investigation of the biological aspects of the problem. Many missing answers doubtless will

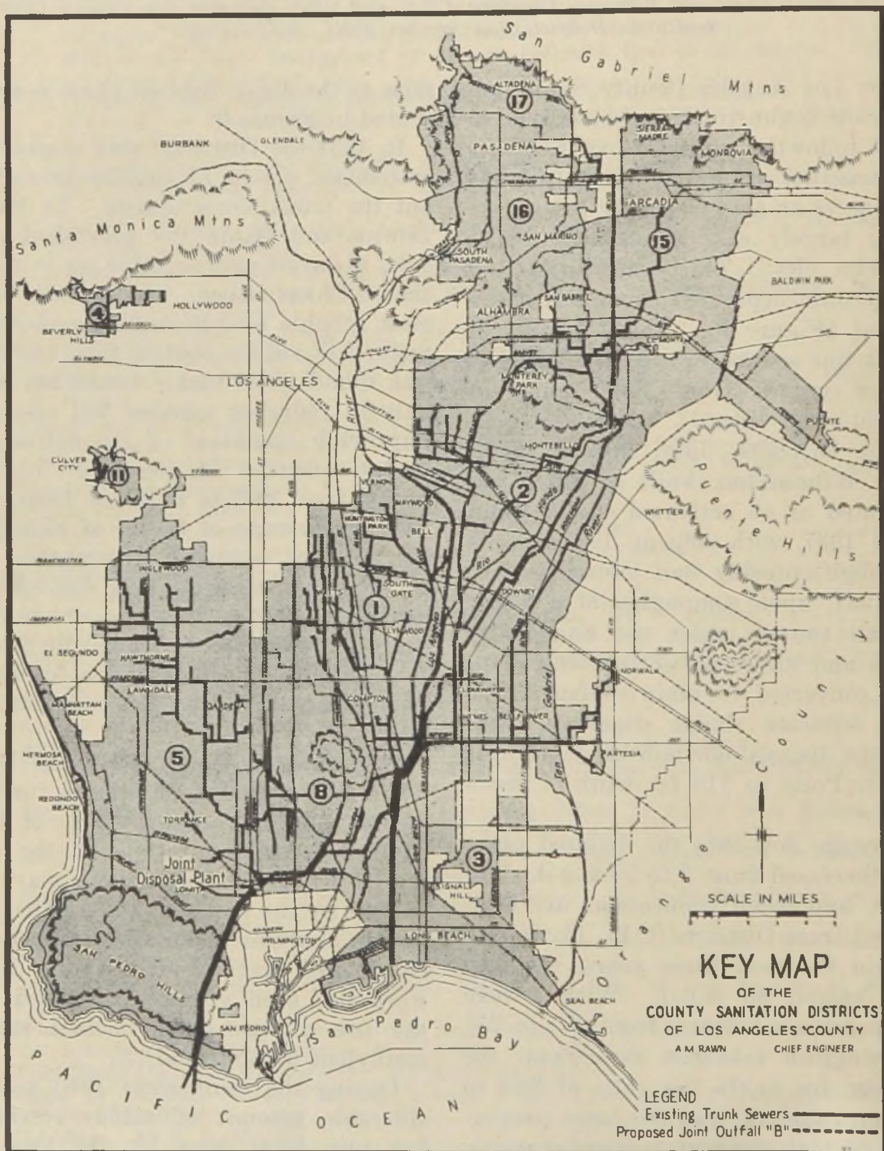

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FIGURE 1.—Map of Los Angeles County Sanitation Districts.

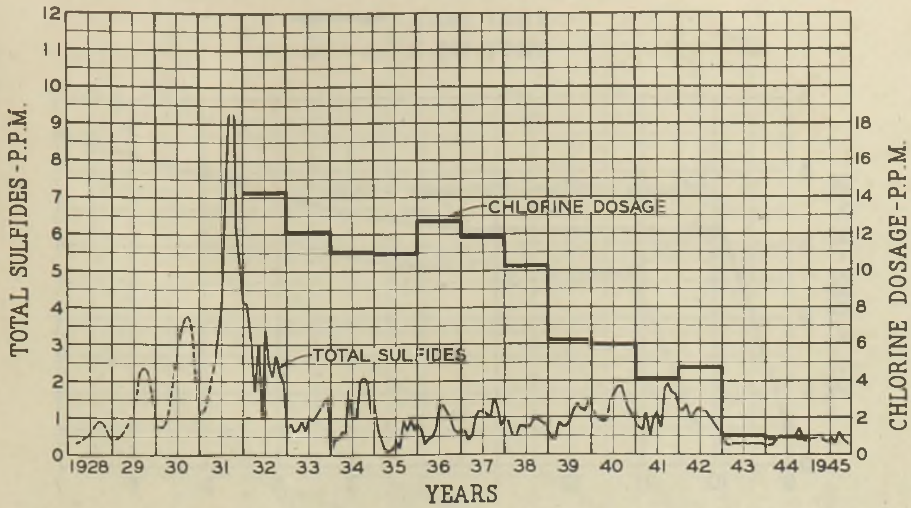

FIGURE 2.—Total sulfides at joint disposal plant—1928 to 1945.

be supplied in the next decade by the continuing research in Southern California and elsewhere.

Principles of Sulfide Generation

The influences of various factors on sulfide generation and evolution have been investigated. Before discussing these factors in detail, it is necessary to set forth a fundamental concept of sulfide generation in sewers. This may be summarized as follows: *In free flowing sewers sulfides are produced only by slimes on the submerged surface of the sewer and by deposited sludge. In the flowing body of the sewage, sulfides are not generated but, on the contrary, are destroyed by oxygen which is continually being absorbed from the surface. Even in completely filled sewers where oxygen absorption cannot occur, the amount of sulfide generation in the flowing sewage is generally negligible.* The correctness of this view will become increasingly apparent as subsequent data are adduced, but one of the most important supporting facts will be given here.

Sewage, which in the course of its flow in a conduit is showing a rapid increase of sulfide concentration, will not show this same increase when a sample is enclosed in a bottle. On the contrary, for some time after sampling there may be a slight decline, and generally many hours must pass before rapid sulfide generation occurs. This fact is well known to all who have studied the sulfide problem, but in order that definite data may be available, tests were run on sewage from a main in which generation was occurring at the rate of 2.0 to 2.5 p.p.m. per hour of flow. Three bottles of two and one-half liter capacity were filled with the sewage, using great care to avoid aeration during the sampling. These were connected in series by tubing. Additions of sewage to the first bottle displaced enough sewage from the third bottle for periodic tests without permitting oxygen absorption or any other appreciable change in conditions in the third bottle.

The results are presented graphically in Figure 3. The practical absence of sulfide generation in the bottled sewage for several hours after its removal from the sewer is a strong indication that no sulfides were being produced by the sewage itself. The ultimate generation of sulfides in the bottles presumably had to wait for the

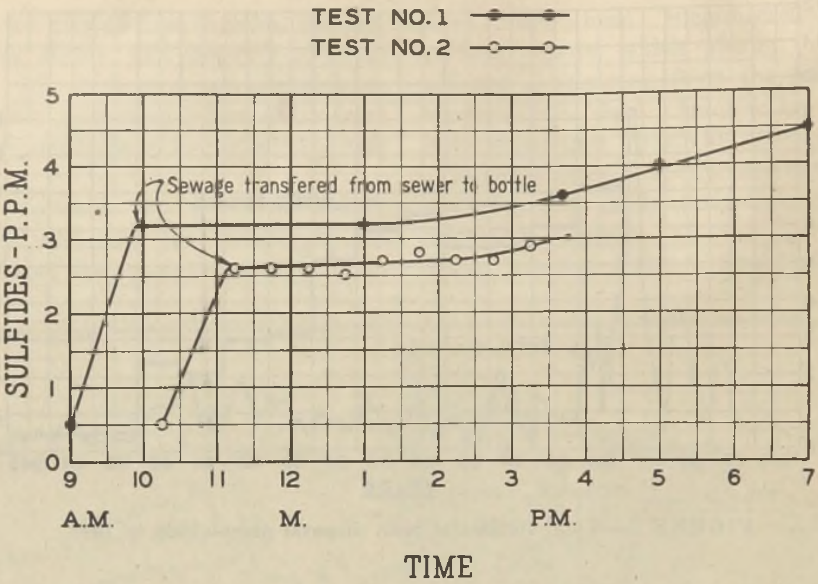

FIGURE 3.—Relation between sulfide generation in a sewer and in bottles.

development of active cultures of sulfide producers.

Effect of Temperature

Since sulfide generation is a biological phenomenon it is, of course, to be expected that it will be markedly affected by temperature. Baumgartner (3) measured rates of sulfide generation at four temperatures, using bottle experiments. Up to 30° C. the rate of sulfide generation was found to increase about 7 per cent per degree rise of temperature. At 30° and 37° the rates were similar, indicating an optimum somewhere in this range.

In order to explore this effect further, bottles of sewage were incubated * at nine temperatures from 5° to 52° C. The technique of these experiments was to fill about 15 bottles, each of 30 ml. capacity, for use at each temperature. Thus for each point on a curve one or more bottles could be analysed and then discarded, avoiding the problem of removing part of the contents of a bottle without influencing the subsequent rate of sulfide generation in the liquid remaining in the bottle. The results tend to be somewhat more erratic when using this technique, as compared to results obtained by following sulfide generation in a single bottle, since the behavior of supposedly identical bottles may vary somewhat. But the averaging of results from two or three bottles, or the drawing of a smooth curve through a series of points, probably tends to represent average behavior with considerable reliability. The material used for this test was settled sewage plus 25 per cent of oil field waste water.

Figure 4 shows the results. The rate of sulfide generation increases progressively up to 38°. At 42° there is an appreciable lag before the rate of generation reaches a maximum, and this maximum rate is not as great as at 38°. At 46° and 52° the lag is even more pronounced but eventually maximum rates are attained exceeding those at lower temperatures.

* The assistance of Dr. T. D. Bechwith, Dr. Blaine Ramsay, and Dr. Hesmer Stone, of the faculty of the University of California at Los Angeles, in providing thermostatic baths for this work, is gratefully acknowledged.

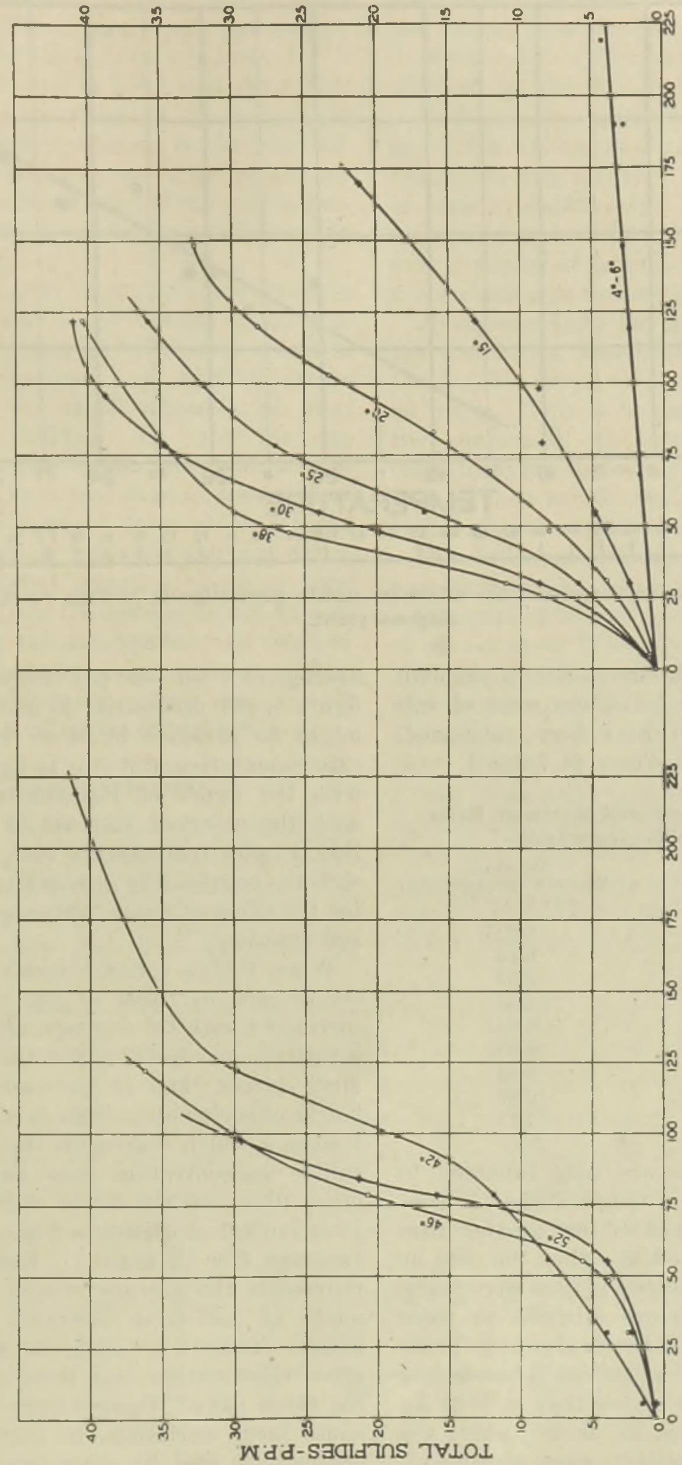

FIGURE 4.—Bottle tests showing temperature effect on sulfide generation.

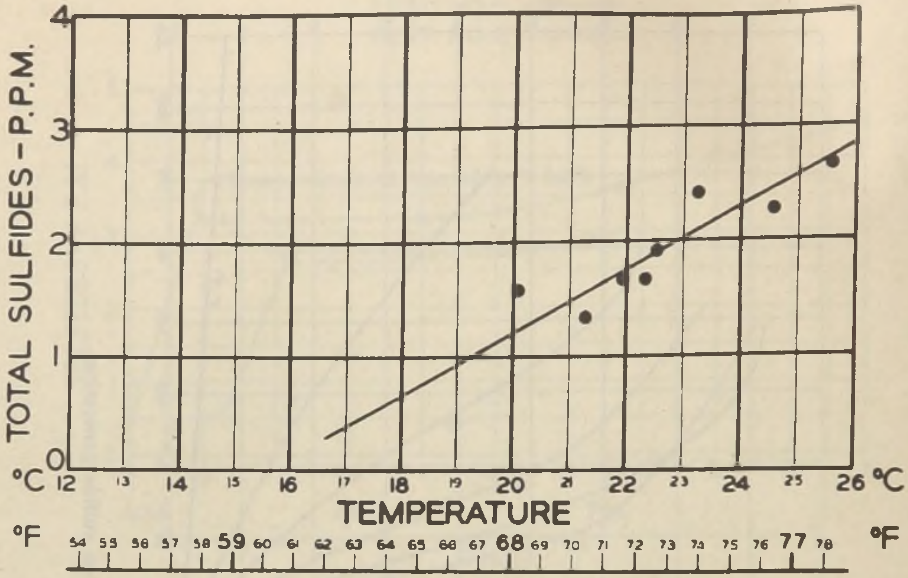

FIGURE 5.—Seasonal temperature effect on sulfide generation in sewage reaching joint disposal plant.

From smooth curves drawn through the points, the maximum rates of sulfide generation have been estimated. These rates are shown in Table I.

TABLE I.—Estimated Maximum Rates of Sulfide Generation

(°C.) Temperature	Maximum Rate of Sulfide Increases (p.p.m. per hr.)
4–6	0.015
15	0.18
20	0.34
25	0.50
30.5	0.68
38	0.89
42	0.49
46	0.87
52	1.15

These figures are only intended to show the effect of temperature in a general way. It is likely that greater rates could be reached at either the cold or hot end of this series if time were taken to develop cultures adapted to those temperatures, and it is also very probable that at 42° a rate could be reached which would be higher than at 38°. In the interval from 15° to 38°, where the figures are probably most significant, the rate appears to increase by an average of 7 per cent per degree. This figure is not necessarily as accurate as might be attained by more extensive experimentation, but it is in agreement with the figure of Baumgartner and with the observed increase of rate of B.O.D. with temperature and, in fact, with the relationship generally assumed for the effect of temperature on biological reactions.

When sulfide concentrations in sewers at various times of the year are correlated with the corresponding temperatures, one finds temperature effects much larger than in the case of the bottle experiments. This is shown in Figure 5 which represents the average sulfide concentration near the treatment plant at the lower end of the joint outfall of Districts Nos. 1 and 2 (average flow 25 m.g.d.). Each point represents the average results of tests made at half-hour intervals for 48 hours. Tests were made in all cases after chlorination had been shut off for three days. Temperature changes cause large variations in sulfide concentrations, and by extrapolating the line one would judge that sulfides would be absent at temperatures below 15° C. These results are not contradictory to the laboratory tests, for it must be borne in mind that the sulfide concentration reaching the end of the sewer is not equivalent to the total sulfide generations, but only to the remainder after a part of the sulfide production has been lost by oxidation and evolution.

It is indeed true that a reduction in temperature of the sewage of the Districts to about 15° C. would result in the disappearance of sulfides except possibly for small amounts of inert metallic sulfides. *In fact, for any specified flow conditions and sewage strength in a free-flowing sewer, there is a minimum temperature below which sulfide build-up will not occur.*

A different situation exists in force mains where the sewage is not in contact with the atmosphere. In these locations the relationship between sulfides and temperatures follows more closely the results of bottle experiments.

Effect of Sewage Strength

Other things being equal, a high concentration of bacterial nutrients in the sewage will lead to an increased rate of sulfide generation. Unfortunately, we do not know just what nutrients are used by the sulfide-producing microbes, nor how to measure their concentration in sewage, but a fair approximation is afforded by the B.O.D. determination.

It is readily apparent that sulfide generation in sewers is at least roughly related to the B.O.D. Thus, a series of tests of sulfides and B.O.D. of the sewage in one of the Districts' lines, over a period of several hours, showed a correlation as indicated in Figure 6.

It appears from the graph that sulfide generation practically ceases when the B.O.D. drops to a value of about 80 p.p.m. This is because aeration at the surface of the stream provides enough oxygen to destroy the sulfides as fast as they are formed, provided the B.O.D. is below that limiting value.

This relationship leads in many lines to a condition of sulfide generation for only a part of the day, as shown in some of the curves of Bowlus and Banta (1).

Figure 7 shows correlation of B.O.D. and sulfide production in the North Long Beach force main. Here the limiting B.O.D. is somewhat below 50 p.p.m. The sewage gets no oxygen during the 2-hour period that it is in the force main, and sulfide build-up takes place unless the oxygen which the sewage carries with it into the pump station is sufficient to last for the 2-hour

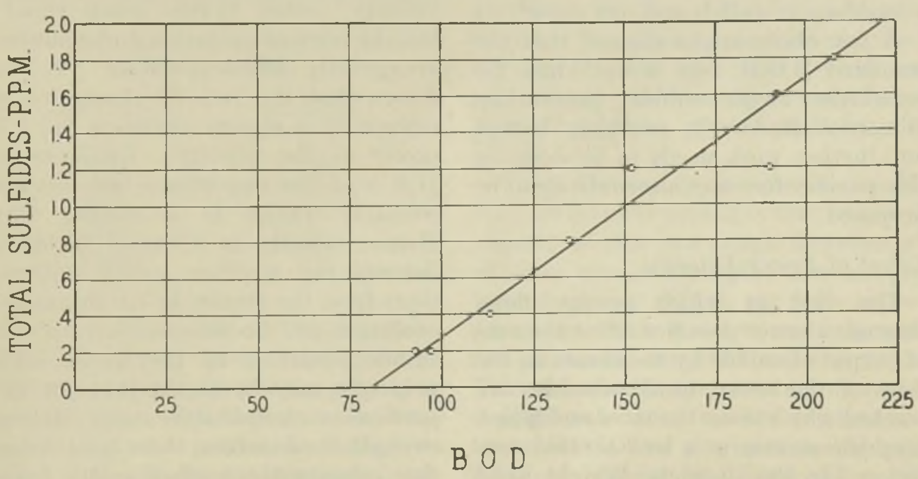

FIGURE 6.—Correlation of B.O.D. and sulfide concentrations reaching treatment plant.

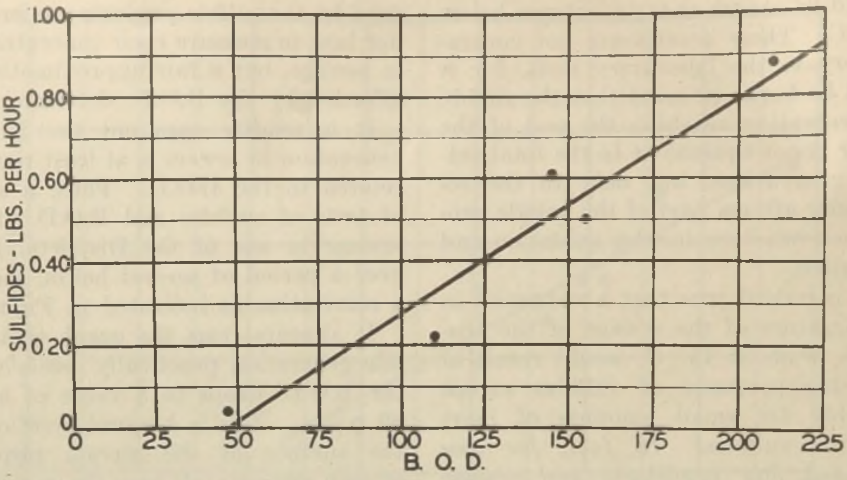

FIGURE 7.—Correlation of B.O.D. and sulfide production in North Long Beach force main.

period—a condition which can be fulfilled only when the sewage is very weak.

In longer force mains, or in situations where the sewage may enter a filled pipe with no oxygen, sulfide build-up may be expected even with very low B.O.D. values, and the amount produced should be at least approximately proportional to the B.O.D.

The foregoing observations point to the generalization that *for any specified temperature and flow condition there is a limiting sewage strength below which a build-up of sulfide will not occur.*

A few observations suggest that the standard B.O.D. test is not ideal for correlation with sulfide generation. Dissolved B.O.D. is probably better, but further work needs to be done on this point before any alternative can be proposed.

Effect of Sewer Velocity

The rate at which sewage flows through a sewer does not affect the rate of output of sulfide by the slimes on the sides of the sewer, until velocities are reached which scour the sides and which keep the stream in a well-aerated condition. In the Districts' Wright Road trunk, where the velocity is 4.9 ft. per sec., the sewer is very clean and the low sulfide concentration found at the upper end of that trunk is reduced still further in the course of flow through a 6-mile section. Even here some sulfide generation takes place in the slimes as demonstrated in the section on ''Zinc Salts,'' but the sulfide output is considerably lower than in lines of lower velocity. This scouring effect is probably not of much consequence until the velocity exceeds 3 ft. per sec.

At lower velocities the rate of sulfide production is not affected by the velocity (other things being equal), but the rates of oxidation and evolution are greatly affected. Kehr (4) has shown that the rate of absorption of oxygen by a stream varies as the 1.75 power of the velocity. Evolution of H_2S is of less importance but this also probably varies in a similar way. Hence, velocity is a major factor in determining whether sulfide subtractions from the stream by oxidation and evolution will be able to keep up with sulfide additions by the slimes. The principle may be stated that *for any particular temperature and sewage strength combination, there is a limiting flow velocity above which sulfide build-up will not occur.* This, of course, applies only to free-flowing sewers. Apparently shape of the sewer and depth of flow up to one-half full do not greatly affect this limiting velocity.

There are several places in the Districts' system which are marginal with respect to sulfide build-up at certain times of the year. These lines all present a consistent picture in respect to the magnitude of this limiting velocity. The range of velocity covered by these observations is not great, but some extrapolation is permissible on the basis of the assumption that oxidation varies as the 1.75 power of the velocity.

Since the limiting velocity is determined by both temperature and sewage strength, it is desirable to combine these conditions into a single factor called "effective B.O.D." A temperature of 20° C. is chosen as standard. For any other temperature the standard B.O.D. is multiplied by a factor calculated on the assumption that the biological activity increases 7 per cent per degree (geometrically). Expressed as a formula:

$$\textit{Effective B.O.D.} = \textit{Standard B.O.D.} \times (1.07)^{t-20}$$

Table II shows the relationship between effective B.O.D. and velocity required to prevent sulfide build-up, as tentatively deduced from the available data. In order to predict whether sulfide build-up may occur at any time in a sewer line, peak summer temperatures and daily peak B.O.D. values are estimated, and the maximum "effective B.O.D." is calculated. The actual velocity of flow during these peak conditions is also determined. If this actual velocity is below the required velocity as indicated in Table II, sulfide build-up may be expected, but if the actual velocity exceeds this required figure, then sulfide build-up is unlikely.

TABLE II.—Required Velocity to Prevent Sulfide Build-up

Effective B.O.D.	Velocity (ft. per sec.)
55	1
125	1.5
225	2
350	2.5
500	3
690	3.5
900	4

In some instances sulfides do not appear where they might be expected; perhaps because of toxic components of the sewage, or unfavorable pH condition, or other factors.

In one instance, a line carrying waste activated sludge from the present Pasadena plant through the Sanitation Districts' lines into the outfall shows high B.O.D. values, but no sulfide generation. This is easily explained by the fact that during the time of flow through the lines the activated sludge remains "alive" and does not become available as food for anaerobic microbes.

An exception of the opposite sort is found in Section 2 of the Orange County sewer. The following conditions were observed: velocity 3.9 ft. per sec.; B.O.D. 500 to 600; temperature 20° C. Sulfide build-up was found, though it should not be expected from Table II. The high B.O.D. of this sewage is due to waste waters from citrus by-products plants. In these wastes nearly all of the organic load is in solution, and an appreciable fraction is in the form of sugars, which in bottle experiments are found to be rapidly utilized by the sulfide-producing microbes. Apparently the biological activity of this sewage under anaerobic condition is not properly represented by the B.O.D.

These two exceptions do not invalidate the general principle that required velocity of flow is a simple function of effective sewage strength; they simply indicate that B.O.D. is not fully representative of this strength as far as sulfide-producing microbes are concerned. Table II remains useful as a guide, and is applicable whenever the relation between B.O.D. and nutrients available to sulfide-producers is substantially the same as in normal sewage.

Effect of Sewage Age

The opinion has sometimes been expressed that the reason for sulfide problems in certain sewer systems like those in Los Angeles, Los Angeles County, and Orange County is the great length of the lines and, hence, the relatively great age of the sewage when it reaches the end of the system. Actually the age of the sewage is of minor importance. It is not the age that matters; it is how rapidly the sewage flows. Of course, if a continual build-up of sulfide is taking place, then the longer the line, the higher the concentration at the end, but sometimes a considerable degree of natural purification takes place in the very long lines so that sulfides tend to decline in the lower reaches. In the Los Angeles County Sanitation Districts' system, sewage travels 40 miles from Arcadia to the treatment plant. Through the first 35 miles of this distance there is no sulfide generation, for velocities are adequate; only in the last 5 miles, where it is part of a much larger stream of stronger sewage and where velocities are slowed, does significant sulfide generation occur.

Effect of Hydrogen Ion Concentration

Measurements of sulfide generation in bottles of sewage at various pH values were made with results as shown in Figure 8. Each point is the average of two tests. A separate bottle was used for each test in order to avoid the difficulties which arise in attempting to withdraw successive samples from one bottle without altering conditions.

By comparing the times necessary to reach the same sulfide concentrations at various average pH values, relative rates of sulfide generation were calculated and are plotted in Figure 9. The optimum appears to be between 7.5 and 8.0 which is near the average for the sewage throughout most of the Districts' system.

As with the measurement of temperature effects, a test of this sort does not necessarily indicate what may happen under conditions such that microbial cultures may develop which are adjusted to pH values outside of this range. Accordingly, another experiment was run, using sewage from a line in Anaheim (Orange County) where an orange by-products plant keeps the sewage at a pH value around 6.5. Results are shown graphically in Figure 10.

Although these tests were made to show the effect of pH, one is at once impressed by another more striking phenomenon—a two-phase effect in all

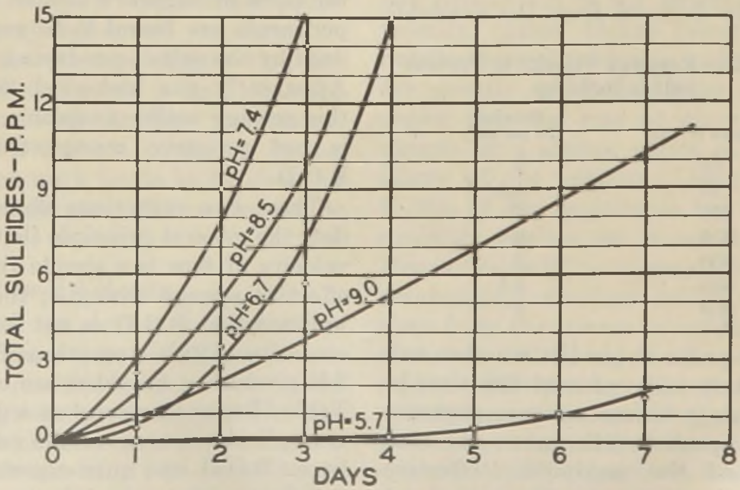

FIGURE 8.—Effect of pH on sulfide production (Los Angeles County Sanitation Districts sewage).

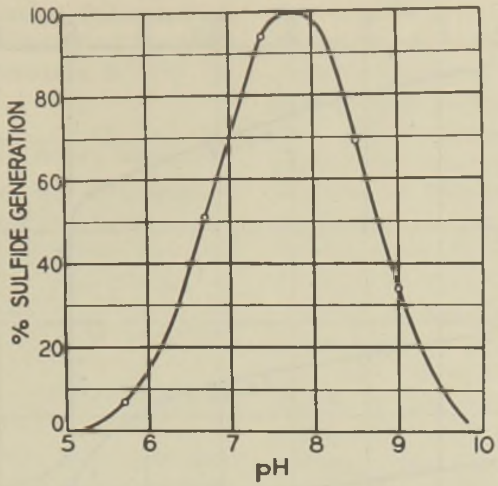

FIGURE 9.—Relative rates of sulfide production at various pH values.

of the curves. Regardless of the pH, all curves show a pause of greater or less duration between 15 and 20 p.p.m. of sulfides. A similar effect has been noted in other instances, including tests with oil field waste waters and with peptone-beef extract medium, and the phenomenon is indicated in the curves of Baumgartner (3). The curves obtained in this experiment are, however, by far the most clear-cut demonstration that sulfide generation in bottles may definitely be a two-stage reaction. The failure of this effect to appear in many curves may be due to the small magnitude of the effect in some cases, as for example, the curve for pH 7.3 in this set, and in other cases to the termination of the experiment before the onset of the second phase.

Certain explanations readily suggest themselves, as for example the successive utilization of different nutrients, but research on this has not been undertaken.

Returning to the question of pH, relative rates of sulfide generation have been derived from the curves. These are shown in Table III. It is found that pH 6.7 is optimum for the first stage and 7.3 for the second stage. It is highly significant that the first-stage optimum is close to the average pH of

TABLE III.—Effect of pH on Rate of Sulfide Generation

	Relative Rate, as Derived from Figure 10	
pH	First Stage	Second Stage
5.4	0.41	0.35
6.2	0.91	0.38
6.7	1.00	0.69
7.3	0.92	0.91
7.6	0.89	1.00
8.6	0.44	0.79
9.0	0.26	0.072

the original sewage, but decidedly lower than the optimum for the Los Angeles County Sanitation Districts' sewage.

Taken together these two experiments indicate a considerable range of adaptability of sulfide producers, or a range of varieties or species, so that pH is not likely to have much effect on the rate of generation in sewers within the range from 6 up to 8 or perhaps 9.

The foregoing paragraphs consider the effects which pH has on the rate of generation of sulfide—meaning the total sulfide content of the sewage. It must be remembered that the proportion of sulfide in the form of H_2S is also greatly influenced by pH, as pointed out in earlier publications (2, 5). Thus when the pH is 6.0, 83 per cent of the dissolved sulfide content is H_2S. When the pH is 7.0 this is reduced to 33 per cent, and when the pH is 8.0 the proportion is only 5 per cent. Since

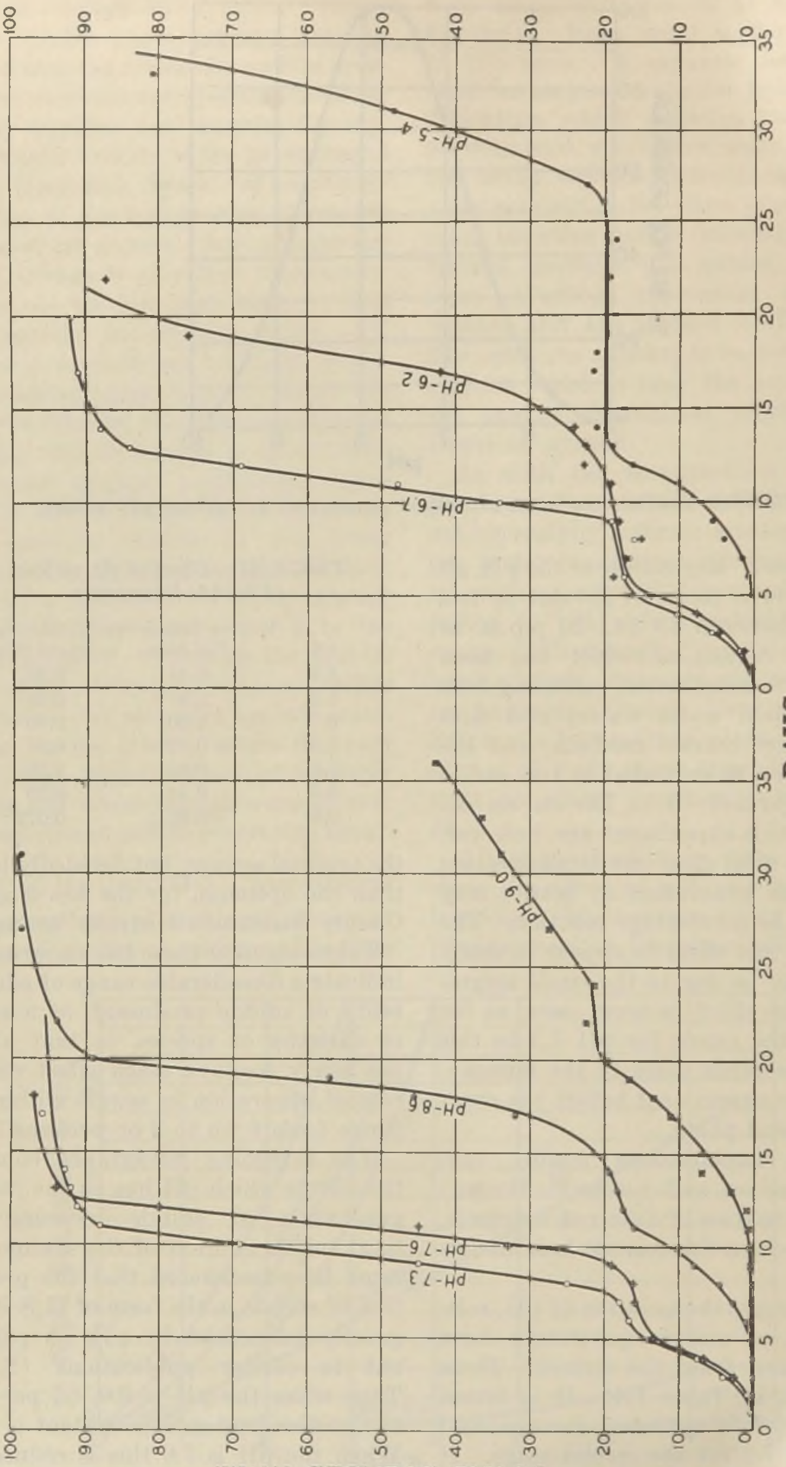

FIGURE 10.—Effect of pH on sulfide production (Orange County sewage).

nearly all of the sulfide nuisances are due to H_2S, it is evident that the effect of pH on this percentage is very important.

Area of Biologically Active Surfaces

Since sulfides are not generated to an appreciable extent in a body of sewage, but only by slimes along the sides of the sewer, it follows that the area of these active surfaces is an important factor in the total quantity of sulfides generated.

Regardless of the quantity of sewage in a tank or conduit, the amount of sulfides produced has an upper limit which is fixed by the available surfaces. It is a well-known fact that when sewage flows through sedimentation tanks the amount of sulfides generated per hour is much less than in sewers, provided that sulfides are not added to the sewage by gas bubbles originating from decomposing sludge.

An impressive illustration of the importance of surface area was afforded by the experience of the Santa Fe Springs Waste Water Disposal Company. The oil field and refinery waste water handled by this company gives rise to sulfide generation. In skimming and settling tanks where the water is retained for about 6 hours, the increase in sulfide concentration amounts to about 1 p.p.m. When this water is passed through sand filters, in which its detention time is only a few minutes, it comes out of these filters with sulfide concentrations of several parts per million.

Tests have been made in several sewers to determine the amount of sulfide generation per unit of area. The most accurate data were obtained from pressure lines, including the outfall tunnel, which is 8 ft. in diameter and 6 miles long, as well as small local force mains. If all measurements are reduced to a standard condition of 20° C. and a B.O.D. of 100 p.p.m., it appears that sulfide production may be expected to fall within the limits of 0.3 and 0.6 lb. per 1,000 sq. ft. per day (1.5 to 3.0 gm. per sq. m. per day).

In this relationship it is necessary to bear in mind, as pointed out previously, that B.O.D. measures only approximately the concentration of nutrients effective for sulfide production. It is interesting to note that sulfide production in an effluent line of the Santa Fe Springs Waste Water Disposal Co. carrying oil field and refinery wastes, amounted to 0.35 lb. per 1,000 sq. ft. per day (corrected to an effective B.O.D. of 100 p.p.m.), which thus is within the range found for ordinary sewage. But for many industrial wastes the relationship may be materially different.

Effect of Sulfate Concentration

It is well known that sulfides in sewage arise chiefly, though not exclusively, from the reduction of sulfate. When sulfate and other sulfur compounds have been completely reduced, no further sulfide generation can occur.

The effect of sulfate concentration on the *rate* of sulfide generation is of considerable interest. In 1932 an experiment was performed in which bottles of sewage containing 220 p.p.m. of sulfate were incubated along with bottles of the same sewage enriched with sodium and magnesium sulfates to 390 p.p.m. and 560 p.p.m. of sulfate. After three days all bottles had 8 to 9 p.p.m. of sulfide.

In another series the sewage used for the test had 251 p.p.m. of sulfate. By adding barium chloride to one portion the sulfate concentration was lowered to 145 p.p.m., while to other portions Na_2SO_4 was added to raise this to 474 and 1,026. Sodium chloride was added to another portion to the extent of 510 p.p.m. At the end of 8 days all samples had 7 to 7.5 p.p.m. of sulfide, but at the end of 14 days the sample of lowest initial sulfate concentration had 11.5 while the others had 13 or 14 p.p.m., thus indicating some slowing of the reaction when sulfate is less than 100 p.p.m.

Results of a third series are shown graphically in Figure 11. In eight days the sulfide concentrations reached 23 p.p.m., and in this interval of time all samples behaved the same within the limits of experimental error. Low sulfate concentrations did not cause any considerable retardation of sulfide production until sulfides had approached fairly close to the limiting concentration fixed by available sulfur resources.

In this series it is interesting to note that the ultimate sulfide production reached values considerably higher than could be accounted for by reduction of sulfate. With each of the first three sulfate concentrations, *i.e.*, 89, 101, and 120 p.p.m., the excess amounted to 16 p.p.m. of sulfide, and for an initial sulfate of 151 p.p.m. (unaltered original sewage) the excess was 15 p.p.m. This indicates substantial sulfide production by decomposition of organic matter or by reduction of other sulfur compounds. Thiosulfate may be mentioned as one of these other sulfur compounds. It is generally present in sewage which contains sulfide, since sulfide is converted by air to thiosulfate in neutral or slightly alkaline solution. A few tests in sewage of the Sanitation Districts have shown thiosulfate concentrations up to 10 p.p.m., equivalent to 6 p.p.m. of sulfide. Larger amounts may have been present in the sample used for this experiment, and some of the many industries served by the collecting system may have contributed other sulfur compounds.

Results of a fourth series are shown in Table IV. Retardation of sulfide production at the lower sulfate concentrations is more noticeable here than in the other groups, but even so it is not of much consequence as long as the residual sulfate is above 50 p.p.m.

On the basis of these four experiments, sulfate concentrations would not be expected to have much effect on the rate of sulfide production in sewers, except in respect to the maximum concentrations attainable by complete reduction. This conclusion is abundantly supported by field observations.

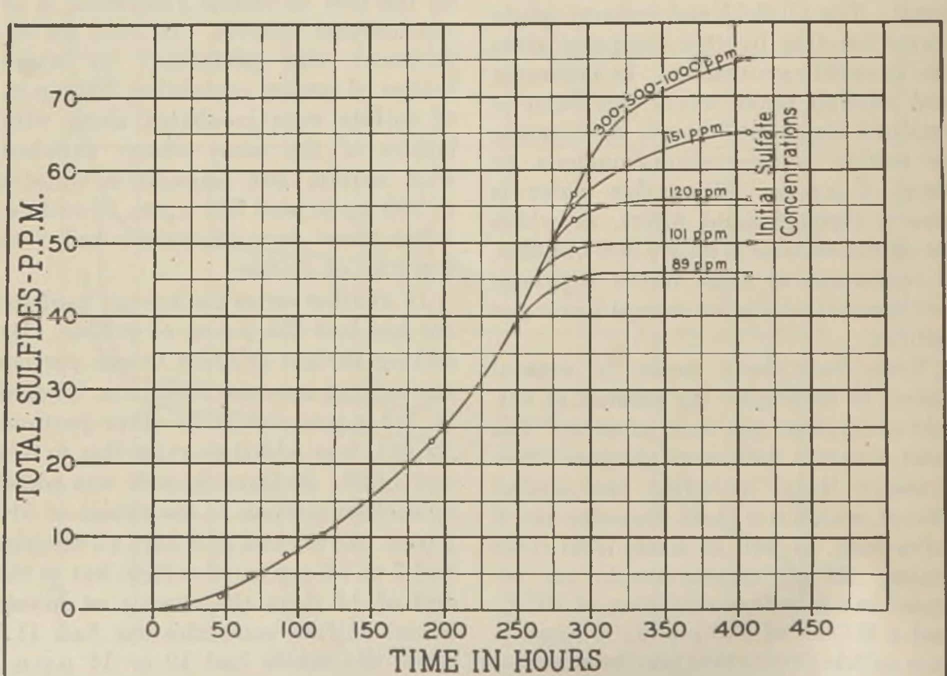

FIGURE 11.—Effect of sulfate concentrations on sulfide generation in bottles.

TABLE IV.—Relationship Between Sulfate Concentration and Rate of Sulfide Generation (Sulfides—p.p.m.)

Chemical Added	$BaCl_2$ Excess Equiv. to 25 p.p.m. SO_4	$BaCl_2$ Equiv. to Initial SO_4	$BaCl_2$	$BaCl_2$	None	$NaSO_4$	$NaSO_4$
Initial Sulfate Concentration (p.p.m.)	0	0	25	96	170	395	1,015
Time in Days							
2	2.7	2.5	4.3	4.3	5.3	5.6	6.5
3	3.1	5.2	6.0	8.1	9.0	9.5	9.5
4	4.0	6.6	9.2	11.1	12.3	11.9	13.4
5	4.2	7.5	11.0	12.9	15.4	16.3	15.6
7	3.4	8.8	13.6	20.1	23.8	26.3	27.6
11	4.0	7.5	13.3	24.7	41.7	53.2	52.5
Calc. Sulfate Concentration at End of Run ..	0	0	0	0	45	235	857

There are many places in Southern California where sulfates in the sewage range from 200 to 400 p.p.m., but with no sulfide problems. On the other hand, there are many places, as in parts of the city of Long Beach, California, and in Winslow, Arizona, where sulfates are low but sulfide problems are present.

The effluent of the Santa Fe Springs Waste Water Disposal Company flows through a pair of pipe lines 15 miles long to the ocean. When conditions are favorable for sulfide generation, concentrations at the end of the line reach 10 to 40 p.p.m. Occasionally the available sulfate is insufficient to supply the full amount which could be used by the microbes. At such times the sulfate concentration at the end of the line is reduced to values so low as to make determination quite difficult. Two or three attempted analyses indicated sulfate residuals below 1 p.p.m. Sulfide production does not seem to depend upon the sulfate concentration in this water as long as an excess of sulfate is present. Thus, on July 9, 1942, the following observations were made at the end of the line:

Hour	Total Sulfides by Titration (p.p.m.)	Sulfate (p.p.m.)
8:00	13.7	74
10:00	14.3	27
16:00	9.4	Less than 1

Even in communities where the water supply is practically devoid of sulfate there is no assurance of freedom from sulfide nuisances in the sewers, for sulfates are added to the water in the course of its conversion to sewage. This is shown in tests from the city of Torrance, Calif., where the water supply shows no detectable amount of sulfate. Samples of sewage taken at various times of the day and incubated in filled bottles promptly produced sulfides. The initial sulfate concentrations and the ultimate sulfide concentrations determined by titration are shown in Table V.

TABLE V.—Sulfates and Sulfide Production in Torrance Sewage

Hour	Initial Sulfate (p.p.m.)	Final Sulfide (p.p.m.)	Sulfide Equivalent of Sulfate (p.p.m.)	Sulfide from Sources Other than Sulfate (p.p.m.)
6:10	17	3.9	5.7	—
7:50	37	19.8	12.3	7.5
9:35	40	16.8	13.3	3.5
12:20	29	16.3	9.7	7.6
15:10	26	9.6	8.7	0.9
18:10	13	7.3	4.3	3.0
20:10	16	8.6	5.3	3.3

Reduction of Other Sulfur Compounds

Sulfite is reduced more readily and more rapidly than sulfate. In one experiment parallel incubations were made of normal sewage at pH 7.2 to 7.4, and the same sewage dosed with sodium sulfite to give 60 p.p.m of $SO_3=$. Sulfide production occurred about twice as fast in the presence of sulfite. At the end of 8 days all sulfite had been reduced. At this time sulfide amounted to 36 p.p.m., of which 24 p.p.m. had come from the sulfite.

A similar test was made with sewage at a pH value between 8.8 and 9.1. Sulfite was reduced to sulfide under these conditions also, but the rate did not appear to be materially different from the rate of reduction of sulfate.

At low pH values sulfide reacts with sulfite to produce thiosulfate. Hence we should expect the reduction of sulfite in acidic solution to yield thiosulfate, at least as an intermediate product before final reduction to sulfide. Parallel incubations of sewage with and without sulfite, at pH values between 6.2 and 6.6, showed that for 6 days there was relatively little sulfide production in the sewage containing sulfite, in comparison with the blank, but sulfite concentrations progressively declined. At the end of 9 days sulfite reduction was complete and sulfide production was in rapid progress, so that in 11 days it had caught up with the blank. The formation of thiosulfate was not analytically established, but the experiment clearly indicates that some intermediate product was formed, and there is no reason to doubt that this intermediate was thiosulfate.

Incubations were made in media containing 670 p.p.m. of peptone, 200 p.p.m. of beef extract, and 1,000 p.p.m. of phosphate and bicarbonate buffering salts, together with various added sulfur compounds. Thiosulfate and dithionate readily yielded sulfide, and elemental sulfur was reduced to sulfide with remarkable rapidity. Persulfate was reduced first to sulfate and then to sulfide. Even barium sulfate was attacked to some extent.

Hydrogen Sulfide in Sewer Atmospheres

Numerous experiments have been made in which concentrations of hydrogen sulfide in sewage in sewer atmospheres have been determined simultaneously. The method has been described by Pomeroy (5). A typical run is shown in Figure 12. It is characteristic in all such tests that the concentration of H_2S in the air responds promptly to changes in the sewage, but when calculations are made of the amount of H_2S which would be in the air if it were in equilibrium with the sewage, it is found that the amount actually present is generally only 5 to

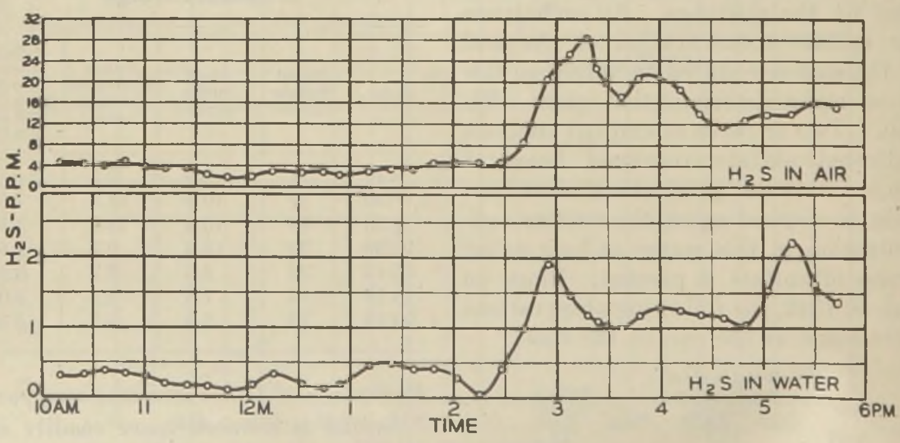

FIGURE 12.—Typical test in a large sewer for hydrogen sulfide in the sewage and air above.

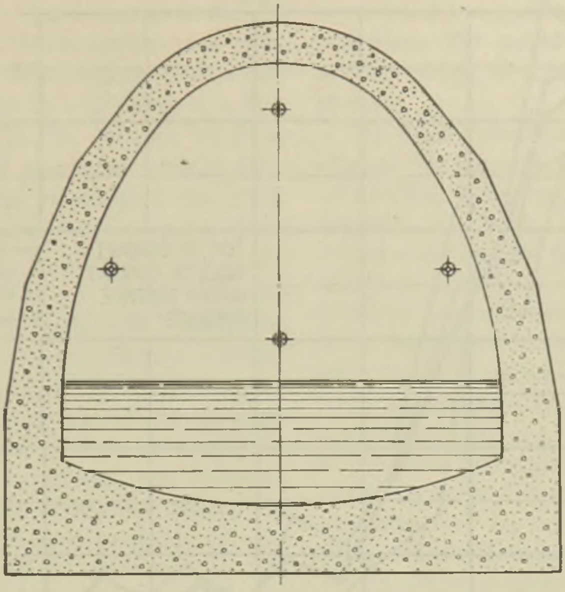

FIGURE 13.—Cross section of 9 ft. 6 in. sewer showing location of sampling points.

10 per cent of the equilibrium concentration. This indicates a rapid removal of sulfide from the atmosphere, presumably by oxidation to H_2SO_4 on the walls of the sewer.

In order to obtain an estimate of the rate of this conversion, a point was found in the 9 ft. 6 in. joint outfall of the Districts where the flow of sewage could be stopped, thus practically stopping the evolution of hydrogen sulfide. The stopping of the sewage flow was accomplished by shutting off the pumps at the treatment plant about a half-mile from the test point. A lower tributary sewer supplied just the necessary amount of flow to fill up the lower part of the sewer, so that the sewage quite promptly came to a dead stop and could be held that way for two hours.

Tests of the atmosphere were made at 5 -min. intervals at each of four test points shown in Figure 13. The results are shown graphically in Figure 14. The very rapid drop of the sulfide concentration close to the walls shows the remarkable efficiency of these surfaces in catalysing the formation of sulfuric acid. It is well known that the change is due to bacteria of the genus *Thiobacillus,* for such rapid oxidation of H_2S does not take place by simple chemical reaction.

This rapid conversion of gaseous H_2S to sulfuric acid would not necessarily occur under all conditions. Rapid oxidation depends upon a suitable environment for the bacteria, which means the presence of moisture and a sufficient supply of hydrogen sulfide to stimulate development of an adequate growth of the bacteria. Under some conditions sulfur is formed as an intermediate oxidation product.

From Figure 14 it is seen that the average concentration of H_2S in the atmosphere declined at the rate of 7 p.p.m. per hour when the sewage was first shut off. This corresponds to the oxidation of 0.15 lb. of H_2S per mile of sewer per hour, or the production of 0.46 lb. of H_2SO_4 per mile per hour, or 4,000 lb. per mile of sewer per year. The rate of evolution of hydrogen sulfide from the sewage and its consequent conversion to sulfuric acid in this sewer should be proportional to the concen-

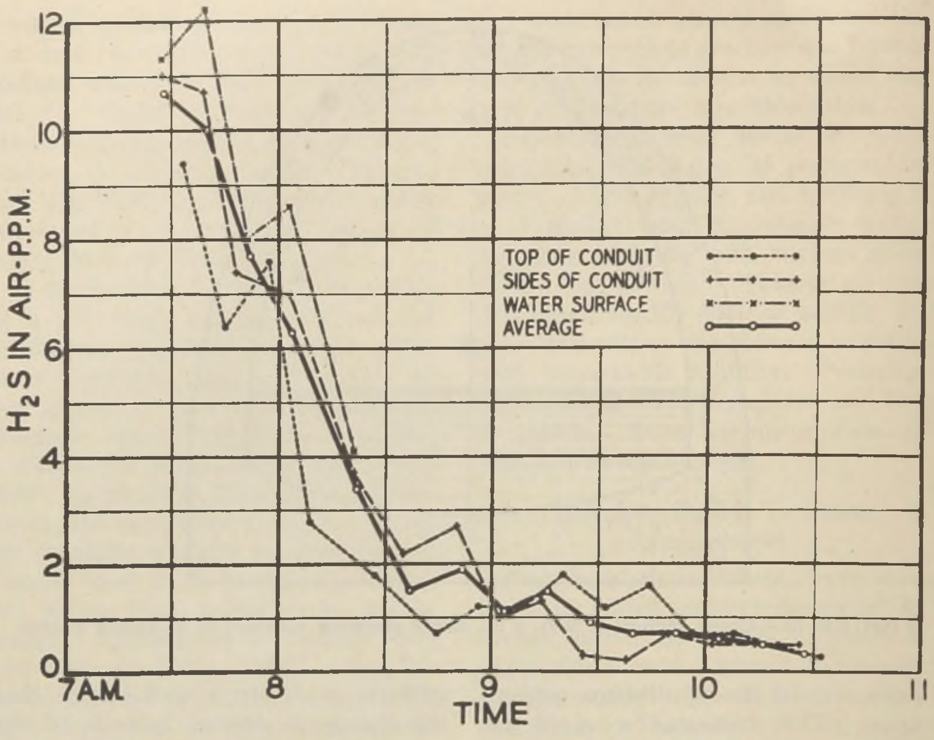

FIGURE 14.—Reduction of hydrogen sulfide in sewer air when sewage flow was suddenly stopped.

tration of H_2S in the sewage, and should also vary with the velocity of flow. Sulfide concentrations and velocities were near average at the time of the test. By making suitable adjustments of the observed rate to correspond to the approximately known average conditions, it is estimated that during the interval from 1928, when this sewer was placed in service until 1939 when these tests were first made, the average production of sulfuric acid amounted to 6,000 lb. per mile per year. This corresponds to 0.7 lb. per sq. ft. of exposed sewer wall in the 11-year period. This quantity of sulfuric acid is sufficient to dissolve the concrete to a depth of 0.3 in. The surface of the concrete is generally protected by clay liners, but in unprotected spots penetration to a maximum depth of ¾ in. was measured. It is estimated that in order to give this sewer a life of 100 years, which it should have, the concentration of dissolved sulfide should be held down to an average of 0.1 p.p.m.

It is of considerable interest to note that in this sewer, which had a flow of 30 m.g.d. at the time of these tests, the amount of sulfide evolved into the atmosphere per mile of flow was only about one per cent of the amount carried by the sewer.

Sulfide Control Procedures

Proper Design

The consequences of sulfide generation should be considered when sewage works are being designed. Many of the problems of sulfide corrosion and odors which plague sewer authorities would not have arisen if the principles of sulfide generation had been known and had been taken into account in design. The design features which should be considered are set forth in the following:

(*a*) Velocity. Assuming fixed B.O.D. and temperature conditions, the controlling factor determining whether or not sulfide build-up will occur in a free flowing sewer is the velocity of flow. On the basis of estimated peak B.O.D. and temperature conditions, the minimum safe velocity can be found from Table II. The velocity at the daily peak flow (which is at about the same time as the peak of strength) should be considered for various degrees of utilization of capacity of the sewer, and if feasible, the design should be made so that this velocity will at all times be great enough to exceed the required minimum. The velocities shown in Table II are the most probable values; an allowance of 25 per cent in the velocity should be made as a factor of safety, and if industrial wastes are present with a high content of dissolved organic matter it may be necessary to increase this allowance to 50 per cent. Sometimes it will be found that sulfides will be a problem early in the life of a line when velocities will be low but that they will disappear later with increased flow, as has been the experience of the County Sanitation Districts in a number of locations. If this condition can be predicted, then it may be reasonable to plan for chemical sulfide control for a limited number of years. In some situations it will not be feasible to reach the necessary velocities. Consideration should then be given to the use of resistant structural materials or linings.

(*b*) Force Mains. Except for cases where the sewage is quite weak and in a fairly well aerated condition, sulfide generation can be expected in completely filled lines. Force mains therefore should be kept to a minimum. Sometimes it will be advantageous to lift the sewage practically vertically from one free flowing line to another, at the expense of some additional excavation for deeper sewers, in order to eliminate the sulfide problem which usually arises in connection with force mains.

(*c*) High Velocities and Drops. If a sewage contains considerable amounts of sulfides, it may sometimes be advantageous to avoid the high velocities which often prevail for a short distance above a treatment plant. Manholes built so that the sewage falls directly into the manhole should be avoided as it leads to excessive release of H_2S even when only a few hundredths of a p.p.m. are present. At one location which was investigated, a force main carrying about 1 m.g.d. of sewage with an average of 2 p.p.m. of dissolved sulfides and a pH value of 7.3 discharges into a large junction chamber with a fall of about 1 ft. A reinforced concrete pillar in the center of this chamber originally had a cross section area of 576 sq. in. At the end of 3 years the cross section was reduced to 300 sq. in.

In another location a large flow of sewage falls a distance of 2½ ft. At a time when sewage tests showed 0.4 p.p.m. of dissolved sulfides and pH 7.4, the atmosphere in the sewer showed 20 p.p.m. of H_2S—a concentration several times as great as would be expected from the same sewage under ordinary flow conditions.

Even when sulfide conditions cannot be avoided in the design, it is still advantageous to know in advance just what may be expected, so that suitable control measures can be considered. An understanding of the principles of sulfide production makes it possible to know, for example, where bare concrete can safely be used, and where protection is necessary. In the new construction now being planned by the Districts this ability to predict future conditions in respect to sulfide production will result in economies exceeding a million dollars.

Construction Materials and Protective Coatings

Closely related to the problem of laying out sewers so as to avoid hydrogen sulfide troubles is the question of how to prevent disintegration of structures where sulfides may be present.

Unprotected concrete has at times been attacked by oxidized H_2S to the extent of causing serious damage to structures. The reasons for this have not heretofore been well known but the comparatively limited areas where such manifestations are apparent all appear to find explanation in the conclusions drawn in this report. Cast iron pipe has been destroyed by conversion to iron sulfide and in the more aggravated instances vitrified clay pipe and liners have split along their laminations. A discussion of structural materials is beyond the scope of this paper but mention will be made of attempts to protect those commonly used.

Of the various materials which have been tried for surface protection, vitrified clay liners seem to be the most hopeful, although the earlier experiences with clay liners were not very satisfactory. Brown (7) described the condition of the Los Angeles North Outfall in 1936, after 12 years of service, reporting that many liners had fallen off and many more were loose. The authors of the present report, and others of the staff of the Districts, have made several trips through the 3-mile long section of 9-ft. 6-in. conduit constituting the joint outfall of Sanitation Districts 1 and 2, and have found conditions similar to those described by Brown, but not so far advanced. It appears that many of the liners in these early installations were quite porous, so that the acid diffused through to attack the underlying concrete. Even though no attention was given to the problem of clay porosity at the time of the County Sanitation Districts' installation in 1928, a vast majority of the liners remained sound through the period of about 15 years during which significant sulfide conditions prevailed. Modern manufacturing procedures assure liners of low porosity, which may afford effective protection.

Another reason for failure of the liners to provide adequate protection was poor jointing. Sulfur-silica mixtures have generally been used for this but are not well-adapted for the purpose. They do not adhere to the clay, and they are themselves subject to bacterial attack. Experimental data now at hand indicate that properly compounded coal tars may prove to be satisfactory.

Acid-proof cements plastered over concrete structures afford a certain degree of protection, but they are porous and usually spall. One sewer system used acid-proof cement to point mortar joints in brick manholes, but it was only a few years until this was being pushed out of the joints by expansion of the underlying mortar as it was disintegrated by sulfuric acid. This, of course, suggests the possibility of a sound structure by using only acid-proof cement in the masonry.

Some of the better paints or resinous coatings seem to offer considerable promise, but there is no proof that any paint has yet been formulated which will endure for any considerable span of years in sewers, and hence no reliance can yet be placed upon such materials for use in locations where periodic replacement is impractical.

Sulfur-silica coatings were tried in an experimental line at Hyperion (Los Angeles city treatment plant) from 1928 to 1933. Applied thicknesses were from ½ in. to 1 in. On the sides at levels which were intermittently wet by the sewage, bacterial attack had eaten away 0.3 in. of the lining material. In the crown of the sewer the lining was firm only if applied in an original thickness exceeding ¾ in. Asphalt coatings tested in the same line proved worthless.

Impregnation of cement surfaces with paraffin has been proposed, but laboratory tests showed that this treatment did not confer any significant resistance to acid attack.

Control of B.O.D.

Since the rate of sulfide generation is roughly proportional to the B.O.D., a reduction in the B.O.D. of sewage may reduce the rate of generation sufficiently to bring it within the oxidizing capacity of the stream. In some cases reduction of the B.O.D. is possible. This is best illustrated by the addition of a flow of unpolluted water to the sewage. Instances have been cited by Wisely (8).

In dealing with industrial waste problems consideration should be given to the effect of high B.O.D. wastes on sulfide generation. In some instances it may be necessary to exclude certain wastes because of this problem. There are also cases in which a high B.O.D. waste may be discharged when the sewage is weak without causing trouble. This situation was illustrated by the case of waste from a fish liver oil plant having a B.O.D. of 300,000 p.p.m. When the normal sewage is at its peak strength the conditions are just marginal with respect to sulfide generation in the line affected, so that an increase of the B.O.D. might lead to a sulfide problem, but discharge of the waste at night causes no harm. Permission to discharge at night was granted on this basis.

In another situation a distillery applied to connect to a line in which sulfides up to that time had been absent. It was predicted that the waste would raise the effective B.O.D. to a level which would probably cause sulfide generation. Permission to connect was granted (partly as a war emergency) with the provision that the company pay the cost for chemical sulfide control. Sulfides appeared as expected and suitable control measures were taken.

In one sewer system a line carrying industrial wastes produces sulfides, whereas domestic sewage alone would not do so. The relationship between B.O.D. and sulfide production has been determined, and the cost of sulfide control has been calculated, and on this basis an ordinance has been drafted to assess a charge for all B.O.D. contributed in excess of 250 p.p.m., these charges being fixed at a level suitable to pay for sulfide control.

Reduction of the B.O.D. of sewage may be accomplished by biological oxidation. Often a meagre degree of treatment or treatment of only part of the flow will suffice. The effluent of the Santa Fe Springs Waste Water Disposal Company flows through a 15-mile pipe line. Sulfides at the end of the line have been the cause of concern. Present studies indicate that activated sludge or trickling filter treatment of the waste before it passes through the pipe line would be cheaper than any other form of treatment for sulfide control.

Control of Temperature

The rate of sulfide generation might be diminished by lowering temperatures, but no situation in which this is a practical remedy is known except insofar as it is an incidental result of adding unpolluted water to the sewage. Of course, the effect of adding waste waters of high temperature must be taken into account, but this may best be done by use of the "effective B.O.D." rather than by considering temperature and B.O.D. separately. Addition of a small proportion of unpolluted water to sewage will increase the effective B.O.D. and hence the rate of sulfide generation if its temperature exceeds the temperature of the sewage by 15° C.

Control of pH

Sulfide-producing microbes can develop over a rather wide range of pH. Hence it will rarely appear feasible to attempt to hold the sewage to a pH value outside of the range suitable for their activity. Extreme changes of pH, however, may destroy them, as pointed out in a later section on the use of acid.

If sewage contains dissolved sulfides, then the proportion of hydrogen sulfide is greatly diminished by an increase in pH. In two situations in Southern California addition of lime to sewage was resorted to as a temporary measure in order to diminish sulfide nuisances. But in most cases this method is more expensive than other forms of control.

The effect of changes of pH on the sulfide situation must often be considered in evaluating the effect of industrial wastes. If sulfides are present in a sewer system, then wastes which lower the pH will increase the proportion of H_2S and thus will be detrimental.

Control of Sulfates

Variations of sulfate concentration in the water supply of an area have no significant effect on the rate of sulfide production. Serious sulfide conditions may be found even in the sewage of areas where the water supply is entirely devoid of sulfate, largely because of sulfate added to the water before it goes to the sewer. But even complete elimination of sulfate from the sewage, as by use of barium salts, would not eliminate sulfides entirely, for several p.p.m. may arise from other sulfur compounds.

With some industrial wastes the situation may be different. This is notably the case with some of the oil field waste waters, for these waters as they come from the wells are generally entirely devoid of sulfate and often carry a little barium. Such waters do not give rise to sulfides, but if some waste containing sulfate is added, then high concentrations of sulfide may make their appearance. The erratic variations in sulfide concentrations sometimes observed in pipe lines carrying these waters is often due to variations in the amount of sulfate available. A solution to sulfide problems with some of these wastes may be found in segregating the sources of sulfate.

Mechanical Cleaning of Sewers

If sewers contain considerable amounts of deposited sludge, anaerobic decomposition of such sludge may produce sulfides. This condition is to be distinguished from the production of sulfides by the slimes which consist essentially of fungi and other microbes. A further disadvantage of deposits of sludge and other debris is that they retard the flow.

In small lateral sewers the holding back of the sewage by partial stoppages is often the cause of high sulfide concentrations. Periodic cleaning is an important procedure for sulfide control in such situations.

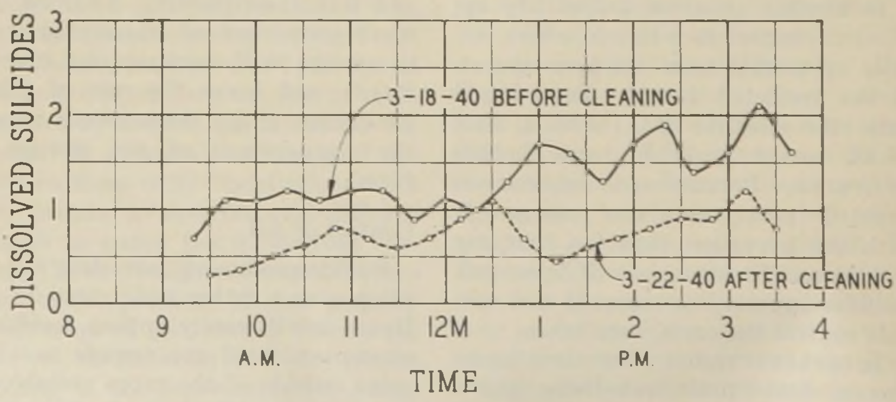

FIGURE 15.—Cleaning and flushing effect on a 15-in. sewer.

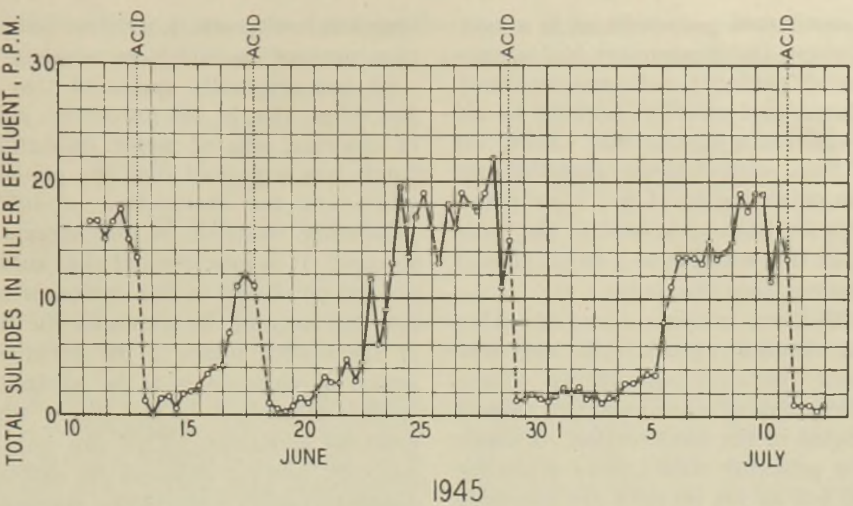

FIGURE 16.—Sulfide generation in petroleum waste water on passing through magnetite filters, showing effect of descaling treatments with acid.

An illustration of the effect of cleaning is afforded by Figure 15 which shows a reduction of about 47 per cent in sulfide concentrations. This line was not excessively fouled before cleaning, and in a period of about 2 or 3 weeks, conditions had become as bad as before cleaning. In lines containing debris in such amounts as to cause considerable retardation of flow, the effect will be more pronounced.

Chemical Cleaning of Sewers

Sulfuric acid is effective in removing sulfide-producing slimes. This is strikingly illustrated in the Santa Fe Springs system. Waste sulfuric acid is occasionally put through the magnetite filters and effluent lines to keep them free from lime incrustation. The acid treatment of the water is at a rate sufficient to lower the pH to about 3.5 to 4 and is continued in each case for about 2 hours. Figure 16 shows sulfide concentrations in the filter effluent as correlated with the acid treatments. (The filter influent generally contains less than 1 p.p.m. of total sulfides.) The effectiveness of the acid is quite surprising, especially in view of the relative mildness of the treatment.

These acid doses have not shown much effect on sulfide generation in the effluent lines, but in July and August of 1945 the lines were used for the wasting of a considerable quantity of acid often amounting to two or three doses per day. It required several days for the lines to again produce sulfides in appreciable amounts after these heavy treatments.

Consideration is being given to the intermittent application of waste acid to some of the Districts' lines as an auxiliary sulfide control procedure. It is believed that this can be done even in concrete lines, in view of the mildness of the required treatment.

Caution must be exercised in any program of this sort. Iron sulfide is often present on the walls of the sewer. When acid is put through such lines, this sulfide will dissolve and may give excessive concentrations of H_2S, at least on the occasion of the first treatment. In one instance extremely acid sewage was received at the sewage plant as a result of a spillage from a sulfuric acid plant. The sulfide concentration reached 60 p.p.m., which of course was all in the form of H_2S. This would quickly produce a deadly atmosphere in a sewer.

In one instance a workman in a manhole where the atmosphere had always appeared perfectly safe was suddenly overcome, and another, seeking to aid him, suffered a similar fate. Both lost their lives, with evidence that this was due to poisoning by H_2S. The circumstances are such as to lead to the opinion that this was due to a batch of acid discharged into the sewer.

In addition to acids, there are other strong chemical agents which may also kill out the sulfide-producing slimes. The functions of chlorine in this respect is treated in the next section. Caustic alkalis probably would have a similar effect, but as yet no data are available on this possibility.

Chlorination

Chlorine has been successfully used in the control of sulfides in sewage during the past twenty years, and it may continue to occupy a dominant place in this field. It acts in three ways: (*a*) it destroys sulfides by chemical reaction; (*b*) it produces mild oxidizing compounds in the sewage and, by temporarily retarding biological activity, it permits the sewage to accumulate a little dissolved oxygen; and (*c*) it destroys microbes which produce sulfides, thus preventing sulfide generation.

It was originally supposed that the last effect, that is, the preventive action of chlorine, was of major importance, for it was supposed that the principal effect was the destruction of sulfide-producing bacteria in the stream of sewage. It is now evident that sulfides are not produced in the stream of sewage, but only in the slimes on the sides of the sewer; hence if the germicidal action of chlorine is to be utilized in sulfide control, it is the slimes which must be sterilized. This can only be done by adding chlorine in sufficient dosages to carry a sterilizing concentration through the section to be treated. Continuous dosage at such a rate would generally be uneconomical. Continuous sterilization, however, may not be necessary, for if the slimes are killed it takes some time for the microbes to develop again. Therefore, if chlorine is to be used as a sterilizing agent, the best application would be intermittent chlorination as is practised in the control of slimes in condensers and cooling systems.

An attempt was made to apply the principle of intermittent sterilization

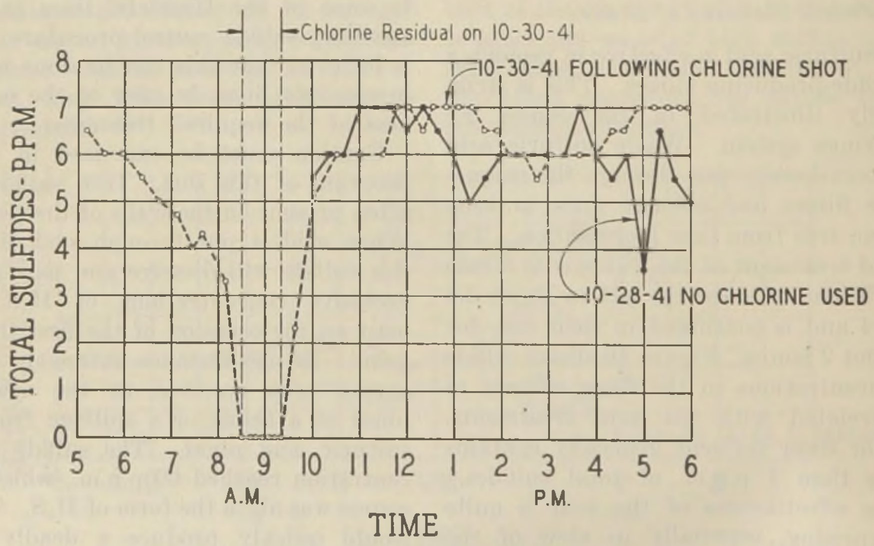

FIGURE 17.—Attempted chlorine sterilization of North Long Beach force main.

TABLE VI.—Effect of Intermittent Chlorine Sterilization of the North Long Beach Force Main

Date (1941)	Chlorine Dosage		Dissolved Sulfides (p.p.m.; 5-hour average)		Increase in Passing Through Force Main (p.p.m.)
	Lb. per Day	Period of Dosage	Pump Station—9 A.M. to 2 P.M.	Discharge End of Pipe Line—10:30 A.M. to 3:30 P.M.	
Oct. 28	0	—	2.19	5.33	3.12
Oct. 20	235	5 A.M. to 8 A.M.	2.34	5.33	2.99
Oct. 30	207	5 A.M. to 8 A.M.	2.41	5.50	3.09
Oct. 31	195	4 A.M. to 7 A.M.	2.11	5.13	3.02

in the North Long Beach force main. High concentration of chlorine, sufficient to carry residuals of several p.p.m. through the 4,300-ft. line, was applied at the inlet end from 5 to 8 A.M. The chlorine was then shut off. Sulfide determinations at the end of the main were made on 3 days following these early morning treatments and also on days following periods when the chlorine had been shut off for 48 hours. Figure 17 and Table VI show the results. In each instance following chlorination sulfides immediately reappeared and within an hour reached substantially the same values as were reached when chlorine had not been used. The attempted sterilization in this instance was a failure. The reasons for this are not clear, but it seems probable that the force main has a fairly thick coating of slime (and corrosion product) which protects the microbes in the slime from the action of the chlorine.

Tests in the Gardena system showed that destruction of the sulfide-producing slimes is possible under favorable conditions. In a 1-mile section the average velocity of sewage flow was 0.9 ft. per sec. During the spring of 1942 the sewage at the upper end of this stretch had an average dissolved sulfide concentration from 0.2 to 0.5 p.p.m. during the 4-hour high, while at the lower end of the mile stretch the average was 2.0 to 3.0 p.p.m. During a test in May chlorine was applied at the rate of 50 lb. per day to a flow of 0.3 m.g.d. After this treatment had been applied continuously for 5 days, the chlorine was shut off at 7 A.M. Throughout that day sulfides were entirely absent at the lower end of the mile section. Not only was there no generation in this section, but the sulfides which came from upstream disappeared, doubtless as a result of oxidation. On the next day they averaged less than 0.1 p.p.m.

In June the experiment was repeated. Tests made 2 days and 6 days after the chlorine had been shut off showed average dissolved sulfide concentrations, respectively, of 0.2 and 0.4 p.p.m. at the lower end of the mile section. Due to low velocity this line had a considerable deposit of sludge, but in spite of this, the chlorine killed out the sulfide-producers, and the original activity in respect to sulfide generation was not restored for at least a week.

This test indicated that sulfide generation can be prevented by killing the slimes, but the advantage in this case was gained at the cost of excessive chlorine. At present the best program on this trunk sewer seems to be to feed chlorine at a constant rate throughout the 24 hours. During high sewage flow the chlorine applied is sufficient to destroy such amounts of sulfide as are generated. When the sewage is weak and the flow is small, the excess of chlorine partially sterilizes the slimes and reduces the amount of sulfide which must subsequently be neutralized chemically.

When the Districts instituted a chlorination program in 1931, the practice then recommended was followed and chlorine was applied on the principle of preventive sterilization in the sewage itself. It would not be possible to apply this principle completely for this would require innumerable chlorinators on many lateral lines, but in general, the chlorinators were located near the upper ends of long trunk sewers. At points of application some of the chlorine was generally consumed by reaction with the sulfides already present, but beyond destroying the sulfides enough more chlorine was usually added to exceed the chlorine demand and thus accomplish at least a partial sterilization in the lines.

In 1939 tests were made to determine the efficiency of this procedure. The seven chlorinators in use were first set to feed a total of 2,210 lb. per day, roughly proportioned to the chlorine demand at the various stations. After this schedule had been in effect continuously for 5 days the sewage at the lower end of the outfall was tested over a period of 48 hours at 30-min. intervals. Following this the chlorinators were shut off for a week, the sewage again being tested for 48 hours on the last 2 days. Then a chlorination schedule was devised using 1,000 lb. per day. In arranging this the hours of chlorination were shortened and in most cases the dosages were reduced below the chlorine demand. Tests were again made on the last 2 days of a week of this treatment. For 7 weeks tests of similar nature were made, the dosages being in the order: 2,210, 0, 1,000, 2,210, 1,000, 0, and 2,210 lb. per day. Thus the 2,210-lb. dosage was used in three tests with two tests each for the other two procedures. This not only gave the advantage of greater statistical accuracy but also balanced out the effect of the seasonal temperature change. The results as shown in Table VII indicate that 19.4 lb. of chlorine were used for each pound of sulfide eliminated.

When chlorine is added to a pure water solution of sulfides, it requires only 2.22 parts of chlorine to destroy one part of sulfide as indicated by the following reaction: $Cl_2 + H_2S = S + 2HCl$. In the case of sewage it is to be expected that other reducing agents would consume a part of the chlorine and thus reduce the efficiency. Numerous small scale experiments have been performed to determine the chlorine-sulfide ratio for various samples of septic sewage. In such experiments samples of sewage are treated with varying dosages of chlorine, and sulfide tests are subsequently made to determine what dosage is just sufficient to eliminate the sulfides. The ratio varies for sewage from different Districts in the system from 3 to 9, averaging 5.3. Similar tests of efficiency may be made in the sewers by testing the sewage above and below a chlorination point. The ratios so obtained are generally similar to the results of the small scale tests, though tending to be somewhat higher. This is probably due to less efficient mixing in the sewer as compared with the bottle tests, for it is to be expected that if a portion of the sewage receives a high dosage of chlo-

TABLE VII.—Efficiency of Chlorination in Removing Dissolved Sulfides

Chlorine Feed (lb. per day)	Sewage Temp. (°C.)	Total Sulfides (p.p.m.)	Dissolved Sulfides (p.p.m.)	H_2S (p.p.m.)	Effective Ave. pH	Dissolved Sulfides (lb. per day)	Lb. Cl Used per Lb. Dissolved Sulfides Removed
0	21.60	1.51	1.05	0.36	7.36	200	—
1,000	21.55	1.18	0.80	0.29	7.27	142	17.2
2,210	21.59	0.77	0.43	0.16	7.21	86	19.4

rine and is not soon mixed with the rest of the flow, a higher proportion of the chlorine will be used up in side reactions.

The efficiency of chlorine in reacting with sulfides chemically shows that it is more economical in many cases to destroy the sulfides after they are formed than to attempt to prevent their generation. But if this principle were to be followed rigorously, it would be necessary to install an excessive number of chlorinators.

Actual practice requires adoption of a compromise, locating the chlorinators where they will destroy sulfides entering the trunk sewers and also, by using moderate excess dosages, keep sulfides out for a distance of 2 or 3 miles downstream. In the Districts' system economies were effected by moving some of the chlorinators to points farther downstream than the original locations chosen on the basis of preventive chlorination. The present control of dosage is not based upon the chlorine demand of the sewage nor upon the sulfide concentration at the point of application, but rather upon the sulfide concentrations at the next control point below the chlorinator. A quantity of chlorine is added at the chlorinator station which is greater than the amount necessary to destroy the sulfides, but generally lower than the total chlorine demand. The excess of chlorine at the point of application produces oxidizing compounds which will destroy sulfides further downstream. Also, it has some sterilizing action and permits accumulation of some dissolved oxygen in the sewage. The dosage is regulated by a method of trial to give desired results at the next control point.

Because of the necessity of using the chlorine in part as a preventive measure and because it is not feasible to feed at all times exactly the right amount of chlorine, it is impossible to attain average efficiencies equal to those theoretically attainable.

No comprehensive tests have been made comparable to those carried out in 1939, but it is believed that with the revised procedure an average of 12 to 15 lb. of chlorine were used for each pound of sulfide eliminated.

It is well known that when a stream of sewage is dosed with chlorine at a rate approximating the chlorine demand, sulfides do not re-appear for some distance downstream. This observation has seemed to support the view that destruction of the sulfide-producers is a major function of chlorination. But unless the dosage materially exceeds the chlorine demand, it is not likely that the microbes in the slimes are much affected. Probably the principal reason for delay in re-appearance of sulfides is to be found in the ability of chlorine to leave oxidizing compounds in the sewage and to permit the accumulation of dissolved oxygen.

This was illustrated in tests at the junction of South Park Ave. and Wadsworth Ave. trunks. An average of nine tests on the South Park Ave. trunk from 12:20 to 3:20 P.M. showed dissolved sulfides averaging 1.49 p.p.m. in a flow of 1.1 m.g.d., corresponding to 13.6 lb. of sulfide per day. Application of chlorine at a rate of 78 lb. per day removed this sulfide, but left no residual chlorine detectable by either orthotolidine or iodide. After a flow time of 5 min. this sewage was joined by the Wadsworth Ave. sewage, with a flow volume about half as great as in the South Park Ave. trunk, and bringing in dissolved sulfides at a rate of 7.1 lb. per day. At the next manhole below the junction the flow of dissolved sulfides was only 1.8 lb. per day. Thus the chlorinated South Park Ave. sewage, though showing no chlorine residual, was able to oxidize the Wadsworth Ave. sewage, knocking out sulfides at a rate of 5.3 lb. per day.

Graham (9) has proposed that oil field waste waters be chlorinated by first treating a portion of the water at high chlorine dosages and then mixing this with the rest of the water; the idea being to produce toxic organic chlorine compounds such as chlorinated phenols. Laboratory experiments were made to test this procedure on water from the Santa Fe Springs system. By varying the total dosage and the split, 28 different treatments were applied.

When the split treatment procedure was followed and when the gross dosage of chlorine was less than 50 p.p.m., no chlorine residual was found when tested by the starch-iodide method in neutral solution, but apparent residuals were found if the sample was acidified. This indicates the conversion of the iodide present in the water at concentrations of about 15 p.p.m. into iodate in the split treatment. Iodate may delay sulfide generation by chemical reaction but is not toxic in neutral solution.

Complete suppression of sulfide generation in the bottles for more than 15 days required gross chlorine dosages in excess of 50 p.p.m. regardless of how applied; lower dosages delayed generation. If the portion of the water first receiving chlorine in the split treatment was dosed at a rate of 300 p.p.m., which was just at the break-point on the chlorination curve, then the effectiveness of the treatment, as judged by the total chlorine requirement to accomplish comparable retardation of sulfide generation, was much poorer than with straight treatment. Under other conditions, with initial chlorine dosages ranging from 100 to 2,500 p.p.m., the split treatment was better than straight treatment provided the gross dosage was less than 40 p.p.m.

The conclusion was that this procedure held very little promise in treatment of the Santa Fe Springs water.

These results do not necessarily apply to water from other fields. The amount of chlorine lost in converting iodide to iodate will be proportional to the iodide content, and the total chlorine demand, as well as the content of various forms of organic matter, may vary widely from field to field.

Aeration

The surface aeration which occurs in the flow of a partly filled sewer is extremely important in the control of sulfides. Where velocities are inadequate to supply enough aeration, it might be possible to install compressed air stations at suitable intervals, such as one mile, but it does not appear that this would often be feasible. Preliminary aeration or "preaeration" ahead of treatment plants is practised in a number of places. Mahlie (10) presented detailed observations on this procedure at Fort Worth, Texas.

The same result is accomplished by returning oxidized effluent. The extensive use of recirculation in trickling filter plants, especially where this is done through the primary clarifier, has effectively eliminated the odor problems which otherwise would arise from the spraying of sewage containing H_2S. Recirculation of activated sludge effluent through a primary clarifier may also be beneficial. At Ryan Air School at Hemet, and at Perris, Calif., the effluent of oxidation ponds is recirculated through Imhoff tanks to assure freedom from sulfide odors.

An important contribution in the field of sulfide control procedures was made by Ewald Lemcke, who in 1942 began the injection of air into a pressure line in Orange County. This line is 2 miles long and carries a flow of about 1 m.g.d. Formerly the sewage coming out of this line carried dissolved sulfides at a concentration of about 7 p.p.m. The initial use of 60 c.f.m. of air reduced this generally to zero. The air input was later cut to 22 c.f.m., with dissolved sulfide being held to a few tenths of a p.p.m. This procedure certainly deserves trials in other situations.

Sodium Nitrate

Next to air, the cheapest industrial oxidizing agent is sodium nitrate. Nitrate does not react chemically with sulfide. There is a possibility that it may react biologically, and in any case it competes with sulfate as an oxygen supplier for oxidation of organic matter. Thus sulfate reduction seems generally to be prevented when nitrate is present.

Fales (11) reported the use of nitrate to control odors from ponded paper mill wastes in 1929, and it is used similarly in treating cannery wastes (12, 13). Carpenter (14) described its use in a polluted stream in 1932, and Gietz and Pigretti (15, 16) reported favorably in 1943 on its use to control sulfide formation in sewage. Heukelekian (17) delineated its effect on sulfide generation in bottled sewage, and laboratory results similar to his have been secured in this research.

In March of this year a test run was made on the Orange County sewer from Anaheim to Garden Grove, a distance of 3½ miles. Without nitrate a build-up of 0.4 p.p.m. of sulfide was noted in this section. After 2 days of treatment with about 20 p.p.m. of sodium nitrate there was a decrease of 0.4 p.p.m. in the same section, and on the third day with a feed of about 40 p.p.m. the decrease was 0.6 p.p.m. These results might seem meagre in relation to the dosage, but the experiment was not made under favorable conditions, in view of the low sulfide generation at the time. Furthermore, tests at the end of the section showed that only about half of the nitrate was used up. The experiment is to be repeated with application of the nitrate farther upstream, and with tests over a greater distance.

Other Oxidizing Agents

In preliminary bottle experiments sodium chlorate showed behavior similar to sodium nitrate. Unless unexpected advantages appear, its higher cost rules it out as a competitor.

Chromate is able to react chemically with sulfides, and no sulfide, at least in dissolved form, is produced in sewers where chromate is present. The costs of chromates are such that this material could not be used economically where it would have to be purchased at market prices. The extensive use of chromic acid plating baths, however, may provide situations where its availability as a waste material may be important.

Powdered manganese dioxide was without effect on sulfide in bottle experiments. Persulfate delayed sulfide generation until it was reduced to sulfate.

A few years ago an attempt was made to promote the use of ozone for sulfide control. In 1936 an "ozonator" was installed on the Orange County Joint Outfall. A weir was set up in the line and ozonized air was blown under the sheet of water falling over this weir, so that bubbles of this air were carried down into the stream. In a test run the ozonator was operated intermittently at intervals of about 10 min. Sulfide concentrations were measured at the next manhole downstream.

Six tests with the ozonizer off gave an average sulfide concentration of 0.9 p.p.m., while six tests with the ozonizer on showed an average of 1.1 p.p.m. The difference is within the range to be expected from the erratic variations of the sulfide concentrations, but in any case no benefit can be attributed to the ozone. This result is to be expected, for the actual amount of ozone dissolved by the sewage must be very small. Since sulfides can be destroyed simply by dissolving oxygen in sewage, the ozonizer seems quite superfluous for this purpose.

Other Toxic Agents

Toxic substances, which in moderate dosages are able to depress biological activity even though not effecting a complete kill of all microbes, may be quite useful in sulfide control. This is especially true in free-flowing sewers, where complete elimination of sul-

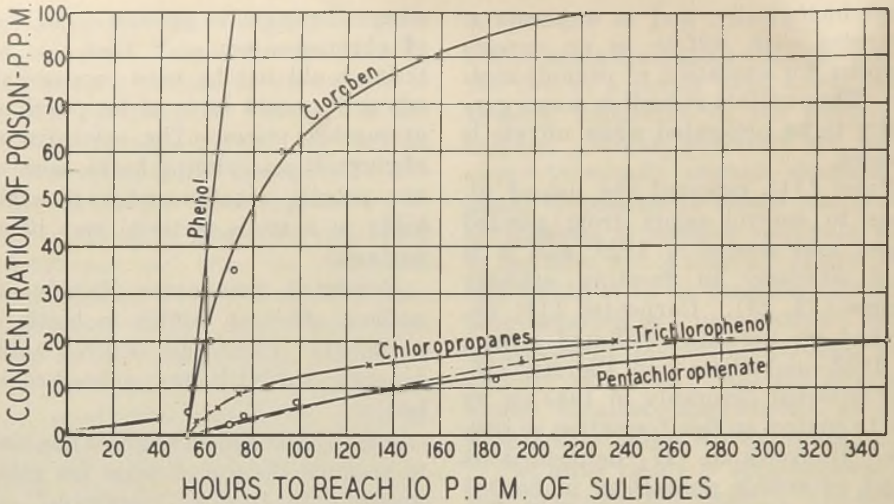

FIGURE 18.—Relative effectiveness of various toxic agents in retarding sulfide production in bottled sewage.

fides may be accomplished with only moderate reduction of biological action.

Bottle experiments have been made to compare the effect of certain of these compounds on the rate of production of sulfides. In the first experiment, sewage was dosed with various concentrations of phenol, "Cloroben," chlorinated propanes and "Santobrite" (sodium pentachlorophenate), using a total of 240 incubation bottles.

The relative efficiencies of these materials in retarding sulfide formation depends somewhat on the basis of comparison. It appeared that the most satisfactory basis would be the time required for sulfide concentrations to reach 10 p.p.m. From smooth curves drawn through the data for individual dosages of toxic agent, these times have been obtained and are represented on the master plot in Figure 18.

The efficiencies of these agents may be compared on the basis the dosages necessary to effect a specified delay in reaching 10 p.p.m. of sulfide. If one considers the amounts necessary to cause a delay of 50 hours, the relative required dosages of Santobrite, chlorinated propanes, Cloroben and phenol as deduced from Figure 18 are in the ratio 1:2:10:40. (The figure for phenol is only approximate, as it required extrapolation from the highest dosage used, which was 150 p.p.m.)

Another similar experiment was performed, but using, instead of sewage, a medium containing 1,000 p.p.m. peptone, 300 p.p.m. of beef broth, and buffer salts and sodium sulfate. The toxic agents compared in this case were Santobrite, trichlorophenol, and Cloroben. In this case also Santobrite was just 10 times as effective as Cloroben. Trichlorophenol appeared to be slightly better than Santobrite at dosages below 8 p.p.m., but slightly inferior at higher dosages. A dotted curve has been drawn on Figure 18 to show the *relative* effectiveness of trichlorophenol and Santobrite (pentachlorophenate), although the actual comparison was made in a different experiment.

An interesting phenomenon was observed after relatively long periods of incubation with phenol and with Cloroben in the second of these two experiments. At all concentrations used the sulfide content ultimately rose to values considerably higher than in the blank containing no toxic addition. This is probably due to a selective action against other microbes which compete with the sulfide producers for available organic food material.

It is impossible to predict behavior in sewers on the basis of these bottle experiments, but one may expect that the *relative* effectiveness in the sewer will be roughly the same as observed in the laboratory tests. Thus the bottle experiments are useful in pointing the direction for field tests.

The complete evaluation of toxic agents for sulfide control in sewers is a prolonged and difficult undertaking, and the tests thus far made are not conclusive for any of these compounds.

Cloroben, which is understood to be about two-thirds orthodichlorobenzene and trichlorobenzenes, with the remainder consisting of emulsifying agents and water, was given a limited test in Orange County, with results which were not encouraging. The Los Angeles County Sanitation Districts tested it in 1942 and 1943 by putting it into the pump station delivering to the San Gabriel force main. It appeared that dosages of at least 40 p.p.m. were necessary to cut in half the rate of sulfide generation in this line. The application here doubtless was not made in the most efficient manner. It would be better to apply the chemical far up in the lines, to get the benefit of reduced biological activity before the sewage reaches the pump station, and the results might appear more impressive in free-flowing sewers than in pressure lines.

Eldridge (18) gave a discouraging report on the use of orthodichlorobenzene for controlling sulfides in sewers.

In contrast to the foregoing rather pessimistic observations, the city of Los Angeles has made tests during recent months which seem to show highly beneficial results with dosages as low as 1.5 p.p.m., and the city of Long Beach has obtained some similar results. It is evident that much more information is needed before reliable conclusions can be reached as to the effect of Cloroben on sulfide generation.

It must be noted that dichlorobenzenes have a remarkable ability to mask other odors. Because of this olfactory effect, Cloroben may do more good in the way of odor control than indicated by sulfide analyses. On the other hand, it may give a false impression as to its effect on sulfide concentrations if analytical studies are not made.

The material identified as "chlorinated propanes" is a by-product material obtained from the Shell Oil Co., and is understood to consist largely of dichloropropanes and dichloropropylenes. On the basis of promising laboratory tests the Santa Fe Springs Waste Water Disposal Co. decided to try this in its effluent lines. When arrangements were made to perform the test, the supplier asked us to try crude chlorinated butanes instead of chlorinated propanes. This was agreeable, and an experiment was carried out in June, 1944, by feeding this material into one of the twin effluent lines, at a dosage of 15 p.p.m. Sulfide tests were made at the plant and at a point 8 miles downstream. On the fourth day of the experiment, when conditions probably had approached fairly close to a steady state, the tests averaged as follows:

At plant:	Both lines	3.4 p.p.m.
8 miles down stream:	Treatment with 15 p.p.m. chlorinated butanes	1.9 p.p.m.
	Control line	7.8 p.p.m.

These results are certainly promising enough to warrant further experimentation, but a combination of intervening circumstances has caused a deferment of any further tests by the company.

"Santobrite," which is a trade name for sodium pentachloropenate, is now undergoing field tests in the Los Angeles County system.

Trichlorophenol can be made at the point of application by pumping a phenol solution into the stream of chlorine water from a chlorinator, so that the two chemicals mix before reaching the sewer. Because of the moderate prices of phenol and chlorine, the product made in this way is materially cheaper than Santobrite and Cloroben.

Experiments are now being made with this process in the Orange County sewer system. Tests will also be made with mixtures containing mono- and dichlorophenols, produced by altering the chlorine-phenol ratio.

Iron Salts

Addition of iron salts to sewage to precipitate insoluble iron sulfide and thus prevent escape of H_2S has been practised in a number of places. It has generally been supposed that the reaction proceeds as shown by the equation:

$$Fe^{++} + HS^{-} \rightarrow FeS + H^{+}.$$

In accordance with this equation, 7 parts of Fe should precipitate 4 parts of S.

Numerous laboratory experiments have been made to test the efficiency of iron salts for this purpose. Figure 19 shows the results obtained when $FeSO_4$ was added to anaerobic sewage with high initial sulfide content. The first part of the curve has a slope close to that required by the above equation, showing that the added iron has an efficiency of nearly 100 per cent under these conditions. But when more iron is added in an attempt to lower the dissolved sulfide content below 3 p.p.m., the efficiency drops off and a rather large excess is required if dissolved sulfides are to be lowered much below 1 p.p.m.

Compared on the basis of equal iron content, ferrous sulfate and ferrous chloride show identical results. Hydrogen ion concentration has no significant effect within the pH range normally encountered in domestic sewage. The reaction is greatly influenced, however, by the presence of a trace of dissolved oxygen. This may be illustrated

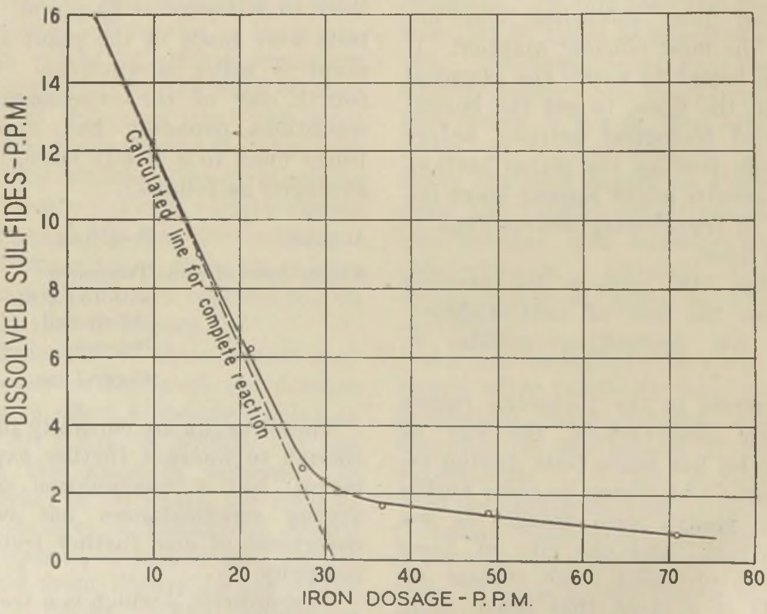

FIGURE 19.—Effect of ferrous sulfate added to bottles of anaerobic sewage.

by the following experiment: A bottle of sewage is allowed to become septic and to produce 1 to 2 p.p.m. of dissolved sulfides. If a small amount of iron, say 5 p.p.m. in the form of ferrous sulfate or chloride, is mixed with the sewage, there is very little darkening of the mixture, but if part of the sewage is withdrawn from the bottle so that the surface is exposed to the air, then darkening near the surface is observed. If the bottle is briefly shaken, quite rapid blackening takes place.

Parallel tests for total and dissolved sulfides in aerated and unaerated samples of septic sewage dosed with ferrous sulfate gave the results as shown in Table VIII.

TABLE VIII.—Reduction of Total and Dissolved Sulfides by Ferrous Sulfate

Fe^{++} Dosage (p.p.m.)	Sulfide Concentrations (p.p.m.)			
	Unaerated		Slightly Aerated	
	Total	Dissolved	Total	Dissolved
0	3.5	3.0	3.0	2.1
4	—	2.4	—	0.4
15	2.7	1.1	1.4	0.1

The results are significant not only in showing the more complete precipitation of dissolved sulfides in the presence of air, but also in demonstrating that in the reaction a part of the total sulfides are destroyed.

It seems probable that the presence of oxygen, or even of any weak oxidizing agents, causes the formation of FeS_2, as may be represented by the following equation:

$$Fe^{++} + 2HS^- + O \rightarrow FeS_2 + H_2O + 2H^+.$$

When iron disulfide in the freshly precipitated form is treated with acid in the sulfide test, it dissolves to produce H_2S and S, thus giving a test for only half as much sulfide as went into the formation of FeS_2.

Support for the theory that FeS_2 is formed is found in the fact that the product of corrosion of iron by sulfides is largely FeS_2, as shown by Pomeroy (6). Further evidence was obtained by examining the black deposit which forms in a sewer of the Sanitation Districts below the point where it receives iron pickling waste from a steel mill. This material was likewise found to be chiefly FeS_2.

Not only does oxygen accelerate the precipitation of iron sulfide but iron also catalyses the oxidation of sulfides even beyond the formation of FeS_2. In many instances the decrease in total sulfide is more than one-half the decrease of dissolved sulfides, thus more than would be accounted for merely by the formation of FeS_2. The catalytic effect of iron salts on oxidation of sulfides is well illustrated by preparing a slightly acidic sulfide solution in pure water. Oxidation proceeds very slowly. If a small amount of iron salt is added, the solution darkens but in the course of a few minutes its dark color gives way to a white turbidity characteristic of collodial sulfur.

Since oxidation aids precipitation of iron sulfides it would be expected that ferric salts would be more effective than the ferrous compounds, but in practice there is not much difference. In the complete absence of oxygen the ferric salt is better than ferrous, as may be seen by comparing Figure 20 with the corresponding part of Figure 19. But a little oxygen greatly improves the effectiveness of ferrous salts and is without effect on the ferric, so that under these conditions the relationship is reversed. Thus the ferrous salts are better when added to a free-flowing sewer, where some oxygen is always present. The principal effect of the ferric salt, when added to sewage of low sulfide content, seems to be oxidation of the sulfide at the time of mixing; very little precipitation occurs unless the initial sulfide concentration exceeds 10 p.p.m.

Mixtures of ferrous and ferric salts

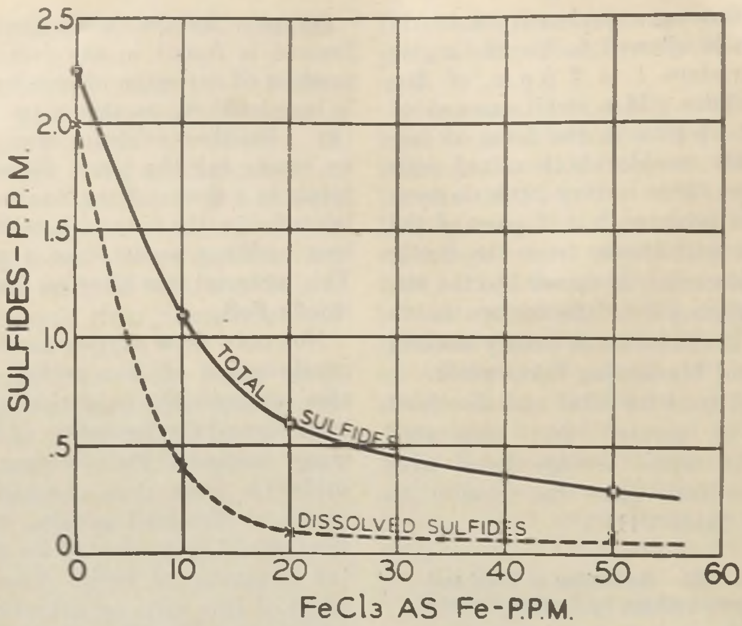

FIGURE 20.—Effect of ferric chloride added to bottles of anaerobic sewage.

were found to be more effective than either alone. By using only a few parts per million of excess iron, sulfides can be reduced to levels of 0.2 to 0.3 p.p.m. in the absence of aeration, or to 0.1 with slight aeration. The most effective results were obtained with solutions containing about two-thirds of the iron in the ferric state. This suggests the possible precipitation of Fe_3S_4, but no evidence is available to indicate that such a compound could be produced in this way. It may exist as an intermediate step in the transition to FeS_2.

One of the most common procedures for adding iron salts to sewage is the Scott-Darcey method, in which iron is dissolved in chlorine solution. A sample of Scott-Darcey solution from an operating plant was used for tests in the laboratory and in the sewers. This solution had a total iron content of 26,700 p.p.m., of which 23,800 p.p.m. was in the ferrous state. Most of the remainder was suspended ferric hydroxide, of which a part was so finely dispersed that it could not be removed by either filtration or centrifuging. In laboratory tests this solution gave results which were superior to ferrous sulfate in reducing dissolved sulfides and were somewhat better even than the mixtures of ferrous and ferric salts. Even so, the results do not show very good efficiency unless sulfides are initially quite high. Figure 21 shows comparative results in anaerobic sewage, using ferrous sulfate and Scott-Darcey solution, and Figure 22 shows a comparison with chlorination. Scott-Darcey solution, compared on the basis of the chlorine requirement, was slightly more efficient than chlorine in lowering dissolved sulfides from 4.8 to 1.5 p.p.m. The sewage used in this test had a chlorine-sulfide ratio of 4.6 for complete removal of sulfide. If sewage having a higher chlorine-sulfide ratio had been used, Scott-Darcey treatment might have shown a substantial relative advantage down to dissolved sulfide concentrations of about 1 p.p.m., but in most cases it would be less efficient than chlorine in getting down to fractional parts.

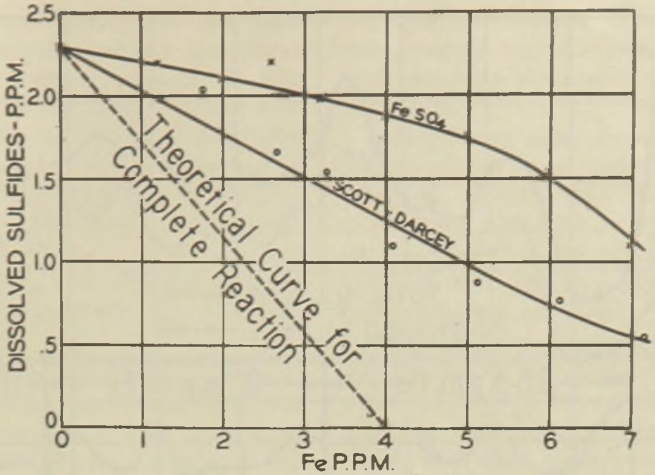

FIGURE 21.—Effects of ferrous sulfate and Scott-Darcey solution added to bottles of anaerobic sewage.

The experiments described with iron thus far deal only with the effects immediately after dosing. A study was also made of the behavior of iron-treated samples during subsequent incubation. The presence of iron, at least in amounts up to 100 p.p.m., had no important effect on the activity of the sulfide-producing microbes, and it was regularly observed that even in the presence of excess iron the dissolved sulfide content rose to levels around 1 to 1.5 p.p.m. This was equally true for sewage dosed with ferrous sulfate and with Scott-Darcey solution.

Field experiments fully confirmed all implications of the laboratory tests. In the Gardena trunk sewer, tests were made with ferrous sulfate, ferric chloride, and Scott-Darcey solution. Tests at manholes immediately above and below a point of application of $FeSO_4$ gave results as shown in Figure 23. This indicates quite good removal of dissolved sulfides, as would be expected from the presence of a small amount

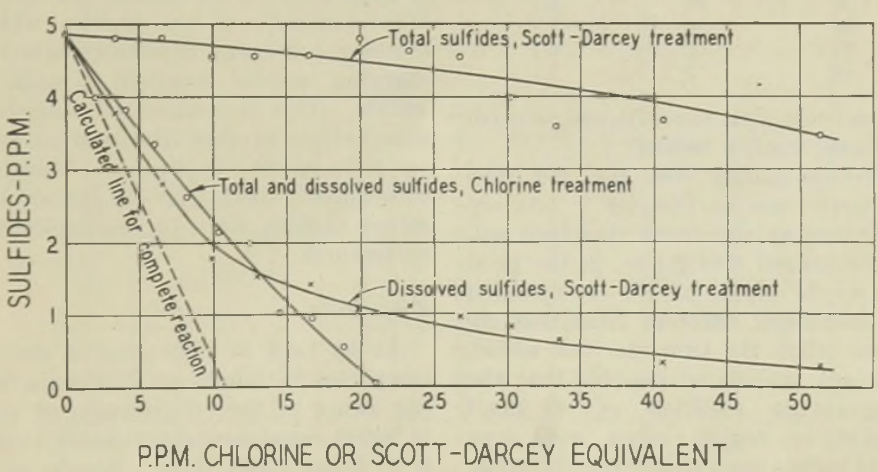

FIGURE 22.—Effect of chlorine and of Scott-Darcey solution added to bottles of anaerobic sewage.

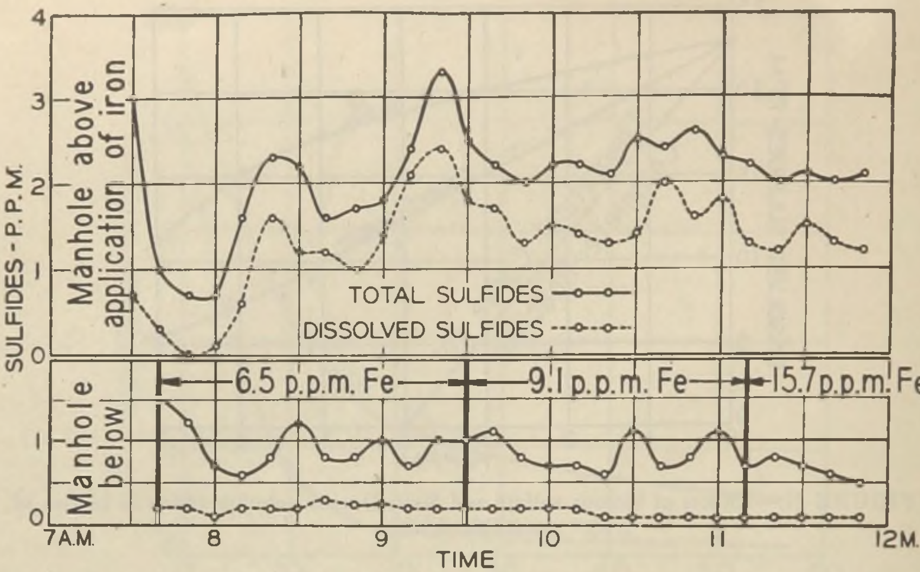

FIGURE 23.—Effect of ferrous sulfate added to Gardena sewer.

of oxygen in the sewage stream. Ferric chloride in similar dosages did not reduce dissolved sulfides below 0.5 p.p.m.

Ferrous sulfate was also fed at the upper end of the Gardena trunk for 2 months. Average dissolved sulfide concentrations at the lower end with various iron dosages were as follows:

Iron Dosage (p.p.m. Fe)	Number of Tests	Average Dissolved Sulfides—9:00 to 10:45 A.M.
0	26	1.7
16	14	1.4
32	17	0.7
48	7	1.1

A brief test with Scott-Darcey solution indicated similar results.

Ferrous sulfate was also fed near the upper end of District 2. At the lower end of the trunk dissolved sulfides averaged 0.84 p.p.m. in the presence of 14 p.p.m. of Fe—a condition not materially different from that observed when the iron was not added.

It was considered possible that the simultaneous addition of a small amount of copper along with iron would induce more sulfide precipitation. Copper precipitates sulfides very completely but when a mixture containing 25 mol per cent of copper was used the results were no better than with iron alone, unless the dosage was so large as to provide enough copper to combine with all of the sulfide.

The mass of information collected on the effect of iron salts clearly shows that other procedures should be used if dissolved sulfides are to be reduced below 1 p.p.m. Yet there are situations where iron may be useful. This is illustrated by the case of the Bond Wool Company of Los Angeles, which discharges a spent depilatory solution carrying several hundred p.p.m. of sulfide. This is neutralized with ferrous sulfate so that dissolved sulfides are reduced to 1 to 2 p.p.m. Dilution subsequently takes the remaining dissolved sulfides down to negligible concentrations.

Zinc Salts

As far back as 1932 some of the oil companies in Southern California, being aware of the effectiveness of zinc in bottle experiments, undertook to use it in waste water lines. Results were judged by use of the antimony method for determining sulfides. In this test the addition of acid before the antimony solution was probably omitted as seems to be customary with those who use the test in this field. If the acid is omitted, zinc sulfide does not react so that the test shows practically only dissolved sulfides. Thus it is not possible to ascertain from the records whether there was any suppression of sulfide generation, or whether the zinc merely combined with the dissolved sulfides.

The practical experience of the Los Angeles County Sanitation Districts with sulfide control by zinc dates from 1938, when the newer methods of sulfide analysis became available and separate tests were made for total and dissolved sulfides. A chlorinator was in service on a line in Compton where high concentrations of total sulfides were known to prevail. When tests were made for dissolved sulfides, they were found to be absent. Investigation revealed that an electrolytic galvanizing plant making wire screen was discharging continuously a rinse water containing enough zinc to combine with the dissolved sulfides. The chlorinator was removed and the sewer has since that time been adequately protected by this waste.

Soluble zinc salts, like chlorine, act both chemically and bactericidally. By chemical reaction they quantitatively precipitate dissolved sulfides as inert zinc sulfide. In their sterilizing action they are very effective against the sulfide-producing microbes. Addition of 2 p.p.m. of zinc in a soluble form to sewage in a bottle will delay sulfide generation for one or two weeks, and even 1 p.p.m. may cause a delay of 4 or 5 days. But when enough sulfide has accumulated to combine with the zinc, it is then inactivated and sulfide generation thereafter proceeds at a normal rate.

If the results obtainable in bottles could be reproduced in sewers zinc would displace most other forms of chemical sulfide control. Unfortunately, this is not the case. In sewers the sulfides are produced by slime accumulations. As the zinc starts to diffuse into the slime layers, it is met by

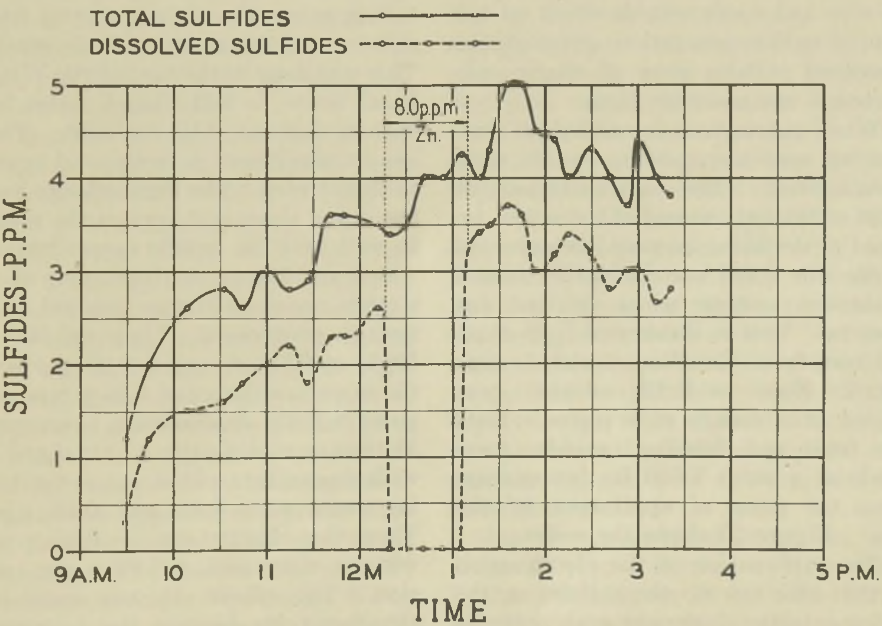

FIGURE 24.—Effect of zinc sulfate added to North Long Beach force main.

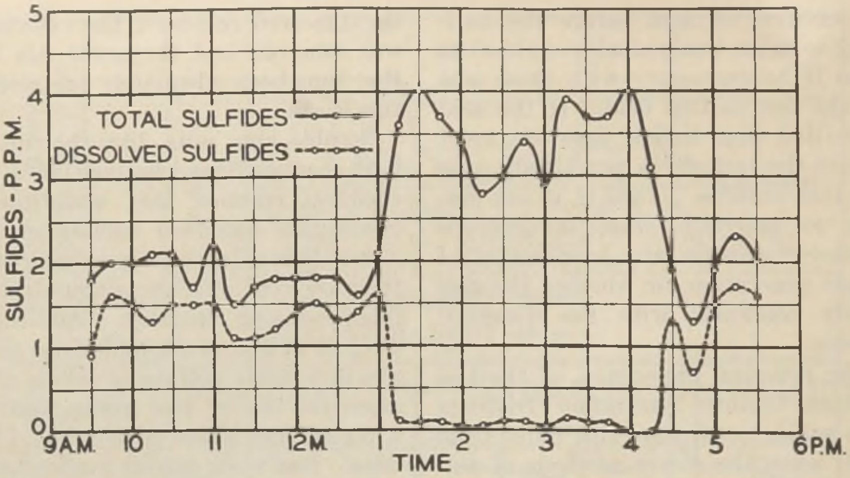

FIGURE 25.—Effect of zinc chloride added to Wadsworth Ave. sewer, showing analyses made 7,600 ft. below point of addition. Sewage contained 6 p.p.m. of added Zn between the hours of 1:05 and 4:20 P.M.

sulfide diffusing out, and thus is precipitated so that it does not reach the guilty microbes.

Experiments were made in the 4,300-ft. North Long Beach force main to determine whether the sterilizing action of zinc would be effective in that situation. Results are presented in Figure 24. It is seen that addition of 8 p.p.m. of zinc had no detectable effect on the rate of sulfide generation, although the dissolved sulfides were of course converted to the insoluble form.

When zinc salts were added to free-flowing sewers surprising results were encountered. The concentration of total sulfides at the end of the sewer, instead of declining as would be expected if the zinc acted bactericidally, showed a marked increase when the zinc was present. This is illustrated by a typical test from the Wadsworth Avenue trunk. Zinc (as $ZnCl_2$ solution) was added at a dosage of 6 p.p.m. Tests for total and dissolved sulfides were made at a point 7,600 ft. downstream from the point of application of the zinc. Figure 25 shows the results.

The explanation of the phenomenon is that zinc ties up the sulfides in the flowing body of sewage and prevents the loss which normally occurs by oxidation and evolution. Thus when an excess of zinc is present, the sulfide concentrations found at the end of the sewer represent the total amount produced by the slimes. In addition to its value for sulfide control, zinc is a useful research tool because of this ability to reveal total sulfide generation. It is even possible to measure the total sulfide generation in a sewer in which sulfide concentrations are decreasing. This was done in the case of the Wright Road sewer, a 3-ft. line 6 miles long with a slope of 0.15 per cent. There are no significant accretions of sewage in this stretch. The high velocity keeps the sewer clean and aerates the sewage so well that the sulfide concentrations, which are low in the beginning of the stretch, are even further reduced as the sewage progresses. Thus on May 8, 1941, sulfides averaged 0.31 p.p.m. at the upper station, and 0.26 p.p.m. at a point 6 miles downstream (average of 31 tests at each station). On April 24, with zinc sulfate added, the corresponding tests were 0.40 and 0.46 p.p.m. Thus the change was − 0.05 p.p.m. without zinc, and + 0.06 p.p.m. with zinc. The effects, though small, are significant in showing the occurrence of sulfide generation in a sewer in which the concentrations were actually declining.

Recently the Santa Fe Springs Waste Water Disposal Co. made carefully controlled experiments in the 15-mile lines carrying petroleum waste water to the ocean. Before the test, analyses at the ocean end of the line were showing 14 p.p.m. of total sulfides. Zinc in the form of sulfate was added to the upper end of the line at the rate of 50 p.p.m., sufficient to convert 24 p.p.m. of sulfide from the soluble to the insoluble form. Total sulfide concentrations fell to 7 p.p.m., showing that sulfide generation was cut in half, but this reduction was attained only at the cost of a very high dosage. In order to obtain any significant reduction in sulfide generation it was necessary to use much more zinc than was required to remove the dissolved sulfides chemically. Hence the sterilizing action of zinc in this situation is of no consequence.

It might be hoped that continued use of zinc in a given sewer would finally kill out the slimes, but this is not the case. The lateral line carrying the galvanizing waste previously referred to has carried several p.p.m. of zinc almost continuously for several years, yet that line still produces sulfides at a normal rate.

In contrast to iron, zinc has the advantage of practically complete reaction with dissolved sulfides. It may be applied at the extreme upper end of a line and, even though it is first converted to $ZnCO_3$ when mixed with the sewage, it will hold dissolved sulfides to concentrations too small to detect all the way to the end of the line. Furthermore, the reaction is quantitative, 2.04 parts of zinc combining with 1 part of sulfide. No excess is needed to cause the reaction to go to completion.

One or two apparent exceptions have been noted to the rule that zinc reacts completely. The observations made at the end of the Santa Fe Springs Waste Water Co. lines in the experiment previously referred to, wherein a large excess of zinc was used, showed colors corresponding to dissolved sulfide concentrations of 0.5 to 0.6 p.p.m. It is believed that this was due to some interfering substance, such as hyposulfite, giving a false analytical result.

The Sanitation Districts have found zinc sulfate useful in a number of locations. In many situations the choice between zinc and chlorine will be based only upon economy, and will depend upon relative costs of the chemicals, chlorine efficiencies, increase of total sulfides upon zinc addition, and cost of feeding equipment. With small sewage flows the choice will generally rest on zinc because of the simplicity of the devices which may be used to feed a zinc sulfate solution.

Other Metal Compounds

Copper sulfate has occasionally been used for sulfide control. Hood (19) reports phenomenal results at Ridgewood, New Jersey, where this compound served to clean out slimes and to kill tree roots growing in the sewers and thus facilitate their removal. It is claimed that after treating the system in this way the alkalinity of the sewage declined and odors were largely eliminated. It is not clear to what extent these results were due to destruction of the slimes by copper, or to what extent the improvement may be attributed to improved flow conditions as a result of the removal of roots and other partial stoppages in the pipes. If conditions in a sewer are favorable for the growth of sulfide-producing slimes, it does not seem likely that any kind of cleaning or sterilizing job will be so effective that these slimes will be kept out for more than a few days though, of course, if sludge deposits are a factor, the results of cleaning may be more lasting.

One very evident effect of the addition of copper salts to septic sewage is the precipitation of insoluble CuS. In this respect copper behaves in a manner similar to zinc. When sulfide tests are made on sewage treated in this manner, there is an apparent fall of total sulfides as well as dissolved sulfides. This, however, is only an apparent effect, due to the fact that copper sulfide is so extremely insoluble that it does not react in any of the ordinary analytical sulfide tests.

It is not to be expected that moderate dosages of copper will have any appreciable sterilizing effect for, as in the case of zinc, it is inactivated as soon as it encounters the sulfides diffusing out from the slime layer. If there is any value in the sterilizing action of copper it could only be when used in shock dosages.

The only field experiment made by the Los Angeles County Sanitation Districts on the use of copper was in conjunction with iron, as mentioned elsewhere in this report. In this instance the copper appeared to reduce both total and dissolved sulfides in the proportion of two parts of copper to one of sulfide, as demanded by theory.

Since copper is generally more expensive than zinc its field of usefulness must be quite restricted. Yet there are situations where copper compounds may be cheaply available as by-products or waste materials. One such situation exists in the Los Angeles County Sanitation Districts' system where a large copper tubing plant has a waste containing copper and zinc salts, derived from metal cleaning operations. When this waste was discharged at an equalized rate, it wiped out sulfides in a line where chlorination was previously required. Plans to transport part of this waste by truck to another line were halted by a reduction of plant activity at the end of the war. The Districts have made no objection to the fact that the waste contains some free acid, for the alkalinity of the sewage at the point of entrance of the waste is sufficient to afford reasonable safety, and the benefit of the waste more than compensates for any possible hazard from the acid.

Many other metal salts will also precipitate sulfides, as nickel, lead, cadmium, mercury, silver, and other less common metals. As in the case of copper, these metals may sometimes be present in industrial wastes, but are not otherwise likely to be of any importance in relation to the sulfide problem.

Ammoniation

It has been shown that the amount of hydrogen sulfide escaping from the surface of the sewage and changing to sulfuric acid on the walls of the conduit is generally very small in comparison with the total amount of sulfide carried by the stream. This leads to the conclusion that corrosion control could be accomplished much more economically by neutralizing the acid than by destroying the sulfides in the sewage.

This procedure was tried out in a junction manhole where turbulence of septic sewage had caused serious deterioration of the concrete structure. Moisture in the putty-like material on the walls showed 6 per cent sulfuric acid. Ammonia was released into this structure at a rate of 1½ lb. per day. The acid content gradually fell, reaching zero in a month. Even at the next manhole nearly 100 ft. distant the concentration was reduced one-half.

It appeared that it would be practical to apply this method for protection of the 3-mile section of 9 ft. 6 in. sewer immediately above the treatment plant. A plan was devised (20) for hanging an iron pipe in the crown of the sewer, with replaceable orifice tubes at 20-ft. intervals. A mixture of air and ammonia was to be fed through this line. Cost of the installation was estimated at $5,000, and the ammonia cost, assuming use of a three-fold excess, would be $1,000 per year. The corresponding cost for complete control by chlorination was estimated at $25,000 per year.

In 1943, before this scheme had gone beyond the experimental stage, sulfides dropped so low that further control on the joint outfall was unnecessary. This is shown in Figure 2, which indicates total sulfides averaging about 0.4 p.p.m. for 1943–45. Dissolved sulfides seldom exceeded 0.1 p.p.m. The drop is attributed to increased flow and to certain industrial wastes.

Since the end of the war sulfide concentrations have come up somewhat, and chlorine is again being used on this section, but when Districts 15, 16 and 17 are cut in and additional pumps are installed at the plant, sulfides in the joint outfall will again drop to negligible levels, so that ammoniation will not have a place in this line.

Ventilation

The experiences of the city of Los Angeles with sewer ventilation have been described in previous publications by Studley (21) and Smith (22), and the general subject of ventilation has been discussed by Pomeroy (23). Suffice it to say here that when properly applied this procedure dries out the sewer walls and thus stops the bacterial conversion of H_2S to H_2SO_4. Results have been satisfactory in the Los Angeles installations. Tests during the summer of 1940 at the station which was ventilating 4 miles of 10-ft. sewer showed the removal of 60 lb. per day of H_2S with the vented air, which otherwise would have formed 170 lb. per day of sulfuric acid.

Summary

In free-flowing sewers sulfides are produced only by slimes on the submerged surface of the sewer and by deposited sludge. In the flowing body of the sewage sulfides are not generated but on the contrary are destroyed by oxygen which is continually being absorbed from the surface.

Sulfate is the chief source of sulfide, yet other sulfur compounds also contribute. Even in purely domestic sewage sulfides may reach concentrations exceeding by as much as 7 p.p.m. the amount which could be formed from the available sulfate. Sulfates are easily reduced by the microbes to concentrations below 1 p.p.m., and under ordinary conditions the rate of sulfide production is very little influenced by sulfate concentration.

Cultures are able to adapt themselves to rapid sulfide production over a wide pH range, from less than 6 up to at least 9.

The rate of generation is proportional to the strength of the sewage and to the area of biologically active surfaces. The rate increases 7 per cent for each degree Centigrade rise in temperature. For a B.O.D. of 100 and a temperature of 20° C. the rate of sulfide production is 0.3 to 0.6 lb. per day per 1,000 sq. ft. of active slime surface.

The amount of sulfide reaching the end of the sewer is always substantially less than the amount generated, since a part is lost by oxidation and by escape of H_2S. If the velocity of flow in the sewer exceeds a minimum value determined by the temperature and sewage strength, the rate of oxidation is great enough so that no sulfide build-up occurs.

In large sewers the amount of sulfide escaping to the atmosphere is usually very small compared to the amount carried by the sewage.

Due to the rapid conversion of H_2S to H_2SO_4 on the exposed sewer walls, the atmospheres are generally far below equilibrium with the liquid. Saturations of 5 to 10 per cent are generally found. Calculations of the rate of production of sulfuric acid in the Los Angeles County Sanitation Districts system gave results in reasonable accord with the observed depths of penetration of concrete. In order to assure a life of 100 years for the largest sewers of the Districts it is necessary that dissolved sulfide concentrations shall not average more than 0.1 p.p.m.

In the design of sewer systems, consideration should be given to the desirability of maintaining velocities sufficient to avoid sulfide build-up and of minimizing pressure lines and points of high turbulence. Large concrete sewers probably can be protected from corrosion by clay liners of low porosity, but no other lining materials have yet been proven safe for long-time protection.

Rate of production of sulfide in sewers may be diminished by diluting the sewage with unpolluted water, by curbing industrial wastes of high temperature or of high content of organic matter, or by partial treatment of the sewage to lower the B.O.D. Raising the pH is sometimes practical to prevent escape of H_2S. Control of sulfates is of no value in sewage, but may be practical in oil field waste waters which contain no sulfate other than that which may be added by mixing with other wastes.

Mechanical cleaning may reduce sulfide generation, especially if the sewer contains sludge deposits or is so fouled as to retard the flow. Chemical cleaning, as by sulfuric acid, destroys the slimes and prevents subsequent sulfide build-up for several days.

Chlorine is efficient as a chemical agent for destruction of sulfides. The ratio of chlorine applied to sulfide destroyed is generally between 3 and 10, but in practical application an excess is needed to meet peak requirements. When an excess of chlorine is applied, it leaves the sewage in an oxidized state, which prevents the re-appearance of sulfide for some distance dowstream. Sterilization of the sewage flow does not necessarily affect the sulfide output by the slimes, but the slimes may be destroyed if sufficient dosages are used.

Aeration may be used to destroy sulfides by oxidation, especially immediately ahead of treatment plants. Return of the effluent of biological treatment processes to mix with the influent sewage accomplishes the same result.

Addition of sodium nitrate to sewers for sulfide control has possibilities, but requires further investigation. Ozonized air has no significant advantage over ordinary air. Chromates and other oxidizing agents may occasionally be of use when they are available as industrial wastes.

Moderate suppression of biological activity in sewers, sometimes only to the extent of 50 per cent, will prevent sulfide build-up. Various toxic agents have been tried for this purpose. Intensive research is now under way with chlorinated phenols, chlorinated propanes and butanes, and chlorinated benzenes. Results of laboratory experiments indicate that the chlorinated phenols are likely to be most satisfactory for this purpose.

Ferrous salts can be used economically if high dissolved sulfide concentrations are to be reduced to a level around 1 to 2 p.p.m. In order to reach lower concentrations it is necessary that some oxygen be present. In free-flowing sewers there is generally enough oxygen in the sewage so that dissolved sulfides may be economically reduced to 0.5 p.p.m. at the point of application. Apparently FeS_2 is a product of the reaction. Ferric salts are less effective than the ferrous, but mixtures of ferric and ferrous and also Scott-Darcey solution are more effective than either pure ferric or ferrous. With all of the iron salts, however, the effectiveness declines after mixing with the sewage so that subsequent sulfide generation will allow concentrations of dissolved sulfides to reach 1 to 1.5 p.p.m. even in the presence of an excess of iron.

Zinc salts react quantitatively to convert dissolved sulfides to ZnS. In the presence of an excess of zinc no oxidation of sulfide occurs and the total sulfide concentration reaching the end of the sewer is greater than when zinc is absent.

Copper and various other metal salts may be useful if available at low cost as waste materials.

Addition of ammonia to the atmosphere of large sewers is an economical method of preventing corrosion, since the amount of acid formed is very small in comparison with the total sulfide load carried by the stream of sewage.

Ventilation of large sewers serves to dry out the walls and thus prevent the conversion of H_2S to H_2SO_4.

Acknowledgment

The sulfide research project of the Los Angeles County Sanitation Districts was started under the administration of A. K. Warren, who was Chief Engineer of the Districts until his death in 1940. A. M. Rawn, who succeeded him, continued an active interest in this work and demonstrated his confidence in the value of a far-reaching research program. Many members of the staff of the Districts made valuable contributions to the work. It is impractical to cite each one but appreciation is especially due to the Field Survey Party under F. N. Smith. Recognition for their active participation in this research is also due to the late Walter Humphries of the Santa Fe Springs Waste Water Disposal Co. and to Ewald Lemcke and the engineers of the Orange County Joint Sewer Board. We are also grateful for the exchange of information and the cooperation which we have received from D. R. Kennedy of Long Beach, and H. G. Smith, E. G. Studley, and Reuben Brown of the city of Los Angeles.

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SOME FUNDAMENTAL CONCEPTS IN EXPRESSION OF LOADINGS AND EFFICIENCIES *

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The term "load" in sewage and sewage treatment plant practice is used in more than one sense. The specific elements that make up a load value will vary with the purpose it is to serve. In general, the purposes are two in number.

One is as a basis for calculation of capacities of plant units or to compare accomplishments of similar units at different plants. For such use, the value must be expressed in terms of factors which contribute to the relative ease or difficulty of doing the work. For example, the load that can be handled by a trickling filter is a function of filter size, stone size, strength of sewage, etc. The truest expression for this "work load" on a filter will be that which can give the nearest relative value to those essential elements that effect the filter capacity.

A second purpose of a load value is to furnish a base line for measuring operation efficiencies of a plant unit. This base line may also serve two purposes: (1) as a *unit rate efficiency* or (2) as a measure of total work accomplished which might be termed *capacity efficiency*. These two efficiency measurements are illustrated in Table 1.

TABLE 1.—Illustration of Unit Work Efficiency and Capacity Efficiency

	Filter A	Filter B
Volume of filter (cu. ft.)	2,000	1,000
Influent B.O.D. (lb. per day)	10	10
Effluent B.O.D. (lb. per day)	1	5.5
B.O.D. removed (lb. per day)	9	4.5
Capacity efficiency = C_{Eff} (%)	90	45
Unit rate efficiency = R_{Eff} (lb. per 1,000 cu. ft. per day)	4.5	4.5

This illustration shows that while the total production or *capacity efficiency*, in terms of B.O.D. removed for Filter A (90 per cent), is twice that for Filter B (45 per cent), the performance of each cubic foot of stone or the *unit rate efficiency* of Filter B is equal to that of Filter A, *i.e.*, 4.5 lb. B.O.D. removed per 1,000 cu. ft. of filter stone per day for each.

It is to be noted that in both of these cases, the load or base line value is the same, or 10 lb. of B.O.D. applied per day.

The following discussion of loadings and efficiency measurements will parallel the above reasoning.

Overall Plant Loadings

An expression for load on a sewage treatment plant has little practical value as such, because the work is performed, not by the plant as a unit, but by the various sections of the plant that specifically operate on certain objectionable components of the sewage.

A measure of work to be done by the plant as a whole would be expressed by the essential elements of rate of sewage flow, settleable and suspended solids, character of solids, biochemically oxidizable organic matter in settleable and non-settleable form, pathogenic bacteria and the extent and character of toxic substances, as from industrial wastes, which might lower the activity level of biochemical processes in the plant.

* Presented at 21st Annual Conference of the Michigan Sewage Works Assn., held at East Lansing on March 18–20, 1946.

Such of these values that apply, however, may be used as loading factors on specific plant units. The values represented by a raw sewage analyses are also essential in measuring overall plant removal or capacity efficiencies. The load on a plant as a whole can, therefore, be best shown by the usual raw sewage analysis and flow volume measurements to be translated to working load terms of the individual units of the plant.

Sedimentation Tanks

Work or Design Load

The use of the term "load" in this sense is intended to express the relative ease or difficulty with which the sedimentation tank removes the settleable solids. This depends on a number of influences, such as settling velocity of solids, rate of flow and dimensions of the tank. Assuming quiescent conditions, the relationship can be shown by:

$$\text{Load} = \frac{\text{Sewage Flow Rate} \times \text{Tank Depth}}{\text{Particle Settling Vel.} \times \text{Tank Vol.}}$$

The volume of flow and surface area for a given tank can be predicted. An accurate prediction of the settling velocity value of the solid particles is, however, very difficult, if not impossible. Such settling velocity value would have to include consideration of the concentration of particulate matter, its density and physical shape, temperature, viscosity of the liquid, and the tendency for particle coalescence. The rate can be approximated by a settling test as, for instance, in the Imhoff cone or any other cylinder which will provide a time-rate curve and, by proper integration, a settling value might be obtained for the specific sewage under consideration. An alternate would be to consider only the rate of settling of the slowest particle. By either method, the value would be an estimation only, since conditions in the tank cannot be duplicated because of the influence of eddy currents, baffling, short circuiting, and other factors that affect the final net rate of particle settling. In the absence of any accurate method of determining the settling velocity, the nearest practical expression for sedimentation tank loading would seem to be rate of flow per unit of time per unit surface area of tank, or a form such as:

$$\text{Load} = \frac{\text{Sewage Flow Rate (g.p.d.)}}{\text{Tank Surface Area (sq. ft.)}}$$

This is one of the expressions used in present day practice.

The only other expression commonly used at present for sedimentation tank loading is:

$$\frac{\text{Sew. Flow Rate (gal./hr.)}}{\text{Tank Volume (gal.)}} = \text{Det. Per.}$$

The latter seems less adequate than the first, since it fails to consider the essential fundamental of tank surface area.

Efficiency Loadings

In measuring the unit work efficiency of the settling unit, the load would be the quantity of *setteable solids* imposed on each unit of tank area per unit of time. And the unit rate of efficiency, or R_{Eff}, would be:

$$R_{Eff} = \frac{\text{Settleable Solids Rem. (lb./day)}}{\text{Tank Surface Area (sq. ft.)}}$$

The efficiency with respect to the settling tank production, or total removal efficiency, would be:

$$C_{Eff} = \frac{\text{Settleable Solids Rem. (lb./day)}}{\text{Infl. Settleable Solids (lb./day)}}$$

The use of suspended solids as often practiced for measurement of efficiencies of settling units is misleading. A tank cannot remove particles which will not settle. As a consequence the unit may show less efficiency with a sewage that happens to be proportionately high settleable solids content. Actually, however, the efficiency in terms of the work the tank can do may be higher in the case of the first tank showing lesser efficiency on a suspended solids basis.

Trickling Filters

Work or Design Load

The primary function of a biochemical oxidation filter is to reduce the biochemical oxidation demand in the sewage liquid. The load in terms of burden on the filter would be, in its simplest expression:

$$\text{Load} = \frac{\text{B.O.D. Applied per Time Unit}}{\text{Eff. Active Biological Conc.}}$$

The B.O.D. of the applied sewage will fall roughly into two categories; one, that in the form of non-settleable suspended or colloidal solids, the other that in soluble form. The ease and speed with which this biochemical oxygen demand is reduced will vary with the proportionate amounts of these two forms of decomposable organic matter and according to the character of the organic matter in each. To express these characteristics some variable V would be required.

The effective biological concentration is, however, a function of surface area, which in a trickling filter is proportionate to the effective surface area provided by the filter stones. For a given size stone this area is proportional to the volume of stone. In consideration of these effects on the surface area the load on a trickling filter of given size stone would become:

$$\text{Load} = \frac{\text{Applied B.O.D. (lb./day)} \times V}{\text{Stone Volume (1,000 cu. ft.)}}.$$

The surface area in a unit volume of stone varies considerably, however, with the size of stone. This can be illustrated by the following simple example where the relative surface areas are compared when an original cube is subdivided into fractional parts.

Relative State of Subdivision	Surface Area	Relative Area
1	6	1
0.5	8	1.3
0.1	24	4.0

For as completely a generalized formulae as is practical, therefore, the load on a trickling filter might be expressed as:

$$\text{Load} = \frac{\text{Applied B.O.D. (lb./day)} \times V}{\text{Stone Volume (1,000 cu. ft.)} \times K_1}$$

where K_1 evaluates the effect of variation in stone size between filters. There is, of course, a minimum size stone that can practically be used because of filter clogging, with the result that in design loadings for the normal domestic sewage this variable between filters is not too great. It is, however, a definite factor.

An accurate expression of comparative loadings on a trickling filter would thus seem to include as a minimum the above terms and values. The values represented by the coefficients V, and K_1, as representing the form and character of B.O.D. and the effective area, respectively, are difficult or impossible to define. This is illustrated by such additional variables as the character and thickness of film as influencing surface area effect, or the accumulation of suspended and colloidal sewage solids in and on the filter stones as influencing both the B.O.D. and surface film area. The pounds of total B.O.D. applied per day and volume of stone are, however, readily determinable.

The common expressions used today for trickling filter loadings are:

1. Gallons per acre per day.
2. Gallons per acre-foot per day.
3. Population per acre-foot per day.
4. Pounds of B.O.D. per day per 1,000 cu. ft. of filter.

Neither of the first three of these expressions take into consideration the specific quantity or weight of organic matter applied, nor the volume of stone to which the load is applied. The fourth expression, or pounds of B.O.D. per day per 1,000 cu. ft. of filter, approaches most nearly the fundamental equation.

Efficiency Loading

The loading for measurement of unit working efficiency of filters would be the pounds of B.O.D. applied to the filter per given interval of time, and the unit rate efficiency would be:

$$R_{Eff} = \frac{\text{B.O.D. Removed (lb./day)}}{\text{Stone Volume (1,000 cu. ft.)}}$$

The total work efficiency performed by the trickling filter unit would be:

$$C_{Eff} = \frac{\text{B.O.D. Removed (lb./day)}}{\text{B.O.D. Applied (lb./day)}}$$

Activated Sludge Aeration Units

Work or Design Load

Since the primary work to be done by an activated sludge aeration unit is the same as a biological filter, namely removal of B.O.D., the load would fundamentally be the same, or:

$$\text{Load} = \frac{\text{B.O.D. Applied per Time Unit} \times V}{\text{Eff. Active Biological Conc.}}$$

Specifically, the expression will differ from the fundamental one with respect to the physical state of the biological component. Whereas in the trickling filter, the fixed surface area of filter stone is ultimately translated into unit volume of stone as a unit measure of biological life, in the activated sludge unit the biological medium is in the form of the suspended and mobile activated sludge floc. The unit of measure of this material would thus be in terms of concentration of floc per unit volume of aeration liquor and theoretically multiplied by the variable V. Also, since the time of aeration is a flexible factor between different plants, the effect of rate of sewage flow and volume of tank is a factor, as in the sedimentation tank. The expression would thus become:

$$\text{Load} = \frac{\text{Appl. B.O.D.} \times V \times \text{Flow Rate} \times K_2}{\text{Act. Sludge Conc.} \times K_1 \times \text{Tank Vol.}}$$

As in the trickling filter the V, K_1 and K_2 values are impossible to determine. But the ratio of volume of sewage flow to volume of tank is the reciprocal of the detention time and the closest practical load expression thus becomes:

$$\text{Load} = \frac{\text{Applied B.O.D. (lb./hr.)}}{\text{Act. Sludge (lb.)} \times \text{Det. Period (hr.)}}$$

The most common loading values used in today's practice are based solely on the time of aeration in the activated sludge units and put in terms of detention period. This practice recognizes, however, only the volume of sewage liquid applied and fails to take account of the difference in strength of sewage or the quantity of activated solids carrying the load.

Efficiency Loading

As in the case of trickling filters, the load for efficiency measurements would be the pounds of B.O.D. applied per hour or day and the unit rate efficiency assumes the form:

$$R_{Eff} = \frac{\text{B.O.D. Removed (lb./hr.)}}{\text{Act. Sludge Solids (lb.)}}$$

The total capacity efficiency would be:

$$C_{Eff} = \frac{\text{B.O.D. Removed (lb./day)}}{\text{B.O.D. Applied (lb./day)}}$$

Sludge Digestion Tanks

Work or Design Load

Reduction of the volatile portion of the sewage solids is the primary function of a digestion tank. The load expressed in terms of the fundamental factors operating toward this end would be:

$$\text{Load} = \frac{D}{T \times S \times \text{Tank Volume}}$$

where D is the amount of digestible solids per unit of time, T is the digestion temperature and S is the amount of seeding sludge present.

If the temperature of digestion is considered at a standardized value as, for instance, 85° F. as used for the mesophilic range, this factor is reasonably constant and can be eliminated from the equation.

The quantity of biochemically decomposable matter or volatile component is, however, a function of the character of the organic matter. The ease with which this volatile matter decomposes will vary.

Likewise, the character and quality of a given quantity of seeding material will vary in its ability to digest the fresh material added to the tank, depending on the ratio of volatile matter to ash, bacterial population, etc., in the seed. Consequently, variability factors such as V_1 and V_2 would be needed to identify these characteristics. Hence, the fundamental expression would be:

$$\text{Load} = \frac{\text{Volatile Solids (lb./day)} \times V_1}{\text{Seed Sludge (lb.)} \times \text{Tank Vol.} \times V_2}$$

The amount of volatile matter added per day the quantity of sludge seed and the volume of the tank can be determined. Here again, an evaluation of the variability factors V_1 and V_2 would be too complex and practically impossible. It is therefore necessary to consider them constant for all sludges and in the nearest approach to a practical fundamental expression they would be omitted as in previous instances.

CONSTANT VELOCITY GRIT CHAMBER WITH PARSHALL FLUME CONTROL *

By Ming Lee and Harold E. Babbitt

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It is possible to design a grit chamber with plane surfaces for the sides and bottom so that the velocities of flow vary only slightly as the rate of flow varies between maximum and minimum. If, for simplicity of demonstration, a rectangular cross-section with flat bottom is assumed, a longitudinal section through the chamber will appear as indicated in Figure 1, in which point A is the outlet of the grit chamber or the inlet to the control flume. In the method presented it is necessary to find the height Z, so that the depth (d') in the grit chamber will vary directly with Q, the rate of flow through the channel. To do this, a relation between $Q_{max.}$ and $Q_{min.}$, the maximum and minimum rates of flow, must be established in terms of Z and W, the width of the flume. This can be done as follows:

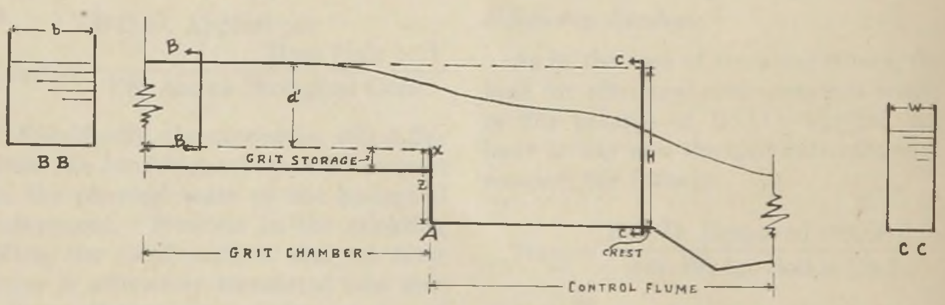

FIGURE 1.—Diagrammatic section of grit chamber and control section.

If the velocity head in the grit chamber is neglected, then

$$d' + Z = H \qquad \text{(a)}$$

where H is the total head (depth plus velocity) at the crest of the control flume. If the discharge Q through a rectangular control section is written in terms of the total head H the following relation holds:

$$Q = CWH^{3/2} \qquad \text{(b)}$$

in which Q and H are expressed in c.f.s. and ft., respectively; W is the width, in ft., of the flume as the throat; and C is a constant depending on the type of flume used. (For the Parshall flume, $C = 3.5$ approximately; for the Venturi flume, $C = 3.09$.)

Transposing equation (b) and substituting in (a):

$$d' = \left[\frac{Q}{CW}\right]^{2/3} - Z$$

and, since $Q = Vbd'$ where V is the velocity of flow in ft. per sec. in the grit chamber:

$$V = \frac{Q}{bd'} = \frac{Q}{b\left[\left(\frac{Q}{CW}\right)^{2/3} - Z\right]}$$

in which b is the ··idth of the grit chamber.

* Presented at 18th Annual Meeting, Central States Sewage Works Assn., Lafayette, Indiana, June 13–14, 1946.

Since the velocities are to be the same at $Q_{max.}$ and $Q_{min.}$, then

$$\frac{Q_{max.}}{b\left[\left(\frac{Q_{max.}}{CW}\right)^{2/3} - Z\right]} = \frac{Q_{min.}}{b\left[\left(\frac{Q_{min.}}{CW}\right)^{2/3} - Z\right]} \quad \text{(c)}$$

and

$$\frac{Q_{min.}}{Q_{max.}} = \frac{\left(\frac{Q_{min.}}{CW}\right)^{2/3} - Z}{\left(\frac{Q_{max.}}{CW}\right)^{2/3} - Z} \quad \text{(d)}$$

Application of Method

The preceding formulas can be used in the design of a rectangular flat-bottom grit chamber with the same velocity of flow at maximum and minimum rates of flow, as is shown in the following example.

Let it be desired to design a grit chamber with flat bottom and vertical sides in which $Q_{max.} = 8.0$ m.g.d. = 12.4 c.f.s., $Q_{min.} = 1.5$ m.g.d. = 2.32 c.f.s. and in which the velocity at these rates of flow is 1.0 ft. per sec.

Solution: A 6-in. Parshall flume will be used, for reasons given later. Then, from equation (d), using $C = 3.5$, and $W = 0.5$ ft.,

$$\frac{2.32}{12.4} = \frac{\left(\frac{2.32}{3.5 \times 0.5}\right)^{2/3} - Z}{\left(\frac{12.4}{3.5 \times 0.5}\right)^{2/3} - Z} = \frac{1.21 - Z}{3.7 - Z}$$

and $Z = 0.64$ ft.

Then, from equation (a), the depth of flow in the grit chamber for $Q_{max.}$ is $3.7 - 0.64 = 3.06$ ft. and for $Q_{min.}$ is $1.21 - 0.64 = 0.57$ ft. From $Q = AV = Vbd'$, b, the width of the grit chamber $= \frac{12.4}{1 \times 3.06} = \frac{2.32}{1 \times 0.57} = 4.05$ ft.

The depth and the velocity of flow at other rates of flow should be computed. These are determined from equation (a), transposed, in which

$$d' = H - Z = \left(\frac{Q}{3.5 \times 0.5}\right)^{2/3} - 0.64$$

Values of d' in the grit chamber for various rates of flow are shown in Table I. These values, multiplied by

TABLE I.—Velocities of Flow at Various Depths in Grit Chamber

Rate of Flow		Depth of Flow in Grit Chamber (ft.)	Area of Flow in Grit Chamber (sq. ft.)	Velocity (ft. per sec.)
M.G.D.	C.F.S.			
1.50	2.32	0.57	2.32	1.00
2.00	3.10	0.82	3.33	0.93
3.00	4.65	1.28	5.19	0.90
4.00	6.20	1.70	6.90	0.90
6.00	9.30	2.41	9.75	0.96
8.00	12.40	3.06	12.40	1.00

the width of the grit chamber, give the areas of flow as shown. Velocities of flow at various depths are also shown. This indicates a maximum departure of 10 per cent from the desired velocity of 1 ft. per sec. When the maximum and minimum rates of flow through the grit chamber are known it is possible to find the maximum departure from the desired velocity of 1 ft. per sec. from Figure 2, which is applicable to any grit chamber of rectangular cross-section with a rectangular flume for velocity control.

If it is desired to use a cleaning mechanism in the grit chamber, it may be necessary to narrow the bottom and use fillets as indicated in Figure 3, where the line XX is at the same level as XX in Figure 1. The dimensions of the fillets should be so fixed as to give "equivalent rectangular cross-section," *i.e.*, area 1 + area 2 = area 3. The velocities shown in Table I are not affected if the height a is not greater than the depth for the minimum rate of flow shown in Table I. For best distribution of velocity across the cross-section of flow the height f should not be greater than the height Z in Figure 1.

The Control Section

The practicability of the preceding design depends upon the ability to construct a control flume through which

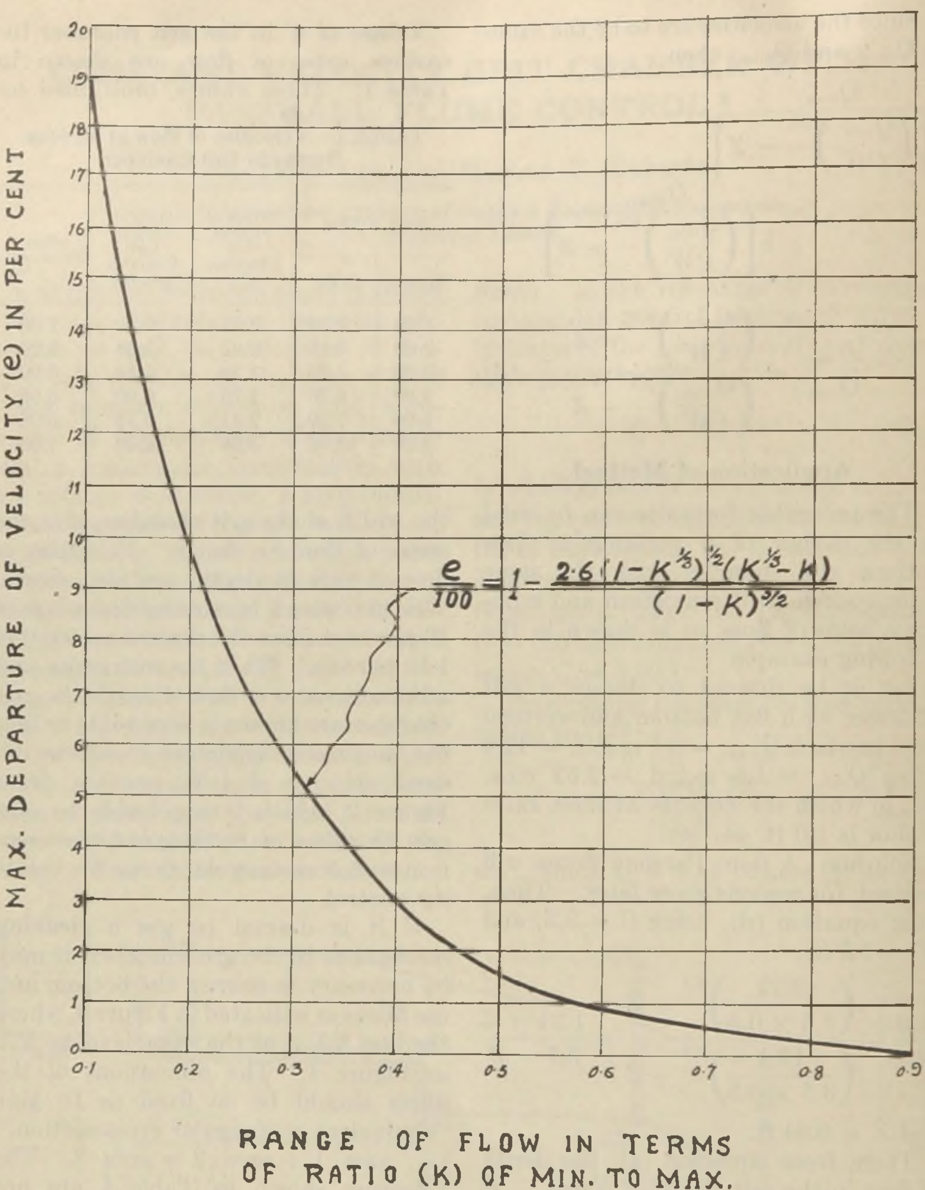

FIGURE 2.—Maximum departure from desired velocity of 1.0 ft. per sec. for various flows.

the flow corresponds to the expression:

$$Q = CWH^{3/2} \qquad \text{(b)}$$

The Parshall flume (1) (2) can be used as a satisfactory control chamber, provided "free flow" conditions exist in the flume. A plan and longitudinal section through a grit chamber and a Parshall flume are shown in Figure 4.

In the Parshall flume, flow is measured in terms of the depth H_A (Figure 4) and not in terms of the total energy H at the crest. A statistical study of the information given by Parshall (2) indicates that under free flow conditions,

$$Q = 4.1\ WH_A^{3/2} \qquad \text{(e)}$$

and

$$H = 1.1\ H_A \qquad \text{(f)}$$

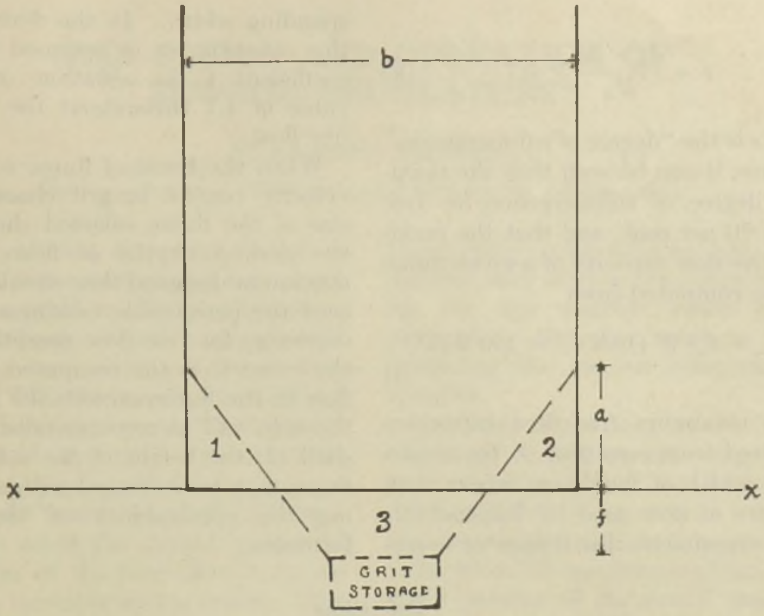

FIGURE 3.—Cross-section of grit chamber with fillets.

In order that free flow may exist, the conditions in the tail water below the crest of the flume must be such as not to cause backing up of the water at the crest, *i.e.*,

$$d_t + \left[\frac{Q}{d_t W}\right]^2 \frac{1}{2g} \lesseqqgtr H + N \qquad \text{(g)}$$

By means of equations (e) and (f), equation (g) is reduced to

$$\left[\frac{d_t}{H_A} + 0.26\left(\frac{H_A}{d_t}\right)^2\right] - 1.1 \lesseqqgtr \frac{N}{H_A} \qquad \text{(h)}$$

The maximum free flow capacity of a given flume may be found from equation (h), as follows:

Under maximum flow, H_A is a maximum, therefore, the left hand side of equation (h) should be a minimum. This occurs when

$$\frac{d_t}{H_A} = 0.8 \qquad \text{(i)}$$

Then, from equation (h),

$$H_A \lesseqqgtr 10N \qquad \text{(j)}$$

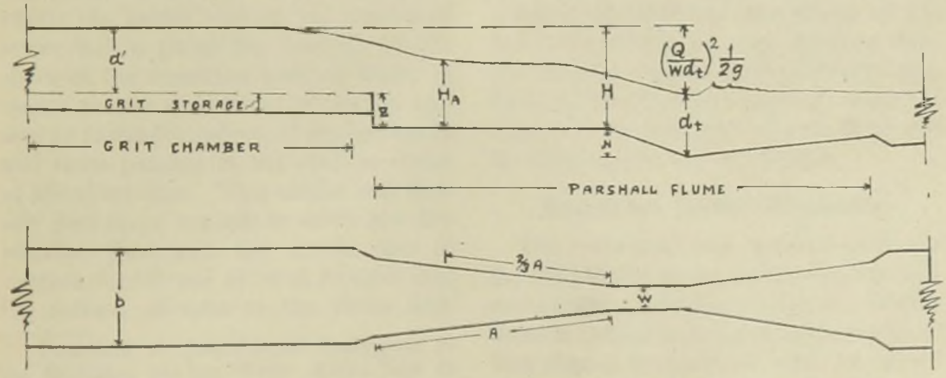

FIGURE 4.—Plan and longitudinal section of grit chamber and Parshall flume.

and

$$s = \frac{d_t - N}{H_A} \leqq 0.7 \qquad \text{(k)}$$

where s is the "degree of submergence."

Hence, it can be seen that the maximum degree of submergence for free flow is 70 per cent, and that the maximum free flow capacity of a given flume may be computed from

$$Q_{\text{max.}} = 4.1\, W\, (10N)^{3/2} = 130\, WN^{3/2} \qquad \text{(l)}$$

The maximum free flow capacities computed from equation (l) for a particular width of flume are larger than the rates of flow used by Parshall (2) in his experiments for flumes of corresponding width. In the derivation of the equation, it is assumed that the coefficient C in equation (e) has a value of 4.1 throughout the range of free flow.

When the Parshall flume is used for velocity control in grit chambers the size of the flume selected should give the desired depths of flow and the maximum designed flow should not exceed the permissible maximum rate of discharge for free flow conditions. In the event that the computed depth of flow in the flume exceeds the height of the side wall as recommended by Parshall (2) the height of the sides of the flume may be increased without affecting the applicability of the design formulas.

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THE DESIGN AND OPERATION OF SEWAGE REGULATORS *

By Kenneth Fishbeck

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The regulation of sewage flow from combined sewer systems has been something of a problem since the beginning of the movement of our population toward the industrial and commercial centers. With the development of sewage treatment the sewage flow regulator increased in importance until it now is the link between the collection system and the treatment plant. Its function is to select the proper amount or proportion of the total flow to be admitted to the intercepting sewer. Upon this amount or proportion the engineer must base the design of the treatment plant and, of course, the efficient operation of the plant is directly reliant upon the ability of the regulator to maintain this amount or proportion within reasonable limits.

The scope of this paper is, of necessity, limited to the writer's experiences with regulators in use in Lansing plus scattered bits of information which have been picked up while comparing notes with engineers from other localities.

Before sewage treatment plants became common, the regulator was usually considered as an outfall structure and it provided a restricted connection between the outlet end of the combined sewer and a point far enough off the shore of the receiving body of water to insure proper dispersion of sewage and also to avoid formation of sludge banks and scum patches in the shallow water at the shore line. This outlet was usually just large enough to carry the dry weather flow and the excess due to surface runoff was allowed to spill into the stream or lake at the shore line. Incidentally, maintenance was rather difficult, and after a few years of service the dry weather outlet became plugged or the pipe went to pieces, rendering the control completely ineffective.

As cities began to plan for sewage treatment it became apparent that it was neither practical nor desirable to provide sufficient capacity in intercepting sewers, pumping stations and treatment plants to handle more than a very small portion of the runoff caused by rainstorms or melting snow and ice. This fact caused designing engineers to seek a reliable means of regulation. The results included everything from a simple adaptation of the old outfall structure to elaborate and complicated combinations of dams, chambers, gates, valves, floats, pipes and tanks that were thereafter major problems to those responsible for adjustment, operation and maintenance. As time goes on, research and experience are bringing out refinements which are making sewage regulation somewhat more simple and reliable.

In the last twenty years Lansing has built and put into operation between forty and fifty regulators of various types including two variations of the restricted outlet for dry weather flow, the leaping weir and two different systems of mechanical control. None of these are perfect and no one type can be used under all conditions.

Restricted Outlet Regulators

The restricted dry weather outlet is the simplest to build and one of the easiest to keep in working condition. Where there is sufficient fall available the small line should be installed with its invert at a depth about equal to its diameter,

* Presented at 21st Annual Conference of the Michigan Sewage Works Assn., held at East Lansing, on March 18–20, 1946.

below the invert of the combined sewer. It must lead out of a depression cut across the bottom of the combined sewer. The long dimension of the depression should run transversely to the line of the main and be slightly greater than the width of the dry weather flow. The short dimension depends on the velocity of this flow and should be great enough to prevent any part of it from leaping across. Careful shaping of the sides and bottom of the depression will prevent deposition of solids therein.

Where fall is limited the invert elevations of the two lines may be the same. In this case the depression in the main sewer is replaced by a dam located with its upstream toe at the downstream side of the small outlet. In either case an access manhole should be provided over the junction of the two lines. A careful estimate of the volume of sanitary flow to be handled should be made, either by a study of the contributory area or by actual measurement of the flow in the combined sewer, and a size of pipe and a gradient selected which will provide ample capacity for the sanitary flow and also insure against too great an increase over this amount when the main is carrying a heavy storm flow.

Considerably more flexibility may be obtained by installing a sanitary line of somewhat greater capacity than require to carry the immediate flow. The entrance end of this line may then be fitted with an orifice plate with an opening of a size which will just take the sanitary flow. The advantage of this arrangement lies in the fact that several plates with different sized orifices may be provided and they may be interchanged to meet varying conditions.

Leaping Weirs

Probably the next simplest type of regulator is the so-called leaping weir. This consists of an adjustable plate or lip set over the upstream side of a hole cut in the invert of the combined sewer. The size of the hole and the adjustment of the plate should be such that the dry weather flow will drop through the hole and thence into the intercepting sewer. The higher velocities resulting from storm runoff cause the flow to leap across the opening and continue on its way to the outfall. This type has a reasonable amount of flexibility because it is possible to adjust both the pitch of the weir plate and the distance from its edge to the downstream side of the opening. It should only be used where the hydraulic grade in the sanitary outlet never rises above the invert of the combined sewer.

Mechanical Regulators

The type most commonly used in Lansing is a float-actuated mechanical regulator which is designed to operate automatically and shut off the entire flow to the interceptor when it reaches a predetermined height in the combined sewer.

The structure enclosing this regulator is built of reinforced concrete and consists of three rooms or chambers (Figure 1). The first or dam chamber is built directly over the combined sewer. The dam across the sewer is located in such a way as to channel the dry weather flow across to an opening into the second or gate chamber. Here is located a shear gate having a shape and principle of operation similar to a Taintor gate. Also in this chamber is the outlet to the intercepting sewer. The third or float chamber, as the name implies, houses the float which operates the gate. The fluctuation of the water level in the sewer is transmitted to this chamber by means of a 6-in. telltale pipe extending from the invert of the sewer to the chamber. The float and gate are suspended by chains from a system of shafts and lever arms which extend through the wall between the two chambers.

In so far as possible all metal parts are made of cast iron. The original cast iron float was found to be too

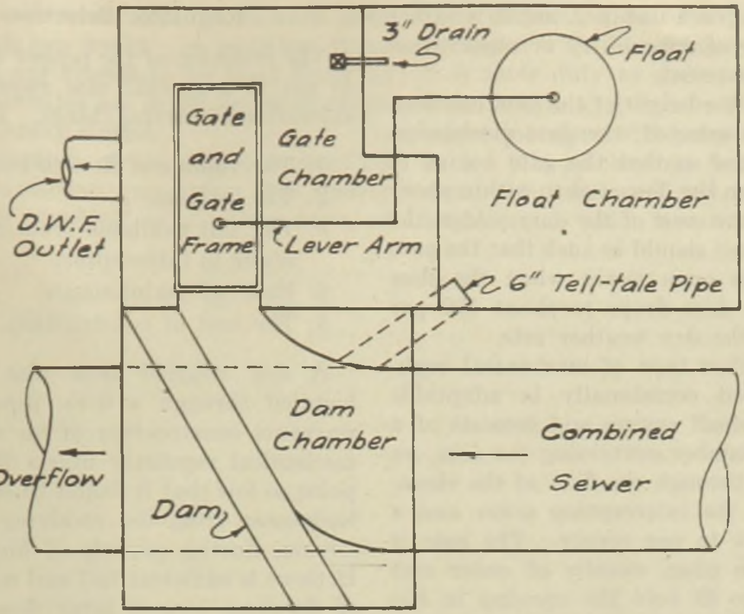

FIGURE 1.—Diagrammatic sketch of mechanical sewage regulator used at overflows on large combined sewers at Lansing, Mich.

heavy for the lever arms so the pattern was reduced until the weight was lowered to a point where the float could be used. All steel chains, clevises, bolts, etc. are cadmium plated.

In the design of the regulator the first consideration must be the amount of flow which it is desired to divert from the combined sewer to the intercepting sewer before allowing the gate to close. This usually amounts to 150 to 200 per cent of the dry weather flow to allow for treating the highly polluted early runoff from a storm and also to prevent the closing of the gate by every light rain.

The height of the dam necessary to divert this amount of flow may be determined as follows: Compute the capacity of the combined sewer and, by dividing the quantity to be diverted by this capacity, the proportion to be diverted is obtained. By application of one of the several formulas for flow in sewers or by the use of available tables showing relative discharge for various depths of flow, this proportion may be converted to depth of flow in the combined sewer expressed in terms of a fraction of its diameter, which is the height of dam necessary. The next step is the determination of the size of gate or opening required. This depends, of course, upon the volume of sewage that must pass through it and upon the fall available across the regulator.

Only one size of opening (16 in. wide by 10 in. high) is used at Lansing and the capacity is adjusted by controlling the distance that the gate is allowed to open.

By adjusting the lengths of the chains upon which the gate and float are suspended, and by a careful use of counterweights, it is possible to select the depth of flow in the combined sewer at which the gate will start to close as the flow rises, and similarly the depth at which it will start to open as the flow drops. While the wide-open gate has a capacity of 4.5 to 5 c.f.s. at the minimum 3-in. head, no attempt is made to compute the amount of opening required in each instance, but it is rather a matter of cut-and-try or observation and adjustment.

When the height of the dam has been properly selected, the gate mechanism is adjusted so that the gate begins to close when the flow rises to within about 1 in. of the crest of the dam. Also, the adjustment should be such that the gate begins to open again when the flow over the dam drops to about 150 per cent of the dry weather rate.

The other type of mechanical regulator used occasionally is adaptable only to small sewers and consists of a single chamber containing the dam, an opening through the floor of the chamber into the intercepting sewer and a float tank in one corner. The gate is a wooden plug, usually of cedar and shaped to fit into the opening in the intercepting sewer, attached to the galvanized iron float by a system of rods and a walking beam. The problems of design and adjustment are similar to those of the larger regulators and the device gives satisfactory service where the flow is small.

The writer has recently received, from the Milwaukee Sewerage Commission, information regarding a very interesting regulator which has been developed by their staff. It consists of a rectangular gate which is mounted on a shaft in such a manner that the center of the gate is a little above the point or line of pivot. By the proper application of stops and counterweights the gate can be adjusted to allow the low flows to push it open and flow through. As the flow rises, the amount of opening being limited by a stop, the water rises above the gate until the pressure on the portion above the pivot pushes the gate shut and diverts the flow to the outfall line. This is one of the simplest automatic regulators that has come to the writer's attention and reports from Milwaukee indicate that its operation is very satisfactory. Apparently its simplicity is the key to its reliability and ease of maintenance.

Regulator Selection

The selection of the proper regulator to use in a specific case requires consideration of several things. They are:

1. The volume of flow to be handled.
2. The location.
3. The fall available from combined sewer to interceptor.
4. Ease of maintenance.
5. The cost of construction.

A dry weather flow that can be handled through a 6-in. pipe hardly warrants construction of an elaborate mechanical regulator unless it is at a point so low that it would be subject to backwater from the receiving lake or stream, during periods of high stage. If there is sufficient fall and no danger of flooding, even a large flow can be handled over a leaping weir and the cost of the installation is very reasonable. But for the location at which there is danger of floods, or the available fall is limited, it seems that some type of automatic mechanical regulation is necessary.

Regulator Maintenance

No known type of regulator will operate in a satisfactory manner without regular and frequent attention. At Lansing, we have removed everything from power pole cross-arms and wash boilers to bed sheets and dead dogs, not to mention the small rags, sticks and other annoying trivia which persist in collecting in the gate, orifice or opening, as the case may be. In the mechanical type regulator the float becomes weighted down with sludge, the bearings stick or the face of the gate collects so much grease that it binds. Any of these things can prevent the proper functioning of the regulator, but frequent inspection can prevent a goodly percentage of the failures and shorten the duration of those which do occur.

We attempt to maintain a schedule whereby most installations are checked once each week and the balance once in each two weeks. In addition, those which are known to be most likely to cause trouble are given an extra check after heavy storms.

Inspection of regulators is handled by a two-man crew who also answer "sewer trouble" calls. They have, at their disposal, a half-ton pickup truck equipped with all necessary tools, and it is their duty to clear away any accumulations of debris or sludge which might interfere with proper operation, to see that all moving parts are kept clean and lubricated and to make any adjustments which are necessary.

FUNDAMENTALS OF BIOLOGICAL OXIDATION–CLARIFICATION *

By John W. Hood

Superintendent of Sewage Treatment, Ridgewood, New Jersey

As indicated by the title, the scope of this paper will be confined to a consideration of the inter-relationship between biological oxidation and the phenomenon of clarification, with particular emphasis on the numerous factors which are involved and which dictate the success or failure of the process.

Clarification of water and sewage by the application of chemicals is a common and familiar practice, and is simpler and more easily understood in its fundamental principles than is clarification by biological oxidation, since the latter is complicated by so many more environmental considerations than the chemical coagulation process. Then, too, the art of clarification of water by chemicals is of considerable antiquity.

On the other hand, the practice of biological oxidation-clarification treatment is comparatively new, and so many additive factors attach themselves to its application, on account of biological environmental requirements, that possibly we have lost sight of certain basic information which the record of chemical clarification of water and sewage contains.

In view of the foregoing, it is expedient that our approach to the subject begin with the foundation of knowledge afforded by the art of chemical treatment. We will commence, therefore, with a consideration of the phenomenon of clarification of aqueous solutions by means of chemical coagulants, ascertain the basic factors involved, and then proceed to consider the facts of biological oxidation.

Chemical Coagulation

Fundamentally, there is no difference between the chemical coagulation of water and of sewage, but invariably much higher dosages are required for the successful treatment of sewage. This is due to the greater concentrations of suspended and dissolved matter, both organic and inorganic, that are normally contained in sewage. This is not to be construed, however, as meaning that the water treatment industry has no coagulation problems!

Early British practice employed lime and alum. Using lime, the aqueous subject was adjusted upward in pH and alkalinity and the phenomenon of coagulation and clarification was encountered at pH 10.5 or higher, accompanied by an enhanced alkalinity concentration. When referred to the carbonate equilibrium curve of water practice (Figure 1), the residual condition of the liquid is found to be high in the "deposition of carbonates zone" (1). Ninety-eight per cent bactericidal effects were reported from this lime treatment, when carried to the point of optimum clarification. A voluminous sludge was produced from the addition of lime, alum and clay, especially when the dosage reached 5 tons per m.g. or 1,200 p.p.m. This voluminous sludge production from clarification at high pH values was largely responsible for the substitution of alum at more normal pH values, to replace the "excess lime" treatment.

* Presented at 31st Annual Meeting, New Jersey Sewage Works Ass'n., Trenton, March 20–22, 1946.

The application of alum, an electrolyte having an acid reaction, depresses the pH-alkalinity value, and brings about the agglomeration and precipitation of suspensions. When referred to the carbonate equilibrium curve, the residual condition of the liquid thus clarified is usually found to be in the "corrosion zone." Joseph W. Ellms (2) states "that a water treated for optimum coagulation may exert, when filtered, its maximum corrosive action on metals." Thus we recognize that there are two distinct and separate zones in which successful results may be achieved; (a) in the high pH-alkalinity values, or "deposition of carbonates" zone; (b) in the low pH-alkalinity values, or "corrosion zone." It will develop, however, that our interest centers on clarification in the "corrosion zone," regardless of whether chemical or biological treatment is practiced. Reduction in B.O.D. is effected by the agglomeration and precipitation of suspensions during floc formation. This gelatinous precipitate, formed by the mutual decomposition of the alum and a proportionate amount of the alkalinity present, also carries a positive electric charge contributed by the alumina ion which attracts and adsorbs negatively charged suspensions. Microscopic examination of a single floc particle from a sewage clarification process affords visual confirmation of the tenacious property of the gelatinous precipitate, as higher organisms strive to free themselves from its clinging structure and innumerable smaller varieties move briskly to and fro, within the structure itself. Chemical coagulation may therefore be termed a physio-electro-chemical phenomenon.

Ridgewood, New Jersey, successfully employed aluminum sulfate as a sewage coagulant for a number of years prior to the war. A sparkling effluent of crystal clearness was obtained. Numerous difficulties were encountered and overcome before plant scale operation became routine and the plant laboratory facilities were a big factor in bringing the problem under control. A paper on this work was presented at the 1941 annual meeting of the N. J. S. W. A. and a complete account may be found in the proceedings for that year (3).

Of immediate interest was the discovery of the significance of pH-alkalinity value in relation to the precipitation of finely divided and colloidal suspensions (Figure 1). *It was found that when optimum removals are effected, the solution is not only in the "corrosion zone" but that there exists a definite relation between the degree of clarification effected and the residual pH-alkalinity value of the treated subject.* Previous ideas about the coagulant demand being dictated by the B.O.D. had to be discarded, since it was repeatedly demonstrated that the buffer value of the subject, expressed as its pH-alkalinity value, was the determining factor, necessarily modified by variations in the surface adsorption demand. Three general zones influencing coagulation were established, as follows:

Zone	pH	Alkalinity (p.p.m.)	Remarks
1	7.0	100–125	Easily clarified with moderate coagulant doses.
2	7.5	125–175	Less easily clarified and requiring higher doses.
3	7.5 to 8.0	200 and over	Difficult to coagulate, requiring excessive doses.

To ensure continuously successful coagulation, adjustment of the pH-alkalinity value was practiced by recirculation of treated effluent of low pH-alkalinity value to the influent, followed by precarbonation, before introduction of the coagulant. Only by continuing this practice was it possible to produce continuously an effluent of near zero turbidity, divested of its colloidal and other suspensions. The effects of low temperature were thought to be responsible for the difficulties but this proved to be circumstantial evi-

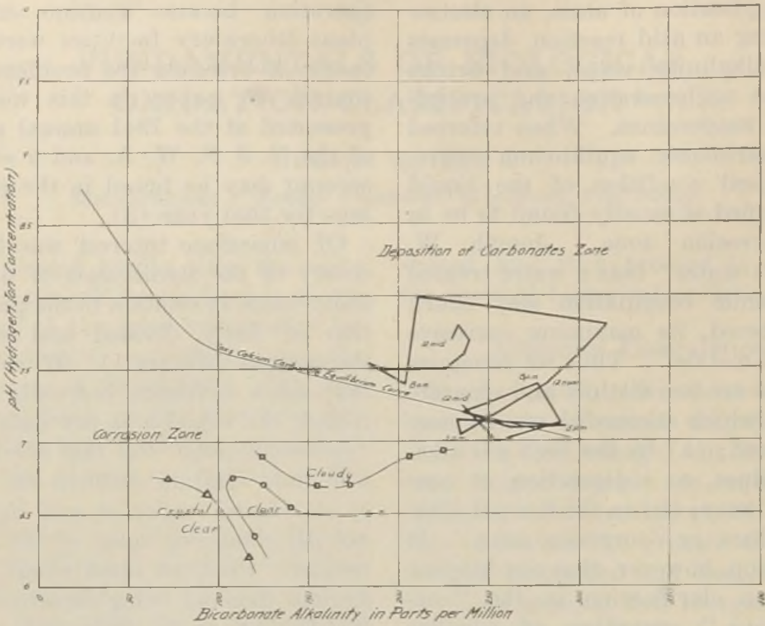

FIGURE 1.—Illustration of the carbonate equilibrium curve of water treatment practice, which delineates the "deposition of carbonates" and "corrosion" zones. Also plotted are the "buffer" pH-alkalinity values of Ridgewood plant influent through a 24 hour cycle with the residual values in the plant effluent arranged in turbidity "contours."

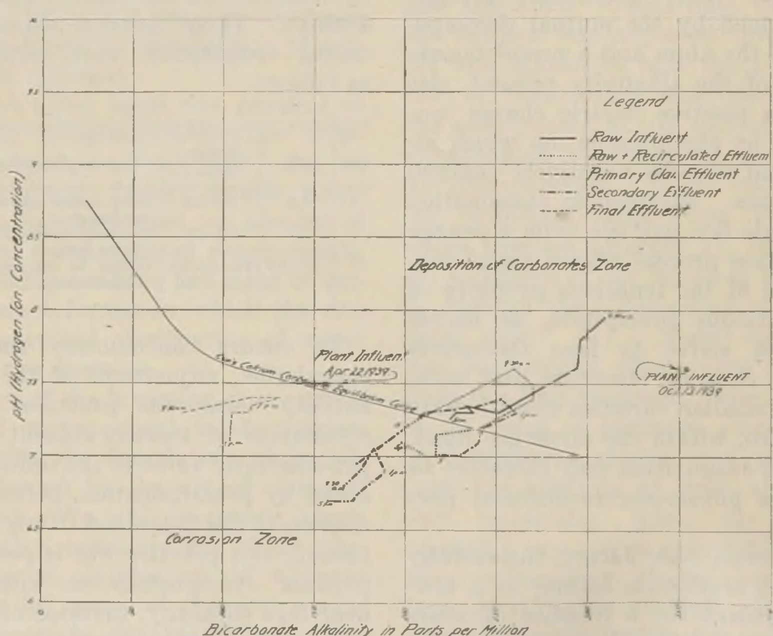

FIGURE 2.—Equilibrium curves as determined in the Ridgewood, N. J., sewage treatment plant on September 6, 1939.

dence, as daily laboratory pH-alkalinity determinations disclosed that these reached their maximum during the winter months.

The story of successful chemical-biological plant scale operation, told in buffer values, is shown in Figure 2. The "southwesterly" adjustment will be noted. This was brought about by a combination of dilution with treated (corrosive) waters and mild acidulation with alum. The rise in pH through the filter will also be noted, which result is considered to be due to the liberation of CO_2 from the chemical coagulation step. The filter effluent did not have the sparkling quality of the filter influent but was otherwise superior.

Ellms (2) concludes a chapter on pH by quoting from the "Report of Committee No. 4 on Colloidal Chemistry of the Council of Standardization," *Jour. A. W. W. A.*, March, 1923: "As a matter of fact, the isoelectric point for the coagulation of all waters by sulphate of alumina, is not the same—while the hydrogen ion concentration is important, it is not the sole determinant." The truth of this negative conclusion may be readily seen from Figure 3, which shows precarbonation and chemical coagulation tests of various subjects. These curves reveal the significance of initial buffer value in relation to coagulant dose and residual turbidity. The general direction of all curves is toward the point of origin.

Biological Oxidation

Substitution of biological oxidation processes for chemical treatment of sewage is simply a change of *means*, because biological oxidation necessarily must bring about the same changes within the subject in order to achieve the same degree of clarification. It is

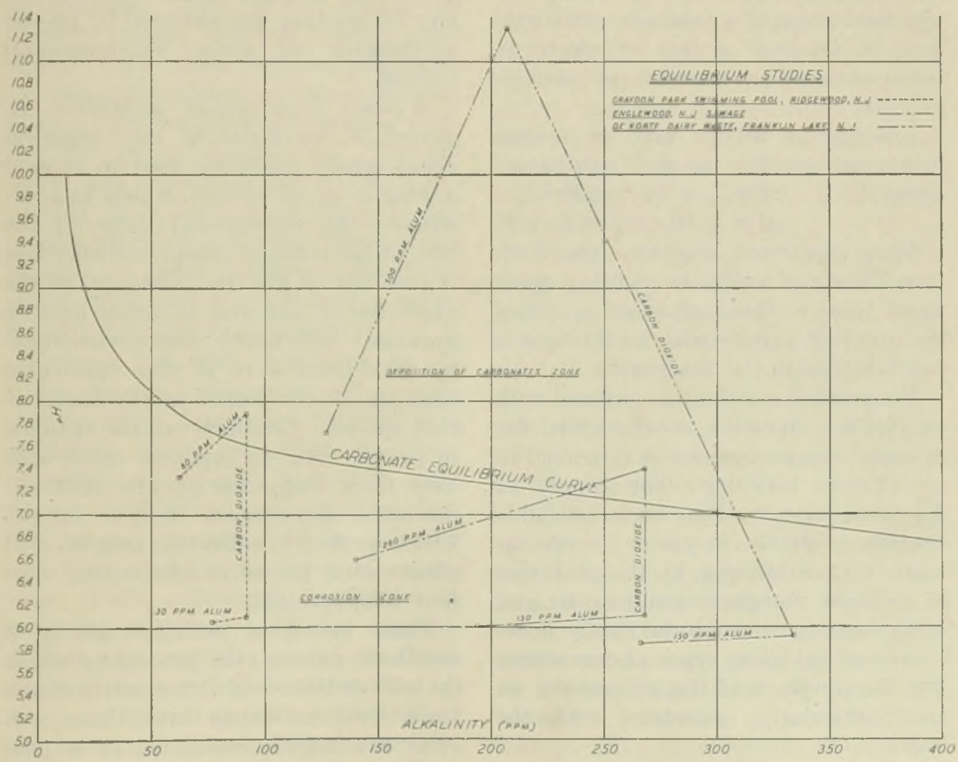

FIGURE 3.—Comparative equilibrium studies on swimming pool water, sewage and milk plant waste.

not surprising, therefore, to find that the functioning of a favorably environed biological oxidation process produces its own electrolytes or salts from non-electrolytic materials present in the sewage; forms "flocs" or settleable particles from finely divided or dissolved constituents; and produces near-zero turbidity effluent, lacking only in the color-free quality of that produced with alum. As we are well aware, however, not all biological oxidation plants are capable of these complete results. Why?

Before attempting to answer this query, let us consider a few pertinent definitions.

Oxidation is variously defined as "*Any process which increases the proportion of oxygen or acid forming element or radical in a compound*"; "*A process whereby hydrogen is removed.*"

According to the Electron Theory, oxidation involves much more than the chemical union of a substance with oxygen—*it involves a loss of electrons, which means an increase in positive valence.*

Chlorine is widely used in sewage treatment practice as an "oxidizing" agent; *e.g.*, $2FeCl_2 + Cl_2 = 2FeCl_3$

$$H_2S + Cl_2 = 2HCL + S.$$

These equations illustrate the Electron Theory of oxidation as being much more than a chemical reaction, since the union of oxygen with a substance is not involved in the reactions.

Frequently, *aeration* is confused with *oxidation*. *Aeration* occurs when, for example, compressed air is dispersed in an aqueous medium. The supply of dissolved oxygen thus made available enables *oxidation* to ensue in various ways, *e.g.*, *chemically*, by the oxidation of reduced inorganic compounds, and *biochemically*, through the catalytic activities of oxidizing types of organisms. For the purposes of this discussion, we are particularly concerned with the latter.

With these various definitions in mind, we will proceed to a consideration of biological oxidation. This process, as the name implies, relies entirely upon the activities of living things, both plant and animal (flora and fauna), for its success. It is applicable to sewage treatment because sewage is rich in organic matter, dissolved gases and minerals essential to the life and growth of the flora and fauna. Conversely, it is not applicable to water treatment problems because of the general absence of these nutrient factors. In this connection, it is of prime importance to recall the work done by Dr. Charles O. Chambers at the Botanical Gardens in St. Louis, Mo. Reporting on several years of extensive research (4) on the culture of aquatic plants in lagoons, he concluded that the amount and nature of life that a body of water will support is directly related to the concentrations of dissolved gases and minerals present in that water. He states that in many instances the necessity for seeding was obviated by proper adjustment of these environmental factors.

A local high school instructor inquired if we knew of any chemical agent which could be used to control a plague of bloodwort which had destroyed the recreational value of the lake at his summer camp, and why had it run riot in the first instance, to the exclusion of any and all other aquatic growths? Obviously, the environmental conditions were at that particular time eminently suited to the needs of that species. Similarly, sulfur springs, so prized their therapeutic value, also have their *Beggiatoa* growth, that undesirable filamentous fission fungus which we find in collection systems and plant units wherever the sulfur content is appreciable.

These biological activities are of a metabolic nature (the process by which the cells or tissues of living entity transform food materials into their own vital substance), consisting of a progression of ingestion and excretion, and are embraced by that branch of science known as biochemistry, since both biology and chemistry are involved. Suffice it to say that the amount and nature of the organic and mineral matter deposited in sewage dictates to a large extent the amount and nature of life which it will support.

The general term "aerobic" is applied to the types participating in a biological oxidation process, where molecular or free or atmospheric oxygen is present in the environment. It is of passing interest to note that "anaerobic" types are responsible for the useful work performed in sludge digestion, where free oxygen is deliberately excluded from the environment and where the oxygen required for their metabolic processes is obtained by reduction of compounds containing oxygen.

Activated sludge, stone and sand filter plants are examples of biological oxidation systems employed in sewage purification. They differ mainly in physical feature, but not in basic principles. Since these features constitute an important biological environmental factor, however, physical variations affect the degree of treatment. For example, the more complete oxidation occurring in a slow sand filter is not readily attained in a stone filter, solely because of these physical differences, which affect both the volumetric capacity and the biological activities.

Sewage has been described as "a heterogeneous combination of organic and inorganic, suspended, colloidal and dissolved solids, dispersed in large quantities of water." It will be helpful also to think of it as a nutrient media for the promotion of the life and activities of desirable types of organisms. Plain subsidence is effective in removing the coarser particles. Agglomeration and precipitation of the finely divided and colloidal suspensions is the more difficult problem, necessitating some form of "secondary" treatment for their removal. In practice, the colloidal suspension has proved the most difficult to remove by either chemical or biological means.

Where a substantial degree of clarification is required, costs will increase in proportion to the concentration of colloidal suspension. What are colloids? Colloids are substances so finely divided that they may remain permanently in suspension in a medium and cannot be separated by filtering. Casein in milk and soap particles in water are examples of colloids. They form colloidal "solutions" which are intermediate between true solutions and suspensions. In sewer systems, coarse solids are broken down in transit by scouring velocities due to pumping and steep grades, then acted upon further by biological agencies, which progressively decrease the particle size until presently a certain amount of these solids reach the colloidal state.

In Nature's economy, there ensues the double micron state, or true solution. But the time element in the case of municipal plants does not permit the final state to be reached and it devolves upon the treatment facilities to effect a reversal of the natural trend, by agglomerating and precipitating these suspensions. Not all biological oxidation plants are capable of doing so. Since oxidation of decomposable organic matter to stable mineral forms proceeds through many intermediate stages, we frequently find that a plant effluent reflects an intermediate stage. For example, oxidation of the organic matter may occur, but conditions may not permit the further conversion to stable mineral forms.

In Figure 4 the performance curves of three biological sewage treatment plants are superimposed on the carbonate equilibrium curve. The Ridgewood curves reveal differences in initial buffer values and plant performance in a plant employing only controlled biological oxidation in a stone filter. The trickling filter effluent is near zero in turbidity. The Pitman results show the difference in the trickling filter

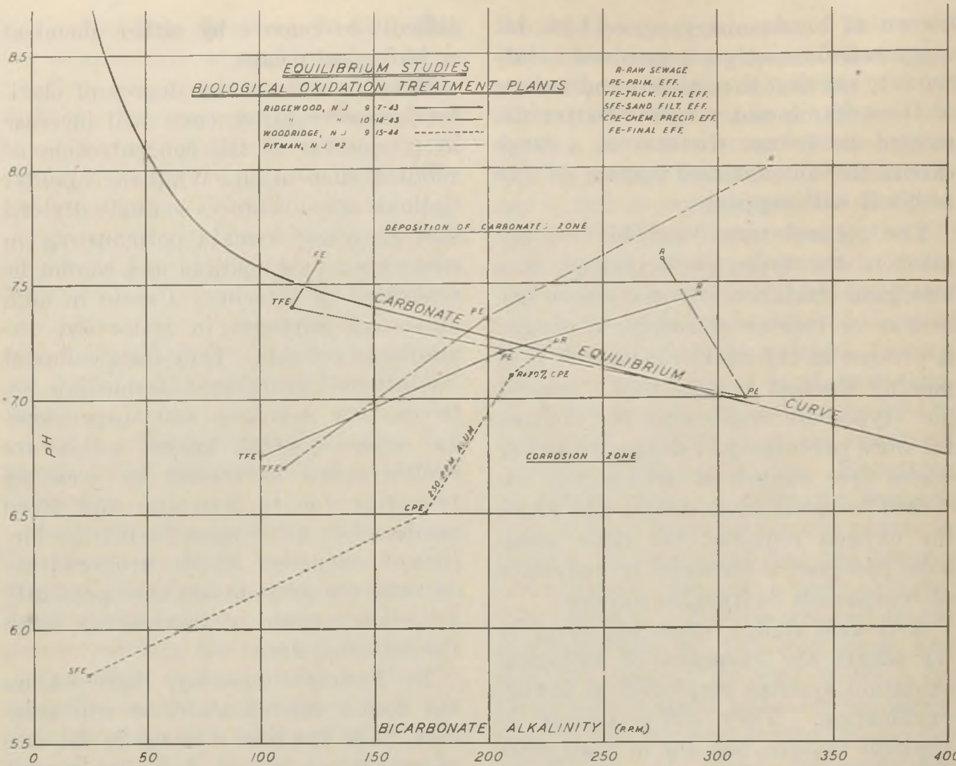

FIGURE 4.—Comparison of equilibrium studies in three biological sewage treatment plants.

effluent due to the absence of the control features used at Ridgewood. Woodridge, N. J., uses a partial coagulant demand chemical treatment, preceded by a token recirculation and followed by a highly efficient sand filter as witnessed by the remarkably low buffer value of the sand filter effluent.

The similarity between the performance curves of successful biological oxidation methods and chemical coagulation processes is obvious. Either system must "crack" the buffer value to be effective as a decolloiding device.

Environmental Factors

To achieve the same clarification results as chemical coagulation, biological oxidation must necessarily bring about similar physio-electro-chemical changes in the subject. In addition to requiring favorable initial conditions similar to those found necessary for successful chemical treatment, we find that other environmental factors must be met.

These are dictated by the ecological requirements of the general aerobic types involved, and include food; temperature; time; pH; free oxygen; physical conditions; positive oxidation-reduction potential; pH-alkalinity value.

Sewages reflect the diet of the contributing population. Metcalf and Eddy state that the organic content of the average American domestic sewage is 400 p.p.m. Of that total, 50 per cent is carbohydrate; 37½ per cent nitrogenous matter and 12½ per cent fats (5). However, the economic status of a population will serve to modify these percentages. For example, it was found that the nitrogenous content of the average sewage at army camps was 60 per cent.

Obviously, a plant should be capable of adequately handling all three constituents of the total organic loading. The source of potable water supply is also of vital importance in connection with the treatment problem for reasons previously set forth. Invariably, a successful installation owes its success to a "soft" or even "acid" water supply, having low pH-alkalinity value and poor nutritional value, thus lessening the treatment problem in two highly important respects. The failure of many biological oxidation plants designed solely on B.O.D. considerations can be attributed to exclusion of the pH-alkalinity value of the water vehicle as a design consideration.

During discussions on this subject at Washington two years ago, Army officials stated that the results at a certain midwestern camp did not begin to meet minimum requirements. They requested an estimate of the pH-alkalinity values. After these estimates had been given, the Army representatives felt that there must have been a foreknowledge of them, in view of the accuracy of the values quoted. The water supply was in the neighborhood of pH 7.7—alkalinity 357 p.p.m. (M.O.) and the raw sewage pH 8.3—alkalinity 770 p.p.m. A comparison of these values with the figures in the three zones of excellent, fair and poor results given previously in connection with chemical treatment will serve to convey some idea of the magnitude of this treatment problem, the subject being high in the zone of poor results.

Since plant performance depends on the activities of desirable biological entities, a consideration of the major environmental factors involved will be advantageous. Food available is directly related to the ability of a plant to break down pH-alkalinity or buffer values.

Ingols and Heukelekian (6) state that the buffer value of several sewages under examination differed in quantity but not in quality. They stress the importance of the role of ammonium bicarbonate in the sewage buffer, and note the changes in pH and alkalinity which frequently occur during the aeration of sewage with activated sludge. The effect on the buffer value of the transformation of ammonium bicarbonate to nitrate is described.

Forman and Shaw (7) of the New Jersey State Department of Health, in a comprehensive survey of New Jersey trickling filter performance, have furnished invaluable data concerning nitrogenous contents of sewage and the changes in pH-alkalinity value occurring at different plants. Loss of ammonia nitrogen and reduction in alkalinity were definitely related. An average loss of 46.4 per cent alkalinity was noted in the passage of the sewage through the filters.

Waksman (8) describes the chemical changes brought about by microbial metabolism, *including the formation of electrolytes from non-electrolytes* (ammonia and nitrates from proteins and amino acids; phosphates and sulfates from complex protoplasm). Oxidation of sulfur in soil may be followed by an increase in acidity as expressed by a change in pH. Waksman deals extensively with the significance of elemental ratios, *e.g.*, carbon nitrogen; sulfur-carbon; phosphorus-nitrogen, etc.

Lea and Nichols (9) report the significance of the latter in connection with the B.O.D. determination, which is after all, but an extension of the plant oxidation process.

At the 1944 annual meeting of the N. J. S. W. A., Lehman of Hackensack reported a plant scale experiment in which he had introduced digested sludge to the activated sludge process with beneficial results. Undoubtedly he had supplemented a deficiency in the carbon-nitrogen ratio from this rich source of nitrogen, which in turn increased the electrolyte produced and further depressed the pH-alkalinity value.

Kraus (10) cites the efficacy of digested sludge in the control of bulking in activated sludge, and offers as part of the solution to the problem "Provide in the process, additional ammonia nitrogen to balance the excessive quantities of carbohydrates present in the sewage." The practice is not recommended unless there exists a sufficient oxidizing capacity to care for this additional load.

Plants invariably have an ample supply of digested sludge but, for the most part, they lack the surplus capacity to oxidize and utilize that material, except in the case of activated sludge plants. The standard practice of returning supernatant to the plant therefore may or may not be beneficial, depending on aforesaid conditions. It is therefore found advisable in most instances to return the liquor uniformly over the 24-hour cycle.

Nitrification

The role of nitrification in sewage treatment has become somewhat controversial in recent years and its proponents and opponents have put forward claims concerning its respective merits and demerits. Townend (11), an eminent English authority reporting on 10 years' operation at Mogden, England, including the difficult war years, makes a strong case for nitrification for elimination of bulking and other operational problems, the maintenance of fresh "aerial" conditions, and for the preservation of good stream and river conditions. Eliassen (12), on the other hand, states "the disadvantage of algae growths stimulated by nitrates, are so many, that every attempt should be made to eliminate them wherever possible."

Edmondson and Goodrich (13) state that "A nitrifying filter working in circuit with a bio-aeration plant, considerably enhances the efficiency of the latter plant by: (a) Producing a much superior effluent and for treating an increased quantity of sewage, (b) producing and maintaining a good type of activated sludge, free from any tendency to bulk."

Fuller and McClintock (14), discussing the significance of nitrification in connection with activated sludge, considered higher production of nitrates an added safety factor and state that at the Des Plaines plant, the filterability of the sludge becomes progressively poorer, as the nitrates disappear.

To the case for nitrification must be added the important function of the nitrates (and sulfates) in adjusting the pH-alkalinity value downwards into the corrosion or clarification zone. Oxidation of sulfur participates to a lesser extent, because of lower concentrations of organic sulfur normally present in domestic sewage and unfavorable pH. Metcalf and Eddy (15) diagrammatically portray the carbon, nitrogen and sulfur cycles. Woodridge and Ridgewood plant performance curves reveal the significance of food factors and environment in biological oxidation processes (Figure 4).

Carothers (16), in a racy and thought provoking article, highlights the indispensable role of nitrates in the successful treatment of sewage. He describes "How we finally accomplished this nitrification to gain monthly average B.O.D. removals as high as 98.7 per cent . . ." and comments "Even *we* get suspicious when final B.O.D.'s drop below 1 p.p.m. . . ." Previous inability to produce satisfactory results was attributed to inability to attain the nitrification stage, and this in turn was traced to "Alkaline Peaks in Nature's Equilibrium." Confronted with high pH-alkalinity values (maximum pH 9.5 is given, but no analyses on carbonate alkalinity), high in the deposition of carbonates zone, he resourcefully employed "some aerobic and facultative anaerobes to break down the easily oxidizable carbohydrates and proteins with the production of acidifying CO_2 gas" by detaining the primary clarifier sludge for as long as 30 days, or until the borderline of aerobic-anaerobic conditions had been reached. The sewage passing through the primary tank was thus "carbonated" and adjusted downwards in pH-alkalinity value to a zone favorable to the nitrifying bacteria. Since the downswing in pH is identified with the initial states of digestion, it is readily seen that Carothers has established this phenomenon in the primary clarifier. Once again it must be noted that adequate oxidizing capacity ensued, enabling the reported benefits to be realized. Hence, this practice is feasible only under similarly favorable conditions.

The transformation of nitrogenous as well as carbonaceous organic matter to stable chemical form seems vital, therefore, to the success of the entire process. Having attained the desired treatment results, by what method can demineralization be economically effected? The phenol-resin method is an effective process but is not cheap and may cost as much as would distillation, where complete demineralization is required. Ultimately, where stream conditions necessitate de-ionization, may we not look forward to its accomplishment by economical, controlled biochemical means?

Temperature

Having no control over temperature, we content ourselves with observations of its significance in relation to results. For the most part, low temperatures imply lowered biological activity. We have scattered instances of growth stimulation at low temperatures, however, through highly conducive nutrient conditions and a facultative ability on the part of the organism to adjust itself to the adverse temperature condition. For example, we find *Beggiatoa* exhibiting prolific growth in the winter months at temperature levels well below 50° F. and as low as 34° F. Metcalf and Eddy (17) portray the effect of temperature on production of nitrate nitrogen. Covering of filter units is practiced in the Northwest to offset, in part, the lowered efficiency caused by low temperature. An extension of the time element may well serve to reduce the significance of adverse temperature levels.

Time

When we consider the brief time element involved in passage through a stone filter and observe the changes effected within the liquid, we are apt to minimize this factor. A comparison with results obtained in plants having a longer time element, however, will serve to show its significance. Increased rates of application result in decreased time factor, and modification of work done. Hoskins (18) treats extensively on the lag effects in a comprehensive discussion of the B.O.D. test.

pH

Waksman (19) states optimum and limiting reactions for given species, but in practice, we are to a large extent unable to control this factor. The nitrobacters, for example, may have to get along on a pH invariably above their optimum range of pH 6.8 to 7.3 while *Thiobacillus thioxidans*, having an optimum range of pH 2.0 to 4.0, is generally inhibited.

E. T. Roetman has charge of an interesting biological oxidation filter at the American Viscose Corporation plant at Marcus Hook, Pa. The problem is a sulfite waste and the filter is doing a remarkable job of stabilizing this material, operating at a pH level of 3.0 to 5.0.

Static concentrations of the comparatively new synthetic organic detergents display widely divergent bactericidal properties at various pH levels (20). With a concentration of 0.2 per cent detergent, 5-min. contact, initial inoculum 6,400,000 and pH 6.0 the residual count was 1,060,000; at pH 5.0 the residual count was 0.

Bactericidal effects of lime treatment at pH 10.5 or higher has been mentioned previously. Obviously, a favorable pH level is essential for the successful operation of a biological process. Ascending pH values are also progressively inimical to the life and activity of the bacteria. While we have no control over the initial composition of the waste to be treated, there is much we can do, through knowledge of this subject, to extract the maximum efficiency from plant facilities.

Free Oxygen

An adequate oxygen supply is a basic requirement of an oxidation process. Its deficiency impairs the results and total depletion inhibits the organisms and brings about putrefactive conditions in which the anaerobes predominate.

The performance of a biological oxidation plant, regardless of its type, may be entirely changed simply by exposing the sewage to aeration, inoculation, and downward pH-alkalinity adjustment before passage to the process; *i.e.*, aeration tank, filter, etc. Nitrifying bacteria are particularly critical of their environment and their activities are tremendously accelerated by this pretreatment.

Nitrate production in the Ridgewood filter was increased from 4 p.p.m. to as high as 28 p.p.m. Maintenance of a minimum D.O. of 2 p.p.m. from the influent to the oxidizing units inhibits putrefactive types, and thus effectively controls odors throughout the entire plant. Ponding of filters previously experienced is now unknown, although organic loadings on the Ridgewood filter have been greatly increased by the omission of the intermediate chemical coagulation step. Ponding has therefore been found to be due to the application of a poorly aerated or septic sewage to the filter media, whereby filamentous types of growth occur, particularly in the upper layers, resulting in sealing the interstices between the media. Adequate air supply creates an environment favorable alike to the aerobic carbonaceous and nitrifying bacteria and permits the simultaneous oxidation of carbon and nitrogen throughout the bed.

Chambers (4) found that ''aeration tends to the formation of individual cells, while in poorly aerated water, there is a tendency for organisms to form colonies and filaments.'' Degreasing effected by preaeration also contributes substantially to better surface conditions on the filters and to better filter performance.

Fuller and McClintock (14) state, ''Nitrification occurs in some English plants only on Sundays and holidays.'' Overloading has always been at the expense of the more critical nitrifiers, with nitrification moving downwards and finally ceasing as filters were progressively loaded.

Physical Conditions

Activated sludge invariably employs ample aeration capacity, where a stock in trade of the flocculent matrix is regularly plied with ''fresh'' food and oxygen. Sand filters and stone filters afford interface areas for the adherence of the zoogleal film over which the polluted material flows. The trend in activated sludge is toward shortened aeration periods and in stone filters to reduction of cubic contents and increase in rates of application. We have seen how a slow sand filter with media having an effective size of 0.3 to 0.5 mm., capable of handling 150,000 gal. per acre per day, can produce a superlative purification result. ''Standard'' filters of 1-in. to 3-in. trap rock, rated at from 300,000 to 600,000 gal. per acre per day, can produce a stable and well-oxidized effluent. ''High rate'' filters of larger stone size and lesser cubic content, loaded up to 30 m.g.a.d. with recirculation ratios of up to 4 : 1, produce less stable effluents than either the standard or the sand filter, reflecting an intermediate stage of oxidation.

The Ridgewood filter, composed of 1-in. to 2-in. basalt, 5 ft. average depth, is now being loaded at maximum rates of 5.5 m.g.a.d., or 1.1 m.g. per acre-ft. per day (the maximum capacity of the pumps delivering pretreated sewage to the filter). Despite inadequate presettling and pretreatment capacity, this filter is producing a high grade effluent, whereas in 1934 this same filter installation was unable to handle the load and produce an acceptable quality of effluent. This demonstrates how limiting physical conditions may be compensated for by favorable adjustment of other vital controlling environmental factors. The production of stable and well-oxidized and clarified effluents at higher rates of application, under adequate conditions of pretreatment, is now a definite prospect.

Rudolfs has shown the significance of rates of application to biochemical change with an unaerated Imhoff tank effluent as the subject (21), also the significance of the size of media used (22). His conclusions are of the greatest significance in evaluating the various systems in use.

The reduction of chemical change occuring at higher rates may therefore be interpreted ecologically and is the direct product of structural difference. B.O.D. values for high rate and standard filters may not be directly compared, according to the "Joint Statement of Policy of the Upper Mississippi River Basin Authority," which report states that "Well nitrified effluents from conventional filters with B.O.D. of 50 to 60 p.p.m. may be considered equivalent to effluents from a high rate filter with 30 p.p.m. B.O.D."

Oxidation-Reduction Potential

Rohlich (23), in a revealing study of potentials in an activated sludge plant, has focused our attention on yet another important environmental factor. The role of oxygen in creating and maintaining a positive potential, favorable to oxidizing types, is effectively portrayed.

Determinations of oxidation-reduction potential of Ridgewood filter effluents disclose values comparable with those attained in activated sludge. A platinum electrode and a dial graduated in millivolts were substituted for the glass electrode and the pH dial, respectively, in a standard Hellige potentiometer.

Waksman (24) states that "a knowledge of the oxidation-reduction potention of the media is important . . . in obtaining the optimum growth of an organism." Positive values indicate a potential favorable to aerobic or oxidizing types; negative values favor anaerobic or reducing types.

Determination of the oxidation-reduction potential in a raw sewage of zero D.O. reveals the extent to which reduction has progressed beyond the point of D.O. depletion. Zero potential obtains when the D.O. reaches depletion. Higher negative potentials are indicative of a more highly reduced condition. On the other hand, Rohlich gives positive values of up to 400 millivolts for the aeration tank stage of activated sludge treatment.

pH-Alkalinity Value

As shown on the graphs, this value is plotted as a function of two simple easy-to-run determinations. Unlike other values in general use, where hours or even days are involved, but a few moments are required to determine them. Its basic significance in relation to the phenomenon of clarification has already been stated. It has been shown that high values are related to treatment problems in both chemical and biological plants.

High initial values may be due to (*a*) water supply (*b*) trade or laundry waste (*c*) decomposition occurring in the sewer system trunk lines, mains or house connections, because of tree root obstructions (25), flat grades or low flow.

While an ample pH-alkalinity value must be present to act as a buffer and to prevent the development of an early unfavorably low acid environment for certain desirable oxidizing organisms, the detrimental effect of higher values is also noted. Gradations of this value, intermediate between low and high, are reflected in treatment results.

Hatfield (26) states that "the relation between loading and effluent quality is dependent on many factors and is a complicated problem not yet solved. . . . If normal variations in sewage strength and rate of application have only a slight effect on the efficiency of a trickling filter, what then are the factors which cause the wide variations in efficiencies of various plants?"

As previously stated, design predicated solely on a B.O.D. basis has repeatedly failed to produce the desired treatment results. Gross failures are indicative of other basic factors, not considered in the design, having taken precedence over B.O.D. considerations. No constant relation exists between the population, and therefore the B.O.D. value of a domestic sewage, and its pH-alkalinity value.

Fortunate alike are the designers, manufacturers and operators whose lot is cast among low pH-alkalinity values! Digester supernatant, returned through a plant for complete treatment, affects results mainly because of its upward adjustment of pH-alkalinity values in raw sewage. Eckert (27) relates benefits derived from pretreatment of supernatant liquor, consisting of chlorination, which effects substantial downward pH-alkalinity value adjustment.

Summary

(1) Beginning with the record of clarification of water and sewage by chemical coagulation, and progressing from that basic knowledge to a consideration of the clarification of non-inhibitive aqueous wastes by biological oxidation processes, it has been shown that certain factors are common to both —that fundamentally, the same work must be performed to bring about the desired results, whether chemical or biological processes be employed.

(2) Enumeration of the additive factors involved in the case of biological oxidation systems follows, indicating the environmental requirements to be satisfied before optimum results can be attained.

(3) It has been shown that the failure of chemical treatment to attain optimum results is due in a large measure to adversely high pH-alkalinity values in the raw subject. "Frontal" assault has been shown to be both costly and unproductive of the desired results. On the other hand, successful and economical coagulation may be ensured by initial downward adjustment of the pH-alkalinity value, using various means such as precarbonation and/or dilution by treated water having lower pH-alkalinity value, *before* introduction of the coagulant.

(4) Biological processes are likewise adversely affected by high pH-alkalinity values and, in extreme cases, may be a complete failure since the biological environmental requirements are also involved.

(5) Changes in pH-alkalinity values which occur in the application of chemical and biological processes to clarification problems are shown graphically. The basic similarity in the two systems is thus demonstrated.

(6) pH-alkalinity value surveys may be used to advantage in several ways by designers and operators alike, *e.g.*, preliminary determinations on public water supply and/or sewage for design purpose; for determining condition of collection systems, including trunks, laterals and house connections; for checking existing plant performance, either overall or by units.

Conclusions

(1) All biological oxidation processes are basically similar, despite the physical dissimilarity of the various types of plants encountered in present day practice. The degree of treatment attainable in the respective systems is a direct product of structural design. Difficulties in correlating the work accomplished by similar plants under comparable loading conditions can be ascribed in a large measure to a disregard of the respective pH-alkalinity values. Likewise, plants designed solely on a B.O.D. basis do not necessarily produce the anticipated results. A survey shows that success attends such plants as are favored by low pH-alkalinity values in the public water supply and in the sewage; failure has been shown to occur when high pH-alkalinity values were encountered. The significance of this aspect of aqueous subjects, in the design and operation of plants, is clearly indicated.

(2) Not all the factors enumerated are subject to control. In the operation of both chemical and biological and of straight biological plants, however, it has been established that adjustment of certain controllable factors such as pH-alkalinity value, dissolved oxygen, food and elemental ratios may substantially improve plant performance, and even turn failure into success.

(3) Existing biological oxidation plants whose effluent quality does not come up to the required standard may require the adjustment of one or more of the factors involved. A minimum of new construction would be involved, since failure does not necessarily originate in structural features. For example, some stone filters do not have the ability to de-colloid and, despite substantial B.O.D. reductions, the effluent is condemned because it is turbid or cloudy. Adequate preconditioning of the sewage before passage to the oxidation process will often enhance performance and make possible the production of an effluent of low turbidity and B.O.D. and of high stability.

(4) Satisfactory performance of new plants will be assured if, in addition to the other design factors involved, due consideration is given to the vital and basic pH-alkalinity value.

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Industrial Wastes

TRICKLING FILTER TREATMENT OF SULFITE WASTE LIQUOR

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Stream pollution by spent cooking liquor from the manufacture of wood pulp by the sulfite process is a problem as old as the process itself, and is one for which no satisfactory solution has been found.

This liquor is a concentrated, strongly acid waste (Table I), which is substantially devoid of nitrogen and phosphorus. Much of its pollutional value stems from its relatively high wood sugar content (approximately 20 per cent on solids basis).

TABLE I.—Typical Characteristics of Sulfite Liquor from a Mitscherlich Cook (Spruce Wood)

pH	2.2–2.8
Total solids—by evaporation (%)	12.5–13.5
Ash (%)	1.7–2.5
SO_2—free and loosely combined (gm. per l.)	5.5–6.5
5-Day B.O.D. (p.p.m.)	32,000–36,000
Specific gravity 20°/20°	1.060–1.064

Believing that this waste would be amenable to biological treatment, Dr. C. N. Sawyer (1) investigated the application of the activated sludge process to its treatment. Sawyer concluded, in general, that when the 5-day biochemical oxygen demand of the process influent exceeded some 1,400 p.p.m., foaming difficulties, sludge bulking, and with some liquors even sludge loading interfered to such an extent as to render the process unmanageable.

The investigation here reported was undertaken to determine in the laboratory whether the trickling filter would offer any advantage over the activated sludge process and, if so, whether it would accomplish enough oxidation of sulfite waste liquor to warrant pilot-scale studies.

Apparatus and Procedure

Two laboratory filters were set up according to Figure 1. Each filter comprised a wooden frame one foot square inside, open at the top, provided with wooden underdrains, and filled with 1-in. ceramic raschig rings to a depth of 5 ft. Distribution of the wastes on the surface of the filter was effected by means of a variable speed, motor driven laboratory stirrer mounted above the filter. Wastes were allowed to discharge from a dosing orifice down the shaft of the stirrer, and were thus dosed to the filter media in a rain-like spray. The rate of dosage was controlled by a constant head on a short glass tube of suitable bore inserted in a stopper, which was in turn located in the bottom of a 2-gal. metal dosing tank. A small centrifugal pump delivered liquid from a 50-gal. raw waste container to the dosing tank, overflow from which returned to the raw waste container. Effluent from the filter was collected in a second 50-gal. drum.

One filter was later modified for recirculation in accordance with the dia-

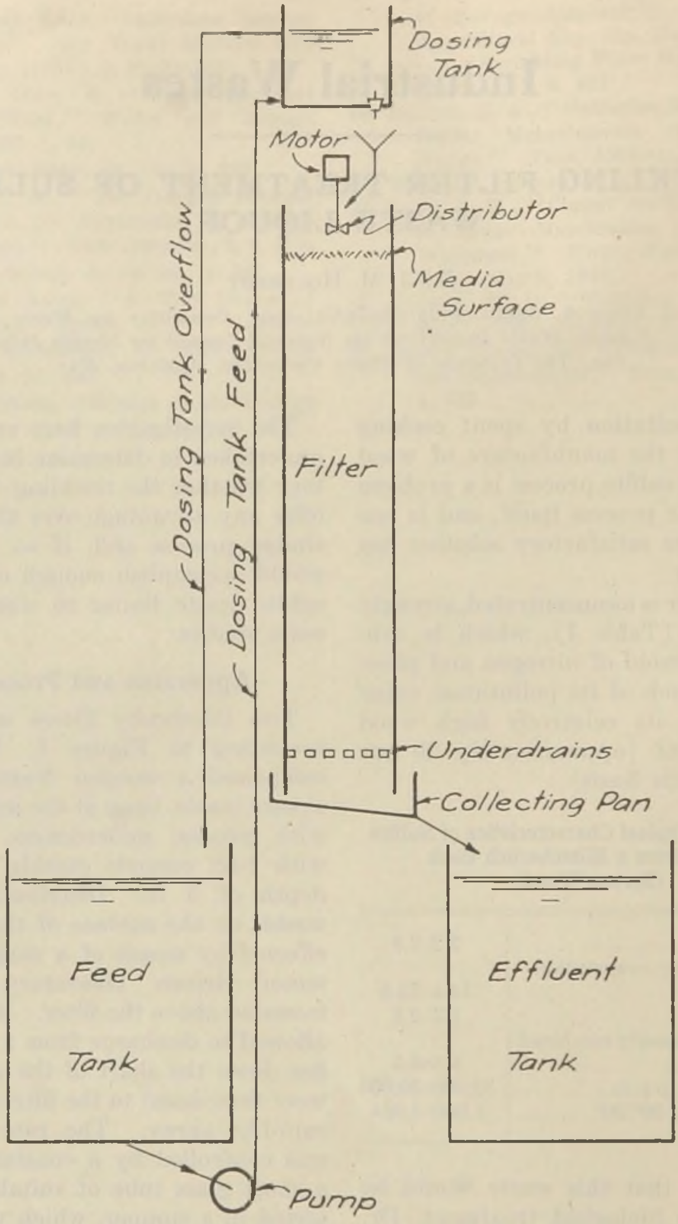

FIGURE 1.—Diagrammatic sketch of laboratory scale trickling filter. No provision for recirculation.

gram shown in Figure 2, by adding a 2-gal. sump connected in such manner that the treated waste would overflow the sump into the effluent tank, and providing a constant level box and orifice to feed the raw mixture into the sump.

Operating procedure was as follows: Waste mixtures slightly in excess of one day's requirement were prepared in the raw waste drum. Samples were taken and the pump started. The filter was dosed continually and at the end of 24 hr. the second drum would contain the effluent from an entire day's run. After stirring and sampling the effluent, both drums would be emptied and a new day's supply of waste prepared.

Individual runs were usually of seven full days' duration, with samples being taken only during the last two or three days.

Both filters were started on settled domestic sewage and no sulfite waste liquor was applied until normal oxidizing efficiencies were attained.

Analytical Methods

The pH was determined with a Cameron glass electrode, suspended solids by the Gooch crucible method and ammonia nitrogen by the macro-Kjeldahl method.

No satisfactory method for phosphates was available at the time due to the interference of the large amount of organic matter in samples containing significant quantities of sulfite waste liquor. A reliable procedure was, however, developed later. After

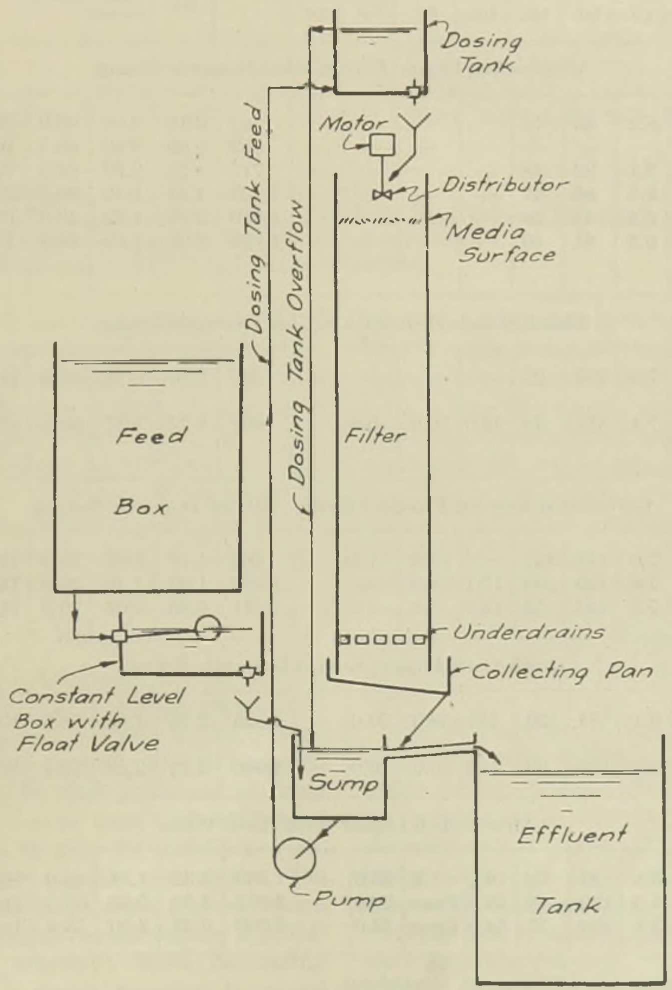

FIGURE 2.—Laboratory sketch of laboratory scale trickling filter with provision for recirculation.

the first few weeks of operation, phosphate was added to the raw waste mixtures in quantities considered to be in excess of actual needs and no attempt was made to determine residuals.

Five-day B.O.D. values were determined in general accord with standard methods (2). Dilution water was seeded throughout and was fortified according to Lea and Nichols (3), after extensive tests proved the oxidation rate with Lea's mixture to conform closely to that noted when aged Fox River water was used for diluting.

Dissolved oxygen was determined by the Winkler method using the sodium

TABLE II.—Summary of Trickling Filter Data (No Recirculation)

Run	Solids in Feeds (%)	pH		Suspended Solids (p.p.m.)		Ammonia Nitrogen (p.p.m.)		Phosphates as PO_4 (p.p.m.)		5-Day B.O.D.				Remarks
										Inf. (p.p.m.)	Lb./Cu. Yd./Day		Per Cent Removed	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.		Inf.	Removed		
Mitscherlich Liquor With Settled Domestic Sewage														
1	0.0	7.8	8.2	63	14	—	—	—	—	59	0.10	0.08	80.0	Brown growth
2	0.1	—	—	—	—	—	—	—	—	352	0.60	0.40	66.7	Whitish growth
3	0.2	6.9	7.1	92	48	—	—	—	—	717	1.23	0.79	64.2	Whitish growth
4	0.3	6.4	6.5	86	37	—	—	—	—	1,133	1.94	1.10	56.6	Ponding
5	0.4	6.0	6.3	44	26	—	—	—	—	1,440	2.46	1.22	49.6	Ponding
6	0.5	5.8	6.2	81	40	—	—	—	—	1,773	3.03	1.95	64.4	Top 3-inch media washed
Limed Mitscherlich With Settled Domestic Sewage														
7	0.2	8.5	7.8	263	25	—	—	—	—	508	0.87	0.78	89.5	Growth heavy and black
8	0.4	7.8	7.4	513	39	22.0	10.9	0.8	—	997	1.71	1.17	68.5	Growth heavy and black
Carbonated Howard Process Effluent, Settled Domestic Sewage														
11	0.2	7.0	7.6	115	131	—	21.3	1.1	—	682	1.17	0.87	74.3	Daily flush
12	0.4	6.6	7.3	129	99	17.1	8.0	1.6	—	1,122	1.92	1.46	76.0	Daily flush
13	0.6	6.5	7.5	144	52	14.9	5.4	3.9	—	1,671	2.86	2.01	70.3	Daily flush
Quick Cook Liquor, Settled Domestic Sewage														
14	0.5	4.7	6.1	154	120	145	58.0	20.0	—	1,625	2.78	1.63	58.6	Buildup period, filter washed
15	0.6	4.6	5.9	176	92	110	56.0	20.0	—	1,900	3.25	2.38	73.1	Whitish growth
Mitscherlich Liquor With River Water														
21	0.5	5.3	5.8	91	48	19.2	1.3	26.0	—	1,360	2.32	1.58	68.0	Heavy growth
25	0.8	4.1	4.3	122	49	48.0	Trace	20.0	—	2,742	4.69	2.93	62.5	Daily flush
26	0.9	3.9	3.8	209	57	64.0	Trace	20.0	—	3,050	5.22	3.10	59.4	Daily flush

Notes: (1) Dosing rate 1.66 m.g.a.d. throughout.
(2) No dissolved oxygen in filter effluent at any concentration of sulfite waste liquor.
(3) Phosphates calculated from nutrients added starting Run 14. Concentrations shown in preceding runs probably in error.

TABLE III.—Summary of Trickling Filter Data (With Recirculation)

Run	Solids in Feeds (%)	pH		Suspended Solids (p.p.m.)		Ammonia Nitrogen (p.p.m.)		Phosphates as PO_4 (p.p.m.)		5-Day B.O.D.				Remarks
										Inf. (p.p.m.)	Lb./Cu. Yd./Day		Per Cent Removed	
		Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.		Inf.	Removed		
							Mitscherlich Liquor With Settled Domestic Sewage							
38	0.6	—	—	—	—	75	—	20	—	1,663	2.84	2.10	74.0	Growth heavy
39	0.8	5.2	5.2	154	60	100	30	20	—	2,650	4.53	3.66	81.0	Daily flush
40	1.0	4.8	5.8	196	65	100	22	20	—	3,533	6.05	4.62	76.4	Ponding slightly
							Carbonated Howard Process Effluent With Settled Domestic Sewage							
41	0.6	6.6	7.3	496	200	110	38	20	—	1,888	3.23	2.48	76.6	Daily flush
42	1.0	5.8	7.1	178	178	110	48	20	—	2,700	4.62	3.34	72.3	Daily flush
43	1.0	5.9	7.1	218	140	110	18	20	—	2,750	4.71	3.91	83.0	Daily flush
48	1.4	6.5	7.0	112	315	153	8	20	—	3,730	6.41	5.16	80.5	Evidence of sloughing

Notes: (1) Treatment rate 1.66 m.g.a.d. throughout.
(2) Recirculation ratio 15 to 1 except Run 43—ratio 30 to 1; Run 48—ratio 60 to 1.
(3) No dissolved oxygen in filter effluent at any time.
(4) Phosphates calculated from nutrient addition.

azide modification prepared by Barnett (4) to obviate nitrite interference. The choice of this method over the alkaline hypochlorite method in the presence of sulfite waste liquor, as recommended in Standard Methods (2), was made after a series of comparative tests indicated that the amount of sulfite waste liquor in the B.O.D. dilutions was so small as to occasion no error.

Results

The first combination to be treated after a build-up on sewage was a mixture of acid sulfite waste liquor (Table I) and settled sewage. It will be noted from Table II that removals of from 60 to 65 per cent were indicated with loadings up to 3.03 lb. B.O.D. per cu. yd. of filter media per day. The growth on the filter was a typical brown when the sulfite waste liquor applications were started. With increasing strength of influent, however, it turned gradually to a dirty white and finally to black and increased markedly in quantity. Ponding was in evidence during Run 3, and increased until it became necessary to remove and wash the top 3 in. of media prior to Run 6.

Having demonstrated that acid liquor was amenable to oxidation on a trickling filter, additional runs were made with two types of alkaline liquor and another acid liquor from a somewhat different pulping process. As will be seen from the data, there were evidenced no marked differences in the oxidation rates of any of these mixtures.

The sewage was relied upon in the early runs to furnish nutrients. A decided slump in filter efficiency following a rainy spell, however, emphasized the necessity of maintaining a safe nutrient level with supplementary nitrogen and phosphorus. Ammonium chloride and trisodium phosphate were used for this purpose. No particular attempt was made to work out minimum nutrient requirements.

Realizing that many pulp mills would

have access to limited quantities of sewage only, a series of runs were made wherein sulfite waste liquor was diluted with river water. Data shown for Runs 21, 25, and 26 (Table II) indicate no unfavorable results from this substitution.

Table III summarizes two series of runs calculated to appraise the benefits to be derived from recirculation. The first five runs reported were made with a recirculation ratio of 15 to 1 (dosing rate of 25 m.g.a.d.), the sixth at 30 to 1 (50 m.g.a.d.), and the last at 60 to 1 (100 m.g.a.d.). Indications are that recirculation does offer some advantage, although ponding difficulties still occurred to such an extent that quantitative improvement is hard to evaluate.

Discussion

The choice of filter media, raschig rings, appears to have been an unhappy one due to the extreme ease with which they fill up with slime and thereby prevent the sloughing which is so necessary to successful filter operation. Sloughing never occurred and, obviously, large quantities of material were stored in the filter. Attempts were made to offset this condition by frequent flushing with high-pressure water, by cultivating the surface of the filters, and by actually dumping them, cleaning, and replacing the media. While these expedients permitted the work to go on, numerous runs yielded worthless data because of plugged or freshly scrubbed filter media.

Regardless of the above, however, it would appear to be fairly well established on the basis of the work here reported that there are no constituents in sulfite waste liquor that are sufficiently toxic to prevent its oxidation on a trickling filter at concentrations considerably in excess of that reported by Sawyer for the activated sludge process, provided ponding can be controlled. Results of Run 48 suggest the possibility of extremely high dosage rates (100 m.g.a.d.) accomplishing such control.

Data on nitrogen and phosphorus requirements are much too sketchy to permit any sort of a quantitative interpretation. It is well established, however, that biological activity requires a supply of these elements, and it may be concluded from these data that it is unnecessary to supply them in organic form.

There is apparently no conclusive evidence that any of the feed combinations used possess any advantage as regards amenability to oxidation. Further work under more favorable conditions might, however, alter this conclusion.

There is indication that recirculation might step up the B.O.D. removal somewhat and that extremely high rates of recirculation might favorably effect ponding tendencies. Again, however, further work will be required before firm conclusions can be drawn.

It is of interest to note that the biological films on the filter media were not at all like those usually found associated with filters. While no detailed study was made of the component forms, they were found to consist largely of moulds and yeasts with an almost complete absence of protozoans.

Summary

Work with two laboratory-scale trickling filters treating sulfite waste liquor has demonstrated that this material, either raw or limed, is amenable to biological oxidation.

It is indicated that the various types of sulfite waste liquor vary but little as regards the way they react to oxidation on a trickling filter.

Inorganic nitrogen and phosphorus are acceptable nutrients for the biological forms involved.

Sulfite liquor dilutions having B.O.D. values up to 3,730 p.p.m. have been successfully treated to remove better

than 75 per cent of the applied B.O.D. at loadings in excess of 6 lb. per cu. yd. per day.

It is indicated that for further study of the biological oxidation of this waste, the trickling filter offers more promise than does the activated sludge process.

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STREAM POLLUTION PROBLEMS OF THE ELECTROPLATING INDUSTRY *

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The highly toxic nature of the chemical compounds used in electroplating causes wholesale and widespread destruction of fish and other forms of aquatic life. Cyanides in minute concentrations kill almost instantly. Compounds of many metals such as copper and zinc cause both rapid killings and also have cumulative effect resulting in delayed death of fishes. Lethal limits of many of the constituents of plating wastes have been established and are published in a bulletin entitled "Detection and Measurement of Stream Pollution" by Dr. M. M. Ellis of the U. S. Fish and Wildlife Service.

Cyanide wastes are a menace to sources of public water supplies. An example is found in the case reported in 1944 on the White River above the water supply intake of the city of Indianapolis, Ind. Another occurred in a small community where percolation from impounded wastes endangered both municipal and industrial well water supplies.

Agricultural interests suffer damage by loss of livestock using water from cyanide-bearing streams.

The germicidal action of the various chemical pollutants on organisms in the streams interferes with the normal biological processes of natural purification. The ability of the streams to assimilate other wastes is greatly reduced and depreciation of stream quality results.

Where wastes enter municipal sewage treatment plants, the treatment processes have been impaired, thereby causing an inferior quality of effluent to be produced. They reduce the purification efficiency of trickling filters and aeration processes of sewage treatment by destroying the essential organisms. Copper, chromium and zinc are notable offenders as inhibitors in the digestion of sewage sludge. Control of bacterial pollution from sewage is disrupted by interference of the wastes with chlorine disinfection.

Receiving waters are often rendered unsightly by color and oil in the waste discharges. Chromium compounds are particularly troublesome by reason of the persistence of their color.

From analyses of the circumstances accompanying a large number of these problems, it is possible to define several factors which recur most frequently as the principal causes of pollution.

Little or no attention is given to the wastes as they leave the process. If suitable plant drainage can be obtained, no concern is given to the strength or volume of waste or the point of ultimate discharge. Seldom does management know whether the wastes enter the stream directly through an individual outlet, or by way of connections to municipal storm sewers or through sanitary sewers with or without subsequent treatment. Too often there is no information available as to how the plant is sewered or where the connection leads.

Certain of the constituents of the wastes are extremely injurious in minute concentrations. In most instances there is a lack of understanding of the permissible limits of concentration and the hazards created when they are exceeded.

Dependence upon dilution with other plant wastes or with the stream, for

* From a paper written for *Monthly Review*, publication of the American Electroplaters Society.

disposal of concentrated baths has been misplaced by failure to recognize the limitations which this method offers. For example, dilution with 250,000 gal. of water is necessary per gallon of cyanide dip solution (8 oz. per gal. NaCN) to reduce the concentration to a value which can be tolerated by fish. Few if any plants have sufficient quantity of cyanide free wash and rinse waters to dilute their baths to such a low strength. While the receiving stream might furnish such volumes, it must be recognized that only a small portion of the stream flow is utilized unless special provision is made for discharge of waste at controlled rates and for mixing with the river flow. Failure of this method has occurred where the stream is subject to flow regulation by power dams or grist mills. In such cases the dilution factor is materially reduced or eliminated during periods of stream flow storage and concentrations of pollutants are raised to the toxic range.

Division or lack of responsibility for control and disposal of wastes has resulted in many instances of pollution. Recognition of the problems presented by the wastes has not been developed among the plating room personnel. No attempt has been made to define the duties or responsibilities of disposal nor to delegate authority over this phase of operations to a competent individual. Instances have occurred where such control, once established, has failed due to changes in plating room personnel and neglect in informing new employes of the problem and of proper disposal practices.

Labor and time-consuming methods result in the tendency to seek short cuts in performing disposal operations. Controls that involve hand bailing and carrying of tank contents have proved undependable. They result in dumping to the sewers the untreated or inadequately treated wastes.

Accidental losses of production baths or impounded wastes account for another class of problem. They occur from leaks in tanks or failure of valves and piping within the plating room. The contents of ponds in which wastes are stored are often released to a stream by breaks in the retaining dikes.

Cancellation of government contracts for war materials in late 1945 was followed by suspension of portions or all of plating room operations and by revisions of production and practice throughout the industry generally. Indiscriminate disposal of obsolete baths resulted in an epidemic of pollution cases after VJ Day.

Character of Wastes

From the standpoint of pollution control there are in general two major classifications into which the plating room wastes can be placed. Overflows of hot and cold waters from rinse tanks, drainage from water sprays and tumbling barrels are continuous sources of waste flow to the sewers. Superimposed upon the normal steady discharges resulting from production operations are the intermittent discharges which constitute the second classification. These consist of batch dumps of spent, spoiled, obsolete or otherwise unusable baths, containing the solutions used in the preparation of the metals for surface coating and for plating.

It is difficult to relate waste volume to any unit of production. The size, shape and type of plating work and number of rinses needed to remove the undersirable constituents are all variables which do not directly influence the water usage. Quantities of water needed do not appear to be established in the same degree as the concentration of the electrolytes. As the result, some excess of water is oftentimes consumed over that necessary for good production.

Rates of overflow from running rinse tanks range from 1 to 4 g.p.m. with 3 g.p.m. being a fair average. Tumbling barrels use in the neighborhood of 5 g.p.m. for the rinse operation. The only sound basis for determining the waste volumes lies in measurements either by a water meter on the supply lines or by devices installed in the sewer.

The continuous discharges carry all of the constituents used in the plating process. Among those found present are suspended particles of dirt, grease and metal; metallic ions of copper, chromium, nickel, cadmium and zinc; cyanides, acids and others too numerous to mention.

The intermittent wastes are the most important as the cause of pollution. Tanks of all sizes ranging from the 25-gal. crock in the small job shop to 5,000 gal. and upwards in production plating establishments are an index of the volumes which must be disposed of at intervals. The reasons for such discharges lie in the chemical changes which occur that render them unsatisfactory for further use. Examples are found in the accumulation of carbonates in cyanide baths, excessive amounts of sulfate in chromium solutions used for anodizing, loss of scale-removing properties in acid solutions and the like. Generally the electrolytes are of such value that effort is made to restore them to use and much attention has been devoted by the industry to this subject. Where capable chemical laboratory service is not available, however, or where too much time and trouble is involved, no attempt is made to restore the baths and they are discharged, all claims to the contrary notwithstanding.

Some of the process baths that have been found to be discarded with resulting damage to the stream and their harmful ingredients are:

1. Chromium plating:—chromic acid, sulfuric acid
2. Zinc plating:—zinc cyanide, sodium cyanide
3. Cyanide copper plating:—copper cyanide, sodium cyanide
4. Anodizing:—chromic acid, sulfuric acid
5. Dips:—sodium cyanide, nitric acid, hydrochloric acid.
6. Bonderizing:—chromic acid
7. Cleaners:—caustic soda

Methods of Control

The adoption of control methods has as its objective the reduction in pollution constituents of the wastes entering the sewers. Any waste source which can be prevented, diverted to other uses, or eliminated by improved production practice reduces the expense and difficulty of treatment that may be ultimately required. Examples in many types of industry have been found where control has eliminated the need for further treatment or at least has reduced the extent to which it must be carried. It is therefore sound procedure to explore and apply every advantage of control as a first step in the solution of the problem.

Utilization of waste has received some attention in the industry. The opportunity appears to be far less than in other types of industry but a few developments are worthy of widespread application.

The substitution of a dip tank for a rinse immediately following the plating bath markedly reduces the amount of the electrolyte lost to the sewer by dragout. The solution so collected is utilized by return to the bath for make-up.

In conveyorized systems, a drainage interval following emersion of work from the plating baths permits collection of dragout for return to the bath, or the conveyor can be designed to pass through a dip tank for recovery of the electrolyte and return to the plating bath.

Some progress has also been made in the field of by-product recovery. A method for recovery of chromium trioxide for use as chrome green pigment has been reported to be in use. The chromium is reduced to trivalent form with sulfur dioxide and precipitated with caustic soda or soda ash. The precipitate is dewatered, dried and roasted at 500° C.

Preparation of a solution for tanning leather from waste chromic acid liquor in the anodizing process has also been reported.

Expensive metals such as cadmium, silver and nickel have been recovered by electrolysis from dip tanks in which dragout has been collected.

Separation of sewers and segregation of the various waste sources reduces the volume of wastes which must be treated. Routing of the weak wastes to the sewer or stream and diversion of the concentrated electrolytes, acids, alkalies and first rinse waters to tanks or sumps for ultimate treatment or disposal results in treatment units of smaller magnitude and, consequently, in lower outlay and maintenance cost.

Methods of Disposal

Strong acids and alkalies may be handled by interaction and equalization. In this method the solutions are drained to holding tanks where they are mixed and then discharged at controlled rates over an extended period to the sewer. Equivalent results can be obtained by draining to ponds together with weak wash waters. Such ponds will equalize the flows, settle the solids and effect neutralization by the buffering action of the various components of flow passing through the pond to the sewer. This method is not applicable to plating solutions.

A method which has been widely used in the industry depends upon percolation from impounding reservoirs for disposal. Such ponds are constructed with no overflow to the stream and should receive only the concentrated solutions and first rinse waters. For successful operation, it is essential that they have adequate capacity based upon expected volume and tests to establish seepage rates, they must be situated remote from private or public wells and must be protected against human or animal contact. Frequent relocation of the ponds can be expected as the seepage rates gradually decrease due to sealing of the soil by sludges.

Sub-surface irrigation has been adopted for strong wastes and limited amounts of rinse waters. This system requires presettling of the wastes and their distribution to the sub-surface soil through a system of vitrified tile drains. Again, a porous soil is essential and precautions must be taken to protect well waters from contamination.

Methods of Treatment

Situations are frequently encountered where lack of sufficient area or other restrictions make it impossible for ponds to be used. If control or disposal methods fail to provide the desired protection, one or more methods are available for treating the wastes to remove undesirable constituents.

Metals

Metals are removed by flocculation and precipitation with the aid of chemical coagulants. The most common reagents for removal of most metals are alum or ferric chloride in combination with lime. Removal of chromium has been the subject of extended investigations by the Connecticut State Water Commission. A treatment process has been devised whereby the chromium is reduced from hexavalent to trivalent form by the feeding of barium sulfide or similar reducing agents to the wastes. Addition of lime then precipitates the metal as a chromium hydroxide sludge which is dewatered on sand beds. Satisfactory treatment of waste containing 100 p.p.m. of chromium is reported using 4 lb. of barium sulfide and 2 lb. of lime per 1,000 gal.

When the process was employed for treating combined plating room wastes, it was supplemented by pretreatment with acid to a pH of 3.0 to volatilize the cyanide content. Operating on a fill and draw basis, it gave complete removal of chromium and substantial reduction in copper and cyanide with dosages of 10 lb. of barium sulfide and 5 lb. of lime per 1,000 gal. of waste.

At the Ford Motor Company's Willow Run Bomber plant, fill and draw operation on chromium wastes, using ferrous sulfate and lime, gave removals in excess of 99 per cent.

Cyanides

The removal of cyanide by decomposition with sulfuric acid has proved to be an effective means of treating concentrated solutions. The facilities required consist of a tightly covered receiving tank, rubber lined or otherwise coated to prevent corrosion, and equipped with an air blower and vent stack. The spent solution is discharged to the tank, sulfuric acid is added and the contents agitated by blowing air through the solution. The cyanide is volatilized to hydrogen cyanide which is blown to the atmosphere through the vent stack. With the addition of sufficient acid and an aeration time of about 16 hr., the cyanide is reduced to less than 1 p.p.m. and the treated solution can be discharged to the stream. The poisonous character of the evolved gases requires that the vent stack be high enough to avoid danger from these fumes. The Chevrolet Division of the General Motors Corporation at Flint, Michigan, has operated such a treatment process since 1934, (Figure 1), and similar treatment was performed at the Willow Run Bomber plant during its wartime production period. The Chevrolet installation comprises a 5,000-gal. tank with a 60-ft. vent stack. In a typical treatment operation, 4,500 gal. of solution containing 2.8 oz. of copper cyanide and 1.1 oz. of free cyanide per gal. were treated with 4,255 lb. of 66° Baume sulfuric acid. The cyanide concentration was reduced to 0.98 p.p.m.

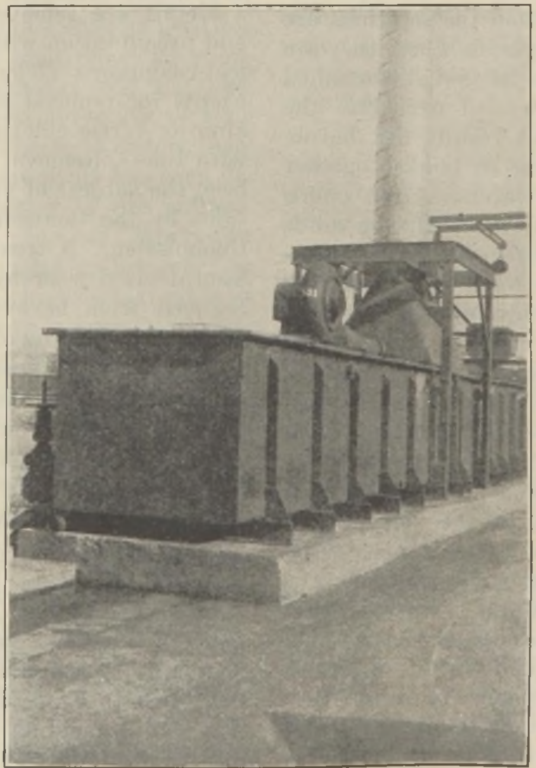

FIGURE 1.—Cyanide waste treatment plant of the Chevrolet Motor Co., Flint, Mich.

Cyanide may also be removed by oxidation with potassium permanganate. A sludge is formed consisting of manganic hydroxide and calcium carbonate amounting to 5 per cent of the volume treated. Although non-toxic to fish, the sludge presents a problem of disposal in itself. The end product cyanate has a toxicity threshold for fishes of 125 to 250 p.p.m. The installation required for this process will be less expensive but operating costs will be higher than for acid treatment.

A method for converting cyanide to non-toxic cyanates is described in a patent (No. 2,194,438) assigned to the E. I. duPont de Nemours and Company. The reacting substance is calcium polysulfide which is available commercially as lime sulfur either in powdered or solution form. Dosages required are 0.43 gal. of lime sulfur solution (29.75 per cent calcium polysulfide) or 1.84 lb. of solid lime sulfur (70 per cent calcium polysulfide) per pound of NaCN present. The reaction time is given as 2 hr. at room temperature or 30 min. at boiling temperature. The hydrogen sulfide produced in the reaction should be removed from the treated effluents prior to discharge either by aeration or by liberation with acid. Equipment needed is inexpensive and the process is simple to control. It is adaptable to the treatment of cyanide ash from carburizing processes as well as wash and rinse waters. Experiments conducted by the Michigan Institute of Fisheries Research show that sodium thio-cyanate is 600 times less toxic than potassium cyanide, and the thio-cyanate radical is 1,000 times less toxic than the cyanide radical. Discrepancies were found when treated wastes were used, indicating that some free cyanide remains. Reduction of the residual cyanide may be obtained by retaining the treated effluents in ponds for an extended period. The reaction is reversed with chlorine to produce toxic cyanogen chloride, thus requiring that precaution be exercised where the effluents reach municipal sewage treatment plants employing chlorine for disinfection. The effects upon sewage treatment processes have been studied and found to be of minor consequence within the ranges which might reasonably be encountered.

Recent studies and developments in alkali-chlorination have produced another method capable of reducing concentrations of cyanide to less than 1 p.p.m. It entails oxidation of the salt with chlorine to cyanate, carbon dioxide, ammonia and sodium chloride. The procedure was the subject of a patent application in 1939, later rejected. Various reagents have been proposed to obtain the desired reaction, such as commercial bleaching powder, sodium hypochlorite and liquid chlorine.

Several features have been encountered with bleaching powder which make it unacceptable. It produces excessive quantities of sludge when used in solutions exceeding 5 per cent sodium cyanide concentration, and presents mechanical difficulties in handling and placing into solution the large quantities of powder required for treating comparatively small volumes of electroplating solutions. The high cost of chlorine in this form raises a further obstacle to its adoption. It is therefore limited to small scale work or where weak solutions are to be treated.

Sodium hypochlorite overcomes some of these objections but does not seem to be practical for large scale treatment.

The widest range of adaptability is offered by the use of chlorine, either as liquid or gas, and caustic soda. The treatment requires that chlorination be performed under highly alkaline conditions to avoid formation of cyanogen chloride and nitrogen trichloride. Maintenance of a pH of not less than 11.5 in the waste during treatment is recommended. Chlorine requirements range from 2 to 3 lb. per pound of sodium cyanide, depending upon the nature of the reducing agents in the waste solutions. Copper is precipitated from electroplating baths as the basic carbonate. Removal of zinc requires addition of carbon dioxide or sodium bicarbonate. Equipment needed will include a receiving or holding tank so proportioned as to furnish a 6-ft. depth of liquid, a platform scale to enable measurement of the chlorine used, and a porous diffuser through which chlorine is fed into the liquid. The process is being studied for the effects which the end products might have on fish life and sewage treatment plant operation.

Recommended Waste Disposal Practice

A full recognition of the waste problem on the part of both management and plating room personnel is a necessary prerequisite to the success of any abatement measures. Many troubles of the industry can be anticipated and steps taken to alleviate them if effort is made to acquire a knowledge and appreciation of the polluting effects of its wastes. In order to be equipped properly to inaugurate and maintain control measures, attention must be given to such items as the layout of the plant sewer system, where it ultimately discharges, and the type and characteristics of the receiving water. An evaluation of the various sources should be obtained. This will serve to reveal where the pollution is originating. When related to the stream or other outlet conditions, this information will assist in determining the type and degree of abatement needed.

Loss of electrolytes to the sewer should be reduced to a minimum by installing dip tanks for collection of dragout or drip. Recover metals from dragout dip tanks by electrolysis. Indiscriminate dumping of spent or spoiled electrolytes and strong baths to sewers should be prohibited.

Control of waste handling and disposal methods must be firmly established to insure dependability. It will be effective when a reliable, competent employee is designated to be responsible for waste disposal. Such duties as inspecting, supervising and maintaining waste disposal operations, sampling and analyzing of wastes should be included in the assignment.

Avoid any unnecessary difficulty or complicated procedure in devising treatment or disposal systems. There is ample opportunity to apply ingenuity, but haphazard and makeshift methods tend to fall into misuse in a short period of time. The hazards from the wastes are of sufficient magnitude to merit good equipment and its availability when and as needed. Delays in obtaining pumps, drums, or transportation when the need arises is generally disastrous to the system.

Systems that require more than a minimum amount of manual labor for operation invite short cuts which result in pollution. For example, no confidence can be placed in the hand bailing of contents of tanks and carrying the solutions to a disposal container or pond as a means of preventing their entrance to the sewer. The best of intentions will not offset the fact that less time and effort is expended by dumping a portion or all of the solution to the floor drain. The only satisfactory way to remove spent cyanide or similar strong baths from the plating room is by draining through an enclosed system of piping directly connected to a permanent tank or sump. The standard type tanks used in plating have no outlet or drain. Nevertheless they are pollution hazards and can be made less so by fitting them with drains and valves leading to a sump outside the plating room. This will eliminate delays in restoring the bath to production and holds the solution for ultimate disposal or treatment at an opportune time by the methods described. Production delays occasioned by waste handling must be avoided in any control plan that is to be effective. Treatment of a bath should therefore not be performed in the plating tank.

Certain minimum requirements must be observed in the correction of injuries and abuses caused by the industry's wastes. Additional restrictions are necessary in specific instances contingent upon abnormally low stream flows or greater than average development and use of receiving waters. The objectives sought are summarized by the following:

1. Removal of cyanide to 1 p.p.m. or less. Fish will not tolerate concentrations of cyanide in excess of 0.1 p.p.m. as cyanide or equivalent 0.25 p.p.m. potassium cyanide.

2. Neutralization of acids or alkalies to maintain an alkalinity-acidity range of 5.8 to 8.2 as measured by the pH scale.

3. No batch discharges which will produce wide variations in waste strength or composition. Exclusion of cyanide sludges from sewers or drains.

4. Freedom from unnatural color, or surface oil film in the receiving stream.

5. Removal of suspensoids which blanket the stream or lake bottom.

6. Reduction of concentrations of metallic compounds below limits toxic to fish and animal life.

A METHOD FOR ACCELERATED EQUALIZATION OF INDUSTRIAL WASTES *

By Willem Rudolfs and J. N. Millar

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The many demands of the chemical and allied industries for increased production and the introduction of new products have created new waste disposal problems for many manufacturers. Some producers undoubtedly have been confronted with these problems for the first time.

The term "equalization" as used in connection with this work is usually understood as the detention of a waste continuously for a sufficient length of time to effect dilution or inter-reaction of substances present in the waste at different times. The object of equalization is to produce a more uniform waste which can be disposed of directly or which can be more effectively treated at a lower cost. The equalization process has been used for many years as an aid to industrial waste treatment, usually preliminary to some other type of treatment.

This process has customarily been accomplished in large ponds and quite often requires large areas of valuable land. Since mechanical agitation is usually out of the question in applying this method, the degree of mixing obtainable is dependent upon circulation caused by the currents in the flowing waste. Velocities are low, hence suspended solids settle out; furthermore, the operation is often hampered by changing density of the influent.

The method of accelerating equalization which is described can be adapted to almost any effluent where it is desired not to settle out suspended solids. The necessary equipment can be installed on the regular plant premises because of its compactness.

Probably the most extensive use of the equalization process is for the neutralization of acid with alkali or *vice versa.* Such is the application illustrated. The data presented herein were obtained from actual plant equipment operating on a waste typical of those being disposed of by a great number of chemical manufacturing plants. It is shown that an efficient neutralization of a predominantly acid waste which varies from strongly acid to mildly or strongly alkaline from hour to hour can be accomplished.

Arrangement of Tank

Figure 1 shows the flow plan and general arrangement of the equalization tank. The waste may reach the equalizing tank by gravity if possible, or it may be pumped from a small collecting tank if the level does not permit gravity flow. If the volume of flow is large, the equalization tank may be divided up into several units, each receiving a proportional amount of the total influent. This is recommended to allow for good mechanical mixing. In this case, the detention time did not exceed 1 hr. The tank was 27 ft. 6 in. long, 9 ft. 6 in. wide and provided a liquid depth of 10 ft. The total volume was 2,610 cu. ft. or 21,800 gal. Three wooden gate type agitators were spaced on equal centers along the center line of the length of the tank, each being operated at a speed of 15 r.p.m. by a 3-h.p. motor. The influent was carried to the bottom of the inlet side of the tank by means of a submerged pipe.

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* A paper presented before the Water, Sanitation and Sewage Division of the American Chemical Society, New York City, September 14, 1944.

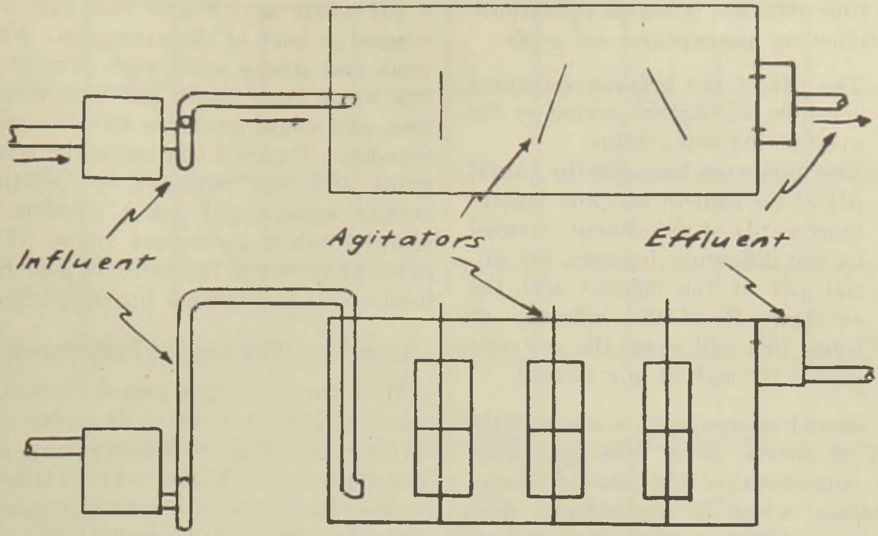

FIGURE 1.—Layout of typical equalization tank.

By bringing the influent into the tank near the bottom, it was possible to utilize the entrance velocity to aid in the mixing and to prevent the settling of suspended solids. The effluent was discharged over a weir at the opposite end.

The pH values of the incoming and outgoing material were recorded continuously by a two-point, strip chart type pH recorder.

The object of the experiment was to determine the effectiveness of the equalization process with this type of equipment. The addition of dyes did not offer means of quantitative study as the waste itself varied in color. The dosage of the influent with a salt or other chemical compound did not appear promising because of the initial prevalence of most of the common ions in the waste. Since the object of the installation was neutralization, and the control of subsequent treatment was based on the pH of the effluent, two periods were studied during which the pH of the influent changed from one extreme to the other and remained there for an interval which was equal to or greater than the detention time.

Results

In Figures 2 and 3, the pH values of the incoming and outgoing material are plotted against the elapsed time. These values were taken directly from the strip charts of the pH recorders. In both cases, once during the period studied the pH of the influent rose momentarily and then returned to the lower value. In Figure 2, the rise was of a sufficient magnitude to cause a slight rise in the alkalinity of the effluent which was apparent about 6 min. later. This effect is not as evident in Figure 3 for two reasons: (1) the change was not as great and (2) considerably more acidity had been concentrated in the tank at the time of the change. A slight tendency for the effluent pH to level off can be noticed, however. These rapid variations of the influent were characteristic of the waste which was studied; however, under ordinary conditions the changes were of greater amplitude and frequency. These two periods were exemplified because of the lack of the usual fluctuations.

In order to arrive at a method of evaluating the average effective detention time obtained in actual operations, the following assumptions are made:

1. The pH of the influent remained constant during the period at the average indicated value.
2. The difference between the initial pH of the effluent and any instantaneous pH of the effluent, divided by the difference between the initial pH of the effluent and the average pH of the influent, all times 100, will equal the per cent passed through at any instant.

The second assumption is not strictly true, of course, as it does not bring into consideration the use of linear functions where a logarithmic relationship actually exists. No attempt was made, however, to include this fact as the "zero point" for pH would be a pH value of 7.0 and this line was crossed in both of the examples. Also, weak and strong acids were present in this waste, both singly and in combination, and would interfere with this relationship. Figure 4 illustrates the latter point and was obtained by plotting acidity against pH for a number of samples taken at various times. The pH-acidity curve for sulfuric acid has been added to Figure 4 for comparison.

Actual vs. Theoretical Performance

With the "per cent passed through" calculated for a number of points according to the above assumptions, the data expressed in Figure 5 are obtained. In this illustration, the "per cent passed through" values are plotted against the elapsed time for the two periods represented by the original data shown in

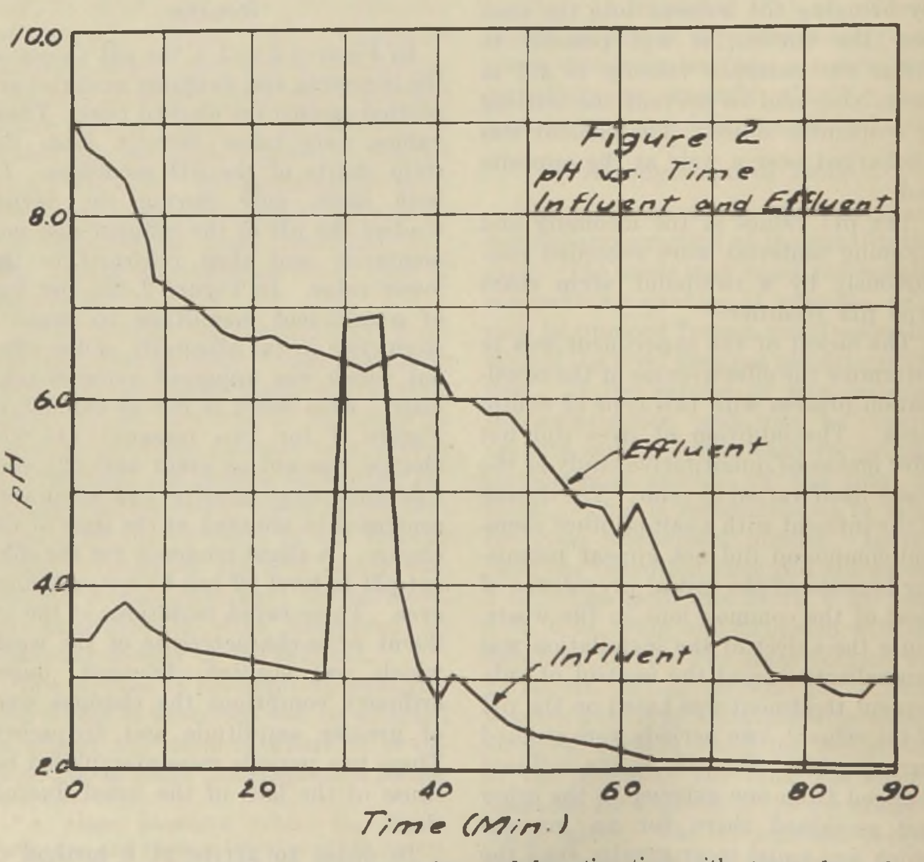

FIGURE 2.—Relation between pH values and detention time with strong dose of alkaline waste received.

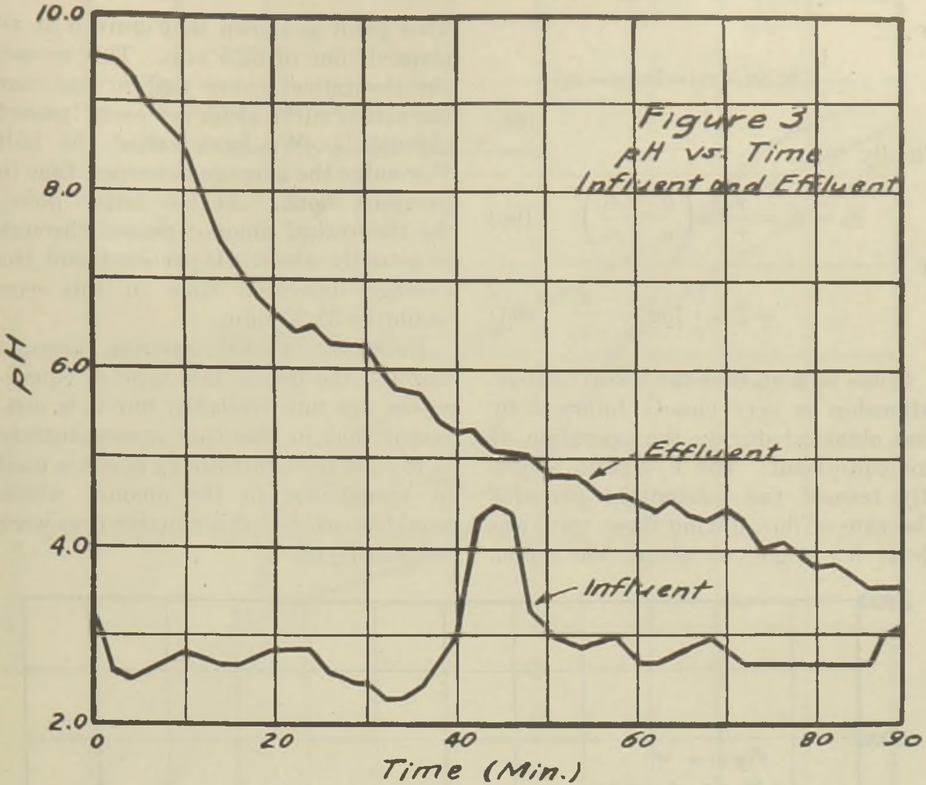

FIGURE 3.—Relation between pH and time with medium dose of alkaline waste.

Figures 2 and 3. The opposite inflections of the two curves are probably caused by the variable strength of acids in the influent, as well as the nature of the reversal of the influent pH at the middle of each run.

In order to be able to compare the actual performance to a perfect system it is necessary to resort to calculus for a general case involving similar conditions. The equalization tank is visualized as one having a volume V, in which material is being added and withdrawn at a constant rate r, the concentration of acid in the influent being a constant a, and the effluent concentration being a variable x. Then, for a small increment of time $\Delta\theta$, the concentration in the tank will change Δx. As $\Delta\theta$ approaches zero so does Δx, hence it is possible to express this relationship in the form of a differential equation. The equation is established by expressing the accumulation of acid in the tank in two different ways; first, as a function of a, r, x and θ, and second, as a function of V and x.

$$\text{Accumulation} = \text{input} - \text{output}$$

$$= ard\theta - xrd\theta$$

$$= r(a - x)d\theta \tag{1}$$

$$\text{Accumulation} = Vdx \tag{2}$$

$$r(a - x)d\theta = Vdx \tag{3}$$

Separating the differentials:

$$d\theta = \frac{V}{r}\frac{dx}{a - x} \tag{4}$$

Integrating

$$\int_{\theta_1}^{\theta_2} d\theta = \frac{V}{r}\int_{x_1}^{x_2}\frac{dx}{a - x} \tag{5}$$

$$\theta_2 - \theta_1 = -\frac{V}{r}[\ln(a - x_2) - \ln(a - x_1)] \tag{6a}$$

or

$$= \frac{V}{r}[\ln(a-x_1) - \ln(a-x_2)] \qquad (6b)$$

Finally

$$\theta_2 - \theta_1 = \frac{V}{r} \ln \left(\frac{a - x_1}{a - x_2} \right) \qquad (6c)$$

or

$$= 2.3 \frac{V}{r} \log \frac{a - x_1}{a - x_2} \qquad (6d)$$

It can be seen that the theoretical relationship is very closely followed by that obtained during the operation of this equipment. The V/r ratio is usually termed the "detention period." The rate of flow during these tests was about 0.5 m.g.d. or about 350 g.p.m. This point is shown in Figure 5 at an elapsed time of 62.5 min. This crosses the theoretical curve and in one case the actual curve at 65 per cent "passed through." We have called the half V/r value the average detention time in previous work. At the latter point, the theoretical amount passed through is actually about 41 per cent and the average detention time in this case would be 31.25 min.

Data on actual savings accrued through the use of this type of equalization are not available, but it is estimated that in this case approximately ⅓ to ½ of the neutralizing agent is used in comparison to the amount which would be used if this equalization were not employed.

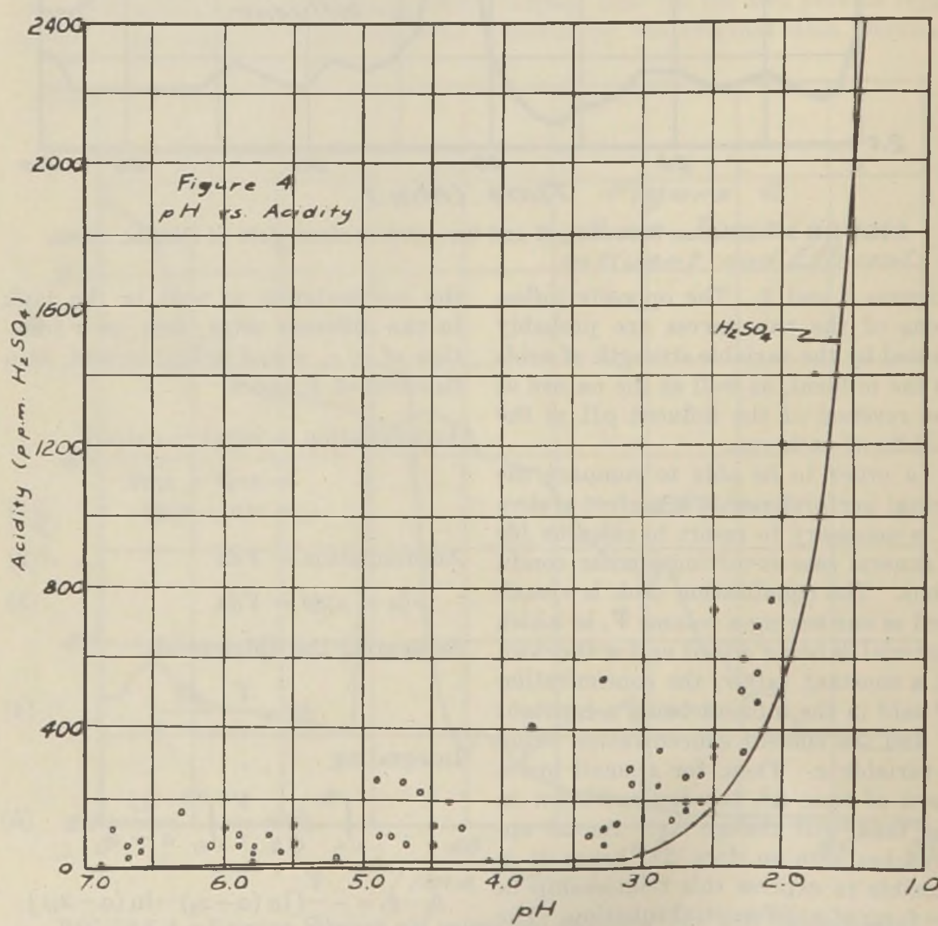

FIGURE 4.—Comparison of pH values and acidity of waste as received with sulfuric acid.

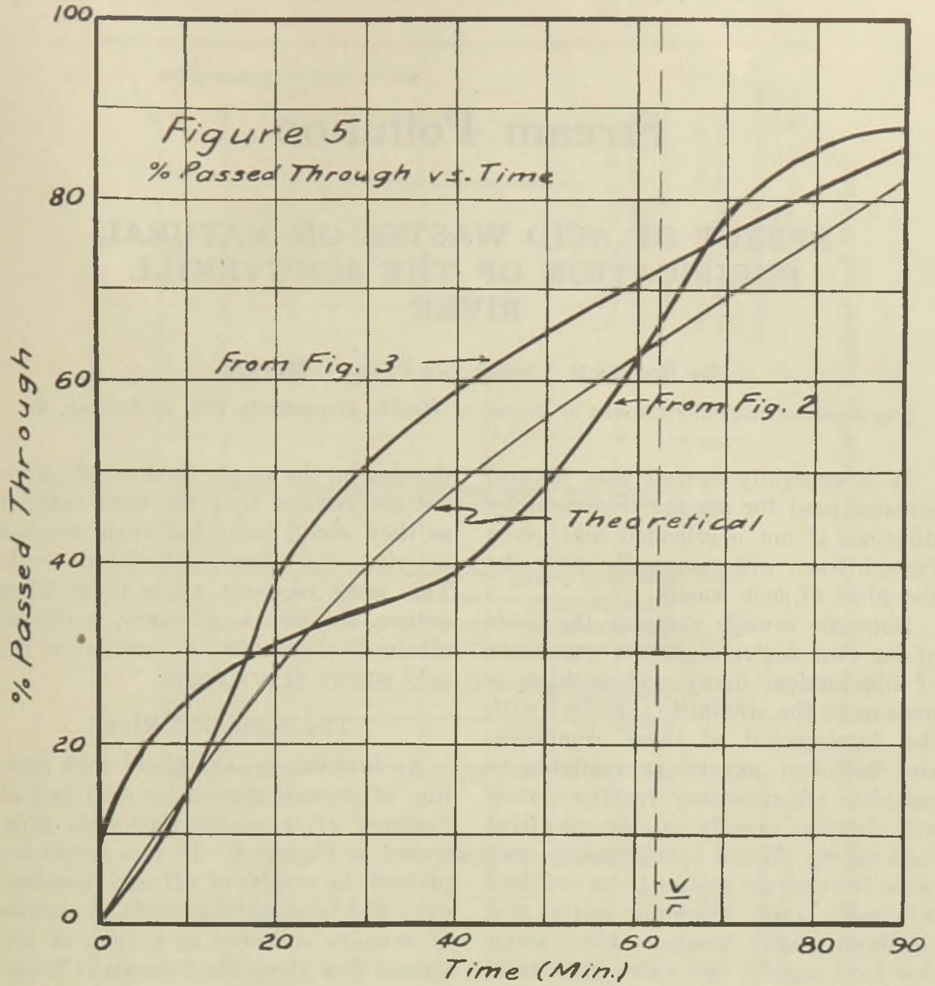

FIGURE 5.—Comparison of observed and theoretical values.

Summary and Conclusions

From the data presented it is evident that the mixing obtained through the use of this method closely approaches the theoretically "perfect" equalization tank. This characteristic, coupled with the fact that the area required for installation is quite small in comparison to other methods, points the way to a good method of preparing varied chemical wastes for direct disposal or final treatment. Automatic control of subsequent treatment is made easier because of the removal of the problem of handling rapidly changing characteristics varying from one extreme to the other.

In summary, this method is one to be desired where:

1. Limited space is available for equalization.
2. It is not desired to settle out suspended solids.
3. Rapid fluctuations occur in the characteristics of the waste being treated.
4. Automatic control of subsequent treatment is desired.

In addition to the use of this type of equipment for neutralization, it should be equally as effective when used for dilution, oxidation, reduction or any other chemical reaction where compounds discharged at one moment will react with other compounds discharged before or after to produce a desirable effect.

Stream Pollution

EFFECT OF ACID WASTES ON NATURAL PURIFICATION OF THE SCHUYLKILL RIVER

By Robert S. Chubb and Paul P. Merkel

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It is generally agreed that natural streams used for sewage treatment by dilution, if not overloaded and given enough time, will eventually overcome the effect of such wastes.

Domestic sewage contains the seeds of its own destruction, the organisms of biochemical decay. If nothing is present in the stream to interfere with the development of these organisms, and sufficient oxygen is available to complete the necessary reactions, they will develop rapidly on the plentiful food supply offered by the sewage and cause the organic matter to be oxidized into gases, water, inorganic matter and relatively stable humus. After using this food supply, the water rids itself of these organisms by starvation. This, together with any possible sedimentation, results in a naturally purified stream.

If the receiving stream contains acid or other wastes toxic to these decay organisms, they will be killed or their activity will be arrested. Biochemical activity then slows down and natural stream purification finally stops. The organic load contained in the sewage then becomes pickled or preserved, the same as occurs in a sewage sludge digester when it turns sour or when it receives toxic industrial wastes. The sewage treatment plant operator, by eliminating the poisonous wastes or by other means, restores a suitable environment for development of the decay organisms. They then develop on the ample food supply present and oxidize it in the same manner as they would have, had their original activity not been interfered with. This same recovery takes place when nature, through a tributary, furnishes alkalinity necessary to neutralize the acid waters of a stream.

The Schuylkill River

An interesting example of such pickling of organic matter by acid and of recovery after neutralization is illustrated in Figure 1. In this graph are plotted the results of pH and dissolved oxygen determinations made on a series of samples collected at a time of low stream flow along the Schuylkill River, in the vicinity of Reading, Pa.

The Schuylkill River drains an area of approximately 1,900 square miles in southeastern Pennsylvania. The upper river branches rise in the mountains of Schuylkill County, which contain Pennsylvania's lower anthracite coal fields. After flowing for about 60 miles, receiving the acid drainage from the coal mines, it leaves the mountains at Port Clinton Gap and flows through rolling farm country and through a highly industralized region approximately 90 additional miles to join the Delaware River at Philadelphia.

Two of the larger communities along the river above Philadelphia are Reading, approximately 60 miles upstream, and Pottsville, approximately 100 miles above Philadelphia. Pottstown,

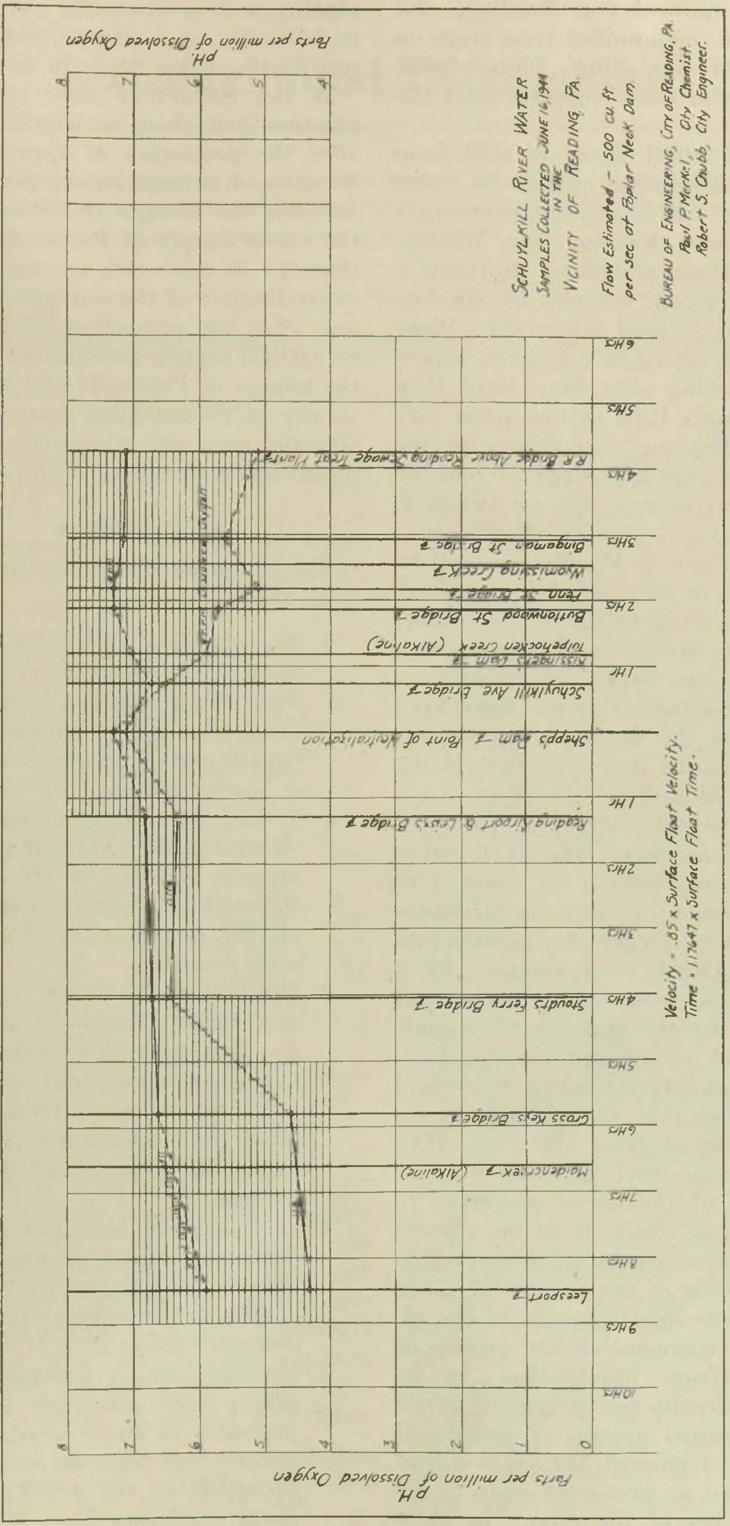

FIGURE 1.—Relationship between pH and dissolved oxygen content in the Schuylkill River between Leesport and Reading.

about 20 miles below Reading, and most of the communities from there on downstream including Philadelphia, take domestic water supplies from the Schuylkill.

The Schuylkill River is acid from the coal fields to the upper city limits of Reading. At a point approximately 7 miles above Reading, the Maidencreek, a large tributary draining a limestone region, empties its alkaline waters into the acid Schuylkill. These waters mix at river bends, at rapids and in passing over dams until they reach Shepp's Dam at the upper city limits of Reading. At this point the river water rises above pH 7.0 and the stream remains generally on the alkaline side until it joins the Delaware.

By reference to Figure 1 it will be noted that so long as the stream remains acid the D.O. curve rises, showing that the stream is picking up oxygen at a more rapid rate than it is using it and indicating the temporary stability of the organic load. After passing Shepp's Dam with the pH rising above 7.0 and the environment becoming favorable for the development of decay organisms, the D.O. curve drops rapidly, showing the recovery of natural stream purification processes which require oxygen at a greater rate than the stream can supply. In a clean normal stream such a drop could be caused by the addition of organic matter, but a sanitary survey eliminates this as a factor on the Schuylkill and discloses that the addition of organic pollution only after the D.O. curve flattens out downstream. The lower end of the curve was fixed to eliminate any effects from the effluent of the Reading sewage treatment plant.

This section of the Schuylkill River offers an excellent example of the effect of environment on the process of natural stream purification. In its upper reaches its acid properties arrest the biochemical process of decay and cause it to transport the organic load in a pickled or preserved state to the lower reaches of the river. In these alkaline waters where the environment is favorable, it is shown that natural purification takes place in the stream.

If the Schuylkill were normal or alkaline throughout its length it would offer the protection of approximately 60 miles of natural stream purification between the sewage of Pottsville and the water supply of Pottstown, rather than the 20 miles now remaining after neutralization of the acidity. It would also offer the protection of 100 miles of natural stream purification between the sewage of Pottsville and the water supply of Philadelphia instead of the 60 miles now remaining after the acid waters are neutralized at Shepp's Dam.

Conclusions

The following conclusions are drawn from this study:

1. An acid stream will carry organic matter in a pickled or preserved state without offense if the stream is not used for recreation or water supply and if it remains acid until it discharges into the ocean.
2. If such a stream is neutralized by natural or by artificial means its organic load will be attacked and disposed of biochemically, with all the objectionable features of such processes.
3. Dilution factor is the important and reliable gauge for determining the ability of a stream to provide sewage treatment by dilution only when the diluting water offers an environment favorable to the development of decay organisms.
4. If treatment is required before dumping organic wastes into a normal or alkaline stream, it is doubly, triply or many times more necessary along an acid stream.
5. Natural stream purification, together with all other biological processes of waste treatment, can operate only when an environment favorable to the development of decay organisms is provided.

Contributed Discussions

Contributed discussions of papers in THIS JOURNAL are invited. Such discussions will be considered for publication if submitted to the Editor within six months of the distribution of the issue containing the original article.

SLUDGE DISPOSAL PRACTICES AT DETROIT *

By A. L. GENTER

There may be some readers of THIS JOURNAL who wonder why the sludge digestion and elutriation test results at Detroit were the reverse of everywhere else in all details. Installation of the digestion and elutriation facilities at Detroit was based upon the recommendations of the late Harrison P. Eddy and John H. Gregory, with the hope that elutriation would be given thorough and expert trial. Due to the writer's responsibility for the origin and general success of sludge elutriation, he feels that the stages of the process involving chemical dosing and vacuum filtration of the elutriated sludge did not receive thorough trial and that the report presented by Messrs. Hubbell and Garrity in the March issue of THIS JOURNAL is open to serious question.

These comments are offered on the possibility that some readers of the published report may not have bothered to analyze the fragmentary data and contradictory nature of some of the assertions in the light of fundamental chemical laws. At the outset the writer calls attention to the fact that the methods of testing the process were likewise contrary to normal procedure in failing, first, to secure the advisory cooperation of the writer and others well-experienced in dosing and filtering elutriated sludges and, second, in failing to check the field results by thorough laboratory tests.

Solids disposal by means of plain sedimentation, digestion, elutriation, chemical coagulation and vacuum filtration is a mechanically manipulated system of correlated, progressive biochemical and chemical stages, namely: (*a*) reducing the amount of solids to be disposed of, (*b*) displacing with relatively pure water large amounts of normal sludge moisture considerably fouled during digestion by solute which is chemically unfavorable to coagulant economy, (*c*) mixing coagulant and elutriated sludge in a manner most favorable to coagulant economy and vacuum filtration and (*d*) draining the major portion of the water from the properly coagulated sludge in the vacuum filter equipment.

As the sludge progresses through this system mechanical manipulation and control of the correlated steps becomes progressively more important. In digestion the simple mechanical manipulations are directed to aiding biochemical activity in rapidly and effectively reducing the volatile solids. Mechanical control in elutriation is also simple and intended to take the best advantage of the laws of dilution and solids concentration in relatively pure water for chemical purposes, while the automatic manipulations in the chemical coagulation of the sludge and its vac-

* Original paper by Clarence W. Hubbell with discussion by L. V. Garrity published in THIS JOURNAL, 18, 2, 212 (March, 1946).

uum filtration are used to produce the most drainable sludge floc with the minimum amounts of coagulant rendered possible by proper elutriation.

When the steps are properly carried out, the combination of digestion and elutriation reduces both the amount of solids and the chemical demand of the sludge with the result that the economic gain over dewatering of raw solids is compounded. The final, lesser total chemical demand of the elutriated digested sludge applies to materially less solids. The simple mathematical computation of this fact has been published elsewhere (1).

With improper mechanical equipment or improper manipulation of the proper mechanical equipment in coagulating the sludge, and certainly with improper vacuum filter operation, numerous things can happen in plant operation to destroy all the beneficial effects produced in the preceding steps of digestion and elutriation. This is the chief reason for checking field results with thorough laboratory tests when something goes wrong in plant scale testing and operation. The technical literature has emphasized these facts repeatedly during the past decade.

The initial mistake in the reports submitted by Messrs. Hubbell and Garrity lies in the assumption that it was the simple laws of dilution and chemical combining weights operating through elutriation that failed to deliver the expected chemical economy, instead of the wrong mechanical manipulation of faulty dosing and coagulating equipment operating on the elutriated sludge. The lack of any corroborative laboratory filtration graphs and essential sustaining solute data relative to the Detroit tests lends strength to this conviction.

The writer can state from his own observations as a visitor at the Detroit plant that the installation for dosing elutriated sludges in the world's largest raw sludge disposal plant is, incidentally, the most awkward and cumbersome for quickly and efficiently dosing elutriated sludges with a single coagulant. He even doubts its efficiency when it is being normally used for two coagulants. Eight years ago he endeavored to have the design changed before plant construction was completed in order to avoid trouble when the time came for testing elutriation. He was entirely unsuccessful in such efforts and therefore believes this mechanical factor had a material effect on the tests made without his cooperation.

That a reasonable amount of elutriation with proper dosing of the elutriated sludge will produce the usual beneficial results at Detroit is evident from the statements published by Hubbell and Garrity. Mr. Hubbell states that at Detroit:

"The usefulness of elutriation under existing conditions has been seriously questioned. A careful 3-month test ending September 8, 1944, resulted in an actual increase in operating costs without any reduction in the chemicals required; and so far as could be determined, no corresponding benefit. The use of the unit as an elutriation tank has been discontinued. *The tank is advantageously used, however, for mixing raw and digested sludge prior to filtration of sludge. . . .*"

Regardless of the question of the economic benefits of elutriation to some sludges, if the elutriating water used to displace normal sludge moisture (even from raw solids) shows less chemical affinity for coagulants than the displaced moisture, with proper solids concentration in elutriation, chemical laws automatically operate to bring about a reduction in coagulating chemical required by the sludge. Such a sludge is not, however, a digested sludge which is particularly suited to elutriation with its highly fouled sludge moisture of high chemical demand, such as Hubbell describes. As long as any raw sludge digests as well as the authors claim for Detroit, the effects of elutriation in removing inimical biochemical solutes will be founded with four-square stability on the fundamental law of chemical combining weights and will operate by reason of same.

Consequently, Hubbell's above quoted statement might be a somewhat serious charge against the usefulness of digestion and elutriation at Detroit if it were not contradicted by the sentence that this writer has taken the liberty to italicize, and that Garrity has verified, namely: that mixed digested and raw sludge at Detroit require less ferric chloride and lime than do raw, digested or elutriated digested sludges alone. In fact, elutriated digested sludge required more chemical than did any of the others. Therefore the elutriation tank is now being "advantageously used" as above noted.

From the basic principles of coagulating sludges with chemicals, it should be quite evident that the procedure of mixing raw and digested sludges before dosing is, to the extent of the sludge assays and mixing proportions involved, a close facsimile of partially digesting a raw sludge and then partially elutriating it. The "advantageous" practice used at Detroit is the same procedure exhibited under another name.

It is comparatively easy to demonstrate that adding three or four volumes of raw sludge of 66 or more per cent volatile matter and of low alkalinity concentration to one volume of digested sludge of higher alkalinity and only 54 per cent volatile matter cannot help but materially drop the ratio of volatile matter to ash in the total mix below that of the raw fraction (a 7.3 per cent drop according to Hubbell's Table 2), while materially reducing the alkalinity of the total mix far below that of the digested fraction. The natural consequence is the production of a sludge mixture of lower chemical demand than that of either the raw or digested ingredients alone. This is equivalent to digesting partially the raw sludge to the volatile content of the mix and elutriating the so digested sludge to the alkalinity of the mix. In less technical terms it amounts to elutriating the digested fraction with a raw sludge of much lower alkalinity and omitting the advantageous step of removing further alkalinity by decantation. It is a rather crude method of practicing what actual elutriation of the digested sludge will accomplish far better but, nevertheless, somewhat effective if one is satisfied to leave enough impurities in a sludge to justify the use of two chemicals and the filtration and incineration of materially more total solids than necessary. In any case, logical incompatibility is involved in the statements that this crude equivalent of partial digestion and elutriation is successful at Detroit while the approved procedure of digestion and elutriation was not.

Reference to the 10-year old exhaustive report made by Keefer and Kratz (2) should also have informed the investigators at Detroit that mixing a partially elutriated digested sludge of about 55 per cent volatile contents with septic raw sludge of about 75 per cent volatile contents produced rather remarkable results. Although the raw sludge at Detroit is not septic there is ample evidence that it contains quantities of digested solids returned to primary sedimentation and conveniently elutriated in the covered primary sedimentation tanks. On two or three occasions when this writer visited the plant he found the raw sludge leaving primary sedimentation quite black with elutriated digested solids returned to plain sedimentation from the crowded single-stage digestion tank.

In 1942 the digester supernatant contained 4 per cent solids. For a time some of these solids were permitted to settle out in the elutriation tanks without dilution. Since these tanks are now "advantageously" used for mixing raw solids with digested (unelutriated and those elutriated in primary sedimentation) the writer assumes that the strong supernatant is again returned to primary settling. During his last visit to the plant he found the plant influent in the huge sewage pumping station plentifully stocked with digested solids on their way to elutriation-sedimentation in the primary tanks.

It is now an established scientific fact that the chemical requirements for both ferric chloride and lime in any digested sludge are largely a function of the ammoniacal and other bicarbonates present in the fouled sludge liquor. If there is no increase in alkalinity in digestion there is practically no volatile destruction and no real digestion. Digested sludges contain from 1,500 to 6,000 p.p.m. of alkalinity ($CaCO_3$) and each weight unit definitely reacts with almost 1.1 weight units of ferric chloride to form hydrated ferric oxide. Informative data relating to alkalinity and other solutes are absent from the Hubbell-Garrity contributions. Nevertheless there are ample quantities of ammonium bicarbonate in the digested sludge mixed into the raw at Detroit. Any visitor to the plant will detect copious amounts of ammonia around the dosing tanks if he is equipped with normal olfactory organs.

The best method of showing what Detroit failed to accomplish with digestion and elutriation is to compare it with one or two plants collecting and digesting similar raw solids and elutriating the digested solids. In making such a comparison (Table I) it should be remembered that Detroit is practically the home of ferric chloride supply and if a ton of anhydrous ferric chloride costs as much as 2.7 times the cost of a ton of available calcium oxide (CaO), the yearly average dose of 2.2 per cent $FeCl_3$ and 7.6 per cent CaO reported by Hubbell in his Table 2 is equivalent in price to using about 5 per cent ferric chloride alone.

In a plant producing upward of 500 tons of filter cake daily from a mixed sludge consisting largely of fresh solids and having almost 9 per cent solids

TABLE I.—Comparison of Sludge Filtration Data

Item No.	Item	Springfield, Mass.	Winnipeg, Can.	Detroit, Mich. 1943–44	Detroit, Mich. Elutriation Test (3 months)
1	Primary solids—% volatile	73.5	71.5	78.8	—
2	Sludge to digestion—% solids	8.6	9.3	9.1	—
3	Volatile content—%	73.5	69.0	65.8	—
4	Digested sludge—% solids	9.5	7.6	6.8	7.3
5	Volatile content—%	49.3	50.3	54.3	49.8
6	Alkalinity—p.p.m.	2400	4500	—	—
7	Alkalinity, solids basis—%	2.3	5.5	—	—
8	Elutriating water alkalinity—p.p.m.	60	310	—	(1)
9	Elutriated sludge—% solids	13.2	9.6	—	—
10	Volatile content—%	49.0	50.5	—	—
11	Alkalinity—p.p.m.	230	900	—	—
12	Alkalinity, solids basis—%	0.15	0.85	—	—
13	Reduction in alk. by elutriation—%	93.5	84.5	—	—
14	CaO dosage—% on solids basis	0	0	7.6	—
15	$FeCl_3$ dosage—% on solids basis	1.5	2.7	2.2	—
16	Total dosage calc. as $FeCl_3$—%	1.5	2.7	5.0	—
17	Cake moisture—% (regular)	65	69	69.7	—
18	Corrected—%	65	69	72.4	—
19	Cake solids—% (regular)	35	31	30.3	—
20	Corrected—%	35	31	27.6	—
21	Filter yield—lb./sq. ft./hr.	5	4.2	6.1	—
22	Cloth life—filter hr.	800	400	400	—

(1) City water.

content with 64 per cent volatile matter, the 5 per cent equivalent ferric chloride dose at Detroit (Item 16) is far from impressive when compared to other well known plants handling similar primary solids alone or elutriated digested primary solids of a similar nature to those reported by Garrity. The data supplied by Hubbell for 1943–44 plant operations and the fragmentary data supplied by Garrity on digestion and elutriation operations indicate that the Detroit sludge is not only typical of primary treatment and digestion plants but remarkably like the sludges collected, digested and elutriated at such widely spread plants as Springfield, Mass., and Winnipeg, Manitoba.

In Table I the data listed for Springfield and Winnipeg are averages for the four years of 1941–44 inclusive. Although the Detroit and Springfield sludges are more alike in some respects, Winnipeg is listed because this plant has problems in sludge filtration that are far more difficult than those at Detroit, *e.g.*, it is most distantly located from the supply source of ferric chloride, ferric chloride costs over three times as much as at Detroit, the digested sludge alkalinity and liquid chemical demand (Items 6 and 7) are unduly high, the alkalinity of the elutriating water is five times higher than at Springfield and perhaps eight times higher than the drinking water used at Detroit (Item 8). Yet, in the hands of the plant organization at Winnipeg, a more economical job of sludge dewatering is shown than at Detroit.

The only two items specifically listed by Garrity for the 3 months elutriation test at Detroit are Nos. 4 and 5. These items are remarkably similar for all three plants. The percentage of solids (7.3) in the digested sludge of 49.8 per cent volatile matter at Detroit should be somewhat less than at Winnipeg and Springfield, due to the use of single-stage digestion at Detroit. The ratio of volatile matter to ash (from Item 5) is practically identical in all cases. In fact, Detroit was the exact mathematical average of Springfield and Winnipeg.

It can be seen from the last column relating to the elutriation tests at Detroit that the balance of essential data is less than fragmentary and not indicative of careful scientific testing. Item 8 of this column informs us that pure drinking water was used for elutriation. With the entire Detroit River adjacent to the plant this is an unnecessarily expensive eluent. With water of equivalent alkalinity at Winnipeg coagulant economies could be pushed to the low limits shown by Springfield.

In using 7.6 per cent CaO on sludge solids, 100 lb. of filter cake containing 30.3 lb. dry solids (Item 19 for Detroit) contains 26.6 lb. sludge solids, including a small amount of ferric hydroxide 3.7 lb. calcium carbonate and 69.7 lb. water (Item 17). Therefore, computing water and sludge solids alone in the cake means at least 72.4 per cent water and 27.6 per cent sludge solids when compared to Springfield and Winnipeg. This is mathematically the same as rating the 3.7 lb. of $CaCO_3$ and 69.7 lb. of water as 72.4 lb. of water and means materially more cake moisture to be eliminated than at the other two plants and especially at Springfield, where the filter cake has been both incinerated and dried for sale as soil conditioner. In fact, rating the 3.7 lb. of $CaCO_3$ (14 per cent on sludge solids) as water does not place the question of cake moisture on an equitable footing in all three plants for the simple reason that if the extra 3.7 lb. were water it would be evaporable. As a matter of fact, it is inert mineral absorbing a lot of extra heat for partial dissociation of CaO and CO_2 while hot and adding its recombined weight as extra ash to be disposed of when cooled and lagooned.

It will be also noticed from comparison of Items 4 and 9 relating to Springfield and Winnipeg that sludge solids are concentrated materially in elutriation, meaning that the ratio of solute bearing sludge moisture to sludge solids (pounds of water per pound of solids) is greatly reduced in elutriation. This reduction is 31 per cent at Springfield and 22.4 per cent at Winnipeg. The former is greater than the latter because of the greater elutriation ratio used and the longer detention time provided in elutriation sedimentation. This valuable information is missing from the Detroit data. It is one of the incidental benefits of proper elutriation practice.

Even if there were no change in the alkalinity assay while changing these ratios through sludge concentration at Springfield and Winnipeg, the mere reductions in solute per pound of sludge solids would automatically operate to decrease the liquid chemical demand per pound of sludge solids (31 per cent at Springfield and 22.4 per cent at Winnipeg). This was demonstrated 12 years ago by Keefer and Kratz (3) for digested sludge coagulated with ferric chloride alone, and 7 years ago on plant scale tests by Flower (4) with ferric chloride and lime at Cleveland. Items 4, 6, 9, 11, 12 and 13 show, however, that alkalinity reduction, combined with solids concentration in the elutriation settling systems of both plants, results in the very material reductions in the alkalinity demand for ferric chloride, namely 93.5 per cent at Springfield and 84.5 per cent at Winnipeg. These are simple mathematical facts of stoichiometry and, as before emphasized, it is to be regretted that all the essential data relating to such items in the Detroit tests are not given.

If the digested solids in the Detroit field experiments were not further concentrated in elutriation, this step in sludge dewatering was obviously improperly operated and not carefully tested. However, even if the solids before and after elutriation remained 7.3 per cent as in Item 4, at the elutriation ratio mentioned by Garrity of two volumes of water to one of sludge, the actual ratio R of water to sludge moisture was 2 divided by 0.927 (moisture percentage) or 2.16. Under these conditions the alkalinity E of the elutriated sludge would have been in the properly balanced counter-current dilution and sedimentation system:

$$E = \frac{D + (R^2 + R)W}{R^2 + R + 1},$$

wherein D is the alkalinity in p.p.m. of the digested sludge and W is the alkalinity of the city water used. For example, with D the same as at Springfield, Buffalo, Cleveland, etc.—about 2,500 p.p.m.—and W as high as 50 p.p.m., the alkalinity of the elutriated sludge E would have been about 360 p.p.m. or 0.46 per cent on solids instead of the original 3.18 per cent. This is a reduction of 85.5 per cent in this important factor. With this low alkalinity and the original 7.3 per cent solids of 50 per cent volatile matter in the elutriated sludge, the total ferric chloride dose (without any lime) computes to 2 per cent, which is 60 per cent less than the 5 per cent price equivalent used on the greater amount of "advantageously mixed" raw and digested sludge of 64.1 per cent volatile contents, and 71.5 per cent less when the combined solids reduction through digestion to 50 per cent volatile and the alkalinity reduction through elutriation are taken into consideration.

The following is quoted from Mr. Garrity's discussion of the Hubbell paper:

". . . A total of 5,691,400 gal. of sludge, containing 1,890 tons of dry solids, was removed from the digesters and elutriated during the test run. Of this total 1,690 tons were filtered, indicating a solids loss in the elutriation wash water of 200 tons, or 10.6 per cent. As these solids are principally soluble and colloidal material it would be expected that the filtration process should benefit by the removal. This was not the case."

He then refers to further unfavorable results of the elutriation test; the elutriated sludge required considerably more chemical than did the unelutriated, the resulting filter cake was wetter and thinner, and the filter cloth life was materially lowered.

All of this evidence listed against the beneficial effects of adjusting the law of chemical combining weight to coagulant economy unite to demonstrate that there was nothing wrong with the procedure of adjustment but in all likelihood there was something essentially wrong with the mechanical manipulation of the chemical dosing and filtration. The contradictory effects listed by Garrity are closely correlated and can be the inevitable results of causes associated with inexperienced mixing of sludge and chemical, if not improper filter operation on the conditioned elutriated sludge.

As coagulation with one or more chemicals is purely a chemical process, it is to be regretted that the authors failed to collect and report essential chemical control data relating to the sludge in order to permit correlation of results with those published elsewhere and with such typical examples as are presented in Table I. Such data should include alkalinities of the elutriating water and digested sludge before and after elutriation, pH of filtrates at various doses, and volatile and solids content of the sludge before and after elutriation. The investigators also failed to mention any mechanical data relating to filter operating vacuum and speeds and, what is of material importance, they did not refer to any complete preliminary or incidental laboratory elutriation and filtration tests that might have explained the results that were reported.

If such laboratory investigations were not carefully made, the field tests were not carefully conducted and did not follow ordinary scientific procedure in determining why elutriation and filtration in plant scale testing led to results that denied normal scientific expectancy. The simple facts relating to the "advantageous mixing" of the raw and digested sludges at Detroit should have made those conducting the investigations realize that there was something wrong somewhere that needed laboratory checking. In all probability such studies would have revealed the fact that the trouble originated in handling elutriated sludge with one coagulant in unsuitable dosing equipment.

The simplest 10-minute test in a laboratory will reveal if elutriation properly diminishes the alkalinity of digested sludge. If it does, it is fulfilling its chemical function and should save chemical coagulant. If doubt exists about this fundamental fact of ordinary chemistry, a series of Büchner filter tests should be run on unelutriated and elutriated samples of the same sludge (5, 6). If such tests on elutriated samples demonstrate alkalinity reductions and good filtration rates with material chemical savings, and similar results are not confirmed in field operation, it is plainly demonstrated that there is something definitely wrong with the dosing equipment and vacuum filter layout.

On a few occasions the writer has experienced similar instances of field testing where those making the investigations found that they were unable to save much, if any, chemical in dosing elutriated sludges. However, they either suspected their dosing methods or dosing equipment, piping and filter operation and worked out their problem or appealed to the writer for advice and help. In a few plants where dosing equipment and piping were suspected by engineers and chemists in charge of operations, laboratory studies were immediately undertaken to see if coagulant economy in the plant could be improved. The reports of Benas (7) and Fraschina (8) are examples worth citing in this respect.

McDonald (9) concisely tells how easy it is to overdose properly elutriated sludge and what the control of alkalinity and pH of the filtrate mean to successful operation. And only recently Brown (10) relates his experience in cutting in half the ferric chloride dose on elutriated sludge at Cranston, R. I., by correcting faulty chemical feeding equipment.

It should be evident from the foregoing comparisons and comments that any failure to reduce the coagulant demand of both the solids and liquid fractions of the sludge at Detroit in the digestion and elutriation tests could scarcely be due to atypical behavior of fresh sludge solids toward biochemical activity in digestion or to the simple law of chemical combining weights after displacing most of the badly fouled sludge moisture with pure water in elutriation. Such failure could, however, be due to the lack of both understanding of the basic principals involved and of experience in proper mechanical control and manipulation of the chemical dosing and filtration of the properly elutriated sludges.

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THE OPERATOR'S CORNER

NO SLIMES—NO SULFIDES—NO ODORS

The sulfide control report by Pomeroy and Bowlus, published in this issue, is one of the outstanding contributions to the sewage works literature of recent years. Aimed primarily at sulfide control for the purpose of protecting sewage works structures from corrosion, the study carries an important secondary message in regard to the reduction of odors in and about such works.

Plant operators are unanimous in their appreciation of general cleanliness as a fundamental odor control measure and now they have scientific proof that good housekeeping has more than psychological value.

A most significant finding reported by Pomeroy and Bowlus is the fact that sulfides originate in the slime accumulations and sludge deposits that gather on the submerged surfaces of conduits and tanks, and that sulfide generation in the sewage proper is generally negligible. This information reveals the true character of that innocuous appearing gray coating that peeps above the sewage surface on the walls of channels, grit chambers and primary tanks and which is intermittently revealed in all its villainy at dosing tanks and wet wells, where the sewage level is variable.

And so a weekly (or semi-weekly) brushing and/or hosing of such surfaces as may harbor sulfide-producing slimes becomes the first line of defense against odors. Prevention of sludge deposits in channels, wet wells and other structures is a complementary action, of course, and adoption of a program of increased frequency of sewer flushing in hot dry weather will minimize sulfide odors that originate in such deposits as may gather in the sewers. All of these things have received routine attention heretofore but they assume much greater importance under the newer concept of sulfide generation.

The Pomeroy-Bowlus studies also yield a deeper understanding of the mechanics of sulfide generation, upsetting several theories now in general acceptance. Effects of physical factors and the *modus operandi* of methods of chemical control are analyzed logically. Several new methods of control are suggested. The value of the work is greatly enhanced by the fact that experimental results determined in the laboratory are checked and confirmed by full-scale observations and tests in the field.

The principal value of industrial waste surveys heretofore has been for the determination of sewage treatment plant loadings. The Los Angeles work emphasizes that such surveys have additional uses where sulfides are a problem, not only for the purpose of isolating potential sulfide-producing fractions of the wastes but to reveal components that may have beneficial effects in the prevention of sulfides and related odors.

Every sewage works designer and operator should give the Pomeroy-Bowlus work the careful study that it deserves. This paper is a *must* item on the immediate reading list—and will be a notable reference for future use.

W. H. W.

SUMMARY OF EXPERIENCE IN THE OPERATION OF STANDARD TRICKLING FILTERS

By Douglas E. Dreier

This article, the seventh of the series on operational procedures in fundamental sewage treatment processes to be presented in *The Operator's Corner*, reviews practices in the operation of trickling filters of so-called "standard rate" design. It is largely based upon data and comments obtained from 35 superintendents, engineers, chemists and operators of 31 representative plants, through detailed questionnaires and by supplementary correspondence. The interest and complete cooperation of the following contributors are gratefully acknowledged:

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Hager, J. W., Chief Operator, San Bernardino, Calif.

Harr, N. F., City Engineer, McPherson, Kan.

Hatfield, W. D., Supt., Decatur San. Dist., Decatur, Ill.

Huffman, Lloyd C., Acting Supt., Dayton, Ohio.

Hunt, L. W., Supt., Galesburg San. Dist., Galesburg, Ill.

Johnson, F. E., Supt., Elgin San. Dist., Elgin, Ill.

Lantenbach, W. H., Sr., Supt., Plymouth, Wis.

Mackin, J. C., Supt. of Operation, Nine Springs Plant, Madison, Wis.

Magennis, J. P., Chemist, Fort Dodge, Iowa.

Malone, J. R., Chief Chemist, Third Fork Plant, Durham, N. C.

Mattson, S., Operator, Oconomowoc, Wis.

Moore, George S., Supt. Water and Light Plant, Albemarle, N. C.

Moran, J., Chief Operator, Nine Springs Plant, Madison, Wis.

Pinney, F. W., Supt., Fargo, N. D.

Schaetzle, T. C., Engineer-Chemist, Akron, Ohio.

Shick, V. R., Supt., Van Wert, Ohio.

Simonton, L. R., Supt. Water and Sewerage, Griffin, Ga. (Cabin Creek and Ison's Branch Plants).

Smith, Bernard F., Borough Engineer, Waynesboro, Pa.

Sperry, W. A., Plant Supt., Aurora San. Dist., Aurora, Ill.

Spiess, R., Supt., Litchfield, Ill.

Walker, W. P., Chemist, Corpus Christi, Texas.

Williams, D. M., Supt. Water and Sewerage, Durham, N. C. (Third Fork Plant).

Winfrey, Paul, Operating Engineer, Des Moines, Iowa.

The data tabulated in Tables I and II indicate a wide variation in design, capacity and loading at the plants forming the basis for this summary. It will be observed that eighteen of the plants receive industrial wastes of consequence, some discussion of which will be included later.

TABLE I.—General Information Regarding Contributing Plants

Plant	Connected Population	Type Sewers (1)	Average Flow (m.g.d.)	Ave. Prim. Sed. Period (hr.)	Type Prim. Tr. (2)	Ave. Final Sed. Period (hr.)	Type Final Tank (3)	Ave. 5-Day B.O.D. (p.p.m.)				Rel. Stab. Eff. (days)	Industrial Wastes Tributary
								Raw Sewage	Prim. Eff.	Filter Eff.	Final Eff.		
Akron, Ohio	275,500	S & C	47.90	1.6	I	1.25	P	269	207	67	46	3	Synthetic rubber
Albemarle, N. C.	9,000	S	1.25	3.07	D	2.07	M	300	130	40	15	10	Textile dye
Aurora, Ill.	51,000	C	7.77	1.15	D	1.11	M	117	72	22	14	13	—
Bemidji, Minn.	6,000	S	0.45	1.5	D	1.5	M	—	—	—	—	—	—
Bloomington-Normal, Ill.	40,000	C	4.20	—	I	—	M	160	70	—	12	10	—
Bowling Green, Ohio	5,000	C	1.00	2.0	D	—	P	275	176	—	38	—	Tomato cannery
Clinton, Ill.	7,000	C	0.75	—	I	—	P	—	—	—	—	10	—
Corpus Christi, Texas	100,000	S	10.0	1.5	D	1.5	M	200	120	25	20	—	Seasonal cannery, milk
Dayton, Ohio	325,000	S	34.4	1.7	I	1.6	M	227	137	46	33	—	Milk, packinghouse, paper
Decatur, Ill.	60,000	C	11.0	1.0	I & D	0.6	M	198	129	32	25	5	Corn products (6)
Des Moines, Iowa	160,000	C	15.3	3.5	D	2.75	M	200	—	—	41	5–12	Packinghouse
Plainfield, N. J.	60,000	S	4.25	1.0	D	1.0	M	629	320	26	13	10	—
Durham, N. C.	20,000	S	1.77	3.5	D	2.5	M	375	264	—	68	—	Textile dye
Elgin, Ill.	34,000	C	4.57	3.4	I & D	0.5	M	128	94	46	41	—	—
Fargo, N. D.	34,000	C	1.94	2.9	D	—	None	213	167	45	—	6	Gas plant, milk
Fort Dodge, Iowa	23,000	S	2.42	1.65	D	1.48	M	751	547	145(5)	105	—	Packinghouse (7)
Galesburg, Ill.	26,000	C	4.46	2.7	D	1.2	M	184	112	56	44	—	—
Griffin, Ga.	13,000	S	0.80	0.67	D	—	P	200	—	—	10	—	Laundry, textile
Huntington Beach, Calif.	3,000	S	0.30	2.0	D	—	None	—	—	—	—	—	—
Lebanon, Pa.	24,000	S	3.61	0.5	I	1.5	M	—	—	—	—	5	—
Litchfield, Ill.	6,000	C	0.52	3.0	D	3.0	M	360	220	16	5	10	Milk, oil
Madison, Wis.	35,000	S	4.82	2.25	I & D	3.44	M	248	139	50	33	13	Packinghouse
McPherson, Kan.	7,000	S	0.75	1.5	D	1.25	P	—	—	—	—	—	—
Oconomowoc, Wis.	4,600	S	1.13	2.4	D	2.1	M	140	99	15	8	10	Milk, pea cannery
Plymouth, Wis.	4,270	S	0.46	2.6	D	2.6	M	—	—	—	—	—	Milk, general cannery
Pontiac, Ill.	9,600	C	0.80	1.5	D	—	M	—	—	—	—	10	Milk
Pontiac, Mich.	70,000	S & C	7.70(4)	1.0	I	1.0	M	253	138	52	38	5	Cutting oil, grease
San Bernardino, Calif.	65,000	S	5.50	3.75	D	3.75	M	170	60	11	6	—	Chromic acid
Van Wert, Ohio	9,000	C	0.96	1.0	D	1.5	M	305	242	18	15	—	Cannery, milk, plating
Waynesboro, Pa.	8,500	S	0.88	—	D	—	M	236	—	—	31	10	—

(1) S—separate; C—combined.
(2) I—Imhoff tank; D—separate sludge digestion.
(3) P—plain hopper-bottom; M—mechanical.
(4) Part of flow treated by activated sludge.
(5) Effluent of second stage filters.
(6) Population equivalent 60,000–100,000.
(7) Population equivalent about 66,000.

TABLE II.—Trickling Filter Data

Plant	No. & Diam. (ft.) or Area (acres)	Depth (ft.)	Type of Dosage	Type of Distrib. (1)	Filter Media					Filter Loading			Effluent Nitrates	
					Type	Size (in.)	Weathering	Years in Service	Soundness Test Used (2)	Lb. B.O.D. per Acre-Ft.		Ave. Cu. Ft. Media per Lb. B.O.D.		
										Ave.	Max.		Ave.	Min.
Akron, Ohio	14 ac.	10	Siph.	N	Limestone	1 –2½	Mod.	17	A	590	703	74	1.32	0.16
Albemarle, N. C.	1–97	8	Cont.	R	Granite	1½–3	Mod.	7	None	—	—	—	—	—
Aurora, Ill.	3.74 ac.	6	Siph.	N	Limestone	1½–2	Sl.	16	B	192	867	227	6.35	2.8
Bemidji, Minn.	1–100	6	Siph.	R	Field stone	2½–4	—	10	—	—	—	—	—	—
Bloomington-Normal, Ill.	2.5 ac.	8	Siph.	N	Limestone	2	Sl.	18	—	188	313	232	—	—
Bowling Green, Ohio	4–100	7.5	Pumps	M	(3)	—	Mod.	10	A	—	—	—	—	—
Clinton, Ill.	1–140	7.5	Siph.	R	Limestone	1 –4¾	Sl.	10	A	—	—	—	—	—
Corpus Christi, Texas	4–160	6.5	Grav.	R	Limestone	1½–3	Sl.	8	None	—	—	—	—	—
Dayton, Ohio	20–165	7.5	Siph.	R	Slag	1½	Sl.	6	None	515	772	85	4.6	1.14
Decatur, Ill.	3.0 ac.	6	Siph.	N	Stone	1½	Bad	20	None	830	1,640	53	—	—
Des Moines, Iowa	12–152	7	Siph.	R	Gravel; stone	1½–3	Sl.	5	A	324	—	135	—	—
Plainfield, N. J.	1.78 ac.	6	Siph.	N	Trap rock	1½–2	None	29	—	1,080	—	40	—	—
Durham, N. C.	0.92 ac.	7	Siph.	N	Stone	1	None	17	None	556	—	78	—	—
Elgin, Ill.	1.54 ac.	8	Siph.	N	(4)	1⅓–3	(7)	3(7)	A	264	330	165	6.7	2.0
Fargo, N. D.	1.66 ac.	8	Siph.	N	Red granite	2 –2½	None	10	None	203	261	215	—	—
Fort Dodge, Iowa	4–151	8	Siph.	R	(5)	1½–2½	(8)	7	A	1,741(9)	3,078(9)	25	7.9	0.9
Galesburg, Ill.	1.06 ac.	6	Siph.	N	Limestone	1 –1½	Mod.	14	C	488	804	76	—	—
Griffin, Ga.	1–75; 1–105	6	Siph.	R	Stone	2½	—	8	—	—	—	—	—	—
Huntington Beach, Calif.	1–155	6	Siph.	N	Stone	1½–2½	Sl.	9	—	—	—	—	—	—
Lebanon, Pa.	1.3 ac.	6	Siph.	N	(6)	1½–3	(8)	17–32	None	600	1,475	73	—	—
Litchfield, Ill.	1–140	6	Pumps	M	Limestone	2½–4	Mod.	8	—	—	—	—	—	—
Madison, Wis.	2.0 ac.	10	Siph.	N	Dolomite	1 –1½	Sl.	17	—	279	434	174	7.0	3.2
McPherson, Kan.	1–90	8	Siph.	R	Stone	2	None	14	A	—	—	—	—	—
Oconomowoc, Wis.	2–140	7	Pumps	M	Gravel	2½–3	Sl.	8	—	—	—	—	—	—
Plymouth, Wis.	1–140	7	Pumps	R	—	—	—	—	—	—	—	—	—	—
Pontiac, Ill.	1–120	7	Pumps	M	Limestone	1½–2½	Sl.	9	—	—	—	—	—	—
Pontiac, Mich.	8–110	6	Siph.	R & M	—	1½–3	Mod.	25	—	136	—	320	—	—
San Bernardino, Calif.	2.46 ac.	7	Siph.	N	Gravel	1½–2½	None	17	—	175	—	250	—	—
Van Wert, Ohio	2–110	8	Siph.	R	Limestone	1 –2	None	10	A	—	—	—	—	—
Waynesboro, Pa.	1–145	6	Siph.	R	Limestone	1½–2½	Sl.	10	—	759	1,620	58	—	—

(1) N—fixed nozzles; R—reaction rotary dist.; M—motor-driven rotary dist.
(2) A—20-cycle Na_2SO_4; B—50-cycle freezing and thawing; C—Brard's test.
(3) Slag used for top 18 in., remainder limestone.
(4) Granite used for top 14 in., remainder limestone.
(5) Two filters limestone; two filters granite.
(6) Two filters limestone; one filter trap rock.
(7) Filter media replaced in 1941. No weathering since.
(8) Limestone weathering bad.
(9) First stage filters.

Filter Loading

It is not the purpose of this discussion to enter the somewhat controversial subject of filter loading, however, a study of the data contributed reveals several plants operating, apparently with reasonably good results, at average loadings considerably in excess of commonly accepted design standards.

The summary of operation data from Fort Dodge, Iowa (Table III), is of interest as it relates to the operation of a two-stage standard trickling filter plant under heavy loading of packing-house wastes. The sewage is first passed through a preaeration tank 18 feet × 15 feet × 7.5 feet liquid depth. Air is applied continuously at 300 c.f.m. through a series of perforated pipes located near the tank bottom. (The grease floated is skimmed off and sold.) The flow is then subjected to 1.65 hr. of primary sedimentation followed by secondary treatment on two-stage trickling filters, each stage consisting of two 151-ft. diameter filters, 8 ft. deep, equipped with reaction rotary distributors. An intermediate settling tank is included in the design. The filter underdrains consist of slotted 6-in. tile, laid with open joints, radiating from the center of the filter to the periphery. The underdrain tile connect with ventilating stacks of the same diameter at 18-in. centers around the filter periphery.

The data in Table III are most interesting in demonstrating the ability of these trickling filters to perform under heavy overload. An average of 7.9 p.p.m. nitrates was contained in the effluent in spite of the heavy organic loading. The maximum monthly average B.O.D. reduction was 93.4 per cent, and the minimum was 78.9 per cent during the fiscal year reported. The maximum monthly average B.O.D. reduction occurred during July, the month which had the highest B.O.D. loading. That operation of the Fort Dodge plant under such a heavy load-

TABLE III.—Summary of Operation Data at Fort Dodge, Iowa
April 1, 1943 to March 31, 1944

	Ave.	Max.	Min.
Raw sewage flow, m.g.d.	2.42	4.92	1.28
Filter loading:			
Flow, m.g.a.d. to each stage	3.02	6.15	1.60
Lb. B.O.D. per acre-ft. per day:			
First stage filters	1,741	3,078	615
Second stage filters	964		
B.O.D. data, p.p.m.:			
Raw sewage	751	1,327	264
Primary effluent	547	767	265
Average per cent removal	26.4		
First stage filter effluent	359	687	168
Intermediate clarifier effluent	304	559	115
Ave. per cent removal primary effluent to intermediate clarifier effluent	44.5		
Second stage filter effluent	145	394	34
Final effluent	105	288	25
Ave. per cent removal intermed. clarifier effluent to final effluent	67.6		
Ave. per cent removal by both stages filters and clarifiers	82.1		
Ave. overall B.O.D. reduction	86.6		
Nitrites in final effluent, p.p.m.	0.8	4.25	0.10
Nitrates in final effluent, p.p.m.	7.9	15.5	0.85
Outlet stream flow, c.f.s.	1,400	5,300	25

TABLE IV.—Summary of Operation Data for Decatur, Ill., Sanitary District, August, 1944

	Ave.	Max.	Min.
Raw sewage flow, m.g.d.	13.8	15.1	11.4
Trickling filter loading, m.g.a.d.	3.67	5.67	2.67
Lb. B.O.D. per acre-ft. per day	830	1,640	510
B.O.D. data, p.p.m.:			
Raw sewage	198	334	127
Primary effluent	129	267	88
Filter effluent	32	57	12
Final effluent	25	55	12
Per cent reduction, primary effluent to final effluent	80.6		
Per cent reduction, overall	87.3		
Nitrates in effluent, p.p.m.	1–2	5	0

ing was not without its difficulties will be observed in the later discussion of operation problems.

Operation results at Decatur, Illinois, as reported by Hatfield for the month of August, 1944, and tabulated in Table IV, are also of interest. During that month the activated sludge portion of the plant was not operating, and although the trickling filters were loaded at 830 lbs. B.O.D. per acre-ft. per day, an average overall reduction of 87.3 per cent was obtained. The average B.O.D. removal by the filters and final clarifiers was 80.6 per cent. The Decatur trickling filters are of fixed-nozzle design, 3 acres in area and 6 ft. deep. The high loading is largely due to starch wastes from a corn products plant.

Operation results at Akron, Ohio, for the year 1944, as reported by Schaetzle, are summarized in Table V. The Akron plant, containing 14 acres of fixed-nozzle filters 10 ft. deep, has been overloaded hydraulically and by solids for many years.

Loading data from many other plants could be added to the above as supporting evidence of the ability of standard trickling filters to provide treatment at higher loadings than they are commonly designed to accommodate. The use of slightly larger filter media to reduce ponding tendencies, adequate filter ventilation design, and the provision of recirculation facilities to assure continous filter operation should permit considerably more optimistic design than has been practiced in the majority

TABLE V.—Summary of Operation Data for Akron, Ohio, 1944

	Ave.	Max.	Min.
Raw sewage flow, m.g.d.	47.9	94.0	27.2
Filter loading, m.g.a.d.	3.5		
Lb. B.O.D. per acre-ft. per day	590	703	482
B.O.D. data, p.p.m.:*			
Raw sewage	269	310	222
Primary effluent	207	241	187
Filter effluent	67	93	41
Final effluent	46	75	27
Per cent reduction, primary effluent to final effluent	77.8	68.9**	85.6**
Per cent overall B.O.D. reduction	82.9	75.8**	87.8**
Nitrates in final effluent, p.p.m.*	1.32	2.56	0.16
Outlet stream flow, c.f.s. (1931–35)	273	—	25

* Maximum and minimum data are monthly averages.

** Correspond to B.O.D. data above.

of designs. Provision of facilities for 1:1 recirculation at average flow can prove most helpful to the operator at times, and evidence of the general appreciation of this fact is found in the increased number of new designs including provision for recirculation. Loadings of 500 to 800 lb. B.O.D. per acre-foot do not appear unreasonably high, provided a fresh sewage is applied to the filters, with lower loadings reserved for situations where outlet conditions are critical or where local factors preclude projection of population equivalent loadings with sufficient assurance to warrant any optimism in design.

Filter Media

Table II includes information regarding the filter media at the various plants. It will be observed that experience with filter media has been generally satisfactory at the plants contributing to this summary, although some disintegration of media is reported.

Hatfield (Decatur, Ill.) reports that after 20 years service the filter stone has disintegrated from 1½ in. to about ¾ in., which has been partially responsible for ponding difficulties.

Johnson (Elgin, Ill.) reports that limestone media 1 to 2 in. in size placed in the Elgin filters in 1927 disintegrated sufficiently by 1939 to cause serious surface ponding. In 1941 the filter media at Elgin was removed and screened, and media retained on a 1½-in. screen was re-used. Twenty in. of 1½ to 3-in. limestone was added, followed by a 14-in. top layer of 2¼ to 3½-in. granite, both of which passed the 20-cycle sodium sulfate soundness test. No disintegration of media has occurred at Elgin since 1941.

Magennis (Fort Dodge, Iowa) reports that limestone media which passed the 20-cycle sodium sulfate soundness test has not successfully withstood weathering. It has fractured badly with some of the pieces being quite small. Granite media in the other two Fort Dodge filters is still in good condition. Magennis calls attention to an important matter in the placing of filter media, suggesting that filter ponding has been most severe in the areas where media was dumped on the beds directly from the trucks, resulting in pockets of fine material. This again emphasizes the importance of care in the placing of filter media.

Care in selecting, grading and placing filter media is one of the most important factors affecting the operation of trickling filters. Unfortunate experiences have come from inadequate attention to this important item. It is thought highly advisable to specify that only a small percentage, never greater than 5 per cent, of a filter media can be smaller than the lower specified size. Fine material fills the voids in the larger media and, when much fine material is present, it is apt to segregate and form pockets during placing. It is important to re-handle media before placing it in the filter in order to avoid excessive quantities of fines and also to avoid segregation. Media should be re-handled with forks and placed with wheelbarrows or conveyors.

In general, experience with filter media sufficiently durable to withstand the 20-cycle sodium sulfate soundness test, in accordance with the sampling and laboratory procedures set forth in the A.S.C.E. *Manual of Engineering Practice No. 13*, has been satisfactory. Due to probable variation in quality of stone on various ledges of a quarry, and even at various places on the same ledge, it is important to exercise care that media is obtained from the same ledge area from which the soundness test sample is obtained. Reliance should not be placed in the results of an ancient soundness test submitted as evidence of general acceptability of the stone from a given quarry for use in trickling filters.

Operation Problems

The questionnaires which were distributed to form a basis for this summary were most complete, and direct quotation will be used frequently in discussing the various trickling filter operation problems.

Ponding

A major problem in trickling filter operation has been that of ponding with resulting decrease in operating efficiency and frequently an increase in odor problems. About one-half of the operators contributing to this summary report ponding difficulties to varying degree.

Schaetzle reports that the Akron plant has been overloaded hydraulically and by solids for many years, which results in a ponding problem. He states:

"The plant was designed for 33 m.g.d. and 185 p.p.m. suspended solids in the raw sewage. The Imhoff tank effluent in 1944 contained 167 p.p.m. suspended solids with a flow of 47.9 m.g.d. The filters are protected by a 20-mesh vertical traveling screen, cleaned by water spray. Ponding is due to the overload. Filters pond in spots aggregating probably 10 per cent of the total area and in the top 6 to 8 in. We loosen the surface with a pick at ponding spots 2 to 3 times annually. Once every other year we harrow the entire 14 acres with a peg-tooth horse drawn harrow."

Allison (Corpus Christi, Texas) reports some ponding at the surface during the summer months due apparently to algal growth. Dragging a hooked bar over the surface is usually a sufficient remedy.

Mackin (Madison, Wis.) reports ponding at or slightly below the surface, apparently due to algal and other growths and accumulated solids joining together as a thin mat. This ponding occurs 2 or 3 times annually, affecting an area of 25 to 33 per cent of the filters. Mackin reports the use of chlorination in the summer for ponding control. The filters are cultivated in spring and fall with a horse drawn 2-wheeled farm cultivator, equipped with eight shovels, to a depth of about 8 in. A horse drawn peg-tooth harrow is then used to level the surface. Downes (Plainfield, N. J.) indicates that when small patches of ponded area occur, the surface of the filters is harrowed with a spike-tooth harrow and tractor. This is done about once annually.

Ponding at Decatur, Ill., was bad over about 5 per cent of the filter area during August, 1944, the month reported by Hatfield in answering the questionnaire. Rather bad ponding occurred at Decatur during the spring and early summer of 1945 due to a combination of heavy industrial wastes loading, undersize surface media, and silt accumulation in the filters after their flooding by the Sangamon River. Hatfield reports control of this ponding by systematic hosing of the entire filter area. Huffman (Dayton, Ohio) reports some ponding due to heavy load and some extra small particles of slag in the filter media. He states that ponding occurs near the surface and it is corrected by going over the ponded areas with picks. Working the ponded areas of the twenty 165-ft. diameter filters at Dayton requires 160 man-hours of labor.

Magennis (Fort Dodge, Iowa) reports ponding of the first stage filters to a serious degree, and to a lesser extent on the second stage filters at least twice a year. He continues:

"The first stage filters pond over about half their areas and the second stage filters over about a fourth of their areas. The clogging seems to extend the entire 8 ft. of their depths, especially on the areas where the rock was hauled out on the beds and dumped directly from the trucks. This deposited any fines, which may have been in the rock, all in one spot on each of the filter beds.

"For the last five years the average overload on the plant has been 78 per cent with an overload of 96 per cent last year. The maximum overload last year, figured on a monthly average, was 154 per cent. About 74 per cent of the total overload comes from a meat packing plant.

"In the spring and fall, when the ponding is worst, the beds are flushed with a fire hose carrying about 105 lb. pressure. This relieves the condition better than anything we have tried.

"Chlorine is used for odor control. It has been used in the past in an effort to relieve ponding, but to no avail even at dosages of 1,000 lb. per 24 hr. per filter for continuous periods of one week duration. The chlorine was applied to the filter influents."

The following is extracted from the 1943–44 annual report on the Fort Dodge plant:

"A clam shell was hired on November 27 to remove some rock from No. 1 filter down to the floor. It was desired to see the condition of the rock through its entire depth as this filter was badly ponded. This hole was dug on the west side of the filter near the periphery in the section that most readily ponds. It was found that every void was completely filled with humus sludge and slime. It seemed remarkable that any water could pass through at all. Some of the rock was quite small but this was not caused by disintegration but was probably due to the fact that all the rock in the filter was dumped from trucks on this one side and then spread out from there. These small rocks naturally remained where they were dumped.

"Samples of this sludge were carefully taken at 1-, 4- and 8-ft. (levels) and analyzed for grease, chloroform soluble on a dry basis, and organic material. That from the 1-ft. level showed 18.7 per cent grease and 63.8 per cent organic. That from the 4-ft. level showed 10.7 per cent grease and 67.6 per cent organic, while that from the 8-ft. level, or the floor of the filter, gave 22.3 per cent grease and 76.1 per cent organic. It seemed a little peculiar that the highest percentages should be found at the bottom of the filter but this may have been caused by the thorough flushings given a few months previous. It is evident that flushing with a fire hose and spotting of the distributor arms (stopping the distributors every foot or so and allowing them to remain stationary for thirty min. or more) will not correct this continuous problem of ponding, but only serves as a slight relief. It was found the following month that chlorine, applied at heavy dosages, would not correct this condition either. As long as the peak flows, B.O.D., and solids loadings remain high and the plant is not expanded or altered to meet these conditions it seems very unlikely that results of operation will improve very much."

Rehabilitation of the filters at Elgin, Ill., in 1941 eliminated surface ponding, however, Johnson reports that clogging of the beds at a depth of 8 to 16 in. has been in evidence during the late winter months of the past three years. Johnson states:

"It is my opinion that during cold weather, bacterial life in the top portion of the beds is retarded and insufficient to act properly upon the suspended solids which are retained, thereby causing an excessive film development which is responsible for the clogging. It appears to me that rotary distributors in place of the fixed-nozzle type of distribution would afford more uniform and continuous application which would be beneficial in maintaining the desired higher temperatures to induce bacterial action in the top portion of the beds.

"During the past winter chlorine was applied to the filters for one 10-hour night period at 3-week intervals in an effort to induce artificial sloughing. The chlorine dosage was sufficient to maintain 3.2 to 5 p.p.m. residual at the nozzles. Increased solids unloading occurred after each application of chlorine, and nitrate nitrogen analyses of filter effluent indicated the beds apparently were not clogged to the extent of previous years; however, the spring unloading was as heavy and enduring as in 1943 and 1944. The unloading extends from April to June, and the filters do not recover to function properly until July. Low overall treatment plant efficiencies reflect to this extensive sloughing period and inadequate final sedimentation capacity as now provided."

Hunt (Galesburg, Ill., Sanitary District) states:

"Ponding occurs during the late winter and early spring. The area covered by ponding has on some occasions covered as much as one-half the filter area. Clogging seems to be in the top six inches of stone. The cause appears to be small voids between the stone, and rather heavy B.O.D. loading. As soon as cold weather appears the filter effluent becomes noticeably turbid.

"Chlorine has been used to control ponding with fair success, but has not been used the past two years. (Hand picking has also been done.) Chlorine is applied to the primary effluent. Settled sewage of average strength has a high chlorine demand and, therefore, night or protracted storm flows are chlorinated, an attempt being made to maintain a residual of 2 to 5 p.p.m. at the surface of the stone."

Spiess (Litchfield, Ill.) reports that ponding used to be a problem during the winter months, presumably due to milk wastes. Spiess used a road scarifier to give temporary relief. During the past few years chlorination of settled sewage has been practiced from April to October, resulting in a "clean" filter to enter the winter period, thus eliminating difficulty from ponding.

Beamesderfer (Lebanon, Pa.) reports that ponding of filters occurred about four times during each of the past winters, and about 50 per cent of the filter area was clogged at the surface. He states:

"The cause was carelessness in skimming and squeegeeing the Imhoff tanks, thereby sending too much settleable solids over the weirs, overloading the filters. After four years of educating the operators, I proved to them that the best method of working the Imhoff tank is to shut off the tank and allow the disturbed settleable solids at the slot line to settle before putting the tank into service. This winter is the first winter in the history of the plant that the filters did not clog."

Lantenbach (Plymouth, Wis.) and Doyle and Dubay (Pontiac, Mich.) indicate that ponding is effectively remedied by going over the ponded area with a crowbar. Slight ponding at Clinton, Ill., is corrected by use of a pick, according to Corrington. Resting the filter is reported by Shick (Van Wert, Ohio) and Craig (Pontiac, Ill.) as the best remedy they have found for ponding.

The above experiences with ponding just about run the gauntlet of causes and remedies. It is axiomatic that an operator who experiences ponding difficulties should study his plant and the sewage to determine the contributing causes, and then take whatever steps are possible or practical to eliminate or control the causes so that it will be unnecessary to apply remedies. This advice is simple to give, but unfortunately its execution is not always readily attained. The author might add here that chlorination has proved very effective at several Illinois plants where filters were badly ponded due to heavy overload from milk wastes. Unless ponding was very deep, chlorine dosages of about 10 lb. per 1,000 sq. ft. of filter proved effective. At Marissa, Ill., where the filter was completely ponded due to milk wastes, the ponding was brought under control by sprinkling HTH on the filter at the rate of about 8 lb. available chlorine per 1,000 sq. ft. After a couple of days the ponding was under control and the stability of the plant effluent increased from less than 1 day to 10 days, within about one week. Steps were then taken looking toward better control of wastes at the milk plant.

Occasional moderate doses of chlorine have been found of value at some plants in controlling excessive surface growths, and many plants have experienced better operation when a small continuous or semi-continuous chlorine dosage is applied to the settled sewage. This tends to keep the filter open and puts it in better condition to enter the winter period when more solids accumulate in the filter.

Nozzle Clogging

Every plant operator does a certain amount of maintenance in keeping filter nozzles clean. In a small plant the time consumed in nozzle cleaning usually is not great; in the large plants, however, this is usually an item of some magnitude.

Schaetzle (Akron, Ohio) reports that it requires 48 man-hours a week to keep nozzles clean and do the necessary weekly flushing of distribution laterals on 14 acres of filters. He reports that it would require two or three times that amount of work to keep nozzles clean if a 20-mesh, water spray cleaned, vertical traveling screen were not in use on the settled sewage.

A number of other plants have settled sewage screens of one kind or another. Green (Bemidji, Minn.) has installed a 30-in. long conical screen of ¼-in. mesh in the primary effluent outlet. This screen is cleaned daily and no trouble with nozzle clogging is experienced. Barnes (Bowling Green, Ohio) reports that a ⅜-in. mesh settled sewage screen, while effective, does not entirely eliminate nozzle clogging. A 3-mesh screen, cleaned weekly, saves Corrington (Clinton, Ill.) a lot of work cleaning nozzles. Hatfield (Decatur, Ill.) uses a ¼-in. mesh settled sewage screen effectively, but he reports it causes some grease separation on the surface of the dosing tanks. Hatfield designed a non-clog nozzle which greatly reduced his cleaning problem, as did Beamesderfer (Lebanon, Pa.). Pinney (Fargo, N. Dak.) uses a 5⁄16-in. mesh screen ahead of the dosing tank, and nozzle cleaning requires 1¼ man-hours daily. Simonton (Griffin, Ga.) reports good results with a ¼-in. mesh screen. Craig (Pontiac, Ill.) finds a ¾-in. mesh screen most satisfactory. Shick (Van Wert, Ohio) reports a ¼-in. mesh screen just about eliminates nozzle clogging if properly handled. Spiess (Litchfield, Ill.) is a "dissenter" regarding the value of a settled sewage screen. He discarded a ⅜-in. mesh screen because he experienced more trouble cleaning it than orifices. Sperry (Aurora, Ill.) sums up the matter by commenting that he would like to install a settled sewage screen, but has not been able to find a way or place where such a screen could be used.

Huffman (Dayton, Ohio) reports that a 50 to 60 per cent stoppage of nozzles occurs when the direction of flow is changed in the Imhoff tanks. He explains that the suspended solids load is considerably greater than the design capacity of the Imhoff tanks, the plant hydraulics are rather "tricky" since the secondary units were added in 1938, and plant personnel is limited, all of which are involved in this problem. He adds:

"Stop logs are provided to keep scum and other material from the idle effluent channel but on peak flows it is very easy to raise the water level sufficiently to allow material to pass over the scum boards, consequently during a four-week period considerable scum collects in the idle effluent channel and this passes on to the filters 'with a bang' when the direction of flow is changed."

In summary, it can be stated that nozzle clogging is a universal problem to a widely varying degree, and the use of settled sewage screens generally is reported to be of considerable assistance in its control. Most operators contributing to this summary indicated that nozzle cleaning is a daily chore.

General Cleaning

From the questionnaire returns it appears that the periods between cleaning of dosing tanks and distribution systems vary from about once weekly to about once annually. Green (Bemidji, Minn.) reports distribution arms are flushed daily, Alikonis (Bloomington-Normal, Ill.) reports a weekly cleaning schedule, while Huffman (Dayton) and Winfrey (Des Moines) indicate the filter distribution system at their plants has never been flushed.

Distributor arms on rotary distributors are normally flushed by merely opening the gates on the ends of the arms one at a time, but the problem is somewhat different at Fort Dodge, Iowa, as described by Magennis in his 1943–44 Annual Report:

"On June 3 the influent lines and distributor arms of filters No. 1 and No. 2 were cleaned with a six-inch auger on sewer rods. A considerable amount of accumulated grease was removed which had been retarding the flow so much that it backed up into the primary clarifiers and overflowed the weirs, permitting large quantities of grease and other floating material to flow out onto the first stage filter beds which were already badly ponded. Large pieces of grease were also removed from the center columns of all four distributors. This remedied the condition."

Johnson (Elgin, Ill.) reports:

"Our procedure for flushing out the filter distribution system, once weekly, is to first remove the end nozzle of each lateral. The two main header drain valves are then partially opened and left open until each dosing tank has discharged three or four times. Thus, the distribution system is largely drained before each siphon discharges, allowing air to be entrained which provides the effective flushing action."

Hatfield (Decatur) flushes the distribution system daily, also by opening the drain valve, allowing the system to partially fill with air, then closing the drain valve and obtaining good flushing action when the siphon discharges. From Hatfield's vivid description, this method of flushing the distribution system really gets results.

While most operators reported that underdrains are not flushed out, Beamesderfer (Lebanon, Pa.) and Harr (McPherson, Kan.) indicated that the underdrains are flushed out twice yearly with a high pressure hose. Shick (Van Wert, Ohio) flushes out underdrains on alternate years. Corrington (Clinton, Ill.) reports the underdrains were flushed out during the first year of operation due to rock dust accumulations. Mackin (Madison, Wis.) flushes underdrains annually by attaching a self-propelling nozzle to a $1\frac{1}{2}$-in. hose.

Psychoda Flies

Probably no nuisance problem in sewage treatment has been wider discussed than that of control of the insect *Psychoda alternata*. Of the plants contributing to this summary, 21 have had or still have a filter fly problem. At the remaining plants no problem of magnitude was reported.

The adult *P. alternata* lays its eggs in the filter growths. The larvae hatch in about 48 hr. and develop into adult flies by the 15th day. The larvae are ravenous eaters, and utilize the growth on the filter media as their source of food. In a heavily infested filter they may almost denude the film from the surface media; however, this is not too common. There is considerable thought that the larvae are beneficial in helping keep a filter loose and open, which is reasonable considering their food source and their huge number. The unfortunate fact is that the larvae will reach adulthood, and during filter rest periods the flies may leave a filter in great numbers.

The most common method of filter fly control is that of flooding the filters every 7 to 14 days for a period of 24 to 36 hr. This drowns the larvae and may also flush out some eggs. This frequency of flooding is within the development cycle of the fly, which is necessary to achieve results. Nine of the contributors to this summary use flooding for fly control with results varying from good control to minor benefit. Moore (Albemarle, N. C.) indicates that some odor is present after 36 hr. of flooding. Spiess (Litchfield, Ill.) states flooding every ten days helps a lot, but he does not consider it the answer due to the necessity of his discharging 0.5 m.g. of primary effluent to the outlet while the bed is flooded. He also indicates that snails and worms float to the surface and result in a bad odor nuisance, which is now effectively controlled by chlorination of the settled sewage.

Chlorination is also utilized in attempting filter fly control, again with reports of both successful and mediocre results. Magennis (Fort Dodge) reports that chlorination has been tried for filter fly control with no particular success. Mackin (Madison) reports that some fly control seems to be realized by chlorine dosage of 6 to 15 p.p.m. to the settled sewage, which is applied primarily for odor control. He describes chlorination as moderately successful for filter fly control at Madison.

Allison (Corpus Christi, Texas) reports successful use of chlorination combined with recirculation in controlling flies, odors, and slime growths. His interesting comments follow:

"When 1,000 g.p.m. recirculation was started, the prechlorination rate was 850 lb. per day. Prechlorination (ahead of primary tanks) at a 25 per cent higher rate gave very little odor control. Five hundred pounds per day (approximately 6 p.p.m.) postchlorination (following filters) gave excellent results in stopping complaints from odors, eliminated 3½ hours of daily cleaning of final clarifiers, and stopped *Psychoda* fly nuisance. Railroad engine shops alongside the plant were contemplating moving away because of the flies interfering with workmen. No complaints have been received since this control was started.

"We can kill larvae by increasing chlorine residual during the night recirculation. Complete control is obtained by returning to the primary clarifiers 1,000 g.p.m. from the bottom of the secondary clarifiers. This carries a chlorine residual during minimum flow at night and carries sufficient residual to the filters to kill fly larvae.

"Continuous dosage (application of sewage) keeps flies at a minimum. Shut off dosage on a sunny day and within two hours you can note the increase in flies. On a warm sunny day shut a well-coated filter down and you can observe the fly larvae clean the surface film at the rate of 4 square inches in 30 minutes, and double their size. Continuous dosage seems to wash the larvae through the filter just previous to their forming into the adult fly."

Hager (San Bernardino, Calif.) reports a fly problem from January to May. He reports that the insects are kept at a minimum by weekly dosage of the filter influent with 300 lb. of chlorine over an 8-hr. period in the early morning hours when the flow is low. This gives a residual of 0.10 p.p.m. at the dosing tanks.

Downes (Plainfield, N. J.) reports *Psychoda* have not been a problem since continuous flow over the entire filter area has been maintained by pumping back filter effluent to maintain a 7 m.g.d. flow rate to the filters (3.9 m.g.a.d.). He reports no adult files on the wing as long as the flow continues, but reminds that they are under the surface stone and emerge if the flow is stopped for even a few minutes. This brings out the advisability of adjusting the distribution, if possible, to avoid dry areas or areas only slightly wetted, which give the flies their opportunity to take wing.

Regarding the possible effectiveness of the small water springtail, *Achorutes viaticus,* in controlling filter flies, replies ranged from completely negative to one positive. As most operators are aware, the *Achorutes* is a small, blue-black, wingless insect which can jump several inches by means of its so-called "springtail." Some filters have been naturally infested with the *Achorutes,* while a considerable number of filters have been seeded with them by transferring media from an infested filter. Not all efforts at transfer have been successful. Downes (Plainfield, N. J.) advises that the *Achorutes* gave no assistance in *Psychoda* fly control; conversely, Corrington (Clinton, Ill.) reports that since seeding the filter with springtails, less and less trouble with filter flies has been experienced until they are now present only in small numbers. Johnson (Elgin) reports *Psychoda* flies were a nuisance, and in 1931 *Achorutes* were transplanted from Madison, Wis. In two years, seemingly with the increase in numbers of springtails, the fly nuisance abated. The flies are now present in greatly reduced numbers and they remain in the filter area. Johnson cautions that he is not sure whether the springtails are entirely responsible or if other conditions were partially responsible for the decrease in fly population. The *Achorutes* survived the filter rehabilitation at Elgin in 1941. Mackin (Madison) reports that the *Achorutes* are occasionally furnished to others by request. He indicates that they may be of some benefit, but that he does not feel their benefit is substantial.

Harr (McPherson, Kan.) indicates he treats the filter with creosote periodically and burns flies with a kerosene torch in the mornings. He did not indicate the effectiveness of these practices. Beamesderfer (Lebanon, Pa.) reports that the rough stone walls of the filters are sprayed with a 3:1 mixture of crankcase oil and kerosene, attracting the flies which come into contact with the oil, stick fast and die. Then, he reports, the filters are by-passed for 4 to 5 days to dry out the film on the beds, which is followed by increasing the rate of sewage application to flush out the dried film and unload the beds. Beamesderfer reports that these procedures keep filter flies under control, but he did not indicate the frequency of this control measure. Outlet stream requirements at most plants would not allow any such period of by-passing secondary treatment.

Other chemicals, such as pyrethrum and ammonia, have been used in attempts at filter fly control, usually with indifferent results. Published results of plant scale experimentation with the new insecticide, DDT, in the control of *Psychoda* flies are awaited with interest. The author has had the pleasure of reviewing one interesting paper based on an entomological study of *Psychoda* larvae and flies as affected by DDT, and it is hoped that this and other worthwhile papers on the subject will be made available soon. (See THIS JOURNAL, **18**, 1 (March, 1946) pages 181 and 208.) Alikonis (Bloomington-Normal, Ill.) has done considerable work with DDT, and he indicated at the 1945 Illinois Sewage Works Operators' Conference that he has found DDT very helpful in controlling the adult flies.

Odors

Odors are usually not a problem if filters are operating well and receive fresh sewage; if a septic sewage is applied, however, a considerable nuisance may result from the release of odorous gases as the sewage is sprayed onto the filters. Needless to say, all odors at a plant are not necessarily released at the filters.

Of the plants contributing to this review, many experience odor problems. Schaetzle (Akron) reports they have had 25 to 30 damage suits because of odors and gnats and have lost all that came to trial. He indicates that cleanliness is the only precaution they can take against odors as no provisions are made for the use of chlorine. He also indicates that he is obliged to lagoon practically all sludge, most of it in an undigested state, which "does not reduce odor complaints."

Eleven of the contributors reported use of chlorination for odor control. Both pre- and post-chlorination are practiced at Bowling Green, Ohio, by Barnes. Odor control is very important at Bowling Green since the plant is located along a main thoroughfare and close to a university and airport. Barnes indicates that 150 lb. of chlorine are used daily. Allison's practice at Corpus Christi of recirculation and chlorination of filter effluent is described in the discussion on *Psychoda* fly control. Allison indicates the chlorine residual in the recirculated flow at 6:00 A.M. is about 1.5 p.p.m. The Corpus Christi plant is 3,000 feet from the center of town, and no odor complaints have been received since practicing this method of control. Downes (Plainfield, N. J.) chlorinates the raw sewage for odor control, as does Mattson (Oconomowoc, Wis.). The latter applies chlorine at 4 to 7 p.p.m. when pea canning is in progress. Lantenbach (Plymouth, Wis.) applies 20 lb. of chlorine daily to the raw sewage during the hot months when the local cannery is discharging chemically pretreated wastes to the municipal sewers. Shick (Van Wert, Ohio) applies 60 lb. chlorine per day, from June to September, to the raw sewage at the lift station one mile from the plant, to prevent the sewage from becoming septic.

services in lawsuits and claims due to alleged odors. Magennis states:

"Odors are not nearly the problem they used to be due to the fact that the packing company waste is now being received in a much fresher state than it was a few years ago when some of the material was held by them for as long as 24 hours before it was dumped, which usually occurred at night during the light flows. Since the construction of a main catch basin with continuous grease skimming equipment, the material is fed to the sewers about as fast as it is produced. This has alleviated

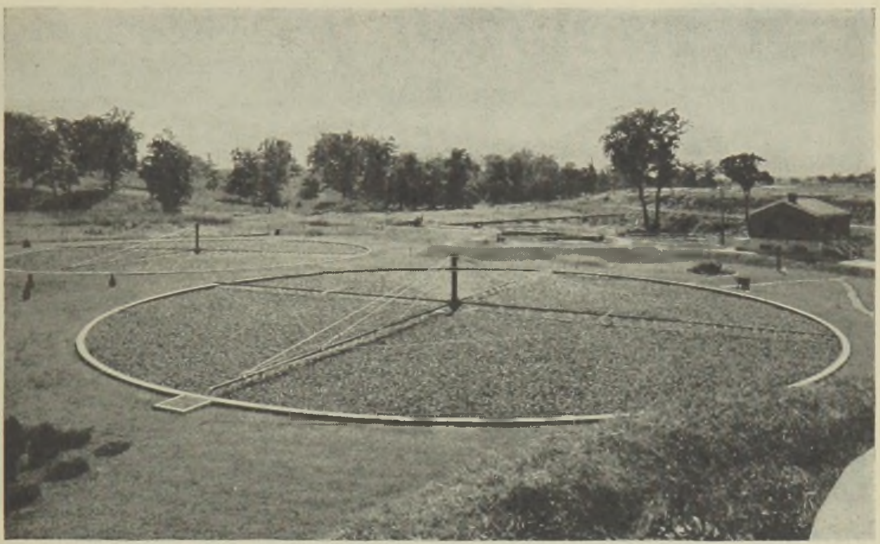


FIGURE 1.—Trickling filters at Anna, Ill., sewage treatment plant.

Mackin (Madison) adds 6 to 15 p.p.m. chlorine to the settled sewage for odor control. Beamesderfer (Lebanon, Pa.) applies 2 p.p.m. chlorine to the Imhoff tank effluent for odor control. Also, dissolved oxygen tests are made on the raw sewage and when no D.O. is present, recirculation is started at a 0.60-m.g.d. rate to the raw sewage. Beamesderfer reports this practice as very effective in controlling odors. Magennis (Fort Dodge) adds about 16 p.p.m. of chlorine at the dosing tanks for odor control. Fort Dodge is another municipality which has paid rather heavily for settlements, judgments, and legal

much of our odor trouble. We do, however, at times have a characteristic packinghouse odor which comes off our preaeration tank which is used for grease removal. The only other odor we have comes from the filters and is more or less a musty odor. Both of these odors can be controlled by the use of liquid chlorine."

Recirculation of final effluent is also used as an odor control measure at Fort Dodge. When the last raw sewage pump stops, a 1,000-g.p.m. recirculation pump automatically starts, which helps reduce odors emanating from idle filters, particularly during the night. This recirculation usually takes place between 1:00 and 6:00 A.M., during which time the recirculation pump operates approximately 50 per cent of the time.

Hager (San Bernardino, Calif.) reports that preaeration eliminates all hydrogen sulfide odors at his plant. Preaeration, if in sufficient amount, can prove very helpful in odor control in addition to its substantial assistance to the efficiency of primary sedimentation units.

Sperry (Aurora) indicates that odors are generally not a problem, as the hydrogen sulfide content of the settled sewage is consistently below 1 p.p.m., which is not enough to cause complaint. He does indicate, however, that many times during the summer a noticeable taint of hydrogen sulfide can be observed across the river from the plant in the quiet of the evening. This is still a function of the weather in the typical way, *i.e.*, the odors tend to stratify and follow ravines on quiet, cool evenings.

With the exception of Shick's practice at Van Wert, none of the operators reported chlorination up-sewer from the plant. Chlorination ahead of long force mains is definitely helpful, both for odor control and to permit delivery to the plant of a sewage which is not rendered much more difficult to treat due to its septicity. Flushing flat, sluggish sewers periodically in warm weather also is helpful in delivering a fresher sewage to the plant for treatment, at the same time assisting in odor control.

Unloading

In general, solids tend to accumulate in low rate filters, particularly during the winter months when biological activity is reduced. These solids slough off periodically, usually in the spring when biological activity increases, but at some plants in both spring and fall. The sloughing period varies considerably in length and intensity at the plants covered in this summary, from a few days at Des Moines to as long as three months at Elgin. Several operators reported more or less continuous unloading. Downes reports continuous unloading at the Plainfield filters since the recirculation practice was started, and Hatfield (Decatur) also reports more or less continuous

FIGURE 2.—Badly pond trickling filter at Madison, Wis. Fine surface media and overloading by packinghouse wastes responsible.

unloading at a plant where no recirculation is practiced. Allison (Corpus Christi) reports filter unloading for four or five days after a temperature drop to 35° to 40° F.

The filter unloading problem assumes greater proportions at Elgin, Ill., where Johnson reports unloading continues from April to June with the humus load during unloading from 300 to 800 per cent of normal. Sludge storage facilities are taxed during the sloughing period, and the filters do not recover to function normally until July. A sludge lagoon helps to overcome the sludge storage element of this problem at Elgin.

At Galesburg, Ill., Hunt reports 35 to 50 per cent more humus load during the two months filter unloading period. At Galesburg, with digesters loaded to capacity, this results in excessive gas production with the gassing rate sufficient to cause a thin digested sludge. Mackin (Madison) reports 3 to 6 weeks unloading in the spring and 2 to 3 weeks in the fall, with a humus load of 300 per cent above average resulting in the overloading of digesters.

Winter Operation

Less than half of the plants included in this summary reported any particular difficulty in winter operation; the majority of plants, however, do take some common sense precautions to avoid damage to equipment or interruption of operation.

An almost universal procedure at plants having intermittent dosage, where freezing temperatures are encountered, is that of partially opening drain valves in the laterals of fixed nozzle systems to lower the sewage level in the vertical risers between doses, and thus reduce opportunity for freezing in the risers. With rotary distributors, the drain valve in the distributor base is usually opened slightly to prevent freezing in the distributor arms.

In severe weather a rotary distributor may be interfered with by ice building up in a ring (or part of a ring) around the filter wall, or in circular ridges on the bed. A ¾-in. hole drilled in the end gate of the distributor arms to direct a flow of sewage against the wall has been found helpful at some plants in reducing ice

FIGURE 3.—Ice formation at fixed nozzle trickling filters, Madison, Wis.

formation around the filter wall. (Tap the hole so a plug can be inserted during warm weather.) Formation of ice around the filter walls is a problem at Plymouth, Wis., and Lantenbach reports that the 4-ft. arm extensions on the distributor are removed and ice is chopped when necessary to keep the distributor free to operate. Corrington (Clinton, Ill.) corks the last four orifices on the distributor arms to help control ice formation around the outside wall, and chops away this ice formation when necessary. During continued sub-zero weather Corrington blocks the distributor in one position. Barnes (Bowling Green, Ohio) reports that ice builds up sufficiently in extreme cold weather to stop the distributor arms, which are a minimum of 9 in. above the media. During extreme cold weather Barnes by-passes the filters, and prevents the final tanks from freezing by passing the flow through them by way of the handhole plates in bases of the rotary distributors.

Johnson (Elgin) reports:

"Since rehabilitation of the filters (in 1941) no ice formations have developed. In previous years, with weather comparable to the cold winter just experienced (1944), ice would form to heights of 2 to 3 feet. Large surface stone used in repairing the beds is considered the main contributing factor in correcting this condition.

"To minimize freezing in winter operation, dosing tanks are covered with planking, siphon piping on the exterior of the dosing tanks is housed and insulated with straw, nozzles are inspected twice daily, and colored warning lights connected to the dosing tank counters are provided so that the night watchman can observe from the office building that the filters are operating in their proper sequence."

Magennis (Fort Dodge) reports that packinghouse wastes raise the temperature of the raw sewage so that freezing is no problem at the first stage filters, and is of consequence at the second stage filters only when the air temperature is zero or lower. Magennis further reports that the most persistent freezing on the filters occurs at the periphery of the beds over the vertical ventilation stacks. The wall and ventilation stacks extend about 1 ft. above the media and this serves as a "snow fence." The nozzle spray coats this snow and eventually forms ice which keeps building up until it must be removed with a pick. To minimize this difficulty, the outside orifice on each distributor arm is plugged so the spray will not reach the wall. This has solved that particular problem. During prolonged cold weather, the spreader plates

FIGURE 4.—Exterior view of enclosed trickling filters at Fargo, N. D.

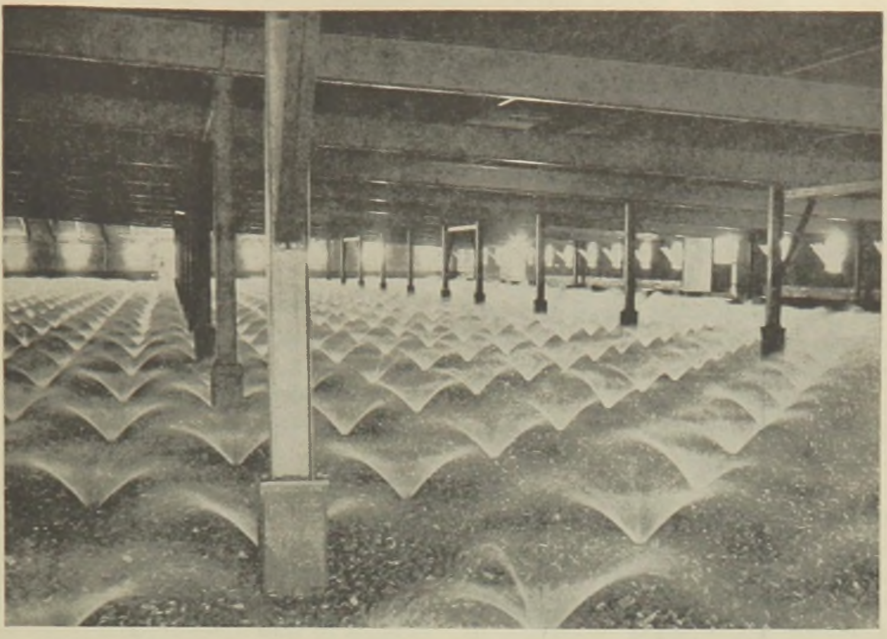


FIGURE 5.—Interior of building housing trickling filters at Fargo, N. D.

over the distributor orifices are lifted, concentrating the flow from each orifice in a confined area around the filter. Magennis reports this practice has aided a great deal in maintaining filter operation during extreme cold weather.

Winfrey (Des Moines) and Spiess (Litchfield, Ill.) report use of recirculation to minimize freezing at the filters by cutting down the dosing cycle during low flow periods. Winfrey also cracks open the end gates of the distributor arms.

Green (Bemidji, Minn.) reports no ice problems (although his city frequently reports the coldest temperature in the nation) due to the housing of the filter. Pinney reports no ice problem at the Fargo, N. D., filters for the same reason (Figures 4 and 5). It goes without saying that Hager (San Bernardino, Calif.) and Clark (Huntington Beach, Calif.) have no winter operation problems related to ice formation!

Unusual Problems

An unusual problem is reported by Magennis at Fort Dodge, Iowa. He describes it as follows:

"For the last fiscal year an average of 6.8 cu. ft. of grit was removed from the detritor daily. Three-fourths or more of this grit was composed of tiny snail shells which were pumped with the humus sludge from the intermediate and final clarifiers. These snail shells came from the filters. Large quantities of them pass through the detritor, settle in the primary clarifiers, and are pumped with the raw sludge to the digesters. In 1942, after four years of operation, two of our digesters were drained for inspection. In the bottoms under the discharge openings into the digesters were found piles of sand, grit and snail shells. These piles sloped down on each side and toward the sump in the center of the floor. This collection of material covered the lower heating coils nearly half way around each digester. This accumulation reduced the digester capacities about 10 per cent. Incidentally, the removal of this material was a slow and tedious process, taking over a month for completion. It was accomplished by the use of the positive displacement sludge pumps and a fire hose. Two or three complete stoppages of the sludge line were encountered before the job was completed."

Spiess (Litchfield, Ill.) reports a difficult scum problem in the digester, with the scum layer accumulating to depths of 6 to 8 ft., which he attributes in part to the large quantities of snail shells flushed from the filter and pumped to the digester with the humus sludge.

An unusual problem at Corpus Christi, Texas, is that of galvanic and

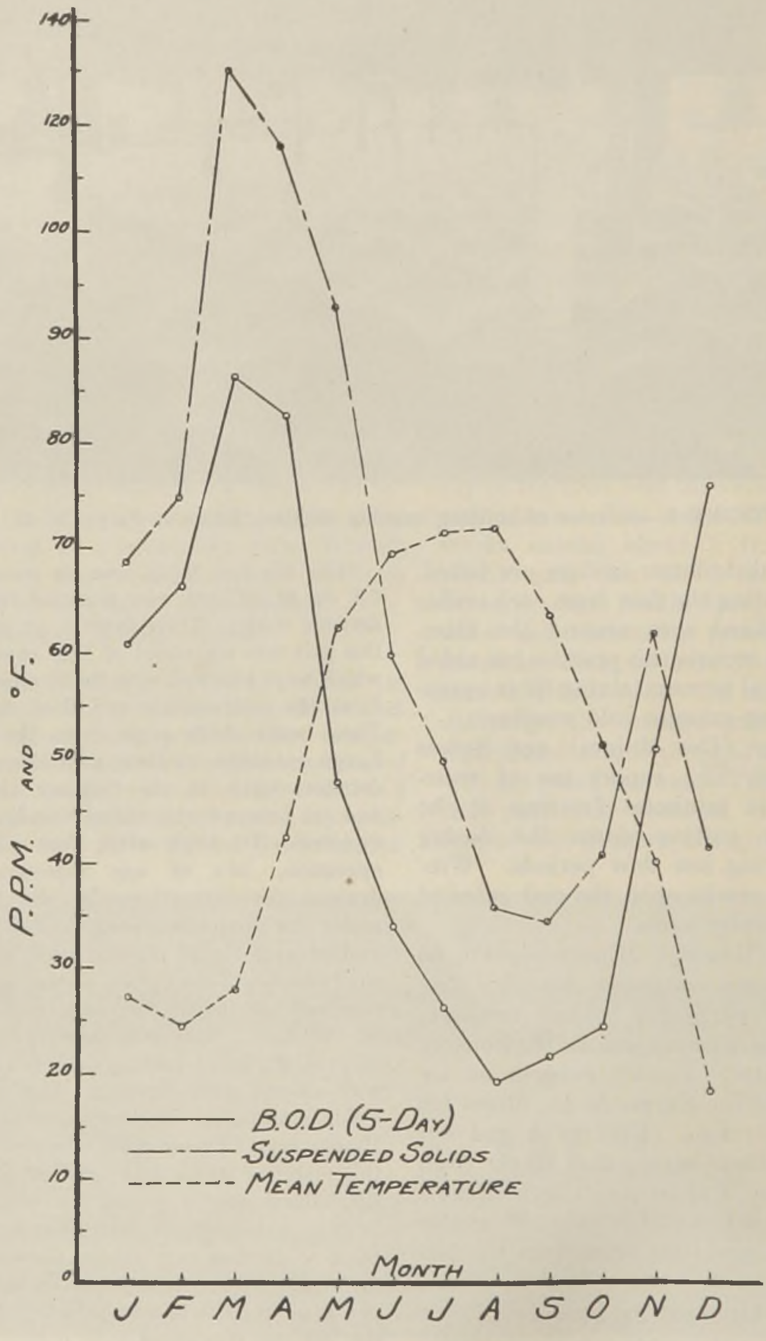


FIGURE 6.—Filter effluent data at Madison, Wis., illustrating effect of temperature variation (1944 monthly averages).

other corrosion of metallic equipment due to the high chloride content of the sewage, which results from infiltration of salt-bearing ground waters. Allison reports that the chloride concentration reaches 3,200 p.p.m. during the night flow, but this causes no operational difficulty other than the corrosion.

Temperature Effect

Temperature is an important factor in the functioning of any biological process, and the trickling filter is no exception. If a filter receives a fresh sewage within its loading capacity, it normally produces its best effluent during the warmer months. This is borne out by the questionnaires returned, and was particularly commented upon by thirteen operators. Several operators indicated, however, that they could not observe any decrease in filter efficiency during the winter months.

Sperry (Aurora), Alikonis (Bloomington-Normal), and Craig (Pontiac, Ill.) all note no particular decrease in efficiency during winter operation. Conversely, a decided drop in efficiency is reported at Akron, Ohio, Albemarle, N. C., Bowling Green, Ohio, Decatur, Ill., Dayton, Ohio, Galesburg, Ill., Griffin, Ga., and Pontiac, Mich. Downes (Plainfield) reports that the effluent stability drops from 10 days in summer to 4 to 5 days during February, March and early April. At Lebanon, Pa., Beamesderfer reports that the effluent stability drops to 50 per cent during the winter. The cold can penetrate the Lebanon filters very deeply as the filter walls are constructed of large stone laid with open joints. Hager (San Bernardino) reports a decrease in filter efficiency when the temperature dropped during the winter of 1944.

Mackin (Madison, Wis.) reports a decided drop in filter efficiency during the winter months, and experiences at Madison are graphically illustrated in Figure 6, which shows B.O.D. and suspended solids in the filter effluent by monthly averages, and mean monthly air temperatures, for the year 1944.

Magennis (Fort Dodge, Iowa), reports a 25 to 30 per cent drop in filter efficiency during the winter months. Figure 7 was plotted from data con-

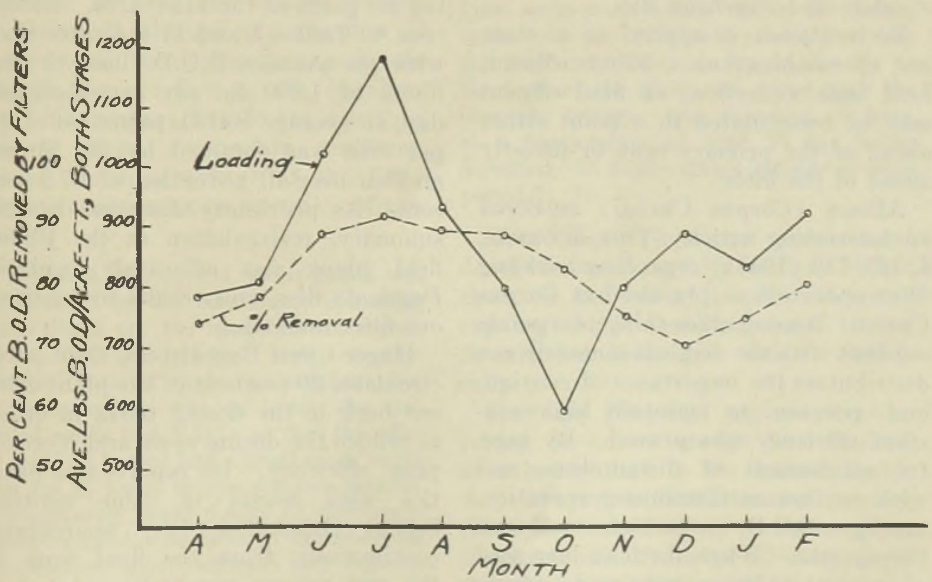


FIGURE 7.—Effect of temperature variation on efficiency of two-stage filters at Fort Dodge, Iowa (1943–44 monthly averages).

tained in the Fort Dodge 1943–44 annual report, the loadings indicated being based on the monthly average pounds of settled sewage B.O.D. per acre-foot of volume of both stages of filters. The final effluent B.O.D. was 44 p.p.m. in July when the overall loading was 1,180 lb. per acre-foot, and the effluent B.O.D. was 188 p.p.m. in December when the overall loading was 890 lb. per acre-foot. The per cent B.O.D. removals indicated in Figure 7 include that removed by filters and secondary clarifiers.

Recirculation

Recirculation has received greatly increased attention in recent years with the development of high-capacity filters. Its application has not been restricted to high-capacity filters, however, as quite a number of plants of standard rate design have applied recirculation with good effect for a number of years. Recirculation applied to standard rate filters has resulted in their ability to handle considerably higher loadings without ponding, has increased efficiency of existing plants, and has assisted greatly in the control of odors and *Psychoda* flies.

Recirculation is applied in a number of combinations. Filter effluent, final tank underflow, or final effluent may be recirculated to a point either ahead of the primary tank or directly ahead of the filter.

Allison (Corpus Christi) authored an interesting article (This Journal, 4, 729–733 (1943)) regarding trickling filter operation as practiced at Corpus Christi. Among other things, he points out that with the original motor-driven distributors the importance of continuous operation to maintain high constant efficiency was proved. By careful adjustment of distribution, and with continuous distributor operation, average B.O.D. reductions exceeded 90 per cent. When the load increased some plant additions were made, among them a change in rotary distributors to the two-compartment arm reaction type. The average B.O.D. reduction then dropped to about 80 per cent due to interruption of operation of the reaction-type distributors during the low night flows. By recirculating 1,000 g.p.m. of underflow from the final settling tanks, the reaction distributors are kept in constant motion, and the average B.O.D. reduction increased to 90 per cent and above. A major advantage of recirculation at Corpus Christi, in conjunction with chlorination of the filter effluent, is in controlling odors and *Psychoda* flies, as described elsewhere in this summary.

A classic example of the effect of recirculation in increasing filter efficiency is the experience of Downes at Plainfield. The average sewage flow is 4.25 m.g.d., and filter effluent is recirculated to maintain a constant rate of 7 m.g.d. to the filters, which is the maximum capacity of the fixed-nozzle distribution system at mean head in the dosing tank. Motor-operated butterfly valves on the dosing tank outlets have a 35-second cycle from zero to full head, which constantly changes the conformation of the spray thus covering all parts of the filter area. Reference to Tables I and II indicates that with an average B.O.D. load to the filters of 1,080 lb. per acre-foot per day, an average B.O.D. reduction of 92 per cent was obtained by the filters, and an over-all reduction of 97.8 per cent. As previously discussed in this summary, recirculation at the Plainfield plant also effectively controls *Psychoda* flies, and results in continuous filter unloading.

Hager (San Bernardino, Calif.) recirculates 20 per cent of the plant effluent back to the dosing tanks in order to reduce the dosing cycle and increase plant efficiency. He reports this practice also assists in odor control. Spiess (Litchfield, Ill.) recirculates continuously from the final tank to the raw sewage wet well, and he reports that this practice improves the effluent, aids in filter fly control, and helps keep down ice at the filter during winter operation.

Humus Sludge

Most of the smaller plants reported that humus sludge accumulations are removed from the final settling tanks, by pumping or gravity flow, from once to six times daily depending upon local factors. The larger plants in general reported longer or more frequent pericds of humus pumping. Humus sludge is pumped eight hours daily at Akron, and continuously at Dayton and Fort Dodge. Humus sludge is either pumped back to the raw sewage and the combined sludge from the primary tank pumped to the digester, or the humus sludge is pumped directly to the digester. The former practice is by far the more common.

Two of the contributing plants reported unusual practices in the handling of humus sludge, those plants being Albemarle, N. C., and Dayton, Ohio.

Moore (Albemarle) reports the interesting use of chemical precipitation of the filter effluent. Sufficient head is available so that the dosing siphon air piping is blocked and the flow is allowed to fill the dosing tanks and pass through the overflow to the distributors. The sewage flow to the distributors is thus reasonably uniform, making chemical dosage of the filter effluent much easier to control. Moore states:

"The need of chemical precipitation was not dictated by the continuous unloading of the filters nor the need for concentrating the final tank sludge. It is true that it helped both of these in our plant, but the main reason was to lower the suspended solids and B.O.D. so that the effluent could be passed into a small creek which dries up at times in the summer months. A considerably lower dosage of chlorine is needed to kill the bacteria in this chemical precipitation plant effluent and quite a saving is accomplished while having a purer effluent.

"We have tried ferric chloride, 'Ferrisul,' ferric sulfate, 'Ferri-floc,' 'Ferrichlor,' copperas, activated alum, and for the past several years we have been using alum only, without lime, as we have plenty of alkalinity added in our industrial dye wastes, along with plenty of sodium chloride.

"We are at present using an average dosage of 60 p.p.m.—our minimum dosage for domestic sewage runs around 30 p.p.m. Some of our dye waste will take dosages up to 150 p.p.m. to produce a suitable floc and then the color will remain at times. Considerable experimentation has been carried out with various dye wastes as to chemical dosages required. The flocculation period is 36 minutes per million gallons per 24 hours. (The average final settling period is 2.07 hr.)

"In answer for data on the per cent solids of the final tank sludge after chemical precipitation, we are submitting the following averages: per cent moisture, 96.2; per cent dry solids, 3.8; per cent volatile matter, 51.7. Considerable trouble was experienced when pumping this chlorinated sludge directly to the digesters. By keeping a graphic record of the per cent moisture at different elevations in the sludge tanks, we could see the effects the secondary sludge had on settling and digestion. Curves on per cent digested at these various elevations within the sludge tanks were not satisfactory, and therefore this secondary sludge is drawn directly to the head of the plant and mixed with the incoming sewage. Our digesters are kept at a temperature of 100° F. for faster digestion—15 days—with a quicker settling period."

Moore also reports that the chemical dosage is based on the alkalinity rather than on the variable pH. Digester supernatant is also discharged to the flocculation tank and treated chemically.

Huffman (Dayton) reports that the return of humus sludge has resulted in a heavy load to the Imhoff tanks. A year's experimentation was undertaken in the laboratory to devise effective methods of sludge thickening so that the humus sludge could be pumped directly to the digesters, relieving the

Imhoff tanks of this extra load. The results of this experimental work as performed by R. Calihan, Plant Chemist, follow:

"The solids concentration of the humus sludge from the secondary clarifiers varies from 0.1 to 5 per cent according to the time of the year (sloughing) and the technique of operation. This variation may occur even within a few hours operation, and so introduces a delicate problem for chemical treatment.

"It was found by jar tests (Figure 8 and Table VI) that mechanical agitation alone produces a good floc with subsequent rapid settling, leaving a supernatant having little or no sludge particles. This reaction could be accomplished by agitating the raw sludge as little as five minutes. Settling required another 10 to 30 minutes, depending upon the solids content of the

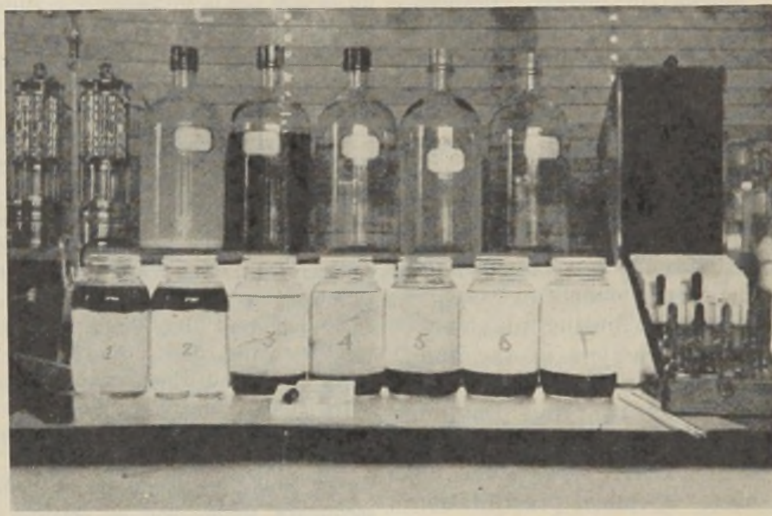


FIGURE 8.—Jar experiments on the treatment of humus sludge at Dayton, Ohio. See Table VI.

TABLE VI.—Experimental Treatment of Humus Sludge at Dayton, Ohio.

Jar Number	Treatment	Final pH	Settling and Compaction	Supernatant Quality	Rising Time (hr.)
1 and 2	None	7.0	Poor	—	2*
3	5 min. mech. agitation	7.2	Good	Turbid	5+
4	10 min. mech. agitation 85 p.p.m. lime	8.4	Better than No. 3	Turbid	5+
5	10 min. mech. agitation 171 p.p.m. $FeCl_3$	6.8	Slower compaction	Clear	5+
6	10 min. mech. agitation 256 p.p.m. $FeCl_3$	6.4	Same as No. 5	Very clear	5+
7	10 min. mech. agitation 85 p.p.m. lime, 171 p.p.m. $FeCl_3$	7.0	Same as Nos. 5 and 6	Very clear	5+

* Rising of sludge began in 15 min.

sample. The sludge having received this treatment remained on the bottom of the jar approximately five hours. Room temperature for the tests was between 85 to 95 degrees F. Longer periods of setting may be expected at lower temperatures due to less active bacterial decomposition of the sludge.

"The supernatant of the mechanically agitated sludge always increases in turbidity due to the elutriation phenomenon which occurs. This would indicate a higher B.O.D. for the supernatant and would probably be dependent upon the length of time the sludge was agitated. Tests were run for B.O.D. of supernatant after the sludge was agitated for different lengths of time, and the following results were obtained:

	5-Day B.O.D. (p.p.m.)
Untreated sludge	323
Sludge agitated 10 min.	423
Sludge agitated 30 min.	603
Sludge agitated 45 min.	700

"These figures support the contention that longer agitation increases B.O.D., and therefore introduces another operation problem, that is, where should this supernatant liquor be placed in order to eliminate the high oxygen demand it has acquired from the sludge it washed?

"The alternative to the production of increased B.O.D. (of supernatant) by continued agitation is undoubtedly proper timing of the flocculation to produce compact settling without causing a transition of the soluble material in the sludge itself to the water in which it is immersed.

"Another method of clarifying the supernatant of solids and high oxygen requirement is mechanical agitation with addition of chemicals. This, too, requires rather careful control in that the chemicals necessary for proper precipitation of the dissolved and suspended solids are dependent upon the solids content of the incoming sludge which, as previously stated, is quite variable. From tests already conducted, it was found that rather high dosages of chemicals were necessary to produce a clear supernatant with a pH of 7.0. For instance, 10 grains per gallon ferric chloride and 5 grains per gallon lime were required to get a clear supernatant and even higher dosages of alum were added for the same results. At present, tests remain to be made to determine the B.O.D. of supernatant from the chemically clarified sludge."

Based upon these results, a humus thickening tank 78 ft. × 10 ft. × 10 ft. water depth has been constructed at Dayton. Mechanical flocculation is provided, and the sedimentation period is 3.83 hr. The tank will operate continuously and is equipped with a sludge collector. The supernatant from this tank can be discharged to the plant effluent, back to the filters, or pumped to the garbage grinder to supply the water needed there. Huffman states it was hoped to obtain 5 per cent sludge from this installation and pump it directly to the digesters. Operation results are not yet available.

Industrial Wastes

No summary of trickling filter operation experiences would be complete without some reference to industrial wastes. Trickling filters are extremely versatile and are capable of providing treatment for a wide variety of industrial wastes provided loading limitations are respected, and provided the waste in question is not in too great concentration, is not in toxic concentration, and that it contains the necessary nutrient material to sustain the biological life on the filter media. Many industrial wastes for which separate treatment is expensive and often impractical are treatable in combination with domestic sewage, provided that precautions are taken against shock loads and provided the industrial wastes are not too great a percentage of the combined flow. Many difficult industrial waste problems have bowed to trickling filters, properly applied.

Eighteen of the plants contributing to this summary receive industrial wastes of consequence. Barnes (Bowling Green, Ohio) reports that the population equivalent from tomato cannery wastes often triples the domestic load. The tomato wastes are received as shock loads after pretreatment to the extent of a fine screen and grit chamber. The plant was designed for a high population equivalent and effective treatment is provided. Schaetzle (Akron) has rubber wastes to contend with, and his interesting report on this problem is contained in THIS JOURNAL, 17, 497–501 (1945). Hatfield (Decatur) reports an industrial wastes loading from a large corn products plant of 60,000 to 100,000 population equivalent, with peak loads of 160,000 on some days. Through considerable work with the industry, Hatfield succeeded in having recovery procedures installed by the industry. With careful operation by the industry the industrial wastes population equivalent at Decatur can be kept to less than 100,000. The Decatur plant contains activated sludge units in addition to the trickling filters.

Winfrey (Des Moines) reports that 1 m.g.d. of packinghouse wastes are received at the plant, resulting in a large quantity of screenings to grind, much grease to skim and barrel, and heavy production of digester gas (over 2 cu. ft. per capita daily). He reports that a revenue of $16,346 from the sale of excess gas and $1,439 from the sale of grease was derived during the 1944 fiscal year. Mackin (Madison) reports that 2 to 3 m.g.d. of packinghouse wastes are included in the total daily flow of 12 to 14 m.g. The packinghouse wastes are pretreated. The trickling filters at Madison are used to treat the excess load above the capacity of the activated sludge process.

Magennis summarizes the industrial waste problem at Fort Dodge as follows:

"Contributors of industrial wastes include creameries, poultry houses, a serum manufacturing plant, a rendering company, and a meat packing plant which we usually consider as our sole contributor of industrial wastes because the others are of no particular magnitude. The packing plant contributes about 0.60 to 0.80 m.g.d. This is about 21 per cent of the total sewage flow. This waste contains about 68 per cent of the suspended solids loading on the plant and about 74 per cent of the B.O.D. load. The plant was designed for 7,700 lb. of B.O.D. per day and a population equivalent of 36,000. Last year the average daily load was 15,140 lb. of B.O.D., 12,350 lb. of suspended solids and a population equivalent of 89,060. The packing plant waste undergoes no pretreatment other than a final grease skimming process at the packing plant. Other than the terrific overload, the chief effect on treatment seems to be caused from large quantities of grease lost by the packing company. We have reclaimed and sold an average of 338 lb. of grease per day last year. (Total revenue from grease sales in the 1943–44 fiscal year was $2,697.) This grease tends to cling to the pipes, decreasing their capacities to the extent of nearly complete stoppage at times, especially in the suction pipe of the grease pit. The walls of the wet wells have to be scraped free of grease quite often. The walls of the control pit, which is ahead of the main lift station, are scraped at least once every two weeks. The grease accumulates here in such large chunks at times that they restrict the flow to the plant and by-pass it to the river. These large chunks are accumulations that have been freed from the inside of the sewer line between the control pit and the packing plant."

Magennis reports a population equivalent for the packinghouse wastes of 42 per hog killed, with a range by monthly averages from 25 to 64.

Simonton (Griffin, Ga.) reports cotton mill wastes are received with no pretreatment or control of the discharge rate. He also advises that oil and grease cause some trouble by forming a film on the filter media. Williams and Malone (Durham, N. C.) report dyes from hosiery mills are received after pretreatment with lime. They report no difficulty if the wastes are not discharged as shock loads.

Mattson (Oconomowoc, Wis.) notes that 40 per cent of the total flow is due to wastes from a condensery and malted milk plant. Pea cannery wastes of 60,000 to 240,000 g.p.d. are received seasonally without pretreatment. He states that the pea cannery wastes result in a heavy growth on the filter media.

Hager (San Bernardino) reports 1,000 gal. of gunk is discharged to the sewers periodically, leaving a distinctive odor throughout the plant which persists at the filters for many hours. Hager observes that the gunk probably affects the digesters, as does 1,000 gallons of chromic acid discharged periodically to the sewers.

Shick (Van Wert, Ohio) reports that installation of a rotary screen by a canning company has permitted his plant to handle this load without difficulty, together with a heavy milk wastes load. He also commented that tar and oil discharged from an artificial gas plant became so bad that the wastes had to be directed to the stream. The tar and oil filled the digester and almost completely destroyed the effectiveness of the filters. The latter units required six months to recover.

BARK FROM THE DAILY LOG

By Walter A. Sperry

Superintendent, Aurora (Illinois) Sanitary District

May 6—Today some galvanized iron bolts were needed to secure creosoted planks that were to be used to raise the height of a weir in a deep gate well, one side of which relieved sewage liquor to the river. Permanence was desired since at unexpected and inconvenient intervals the river reaches flood stages sufficient to top the original weir and flood the plant. No galvanized bolts were to be had so we made them.

Dip galvanizing is a simple process that any one can do well. The tools required are an iron pot large enough to allow immersing the pieces to be galvanized, some scrap zinc—in this case we bought 10 lb. of zinc mason jar lids at the junk yard—and a source of heat such as a kerosene torch or a blacksmith's forge.

First prepare the pieces by boiling them in a 10 per cent solution of muriatic acid in an enameled iron pan and until the entire surface exposes clean virgin iron—this is quite important. Next remove the pieces while still hot from the acid bath and place them into a hot saturated solution of sal ammoniac (ammonium chloride), 65 parts to 100 parts of water. Remove and lay across a clean wire rack to dry. When dry, plunge them into a bath of molten zinc. If the acid cleaning has been done thoroughly the galvanizing will be perfect and very durable. Use a pair of tongs or pliers to handle the pieces throughout the process to avoid grease spots.

May 15—Your Logger is peeved at the designing engineer today and with just cause. Yesterday it was decided to make a complete check on the Venturi meter. The deep meter well was pumped out with an ejector and tools were assembled preparatory to removing the hand-hole plates on the annular pressure chambers at the entrance and throat rings.

Only the two top plates of the four plates in each ring could possibly be reached. Fortunately we could work a hose nearly around the rings and so did a fair job of flushing through the two top holes. Our real trouble started when we attempted to work the plungers set radially around the tube to clean the orifices leading to the pressure chambers. Only half of these could be worked at all and some of them could only be operated from cramped positions and at the cost of skinned knuckles, all because the side walls and floor had been planned with far too little clearance and space to perform the work. Fortunately, our meter works well but half of the plungers that are provided can never be operated.

The next day it was necessary to dewater the detritor basin which is some 30 ft. square and about 3 ft. deep. We were irked again because the drain provided was only a 4-in. pipe and draining required a wait of 2 hours before repair work could be started. This drain could just as well have been of 6- or 8-in. pipe. The cost of the larger pipe is a mere bagatelle to the delay and irritation caused by the failure of the designing engineer to visualize operating needs and problems.

All of us know of many similar instances. Designing engineers please take note that every detail of pipe size, area and general flexibility that can possibly be worked into a design will sooner or later prove to be an all-important item to an operator harassed by an unexpected problem or emergency.

May 20—One of the operators came back from the secondary pump station this morning to report that the west hopper of the tank could not be pumped. He was sent back with several suggestions as to priming but results were still negative. Back-flushing through the line from the main building did no good. Rodding the suction line through the cleanout plate on top failed. The application of the periscope showed no unusual accumulation of sludge to account for the trouble and we decided to have a local plumber clear the line with his "Roto-Rooter." Cost $15; results nil.

Finally we tuned up our portable pump and drained the tank. Due to high water in the river and the very real danger of heaving the floor if we closed the check valve in the bottom against the strong inflow of ground water, it was necessary to put an extra man on to pump all night in order to get it down early enough in the day to accomplish any work. After two days work in a cold raw wind we made it and finally found the trouble. A gallon paint can, half-full of fish bait, was nicely jammed in the sludge shoe of the suction pipe and firmly wedged in with some twigs and gravel. So far as pumping was concerned it might as well have been concrete. We'd like to have laid our hands on the fisherman that tossed it!

May 24—We don't know when an editorial has been better phrased than Editor "Pete's" January editorial on "Personal Courtesy and Public Relations." It deserves comment. This type of helpfulness has long been practiced at the Aurora plant with cumulative and satisfying returns and it costs nothing. If we are sometimes amazed at the willingness of others to lend, share information or render assistance, it no doubt reflects a like spirit on our part.

The secretary of the local YMCA asked us to stop in the other day. He presented the problem of a large steel tank used as a septic tank for a multiple hole latrine at the "Y" camp. Since no soapy water entered the tank we carefully explained the general mechanism of septic action and not only suggested the use of some lime but told them where to buy multiple indicating pH paper (pHydrion) to control its use. Later we demonstrated the use of the paper with some acid and alkali and a glass of water. This kind of service makes fast friends.

May 30—One of the special ballots at a recent election in Aurora was on the question of a Retirement Fund for the employees of the sanitary district under the Illinois law. Aside from one or two news items explaining the law no electioneering was done. We were pleased when the returns showed this particular ballot had carried by more than three to one.

Were we red in the face, however, to note that every precinct of every ward both in and out of the city proper had voted favorably except Precinct 8 of Ward 3—in which your logger resides!! There the vote was 24 for and 48 against.

We could scarcely believe that we had created such a bad impression on our neighbors. On calling the Election Commission office we found that they had noted this same single exception and were also embarrassed. An investigation was immediately made and it revealed that the judges in that precinct had made an error in reporting the total vote. The true count actually stood 124 for and 48 against. We felt much better!

June 4—Williard Pfeifer, our always helpful assistant, contributed a good suggestion today. It is worth passing along, and is particularly pertinent during this period when good labor is hard to get and difficult to keep. The incident that gave rise to the suggestion was the failure of the house water pump. This pump supplies spring water from a large well buried in the ground across the road. The flow of spring water to the well is governed by a float valve and the pin in this valve became corroded, failed to open and the well was pumped dry. This may not happen once in 5 years.

Except for one or two older employees no one else would have the slightest idea what was wrong or where to look. This kind of interruption can happen in many ways around a plant where the machines are generally dependable.

Hence the suggestion of a note book or chart record of such incidents, with proper instructions and explanation, made easily available to all.

June 12—Why do they do it? The paper mill called today asking us to look out for a purse with $920 in it. A discharged soldier returning to work at the mill did not want to wait for the bank to open and came on his shift with the money in his hip pocket.

The suggestions that were made to rake carefully the drainage channels behind the weirs did no good. The money was never found.

June 21—In closing his description of his "scotch" filter nozzle [**This Journal, 8,** 843 (1936)], W. D. Hatfield of the Decatur Sanitary District closes with a challenge to other operators to submit their ideas along this line. It has taken a long time but this will present the Aurora answer to the nozzle salvage problem.

The Aurora nozzles are of the PFT type. They have been in use since September, 1929, and while the pins that lock the spindles into the cross bars have been renewed several times the collars that rest on top of the cross bar are so badly worn that it was necessary either to discard them entirely or find some way to salvage them. To replace them meant an expense of about $1,000.

Since repair expenses are mounting we were pleased to have one of the plant operators suggest an idea that has proven excellent. The stem of the spindle was threaded and a ⅜-in. brass hex nut was screwed on. Then Williard, already mentioned in this column, thought up a simple chuck made of pipe fittings to hold the

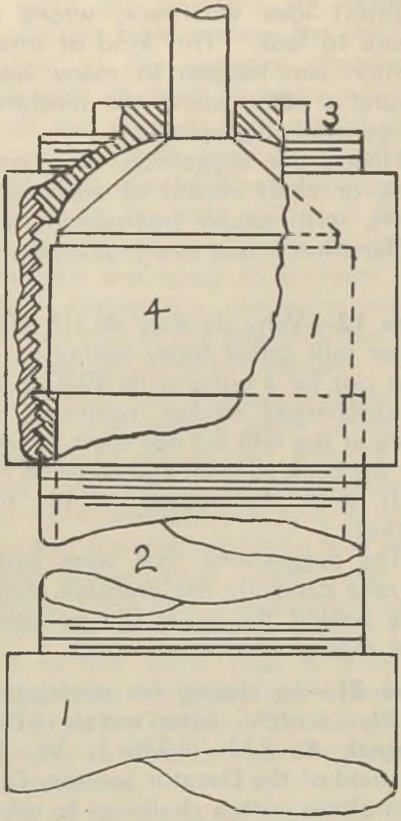


FIGURE 1.—Spindle chuck used in salvaging filter nozzles at Aurora, Ill. Assembly comprises (1) 2-in. couplings, (2) 2-in. by 3-in. nipple, (3) 2-in. bushing, (4) filler block.

spindle while it was being threaded (Figure 1). In placing the spindle the nut is adjusted and given a turn or so which tightens it firmly down on the bar against the pin. The rebuilt spindle is shown in Figure 2.

Our repair scheme was quick, easy, efficient and cost but $25. Dr. Hatfield's scheme possibly has a little edge over ours. While it cost a little more he could eliminate the cross bar leaving an unobstructed hole that does not tend to clog so readily.

June 28—More about weed control. Nurserymen have long been familiar with growth-regulating substances which when applied in minute amounts tend to promote rooting or prevent premature dropping of fruits. A new use for this remarkable group of materials is now found as herbicides. They induce growth responses which make weeds no longer adaptable to their environment or excite them to such activity that they literally grow themselves to death. "Weed-No-More," described in the May **Log** belongs to this group.

Our garden store man told us that there are at least fifty variations on the market using the active ingredient used in "Weed-No-More." They are sold under as many trade names and appear both as liquids and powders. Also, they have widely varying coverage. "Weedicide" and Scotts "4-X" are typical examples. It is also interesting to note that, whereas the

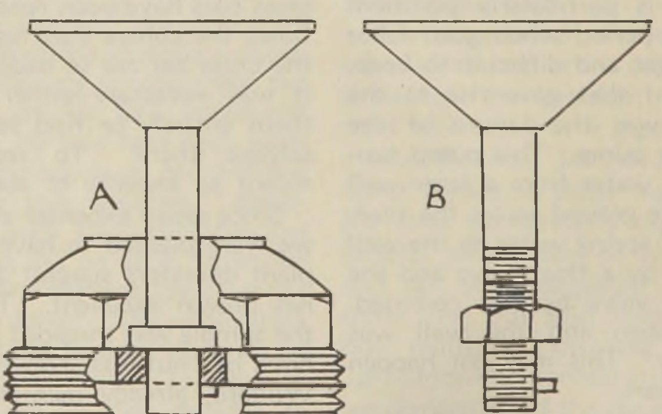


FIGURE 2.—Comparison of original and salvaged filter nozzle spindle.

older group of weed killers, such as salt and arsenic, killed by corrosive effects and had to be used in large quantities, the newer types require much less material and kill by penetrating into the sap system and so affect the whole plant.

Ammonium sulfammate—called "Ammate"—belongs to this newer group. It has been successfully used for the last 5 years. It is non-poisonous, does not endanger live stock or permanently sterilize the soil. It is especially effective in eradicating poison ivy, poison oak and poison sumac. Woody perennials and annuals require about 1 lb. per 100 sq. ft. and deep- and shallow-rooted perennials require from 1 to 3 lb. per 100 sq. ft.

Cyanamide, usually thought of as a fertilizer, is now being sold for the dual purposes of killing weeds and for plant food. It is especially useful in preparing bare ground for crops such as tobacco and asparagus. Use on idle sludge beds and garden plots is suggested. Applied at the rate of 1 lb. per sq. yd. some sixty days ahead of planting, it practically sterilizes the ground and all weeds disappear. In the meantime the cyanamide releases calcium and nitrogen in quantity to be available when planting time comes.

It is important to note that weed killing agents, in general, tend to work best when plant growth is most luxuriant and when the temperature is around 70°, being the time when plant circulation is the most vigorous.

DIGESTER GAS EXPLOSION AT TRAVERSE CITY, MICHIGAN *

By Gerald Forton

Superintendent of Sewage Treatment, Traverse City, Mich.

The Traverse City sewage treatment plant is of the separate sludge digestion type and includes grit chambers, a bar screen, sedimentation tanks, digesters and chlorination equipment. The plant is laid out in three main units: (1) the building housing the sedimentation tanks, garage, office and laboratory, (2) the three glass covered sludge drying beds, each 40 ft. by 100 ft. and (3) the two 45-ft. digesters located at the rear of the plant grounds.

The digesters have fixed covers and are equipped with Dorr stirring mechanisms. The stirring devices are not used continuously but are operated for about one hour twice a day, at 4:00 A.M. and at 4:00 P.M. It is at these times that the settling tank sludge collectors are also operated while sludge is being pumped to the digesters.

A small control building is located over the center of each digester and it was in one of these buildings that an explosion occurred at about 4:30 A.M. on April 26, 1940. This building had no ventilation except for the windows, so it was concluded that the level in the digester had dropped during the night, allowing gas to escape into the building and to accumulate to the level of the open windows.

The stirring mechanism starting switch was located on the wall just inside the door so that the attendant could operate it while standing in the doorway. On the morning of the explosion the operator had started the clarifier mechanism and had proceeded to start the digester mechanism. As he reached in and pushed the starter but-

* Presented at 21st Annual Conference of the Michigan Sewage Works Assn., held at East Lansing, on March 18–20, 1946.

ton, an arc at the switch ignited the explosive gas-air mixture.

The blast threw the operator about 25 ft. clear of the building and down the 14-ft. embankment surrounding the digester. From here he made his way to the telephone in the garage, where he was able to stand long enough to make the telephone operator understand that there had been an accident at the sewage treatment plant and that help was needed. She immediately called the writer, who directed that a doctor and ambulance be dispatched to the plant at once and then went immediately to the scene of the accident.

Upon arrival, the injured man was found on the ground just outside the garage door. Obviously badly hurt, there was nothing to do but to make him as comfortable as possible until the doctor and the ambulance arrived. He was taken to the hospital, where he remained for 3½ months and then was confined to his home under the care of a physician for an additional 5 months.

Damage to the control building and equipment was not so serious, however, the roof was lifted off and displaced about 2 ft., the brick and stone trim at the top of the walls was blown out and the copper flashing at the edge of the roof was damaged beyond repair.

To eliminate a similar explosion at the digester control buildings, turbine ventilators have been installed in the roofs of each of them and louvres have been provided under the east and west windows. These facilities are adequate to change the air in the building every 2 to 2½ min. The starter for the digester stirring mechanism has been moved to the outside of the building and all inside electrical fixtures have been replaced with explosion-proof equipment. The total cost of repairs to

FIGURE 1.—Exterior of building damaged by digester gas explosion at Traverse City, Mich.

FIGURE 2.—Interior of building damaged by digester gas explosion at Traverse City, Mich.

the building and equipment and of the ventilators, explosion-proof fixtures and starter relocation was about $1,000.

As there is only one plant operator on duty during the night, arrangements have been made with the police department for the night shift attendant to call the police station on the hour from 7:00 P.M. until 6:00 A.M. If the police station fails to receive a scheduled call, a squad car is sent to the plant to investigate.

BRITISH INSTITUTE DISCUSSES RECENT RESEARCH

A highlight of the meeting of the Midland Branch of the Institute of Sewage Purification (England), held at Birmingham, on December 11, 1945, was the paper "The Work of the Water Pollution Research Laboratory During the War," presented by Dr. B. A. Southgate. An abstract of the paper is contained in THIS JOURNAL, 17, 3, 578 (May, 1946).

Dr. Southgate's recital of the results of recent studies undertaken by the laboratory precipitated a lengthy and informative discussion from the floor. Several extracts from the reported discussion are presented here.

The Value of Nitrification

Dr. H. Clay of Birmingham, commenting on studies of alternating double filtration with recirculation and of other high-rate filtration methods, noted the low degree of nitrification, presumably due to the limited time of contact in the filter. Dr. Clay referred to the past acceptance of nitrification as an excellent criterion of percolating filter efficiency and the practice of pollution control authorities in adopting standards of effluent quality in which somewhat higher values of oxygen absorbed were permissible in the presence of significant amounts of nitrate nitrogen. Now, however, some authorities deem nitrates to be of no value to an effluent and consider that a high content of nitrates in a percolating filter effluent is a symptom of the medium being overloaded with solids.

Dr. Clay offered the opinion that of two effluents with the same oxygen absorbed value, the one which was well nitrified was the more stable; a fact particularly applicable to streams in his district where dilution was comparatively small. He referred also to the opinion of W. T. Lockett of the West Middlesex Joint Sewerage Board, who holds that, *inter alia,* a well nitrified effluent was much superior for the preservation of good stream conditions to one that was not nitrified.

Dr. E. V. Mills of Birmingham referred to the alternating and recirculating filters at Minworth and that, while part of the price paid for high-rate filtration was some loss of nitrifying power, the capacity for nitrification was not lost altogether. These filters produced an effluent that contained nitrate persistently to the extent of 0.5 to 1 p.p.m., which content he considered to be a significant amount.

In another plant employing high rates of application with recirculation, Dr. Mills reported that an effluent was produced containing 20 p.p.m. of oxidized nitrogen; illustrating a case in which recirculation was consistent with fairly heavy nitrification.

Mr. J. Hurley of Wolverhampton offered the reminder that plant scale experiments with enclosed aerated filters at Wolverhampton showed that a good degree of nitrification could be achieved when a strong settled sewage was applied at a rate of 200 gal. per cu. yd. per day.

Dr. Southgate, in responding to the above comments, admitted that there were many arguments on both sides of the question as to the value of nitrate in an effluent discharged to surface waters. An argument difficult to counter is that the oxygenating value of effluent nitrate is taken into account in determining the biochemical oxygen demand. If the B.O.D. value were satisfactory it would be unlikely that an effluent, whatever its nitrate content, would cause undue deoxygenation when discharged to a stream. He closed the discussion on this topic with the observation that studies would be desirable of the effects of polluting substances on an artificial stream in which the flow could be controlled.

Pro and Con on DDT

A. T. Palin of Coventry commended the work of the Water Pollution Research Laboratory in connection with the usage of DDT and other insecticides. He went on to cite an instance in which DDT was successfully employed to eliminate an infestation of *chironomus* larvae at a water works. These organisms were found to withstand copper sulfate and chlorine dosages as high as 50 p.p.m. but 0.01 p.p.m. of DDT was effective in 8 hr. (*Chironomus* larvae have caused trouble in some activated sludge sewage treatment plants; this procedure may have value in such cases.—*Ed.*)

J. McNicholas of Walsall pointed out that it was unfortunate that quantities of waste acid were produced in the manufacture of DDT and suggested that this acid might have value for the pickling or cleaning of metals. He noted that organic inhibitors are sometimes added to acid used for this purpose so that the organic content of the DDT wastes might be advantageous.

Dr. S. H. Jenkins of Birmingham, in connection with the control of filter flies by chemicals, asked whether it had been kept in mind that some insects were capable of developing immunity to insecticides. He referred to certain attempts to control agricultural pests by chemicals where there had resulted increasingly severe infestations of the pest, because a few of the insects had survived the treatment and then bred generations of insects with similar powers of resistance.

High-Rate Filter Pretreats Water

A. T. Palin described a recent development at the Ryton water works at Coventry where a high-rate filter has been installed primarily for the purpose of nitrification. The raw river water here is high in ammonia content because of the presence of sewage effluents and there are occasionally traces of phenols that have caused objectionable chlorphenol tastes in the treated water. Passage of the raw water through the high-rate filter was intended to effect oxidation of the ammonia and intermittently present phenols.

Dr. Southgate responded to these comments with the opinion that ordinary phenol in reasonable concentrations could certainly be destroyed by filtration, although some of the higher phenols tended to pass through.

Oil Emulsion Wastes

C. E. Winsor of Birmingham expressed interest in the work of the research laboratory on the treatment of wastes containing lubricating oils and cutting oil emulsions. He described the effects of these wastes at the Coleshill Works, where flushes of oil are frequently received. Although the sedimentation tank baffles retain a high proportion of the oil, some of it does pass through to the activated sludge units where it forms a film on the liquor surface of the aeration tanks and interferes materially with surface aeration. It has been found that it takes at least 3 days for the oil to dissipate and for the activated sludge to recover from one of the batches of oil waste.

The oil trapped as scum on the sedimentation tanks, unless present in sufficient quantity to justify separate removal, eventually gets to the primary sludge digestion tanks. Here, although the oil appears to be innocuous, its effect is cumulative. Removal entails the partial or, depending upon the design of the tank, even the complete emptying of the digesters—a task that no works manager holds lightly, especially if the digesters are covered with gas collectors.

INTERESTING EXTRACTS FROM OPERATION REPORTS

CONDUCTED BY LEROY W. VAN KLEECK

Report on Operation of the Hartford, Conn., Metropolitan District Sewage Treatment Plant for the Years 1943 and 1944 *

BY GEORGE H. CRAEMER, *Division Engineer in Charge*

Descriptive

This plant serves Hartford, West Hartford, and all or portions of Wethersfield, Bloomfield, Windsor and Newington. It is designed for an average dry weather flow of 39 m.g.d. and a maximum flow of 80 m.g.d. The treatment consists of coarse screening, sedimentation with grit removal, digestion and elutriation of sludge, vac-

* For a previous extract see THIS JOURNAL, 16, 1, 167 (1944).

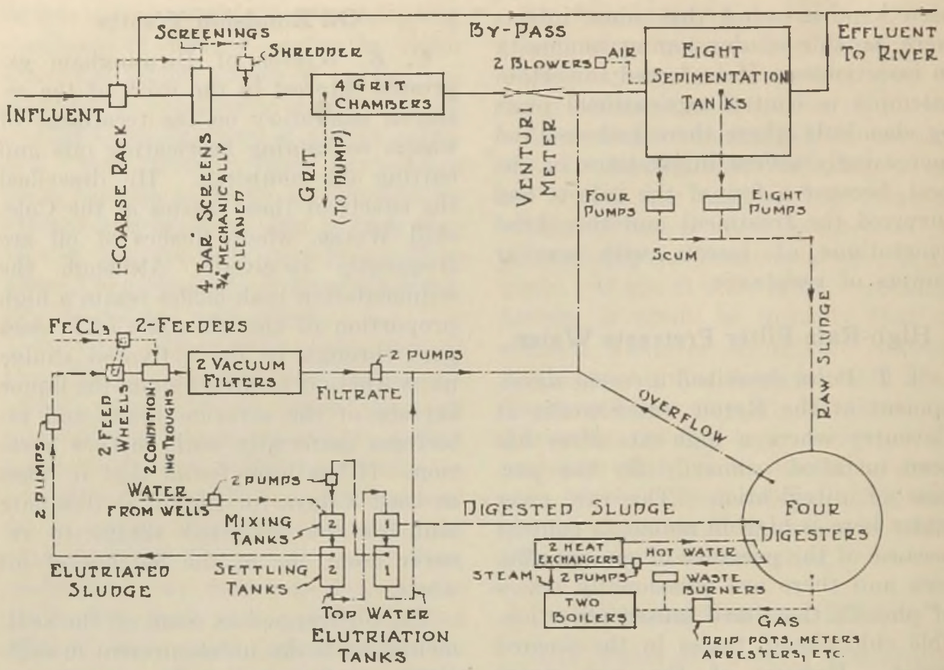


FIGURE 1.—Flow diagram of Metropolitan District sewage treatment plant at Hartford, Conn.

uum filtration, and disposal of sludge cake by fill (Figure 1).

Coarse Grizzly

This screen has 2½-in. clear openings and is hand cleaned. The approximate time spent in cleaning is 1½ hr. per day for one man.

Coarse Screens

There are four of these screens with ¾ in.-openings. They are raked mechanically. During normal days the motors operate approximately 20 hr.

Screenings Grinder or Shredder

This is used an average of 1¼ hr. daily. Except for the necessity of reversing the cutting blades and replacing them when they become dulled (a new set being required yearly), this shredder has performed satisfactorily.

Grit Chambers

These are four in number equipped with endless chain scraper-conveyors. There is one screw elevator washer per chamber. The grit is removed from these chambers after any appreciable rain storm which causes an increase in flow through the plant, and approximately every 2 weeks during dry weather flow.

It has been found advantageous to dewater the various channels when removing grit—a more thorough, quicker and easier way than when sewage is allowed to flow through the channels.

Analysis of Filter Cake

In May, 1943, a fertilizer analysis of the filter cake in the dumping area which has been building up from 1938 to the date of this test was made. Composite samples were taken from three pits, each 3 ft. deep and dug to ground level, equally located over the dump.

The results in per cent were as follows:

Moisture	58.4
Dry solids	41.6
	On Dry Basis
Ash solids	64.2
Volatile solids	35.8
Humus	35.2
Calcium oxide as Ca_2CO_3	1.34
Potash as K_2CO_3	0.103
Phosphoric acid as P_2O_5	1.816
Total nitrogen	1.90
Ammonia nitrogen	2.31
Grease and fats (chloroform soluble)	8.77

Taking the most optimistic interpretation of these figures, this sample containing only 1.9 per cent N, 1.82 per cent P_2O_5, and 0.103 per cent K_2CO_3 does show fertilizing value. However, the major value as a fertilizer lies in its humus value of 35.21 per cent, which is not inconsiderable.

Filter Cloth Life

The wool filter cloths have given approximately 800 actual working hours apiece. When removed the cloths had not deteriorated excessively and were still serviceable except that (even with thorough and regular washing with a dilute solution of muriatic acid or trisodium phosphate) the ferric chloride use had increased beyond the economic limit. We are inclined to believe that 800 hr. is just about the economic life of the cloth under our conditions.

TABLE I.—Summary of 1943 and 1944 Operating Data at Hartford, Conn.

Item	1943 Average	1944 Average
Estimated population served	230,000	240,000
Sewage flow (m.g.d.)*	23.7	21.9
Per cent of operating time, year*	67.2	76.7
Number of employees	17	17
Screenings (cu. ft. per m.g.)	2.5	2.1
Grit (cu. ft. per m.g.)	1.96	1.73
Raw sludge removed:		
Total m.g.	11.3	12.3
Per cent moisture	93.1	93.8
Million lb. dry solids	6.7	6.6
Per cent volatile solids	67.9	72.6
Detention in tanks (hr.)	3.75	3.95
Ether soluble grease (per cent)	26.3	27.5
Digestion tank data:		
Average temperature (° F.)	93.7	93.7
pH	7.08	7.03
Hot water, in (° F.)	124.0	129.6
Hot water, out (° F.)	112.9	115.4
Million gal. sludge removed	3.3	4.6
Per cent moisture	90.9	93.1
Per cent volatile solids	40.3	48.0
Ether soluble grease (per cent)	9.8	11.0
Sludge gas data:		
Total million cu. ft., year	35.9	39.6
Million cu. ft. used, year	15.7	18.2
Cu. ft. per cap. per day of operation	0.88	0.77
Cu. ft. per day of operation	138,140	140,050
CO_2 content (per cent)	35	35.9
Net B.T.U. value	576	576
Elutriated sludge data:		
Million gal. from elutriation tanks, year	3.8	5.5
Per cent moisture	93.7	95.3
Million lb. dry solids, year	1.9	2.2
Per cent volatile solids	42.2	50.2

* Plant closed for portion of certain months. River elevation above operating level.

TABLE I.—Continued

Item	1943 Average	1944 Average
Filter operation data:		
Total days of operation	87	90
Total hr. of operation, yr.	912.95	997.82
Total lb. $FeCl_3$ used	42,317	39,878
Total lb. $Al_2(SO_4)_3$ used	1,196	7,746
Per cent $FeCl_3$ (dry basis)	2.25	2.04
Per cent $Al_2(SO_4)_3$ (dry basis)	2.67	3.70
Million lb. sludge cake, yr.	5.2	6.9
Per cent moist. in cake	63.3	67.0
Rate (lb. per sq. ft. per hr.)	5.8	6.11
Million lb. dry solids in cake	1.9	2.2
pH of filtrate:		
With $FeCl_3$	5.96	5.9
With $Al_2(SO_4)_3$	4.4	4.4
Cu. yds. of sludge cake, yr.	3,067.5	4,057.9
Cost data:		
Construction cost, total ($)	1,450,311.96	—
Const. cost per capita† ($)	4.83	—
Operating cost, total ($)	67,425.73	69,703.99
Per m.g. treated ($)	10.67	10.71
Per capita yearly ($)	0.31	0.38
Analytical data:		
Suspended solids (p.p.m.):		
Influent	120	132
Effluent	29	33
Per cent reduction	74.8	74.0
Raw sludge:		
Per cent moisture	93.1	94.0
Per cent volatile solids	67.9	72.6
Digested sludge:		
Per cent moisture	91.0	93.2
Per cent volatile solids	40.3	48.0
Elutriated sludge:		
Per cent moisture	93.7	95.2
Per cent volatile solids	42.2	50.2
Per cent reduction in volatile matter by digestion	65.7	63.5
Digestion and filtration alkalinities (p.p.m. as $CaCo_3$):		
Digestion tank No. 1	3,290	3,220
Digestion tank No. 2	3,280	3,240
Digestion tank No. 3	3,300	3,180
Digestion tank No. 4	3,300	3,290
Digested sludge	3,210	3,430
Elutriated sludge	195	223
Elutriate	496	594

† On basis of 300,000 design population.

General Comment on Plant Operation

The plant itself, as to type, cost of operation and results obtained, has proven entirely satisfactory. The elutriation process has attracted many visitors and the results obtained thereby have been economically gratifying. The State Department of Health has taken samples at various intervals during the year and their laboratory results have been satisfactory at all times. (*Abst. note:* Let this abstractor add from personal knowledge of this plant that maintenance, attention to operating details and cleanliness are also of a high order at Hartford.)

Table I is a summary of the plant operating data for 1943 and 1944.

Annual Report for the Year Ending March 31, 1945, of the Sewage Disposal Commission of New Britain, Conn.*

By John R. Szymanski, *Supt. and Chief Chemist*

Plant Description

This plant began operations in May, 1937, employing the Guggenheim biochemical process. The successive stages in the treatment of the sewage are bar screens having 1-in. clear openings; a dosing tank used as a grit settler; primary settling tanks; a chemical dosing tank at which point return sludge is added; mixing tanks (aeration units); and final settling tanks. For additional details on the treatment units see the previous extracts.

Iron Wastes

It would be impossible to report the great fluctuation in iron wastes arriving at the plant at the present time. The quantity varies from 10 p.p.m. to 350 p.p.m.

Recommendations of Superintendent

The grit removal problem is rapidly becoming serious, and some action should be taken to alleviate this problem.

Both chlorinators should be completely overhauled.

Civil Service or a similar system for plant employees should be considered.

A retirement program with pension rights should be considered.

The chemical dry feed machine should be replaced as soon as materials and equipment become available.

More air capacity for sewage treat-

* For previous extracts see This Journal, 10, 4, 770 (1938) and 17, 3, 617 (1945).

TABLE II.—Summary of 1944–45 Operating Data, New Britain, Conn.

Item	Average
Estimated population served (also design pop.)	80,000
Sewage flow (m.g.d.)	9.49
Sewage by-passed after primary treatment (m.g.)*	300
Sewage by-passed to sand filters (m.g.)*	8
Screenings (cu. ft. for year)	15,442
Grease (cu. ft. for year)	12,225
Screenings (cu. ft. per m.g.)	4.4
Grease (cu. ft. per m.g.)	3.5
Mixed sludge from primary tanks (gal.)	7,836,126
Per cent solids	7.5
Chemical and air dosage for sewage treatment:	
Copperas (lb. per month)	45,900
Chlorine (lb. per month)	7,487
Air (cu. ft. per gal.)	0.146
Return sludge wasted to primaries (m.g. per month)	2.37
Per cent solids	0.84
Sludge disposal data:	
Days of filter operation, year	219
Filter hours, year	5,338.7
Ferric chloride used, year (lb.)	157,357
Prestolime, year (lb.)	1,714,590
Filter cake, year (million lb.)	17.3
Dry solids, year (million lb.)	4.9
Incinerator, hr., year	4,404
Filter yield (lb. solids per sq. ft. per hr.)	4.56
Fuel oil used, year (gal.)	44,858
Ash removed, year (cu. ft.)	42,442
Analytical data:	
Suspended solids (p.p.m.):	
Raw	247
Primary effluent	183
Final effluent	38
Mixed liquor	1,040
5-Day B.O.D. (p.p.m.):	
Raw	180
Final effluent	47
Total iron (p.p.m.):	
Raw	33
Final effluent	7
Settleable solids (ml. per liter):	
Raw	7.7
Primary effluent	3.2
Final effluent	0.0
Per cent solids:	
Return sludge	0.84
Raw sludge	7.5
Filter cake	30.0
pH range in raw sewage	5.0 to 9.0
Cost data ($):	
Total operating cost	68,025.87
Supervision and labor	34,088.51
Chemicals	15,358.48
Light, power and gas	10,834.74
Fuel and supplies	4,908.37
Maintenance	2,500.00
Building maintenance	335.77
Cost per m.g. sewage treated	19.63

* Total for fiscal year.

ment would help in producing a more stable effluent; also more return sludge capacity.

Table II is a summary of the plant operating data for the year ending March 31, 1945.

Fourteenth Annual Report on the Aurora, Illinois, Sanitary District Sewage Treatment Plant for the Year 1944 *

By Walter A. Sperry, *Superintendent*

1944's Most Annoying Problem

The most annoying unexplained problem of 1944 was a luxuriant growth of weeds on the sludge beds. This difficulty began to appear in 1942 and is difficult to explain, unless it be due to a combination of increased bed area with longer periods for the sludge to lay before removal and a close proximity to a weeded area not under plant control but since purchased. Aside

* For previous extracts see This Journal, 8, 4, 659 (1936); 13, 6, 1242 (1941); 15, 5, 949 (1943); 17, 3, 626 (1945).

TABLE III.—Summary of 1944 Operating Data at Aurora, Ill.

Item	Average
Estimated connected population	51,000
Sewage flow (m.g.d.)	6.62
Screenings (cu. ft. per day)	7.2
Grit (cu. ft. per day)	23.7
Settling tank scum (cu. ft. per day)	2.5
Settling solids (ml. per liter):	
Raw sewage	6.6
Settling tank effluent	0.7
Filter effluent	0.4
Final effluent	0.1
pH:	
Raw sewage	7.6
Settled sewage	7.6
Filtered sewage	7.6
Final effluent	7.6
5-Day B.O.D. (p.p.m.):	
Raw sewage	116
Settled sewage	71
Filtered sewage	22
Final effluent	12
Suspended solids (p.p.m.):	
Raw sewage	188
Settled sewage	79
Filtered sewage	46
Final effluent	23
Fox River data:	
Flow (c.f.s.)	560
D.O. (p.p.m.)	10.1
Oxygen saturation (per cent)	88.0
D.O. in plant effluent (p.p.m.)	6.3
Primary sludge to first stage digestion:	
Average per cent solids	4.8
Volatile solids (per cent)	74.3
Lbs. dry solids pumped daily	7,340
Digestion tank temperatures (F °.):	
Tank No. 1	84
Tank No. 2	89
Tank No. 3	87
Sludge gas (cu. ft. per day)	52,530
Gas engines (cu. ft. used per day):	
Engine No. 1	17,160
Engine No. 2	16,040
Engine No. 3	11,770
Engine No. 4	11,580
Sludge gas:	
Cu. ft. per m.g.	7,935
Cu. ft. per capita	1.03
Cu. ft. per lb. volatile matter	8.7
Total lb. suspended solids in raw sewage	4,032,380
Total lb. screenings removed	22,280
Total lb. grit removed	260,640
Total lb. grease-scum removed	41,720
Total lb. finely divided solids removed by:	
Clarifiers	2,111,100
Filters	558,460
Secondary tanks	376,560
Total lb. removed	3,370,760
Total lb. solids discharged to Fox River	661,620
Total lb. B.O.D. of raw sewage	2,212,200
Lb. B.O.D. reduced by:	
Clarifiers	849,020
Filters	834,440
Secondary tanks	143,640
Total lb. B.O.D. reduced	1,827,100
Total lb. B.O.D. discharged to Fox River	385,100
Administrative—Operating cost, total dollars	34,123.89
Cost per m.g. sewage (dollars)	14.08
Cost per capita (cents)	66.9

from the annoyance it is a magnificent demonstration of the growth-promotional properties of sludge. What to do about it is another matter.

Use of Alum for Sludge Drying

Alum was applied to the beds during November discharge. Alum continues to be useful in hastening the dewatering of the sludge beds during the late fall and winter months. The usual good drying conditions of the summer make it doubtful whether the expense is justified.

Table III is a summary of the plant operating data for 1944.

Annual Report on the Operation of the Joint Meeting Sewage Treatment Plant in Elizabeth, New Jersey, for the Year Ending 1944 *

By Edward P. Decher, *Acting Chief Engineer*

Sludge Barging

Barging is no longer considered a troublesome problem as in the past. The installation of the 75 h.p. motor, the removal of the 20-in. restricted cone valve together with using air directly into the storage tanks to create turbulence have all together materially improved this phase of operation.

These changes have not only increased the efficiency in this phase of operation but have also greatly reduced the amount of dilution water used heretofore which had to be pumped and barged to sea. It is a direct saving in money and will continue as a saving as long as the plant is in operation.

Use of DDT for Fly Control

DDT has been used experimentally at the treatment plant. In previous years, during the months of July and August, the fly situation at the treatment plant was a very troublesome problem. In fact, when barging operations took place at night, great swarms of flies were attracted by the lights in the building and on many occasions, in order to open the screen door, it was necessary to first spray some insecticide on the screen doors before attempting to open the door,

* For a previous extract see This Journal, 15, 5, 945 (1943).

TABLE IV.—Summary of 1944 Operating Data—Elizabeth, N. J., Joint Meeting Plant

Item	Average	Item	Average
Estimated connected population	365,000	Settleable solids (ml. per liter, 2 hr.):	
Sewage flow (m.g.d.)	37.172	Influent	4.76
No. of sludge bargings, total	25	Effluent	0.17
Tons of sludge barged for year	87,475	Per cent removal	96.4
Per cent solids in sludge barged	8.2	Sludge storage tanks:	
Cost of barging, total for year (dollars)	33,314.15	Reduction in sludge volume (gal. per day)	43,056
Trash (cu. ft. per day)	15.5	Suspended solids (p.p.m.):	
Screenings:		Influent	200
Cu. ft. per day	174.5	Effluent	67
Cu. ft. per m.g.	4.7	B.O.D., 5-day (p.p.m.):	
Grit:		Influent	245
Cu. ft. per day	174	Effluent	146
Cu. ft. per m.g.	4.69	Plant costs:	
Detention in settling tanks (hr.)	2.27	Total cost (dollars)	112,768.08
Raw sludge removed from settling tanks:		Per m.g. (dollars)	8.31
Gal. per day	93,803	Per capita (cents)	30.8
Cu. ft. per m.g. sewage	337		

as it would be covered with flies from top to bottom. Through the courtesy of Dr. Rudolfs, a small quantity of DDT was obtained and since applying this material to the screens and screen doors of all the buildings for the past two months, the flies in the building can be counted on one hand and at no time will a fly be found on the screens or screen doors where this material has been applied. The elimination of flies from the interior of the buildings has greatly improved the sanitary and health conditions at the treament plant.

Table IV is a summary of plant operating data for the year 1944.

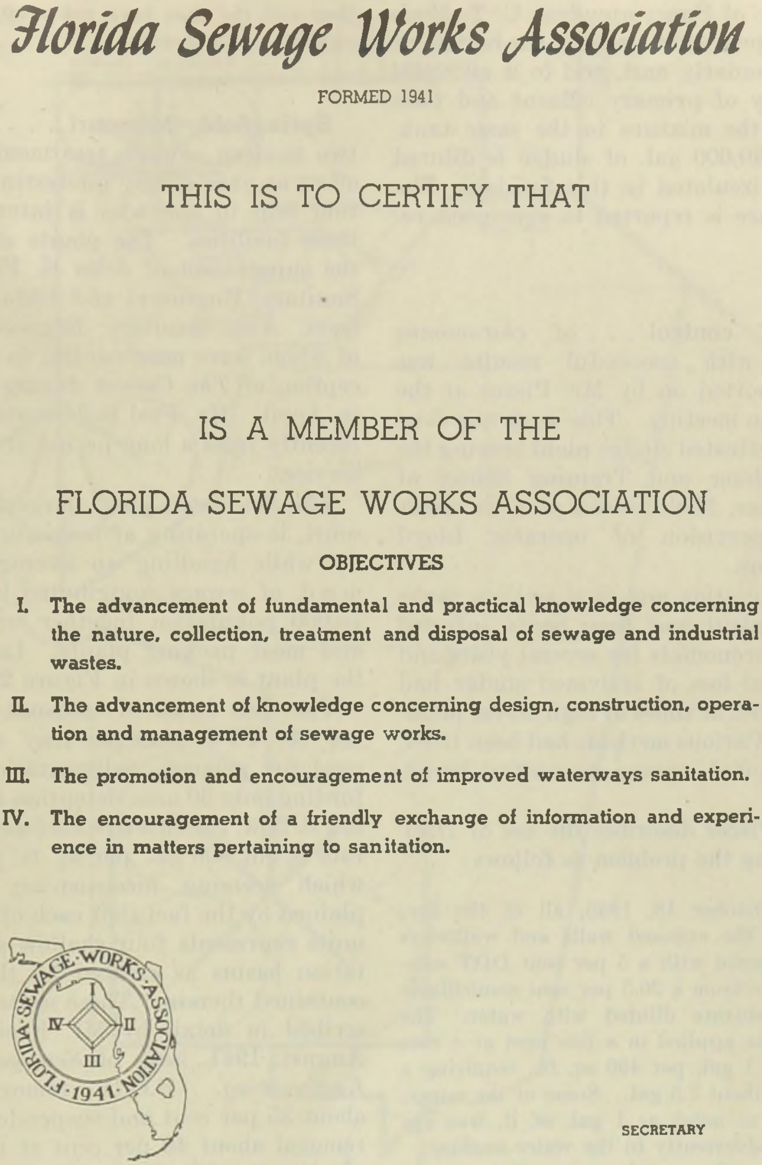
TIPS AND QUIPS

Tidbits from Tucson . . . where the 1946 Annual Meeting of the Arizona Sewage and Water Works Assn. was held on April 16–17 . . . with about 80 members and guests in attendance . . . all of whom were amply rewarded by the sulfide control summary given by Fred D. Bowlus of Los Angles . . . and the paper on the "autoxidation process" by Dario Travaini . . . and the lucid discussion of Reynolds Number by Harold Yost . . . and the chlorinator demonstration by R. T. Gardner . . . and the program contributions by R. F. Poston, Byrl D. Phelps, G. G. Robeck, Walter Johannesen and others . . . followed by the round table forum in which John A. Carollo reviewed the entire program and led a general commentary that was notable for the spontaneous participation by those present. . . . The hospitality of the Association in resolving to "second" the invitation of the California Sewage Works Assn., which has asked the Federation to hold its 20th Annual Meeting in Los Angeles in 1947. . . . The gratification of *The Corner* at being elected to the SSOSS (Select Society of Sludge Shovelers) . . . and its enjoyment of the initiation ceremony. . . . The efficient management and conduct of the meeting by Prof. E. S. Borgquist and George W. Marx, President and Secretary-Treasurer of the Association, respectively . . . and the expert toastmastering of A. W. "Dusty" Miller, who presided at the luncheon and banquet functions. . . . All of which congealed the conclusion that the warmth of the Arizona sun is only a reflection of the warmth of its people . . . and that this unit of the Federation, though not large in numbers, is greatly magnified by its inherent enthusiasm and by the degree of its fulfillment of its objectives!

The Florida . . . Sewage Works Association, though one of the younger units of the Federation, is losing no time in expanding services to its members.

News and Notes, a mimeographed newsletter edited in interesting style by Secretary J. R. Hoy, made its debut in November, 1945. The second issue, in March of this year, features items of association business, personal notes and initiates a series of semi-technical articles on sewage treatment that are intended to aid plant operators who have had limited training and experience. Member association publications of this nature fill a real need and we extend every wish for continuing success to *News and Notes*.

Another recent action by the association makes membership certificates available to members who desire them, at the nominal charge of 50 cents each. One of the blank certificates is pictured in Figure 1. The certificate is 8½ in. by 11 in. in size and, when framed, makes an attractive wall ornament for office or laboratory. Secretary Hoy assures us that future printings of the certificate will carry the words "Affiliated With the Federation of Sewage



Florida Sewage Works Association

FORMED 1941

THIS IS TO CERTIFY THAT

IS A MEMBER OF THE

FLORIDA SEWAGE WORKS ASSOCIATION

OBJECTIVES

I. The advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes.

II. The advancement of knowledge concerning design, construction, operation and management of sewage works.

III. The promotion and encouragement of improved waterways sanitation.

IV. The encouragement of a friendly exchange of information and experience in matters pertaining to sanitation.

SECRETARY

FIGURE 1.—Blank membership certificate used by the Florida Sewage Works Association.

Works Associations'' below the name of the association!

Improved Supernatant . . . from sludge digesters is obtained at Muskegon, Mich., by a novel operation quirk, according to Assistant Engineer Donald M. Pierce of the Michigan Department of Health, who reviewed wartime operation observations in the program of a recent meeting of the Michigan Sewage Works Association.

Because of inadequate capacity at the two-stage digesters at Muskegon, the supernatant produced in the second stage occasionally carries a very high solids content. At such times, it is the practice of Superintendent C. T. Mudgett to pump sludge from the bottom of the secondarly unit, add to it an equal quantity of primary effluent and then return the mixture to the same tank. About 30,000 gal. of sludge is diluted and recirculated in this fashion. The procedure is reported to give good results.

DDT control . . . of *chironomus* larvae—with successful results—was also reported on by Mr. Pierce at the Michigan meeting. This work was done at the activated sludge plant serving the State Home and Training School at Coldwater, Mich., which plant is under the supervision of operator Lloyd Tompkins.

The aeration and final settling tanks of the plant had been badly infested with choronomids for several years and a marked loss of activated sludge had been noted at times of high larval population. Various methods had been tried, with limited success, to control breeding.

Mr. Pierce describes the use of DDT in solving the problem as follows:

"On October 18, 1945, all of the surfaces of the exposed walls and walkways were sprayed with a 5 per cent DDT solution made from a 26.5 per cent emulsifiable oil concentrate diluted with water. The spray was applied in a fine mist at a rate of about 1 gal. per 400 sq. ft., requiring a total of about 7.5 gal. Some of the spray, perhaps as much as 1 gal. of it, was applied inadvertently to the water surface.

"Before the spray was applied, a very few widely scattered larvae could be detected in the aeration tanks. Three hours later, the surfaces of the tanks were covered with the larvae. At that time they appeared to be partially paralyzed and within a few more hours there was almost a complete kill. The adult fly was completely eliminated.

"There was no noticeable deterioration of the activated sludge or plant effluent as a result of this operation. No further control measures have been employed since then and the flies have not reappeared in significant numbers."

Springfield, Missouri . . . with its two modern sewage treatment plants, offers an exceedingly interesting inspection trip to one who is interested in these facilities. The plants are under the supervision of John K. Frei, City Sanitary Engineer, and Okla C. Collison, Asst. Sanitary Engineer, both of whom were most cordial in their reception of *The Corner* during its visit in April. Mr. Frei had returned only recently from a long period of military service.

The Southwest plant, largest in Missouri, is operating at maximum capacity while handling an average of 11 m.g.d. of sewage contributed by about 75,000 population together with milk and meat packing plants. Layout of the plant is shown in Figure 2.

The first items of unusual interest are the PFT multiple tray clarifiers used for primary sedimentation. Affording only 30 min. detention at the 11 m.g.d. flow, the effective surface settling rate is but 800 gal. per sq. ft. per day, which seeming inconsistency is explained by the fact that each of the two units represents four shallow sedimentation basins as created by the trays contained therein. These units are described in detail by Mr. Frei in the August, 1941, issue of *Sewage Works Engineering.* B.O.D. removal was about 35 per cent and suspended solids removal about 40 per cent at the time of visit, but Mr. Frei pointed out that the outlets of the trays were in need of adjustment and that these removals were not entirely representative. The sludge produced at the units is of normal consistency as compared to that produced by other types of primary tanks.

After primary sedimentation, the sewage is applied to 3 ft. deep roughing filters before treatment on secondary trickling filters of 6-ft. depth. The

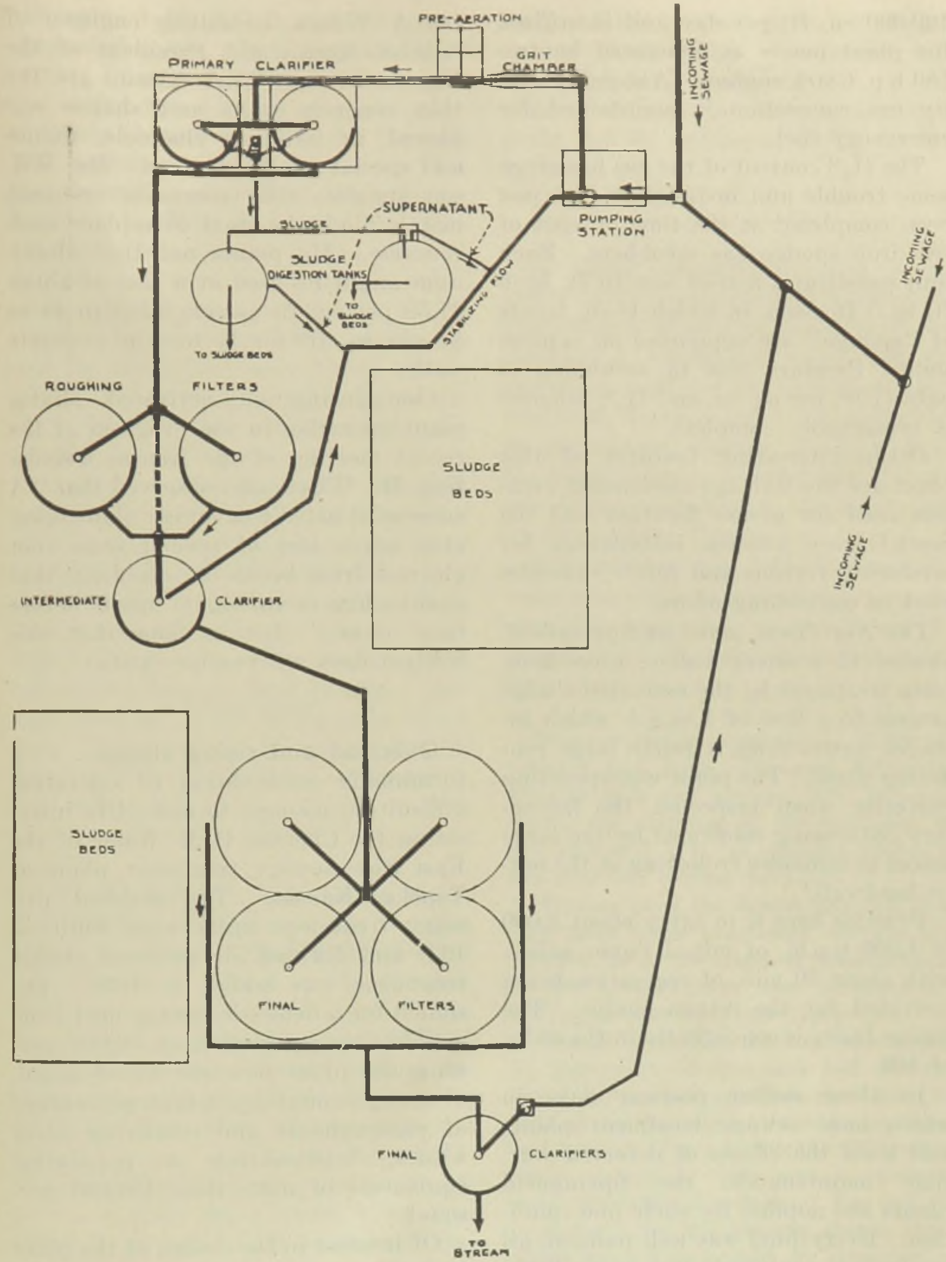


FIGURE 2.—Flow diagram of the sewage treatment plant at Springfield, Mo.

applied sewage B.O.D. was about 140 p.p.m., amounting to a roughing filter loading of about 8,000 lb. per acre-ft. per day. Intermediate sedimentation after the primary filters gave an effluent of 83 p.p.m. B.O.D., representing a removal of 41 per cent. Sludge from the intermediate and final clarifiers is returned to the raw sewage, the volume amounting to about 6 to 10 per cent of the total flow.

Gas production in the plant is about

100,000 cu. ft. per day and is utilized for plant power as generated by two 180-h.p. Clark engines. A standby utility gas connection is maintained for emergency fuel.

The H_2S content of the gas has given some trouble and installation had just been completed at the time of visit of two iron sponge gas scrubbers. Each unit constitutes a steel box 10 ft. by 6 ft. by 5 ft. deep, in which 18-in. layers of "sponge" are supported on cypress slats. Pressure loss in scrubbing is only ¼ lb. per sq. in. and H_2S removal is remarkably complete.

Other interesting features of this plant are the Chicago mechanical aerators used for grease flotation and the Scott-Darcey process installation for producing ferrous and ferric chlorides used in controlling odors.

The Northwest plant at Springfield, located in a scenic valley, gives complete treatment by the activated sludge process to a flow of 1 m.g.d. which includes wastes from a fairly large rendering plant. The plant was operating perfectly when inspected, the laboratory data being confirmed by the large school of minnows frolicking at the outlet headwall.

Practice here is to carry about 3,000 to 4,000 p.p.m. of mixed liquor solids, with about 30 min. of reaeration being provided for the return sludge. The sludge index is consistently in the order of 100.

In these earlier postwar days in which most sewage treatment plants still show the effects of deferred wartime maintenance, the Springfield plants are notable for their fine condition. Everything was well painted, all mechanical equipment was in top-flight state and the grounds at both plants were enhanced by well-kept landscaping. The facilities reflect great credit to the city and to the operation staff.

High cost items . . . in sewage works construction, according to Murray A. Wilson, consulting engineer of Salinas, Kans., and President of the Kansas Sewage Works Assn., are the thin concrete walls and shapes employed in building channels, flumes and special small chambers. Mr. Wilson suggests that corrosion resistant metals might be used to replace such concrete. He points out that aluminum might be used at a cost of about \$1.50 per sq. ft. as compared to \$3 to \$4 per sq. ft. for 3- to 4-in. concrete walls.

Commenting on activated sludge plant operation in the program of the recent meeting of the Kansas association, Mr. Wilson also observed that "A successful activated sludge plant operator has a sort of special sense, not gleaned from books or schooling, that enables him to anticipate upsets before they occur." Let us hope that this instinct does not become extinct!

Overload and rising sludge . . . a formidable combination of operation difficulties, manage to make life interesting for Chemist P. E. Kaler of the East Side sewage treatment plant at Topeka, Kansas. The original primary treatment units were built in 1928 and diffused air activated sludge treatment was added in 1936. Designed for a domestic sewage load from a tributary population of 50,000 persons, the plant now receives 8 m.g.d. of sewage containing a high percentage of packinghouse and rendering plant wastes, representing a population equivalent of more than 150,000 persons!

Of interest in the design of the plant is the Dortmund type settling unit provided for storm water treatment. Difficulty with operation has been experienced because of the heavy grease content of the sewage, which accumulates to such an extent that flow from the center inlet chamber is obstructed.

The January, 1946, operation report shows that the raw sewage contained

449 p.p.m. 5-day B.O.D. and 508 p.p.m. suspended solids. It is impossible, of course, to give complete treatment to the entire flow of this strong sewage and only about 3 m.g.d. is put through the activated sludge process. This flow is sufficient to load the existing facilities to their capacity. The effluent from the activated sludge plant in January averaged 34 p.p.m. suspended solids and 28 p.p.m. of B.O.D., which results are somewhat better than normal for this plant since rising sludge at the final tank occurred only on one day. In February rising sludge gave trouble on eight days.

Some months ago, the Mallory method of operation control was initiated to the extent that the laboratory control tests were adopted and partially applied to the various operating curves furnished for the plant. Complete adherence to the recommended procedures has not been possible, however, because of the inadequacy of return sludge pump capacity. At the time of visit the Mallory method was not being followed although several of the control tests were being made as routine.

Chemist Kaler is hard put to maintain aerobic conditions at the aeration tanks, in spite of the application of air at rates of 2 to 3 cu. ft. per gal. In January, with an average of 2.1 cu. ft. per gal. applied, there were 11 days on which the mixed liquor leaving the aerators contained no more than a trace of D.O. The final effluent averaged only 1.5 p.p.m. of D.O. for the month.

No purchased electric power is used at the Topeka plant, there being two 180-h.p. engines fueled by digester gas in use for power generation. Digester gas production averages 85,000 c.f.d. and only occasionally is it necessary to purchase city gas to supplement the volume produced at the digesters.

Realizing the total inadequacy of the present facilities, Topeka city officials were about (in March) to engage consultants to undertake a comprehensive study of the entire system of sewage works. Such action is certainly well advised since it is obvious that an economical solution to the problem here could not be developed by any other approach.

A minor explosion . . . at a digester in the sewage treatment plant at Middletown, Conn., in June, 1945, has instilled a wholesome respect in the operation staff for the explosive properties of digester gas. No casualties or permanent damage resulted from the blast, the only result being that the gas domes were blown completely out of their seals (Figure 3).

The digester had been drained for repairs and was being refilled when the explosion occurred. Supt. Henry W. Bauer gives the circumstances as follows:

"The explosion occurred at 6:30 one morning last June. We were filling the digester with raw sewage. The day preceding the morning of the explosion we had siphoned 4 ft. of digested sludge to this tank for seeding purposes.

"Having filled the digesters in this same way three times previously, we are still confused as to the origin of the explosion. Several theories have been advanced but nothing definite has turned up as yet.

"We do know that the man who started the pumps to fill this tank had removed one of the manhole covers to check how the pumps were working, these covers being laid loosely in place during the filling operation. Suddenly there was a rumbling noise followed by a flash of fire and the explosion. We had thought that a spark might have been caused by dragging of the manhole cover or by a nail in the man's shoe, or that he might have lighted a cigarette."

As a result of this experience, practice at Middletown in refilling digesters has been modified. In the future the tank will be completely filled with raw sewage before any sludge is added.

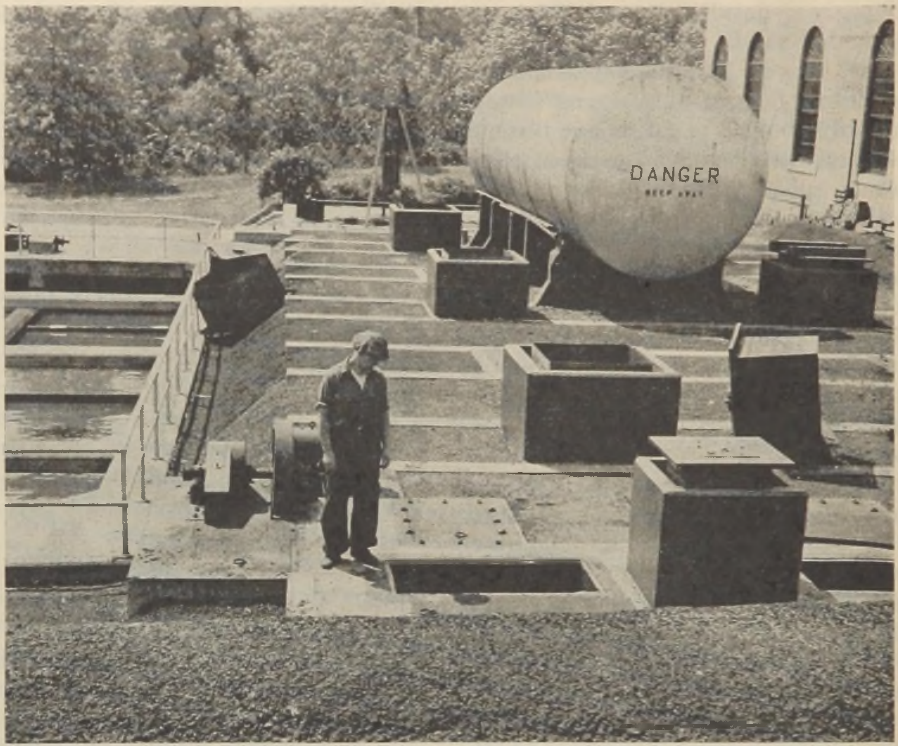


FIGURE 3.—Effects of minor explosion at digester of Middletown, Conn. Note gas domes.

Imhoff tank gas . . . is just as dangerous as that produced at separate digesters! And now the Clinton, Ill., sewage treatment plant is added to the lengthening list of explosion victims.

Gas is collected at the Imhoff tank gas vents of this plant and used only as fuel for building heat, the excess going to a waste burner. Early in the morning of April 29, a spark of unknown origin ignited a gas accumulation in the basement of the building, causing an explosion and fire that wrought damage to the extent of $500.

The only casualty in the accident was a shepherd dog named "Queenie," who had made her home at the plant since it was placed in operation in 1935. C. E. Corrington is superintendent of the Clinton plant.

Editorials

A VIEW OR TWO ON DOMESTIC GARBAGE GRINDERS

In his paper "Effect of Food Wastes on Sewers and Sewage Treatment" published in the May issue of This Journal, Morris M. Cohn likens the present attitude of the sewage works field toward home garbage grinders to the resistance which met the contributions of such pioneers as Fulton, Edison, Marconi and others, including the unknown progenitor of the bathtub. Mr. Cohn's exaggeration of the situation is probably intended to give emphasis to his suggestion that this new development warrants careful consideration rather than forthright rejection.

The writer admits that there is little inclination on the part of sewage works designers and operators to welcome any possible complication of their responsibilities that may come with widespread disposal of shredded food wastes to public sewers. There is certainly not, however, a concerted movement to discourage or to regulate against the practice.

The question "To what extent might we expect domestic grinders to come into usage?" will probably be answered finally by the housewife, economic considerations notwithstanding. Call the device a luxury if you will, but remember that the housewife will think mainly in terms of the elimination of the unpleasant task of handling and wrapping the garbage; of carrying it outdoors in all weather to the garbage receptacle with its complement of odors, flies, ants, and foraging canines; and of the unwelcome semiweekly visit of the garbage collector. The mechanical refrigerator was something of a luxury too, in its early years, but it soon became a "necessity."

Gas heating of homes is another development which is probably unsound economically but which has found wide popularity in modest homes because of its convenience. The writer has been informed that gas heating has found acceptance in homes representing annual incomes of $2,400 and above.

A casual survey of the adjoining cities of Champaign and Urbana, Ill. (population approximately 50,000) reveals that there are at least 37 home grinders in operation today. At this writing, local dealers hold orders for 24 more units, about half of which will go into new homes. These orders were received without sales effort since the postwar models have not yet become available for installation.

It seems reasonable to assume that domestic garbage grinders will be installed in many homes, to a "saturation level" that will be determined by the demand of the housewife and the ultimate cost of the device. Just where the eventual saturation level might be is beyond conjecture but the writer deems it entirely possible that as much as one-fifth of the food wastes of an average residential community might be added in a shredded state to the sewage flow in the next decade.

The public health engineer is concerned with the effects of this trend on general community sanitation, so his views are worthy of analysis. Every garbage can that is replaced by a domestic grinder means that a fly breeding place has been eliminated. Provision for prompt and complete disposal of food wastes at kitchens of public eating places will certainly improve conditions that are none too good in the best of them—as any sanitary inspector who has been behind the scenes can testify. The reduction of the amount of garbage that must be disposed of at dumps, fills and hog farms is a desirable result.

These advantages, however, would be nullified if the addition of shredded food wastes to sewers resulted in interference with the proper operation of sewage collection and treatment facilities. And that is where the viewpoint of the sewage works specialist becomes pertinent.

Where sewage is discharged without treatment the addition of shredded food wastes will certainly increase stream pollution. In most of these places, however, the need for treatment already exists, regardless of the added component, for in nearly every case there should be provision at least for the removal of settleable solids before disposal by dilution. But until treatment is provided some streams will receive an increasing load.

Effect on sewers? Nearly every sewage treatment plant now receives some garbage in an unground state. When properly shredded to a pulp and flushed through a 2½-in. pipe it is difficult to see how sewer clogging could result. In fact, the added "roughage" might have some beneficial effect in scouring away accumulations of grease and of the slimes responsible for sulfide production (see paper by Pomeroy and Bowlus elsewhere in this issue).

If and as household grinder installations increase, there will be a gradual change in the character of domestic sewage. The effects of the change, as manifested in sewage treatment plants, will probably be insignificant in year-to-year comparisons, but might not the aggregate change, say in ten years, be sufficient to warrant attention in plants being designed today?

G. J. Schroepfer, in a special report to the Board of Trustees of the Minneapolis-St. Paul Sanitary District, suggests that about one-third of the homes in the Twin Cities might be served by household garbage grinders in the ten-year period following the end of the war. It is estimated in the report that the *total* production of garbage in the cities, if ground and discharged to the sewers would "increase the material contained in the sewage an average of 18 per cent during the year and a maximum of 25 per cent during the critical months of August and September." Schroepfer goes on to estimate that an expenditure for sewage treatment of about 55 cents per year will be involved for each household grinder installation.

On the basis of one-fifth of the total garbage production discharged to the sewers, the organic load at the treatment works would be increased about 4 to 5 per cent—admittedly not large but sufficient to preclude its being ignored. More important, perhaps, than the added organic load, are the characteristics of the material. The garbage solids added would be greater in proportion than the added volume of water and some readjustment of dilution ratios at storm water overflows may be necessary to prevent offensive conditions. Increased quantities of coffee grounds, crushed eggshells and bone splinters may place additional emphasis on grit removal devices and may involve revised limitations pertaining to design of sludge piping and floors of sludge storage and digestion tanks. Increased grease and floating solids may demand greater attention to skimming facilities, scum disposal and at sludge digestion units. Provision of liberal digestion capacity will be important. Sludge conditioning and dewatering requirements may require some revision.

If there is inclination to minimize these effects, let it be noted that numerous plants now receiving normal sewages experience difficulties of varying degree at these same points!

The writer holds the opinions that (1) household garbage grinders will come into fairly general use in homes representing moderate to high incomes, (2) the reception of the device will be sufficiently rapid in the next decade to justify some attention in sewage works that are now in design and (3) it will behoove most municipal sewage works authorities to analyze the potentialities of the development in their communities, as has been done at Minneapolis-St. Paul. This is just a suggestion to recognize the trend and to plan for it in sane and logical fashion. There is certainly no occasion for alarm or for untoward restraint on the installation of household grinders.

W. H. W.

FEDERAL ANTI-POLLUTION LEGISLATION PROGRESSES

The Mansfield bill (HR 6024) emerged from the House Rivers and Harbors Committee late in April to engage the spotlight on federal pollution control legislation. This measure, a compromise between the original Barkeley-Spence and Mundt bills, has been reported by the Committee and awaits floor action at this writing.

The new bill incorporates rather rigid inforcement features, similar to those contained in the Mundt bill; it requires the Surgeon General to classify navigable waters into "sanitary water districts" and to prescribe standards of purity; it creates a Water Pollution Advisory Board in the USPHS, to consist of the Surgeon General with representatives of the Departments of War, Interior, Commerce and Agriculture and provides for cooperative administration by the USPHS with state and interstate agencies. Appropriations are made for $100,000,000 annually for loans and grants to public bodies for sewage works construction; $1,500,000 annually to be allocated to state and interstate agencies for surveys and special investigations and $1,500,000 annually for administration of the act. Loans to industries for the construction of waste treatment works are also authorized.

The compromise bill is finding a highly variable reception, although many of the proponents of the Barkeley-Spence and Mundt bills appear to be willing to accept the concessions that are proposed and to support the measure in its present form. It is reported that the legislation has found approval in New York and Michigan but that the New England states, with the exception of Vermont, are rather strongly opposed.

According to the *Washington Legislative Bulletin*, the Mansfield bill is expected to pass the House by midyear but Senate action in this session is less likely.

W. H. W.

Proceedings of Member Associations

ARIZONA SEWAGE AND WATER WORKS ASSOCIATION

1946 Annual Meeting

Tucson, Arizona, April 16–17, 1946

The 1946 Annual Meeting of the Arizona Sewage and Water Works Association was held at the Santa Rita Hotel, Tucson, Arizona, on April 16–17, 1946. About eighty members and guests registered.

With President E. S. Borgquist presiding, the meeting was opened with an address of welcome by Mayor Henry O. Jastaad of the city of Tucson. The following technical program was presented in the course of the two-day conference:

"Backflow Prevention," by H. B. Pearce, Sales Manager, Clayton Mfgr. Co., Alhambra, Calif.

"International Sewage Treatment Plant at Douglas, Arizona," by R. F. Poston, Sanitary Engineer, Pan-American Sanitary Bureau, El Paso, Texas.

"Water Treatment Experiences in Williams, Arizona," by I. F. Brown, Water Superintendent, Williams, Ariz.

"The Design of Some Small Sewage Treatment Plants," by Byrl D. Phelps, Sanitary Engineer, San Diego, Calif.

"Sulfide Control," by Fred D. Bowlus, Office Engineer, Los Angeles County Sanitary Districts, Los Angeles, Calif.

"The Yuma Domestic Water Supply," by C. G. Ekstrom, Arizona Edison Co., Yuma, Ariz.

"Sewage Works Safety Practices," by W. H. Wisely, Executive Secretary, Federation of Sewage Works Associations, Champaign, Ill.

"The Control and Handling of Chlorine," by R. T. Gardner, Division Manager, Wallace and Tiernan, Corp., Los Angeles, Calif.

"Various Applications of the Autoxidation Process," by Dario Travaini, Superintendent of Sewage Treatment, Phoenix, Ariz.

"Surplus Property Utilization," by Gordon G. Robeck, Sanitary Engineer, War Assets Administration, San Francisco, Calif.

"Tucson Medical Center Sewage Treatment Plant," by Walter Johannessen, Johannessen and Girand, Engineers, Phoenix, Ariz.

"Reynolds Numbers," by Harold Yost, Yost and Gardner, Engineers, Phoenix, Ariz.

Features of the technical program were the round table discussions which concluded each of the daily sessions and which were led by John A. Carollo. Discussion from the floor was encouraged by the summary of the day's program presented by Mr. Carollo.

Dinner and entertainment programs were held on both evenings, with A. W. Miller presiding as toastmaster. At the dinner on April 16, an address was given by Edward L. Breazeale, Senior Bacteriologist of the Arizona State Laboratories, on the topic "Sanitation Problems in the Army." W. H. Wisely, Executive Secretary of the F.S.W.A., spoke on "Present Activities of the Federation of Sewage Works Associations" at the dinner on April 17.

Several important actions were taken at the business meeting. In order to comply with requirements of the Federation, a Sewage Works Section was created and a constitution and by-laws formally adopted. This move does not involve any change in the administration of the Association and the officers of the Association will serve in ex-officio capacity to handle the affairs of the new Sewage Works Section. By resolution, the Association acted to supplement the invitation of the California Sewage Works Association for the Federation to hold its Twentieth Annual Meeting in Los Angeles or San Francisco in 1947. The Secretary was directed to transmit this resolution to the headquarters of the Federation.

Recognizing the importance of careful control in regard to the use of sewage effluents for irrigation in Arizona, the Association moved to urge the USPHS to establish standards of quality to be applied to sewage effluents where such effluents are utilized for irrigation purposes.

The following officers were elected to serve for the year 1946–47:

President: R. M. Cushing, Temp.
First Vice-President: H. M. Yost, Phoenix.
Second Vice-President: John Rauscher, Tucson.
Secretary-Treasurer: George W. Marx, Phoenix.

A. L. Frick of Los Angeles was designated to represent the Association as Director on the Federation Board of Control for a three-year term beginning in October, 1946.

George W. Marx,
Secretary-Treasurer

ARKANSAS GROUP MOVES TO JOIN FEDERATION

With the aim of becoming the 29th Member Association of the Federation, the Arkansas Water and Sewage conference acted during its 15th Annual Meeting at Fayetteville on April 15–17, 1946, to create within itself a Sewage Works Section designed to meet all Federation requirements.

Organization of the new section was completed on April 17 by the adoption of a constitution and by-laws and by the election of F. L. McDonald, Chief Sanitary Engineer of the Arkansas State Board of Health, to represent the section as Director on the Federation Board of Control. The constitution of the section provides that its officers, except for the Director, are to be the same as those elected annually by the Arkansas Water and Sewage Conference.

The new section does not actually become a unit of the Federation until the constitution is cleared and approved by the Organization Committee and Board of Control, and these final steps will be taken at the annual meeting of the Federation in October. In the meantime the charter members of the section have been extended full membership privileges in the Federation.

Officers of the state conference, who are ex-officio officers of the Sewage Works Section, are W. R. Spencer, Fayetteville, *Chairman;* J. R. Pierce, Pine Bluff, *Vice-Chairman;* and Dr. Harrison Hale, Fayetteville, *Secretary-Treasurer.* These officers, with retiring Chairman Edgar T. Brown and Director McDonald, constitute the Executive Committee of the section.

The Arkansas Water and Sewage Works Conference is an active and progressive organization, well-known for the high caliber of its annual meetings and short courses as sponsored with the University of Arkansas. By becoming a part of the international Federation, the conference evidences its continuing desire to be of maximum service to its members. The Federation extends a cordial welcome to its latest affiliate.

MICHIGAN SEWAGE WORKS ASSOCIATION

21st Annual Conference

East Lansing, Michigan, March 18–20, 1946

The Michigan Sewage Works Association held its 21st annual conference on March 18–20, 1946, at Michigan State College, East Lansing. The conference adjourned at noon, March 20, and was followed by the short course school for operators. Registration of 93 members and guests at the conference was somewhat lower than in prewar years apparently due to reduced personnel in many of the smaller municipalities.

The first session was called to order by President Paul Stegeman on March 18, followed by an address of welcome by K. H. McDonel, Secretary of the Michigan State Board of Agriculture. The balance of this session was devoted to a discussion by D. M. Pierce, Sanitary Engineer of the Michigan Department of Health, on developments in sewage and waste treatment during the past two years. This was followed by a colored motion picture on industrial waste treatment facilities at the Dow Chemical Company, Midland, Michigan, presented and discussed by T. J. Powers.

The Tuesday morning session included papers on "Maintenance Problems in a Large Sewage Treatment Plant" by Virgil Anderson, Engineer of sewage treatment, Detroit, and "Some Accomplishments in Treatment and Control of Industrial Wastes" by L. F. Oeming, Sanitary Engineer, Michigan Stream Control Commission. The entire afternoon session was devoted to discussion of safety practices, with particular emphasis on hazards arising from sludge gases. "Safe Practices in Sewage Plant Operation" was presented by William G. Fredrick, Industrial Hygienist and Chief Chemist, Bureau of Industrial Hygiene of the Detroit Department of Health. Arthur Jennings, City Director of Monroe, gave a detailed account of the explosion at the Monroe treatment plant and corrective measures employed in rehabilitation of the plant. Gerald Forton, Superintendent of the Traverse City treatment plant, described and analyzed the explosion which occurred several years ago at that plant. C. A. Habermehl, Supervising Sanitary Chemist of the Detroit sewage treatment plant, gave a "Demonstration of the Use of Saftey and Protective Equipment" with discussions on current safety practices at the Detroit plant.

The following papers were presented at the Wednesday morning session: "Operation of Sludge Digestion Tanks" by Thomas J. Doyle, Superintendent of the Pontiac sewage treatment plant; "Operation of Sedimentation Tanks" by Stanley Bower, Superintendent of the Ypsilanti sewage treatment plant; "Some Fundamental Conceptions and Significance of Terms Used for Sewage Plant Loadings and Efficiency Measurements" by G. M. Ridenour, Resident Lecturer in Public Health Engineering, School of Public Health, University of Michigan, with a discussion by C. P. Witcher, Superintendent of the Ann Arbor sewage treatment plant; and "Design and Operation of Sewage Regulators" by Kenneth Fishbeck, Sanitary Engineer, Department of Public Service, Lansing, with a discussion by A. T. Kunze, Sanitary Engineer, Wayne County Road Commission, Detroit.

A number of very interesting pictorial slides were shown at the annual smoker on Monday evening by D. W. Granger and F. B. Frost, who recently returned to the Michigan Stream Control Commission after four years in the Army. Granger's pictures were taken in the Aleutian area and Frost's in the Puerto Rico and other Caribbean areas. Following this, the colored film, "Clean Waters," recently produced by the General Electric Company, was shown.

The annual banquet of the association was held Tuesday evening at the Porter Hotel in Lansing. W. L. Mallmann, Professor of Bacteriology at Michigan State College, gave a most interesting and informative talk on the practical application of bacteriological research to sewage treatment, water supply and other aspects of environmental sanitation.

Following the smoker and banquet on Monday and Tuesday nights, the Water and Sewage Works Manufacturers' Association held open house at the Hotel Olds.

At the Tuesday business meeting of the association, Thomas J. Doyle, Superintendent of the Pontiac sewage treatment plant, was nominated and unanimously chosen by the members as recipient of the Kenneth Allen Award, in recognition of some twenty-five years of sewage treatment plant operation and his continuous interest and untiring effort in promoting good operational practices.

The following officers were elected to serve for the ensuing year:

President—R. A. Greene, Jackson.

Vice-President—Stanley Bower, Ypsilanti.

Secretary-Treasurer—R. J. Smith, Lansing.

Federation Director—W. F. Shephard, Lansing.

Directors—C. T. Mudgett, Muskegon; Paul Stegeman, Midland; T. J. Powers, Midland.

The short course school, as usual, consisted of instruction in laboratory methods, both chemical and bacteriological, and actual performance of standard and special analyses conducted in the plants. Instruction and supervision of this work was offered by C. T. Mudgett, Superintendent of the Muskegon sewage treatment plant, and W. W. Dubay, Chemist at the Pontiac sewage treatment plant. Lectures on bacteriology were given by Dr. W. L. Mallmann, Michigan State College; on chemistry by Professor Frank Theroux, Michigan State College; on sludge digestion by C. P. Witcher, Superintendent of the Ann Arbor sewage treatment plant; and on activated sludge by R. A. Greene, Chemist and Operator, Jackson sewage treatment plant. A field inspection of the Lansing sewage treatment plant was conducted by Professor Frank Theroux. The two and one-half day sessions were concluded Friday afternoon.

R. J. Smith,
Secretary-Treasurer

MONTANA SEWAGE WORKS ASSOCIATION

Second Annual Meeting

Butte, Montana, April 11–12, 1946

The second annual meeting of the Montana Sewage Works Association was held in the Finlen Hotel at Butte, Montana, on April 11–12, 1946. Chairman W. M. Cobleigh presided. A total of 55 members and guests were registered.

The program the first day was devoted entirely to papers and discussions pertaining to sewage works engineering and operation. After an address of welcome by Mr. Barry O'Leary, Mayor of Butte, the following papers were presented:

"The Fundamentals of Sewage Treatment" by Chairman Cobleigh, Dean Emeritus of the School of Engineering of Montana State College at Bozeman.

"The Planning and Financing of Sewage Works" by George J. Schroepfer, Professor of Sanitary Engineering of the University of Minnesota at Minneapolis.

"The Present Status of Sewage Treatment in Montana" by H. B. Foote, Director of the Division of Sanitary Engineering, State Board of Health, Helena.

An evening session was held for further discussions and for the business meeting. A report was presented by the Secretary-Treasurer and committees were appointed to serve during the year.

Officers elected by the association for 1946–47 were:

Chairman: Kenneth Chrysler, Billings.

Vice-Chairman: K. J. Winebrenner, Kalispell.

Secretary-Treasurer: H. B. Foote, Helena.

FSWA Director: J. M. Schmit, Lewistown.

Trustees: F. F. Palmer, Forsyth; F. E. Brandis, Chinook.

The Friday session was held jointly with the Montana Section of the American Water Works Association. Papers were presented on subjects of interest to both sewage and water plant engineers and operators.

H. B. Foote,
Secretary-Treasurer

MEMBER ASSOCIATION MEETINGS

Pennsylvania Sewage Works Assn.	Nittany Lion Inn, State College, Pa.	August 28–30
Rocky Mountain Sewage Works Assn.	Santa Fe, New Mexico	September 11
Georgia Water and Sewage School	Ga. School of Technology, Atlanta, Georgia	September 16–18
South Dakota Water and Sewage Works Conference	Deadwood, South Dakota	September 20–21
North Dakota Water and Sewage Works Conference	Mandan, North Dakota	September
Iowa Sewage Works Assn.	Iowa State College, Ames, Iowa	September
Federation of Sewage Works Associations	**Royal York Hotel, Toronto, Canada**	**October 7–9**
Canadian Institute on Sewage and Sanitation	Royal York Hotel, Toronto, Canada	October 7–9
North Carolina Sewage Works Assn.	Hotel Sir Walter Raleigh, Raleigh, North Carolina	November 11–13

Federation Affairs

NINETEENTH ANNUAL MEETING TAKES SHAPE

Technical and social programs of extraordinary interest are in store for those attending the Nineteenth Annual Meeting of the Federation of Sewage Works Associations, to be held at the Royal York Hotel, Toronto, Canada, on October 7–9, 1946. Host to the Federation will be the Canadian Institute on Sewage and Sanitation, the fourth largest Member Association.

Preparations for the first postwar conference of the Federation are rapidly taking shape under the guidance of the Committee on General Arrangements headed by A. E. Berry and including the following subcommittee chairmen: G. A. H. Burns (Registration), J. B. Kinney (Finance), Nicol MacNicol (Hotel Arrangements), George Morgan (Entertainment), H. S. Nicklin (Local Host), Mrs. J. B. Kinney (Ladies Entertainment) and C. H. Taylor (Club Room).

Applications for hotel accommodations should be sent to Dr. A. E. Berry, Sanitary Engineering Division, Ontario Department of Health, Toronto 8, Ontario, Canada. Requests sent to the Hotel Royal York and referring to the Federation meeting will be turned over to Dr. Berry and his Committee on General Arrangements. Room-sharing arrangements utilizing double rooms to the greatest possible extent will be desirable so as to conserve accommodation for the anticipated heavy registration. Rates at the Royal York are $3.75 and $7.50 for single and double rooms, respectively.

The technical program is being developed by the Publications Committee of the Federation, of which F. W. Gilcreas is chairman. A diversified series of papers on timely subjects is in assembly and the complete program will be announced in July.

The Annual Federation Luncheon will be held on Monday, October 7 with Dr. J. T. Phair, Deputy Minister of Health of Ontario, as the speaker. A luncheon and business meeting of the Canadian Institute on Sewage and Sanitation has been planned on Tuesday, October 8.

Preliminary plans for entertainment events include a dinner and entertainment on Monday evening, October 7, with the Annual Dinner-Dance scheduled for Tuesday evening, October 8. A new social feature will be the Club Room to be sponsored jointly by the Canadian Sanitation Equipment Manufacturers Assn. and the Water and Sewage Works Manufacturers Assn. The Club Room will be open before the luncheon events and before and after the evening events.

Ladies entertainment functions will be arranged by a subcommittee under the leadership of Mrs. J. B. Kinney. Meetings of the Canadian Institute are notable for the splendid provisions for the ladies in attendance, and with the many facilities available in Toronto the ladies are certain to have an interesting and enjoyable time.

While no formal inspection trip will be arranged, provision will be made for the transportation of those wishing to visit the 10-m.g.d. activated sludge plant at North Toronto and the new Main Toronto primary treatment plant which is under construction. This will be the first opportunity for plant visitation at a Federation meeting since the 1943 wartime conference at Cleveland.

Final details of the program and a timetable of events will be forthcoming soon.

L. H. Enslow, *Chairman,*
Committee on Publicity and Attendance

Reviews and Abstracts

Edited by

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PROCEEDINGS OF THE FIRST INDUSTRIAL WASTE UTILIZATION CONFERENCE

Purdue University, Lafayette, Indiana

November 29–30, 1944

The preface indicates the cooperating agencies and officers who assisted in arranging the conference The total representation of 203 and its distribution is also indicated.

Waste Saving by Improvements in Milk Plant Equipment. By Dr. H. A. Trebler, Chemical Engineer, Sealtest, Inc., Baltimore, Maryland. Pp. 6–21. Dairy wastes are classified as (1) wastes of spoiled products, (2) wastes of by-products as whey and buttermilk, (3) wastes due to poor equipment or operation, and (4) wastes from rinsing and washing.

Wastes (1) and (2) can be reduced by developing markets for these products though seasonal variations complicate the problem. The fourth type of waste is, in general, the unavoidable waste of the milk producing process. Treatment costs can be greatly reduced or eliminated by the application of known methods of reducing waste. All industries realize that it is more economical to avoid waste and develop utilization of waste products than to treat these wastes.

Utilization of casein and other milk proteins has been developed to a considerable extent, but this outlet is still relatively small and is little relief to the waste utilization program.

Detailed description of the various types of equipment used in the milk industry with nine illustrations are given.

Industrial Wastes at Sioux Falls, South Dakota. By R. E. Bragstad, City Engineer, Sioux Falls, South Dakota. Pp. 22–30. This article is a discussion of the trade wastes originating in the packing plant and stockyards district of Sioux Falls. Because of the city's growth and the operation of a packing plant, the sewage treatment plant was installed in 1927 at a cost of $735,000. Secondary treatment was provided with expected efficiencies of 80 to 85 per cent. At that time the raw wastes had the following characteristics:

	Industrial	Domestic
Volume—m.g.d.	1.9	2.4
B.O.D.—p.p.m.	1,200	300
Susp. Solids—p.p.m.	1,000	300

A sewer rental ordinance led to an agreement between the city and the packers requiring the packers to give the sewage the following pre-treatment: (1) fine screening, (2) sedimentation (30 minutes), (3) grease skimming, (4) disposal of screening and sludge, (5) pay its prorata share of pumping costs as the only money paid the city for waste treatment. Similar agreements were concluded with the stockyards company and the serum company. In 1935 it became necessary to add chemical treatment to the plant and activated sludge treatment following the trickling filters, costing $220,000. Ninety-seven to ninety-nine per cent overall removals were

* It will be appreciated if Miss Swope is furnished all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations and educational institutions are particularly desired.

necessary. In 1940 additional improvements costing $146,000 were required, and new agreements were concluded in which the packers paid a substantial part of plant improvements and contributed to operation costs. It was further agreed that the packers will pay twenty-five per cent of future improvements up to $45,000. Pre-treatment of the waste at the packing plant was continued. In 1943 additional facilities costing $226,000 were added with a further agreement for the packers to share to an even greater extent in financing capital improvements as well as operating costs. The February, 1944, sewage characteristics were:

	Industrial	Domestic
Volume—m.g.d.	3.7	2.6
B.O.D.—p.p.m.	2,407	395
Susp. Solids—p.p.m.	1,870	368

These figures indicate an equivalent population of the industrial load as 390,000 on the basis of 0.19 pounds B.O.D. per capita daily. At that time the city's population was 45,000. Stream pollution drainage suits have resulted in a cost of $85,000 to the city. In one case the packer was made co-defendant with the city on the basis of the plaintiff's hope that the 1940 contract could be declared void. The State Supreme Court declared that contract void, but denied the injunction sought. In spite of this decision the city and the packer continue to follow the agreement.

At the plant electricity is generated by the 700 b.t.u. sludge gas produced by the plant's digesters. Use is also made of this gas in heating plant buildings, for burning screenings, heating the city street department shops one mile away and fuel for the city asphalt plant. More recently the gas has been piped to the State Penitentiary where it is used for cooking and baking in the kitchen. In return the Penitentiary loads and hauls the sludge produced at the plant for use on its state farms.

History and Legal Background of Stream Pollution Control in Indiana. By Robert Hollowell, Jr., Deputy Attorney General, State of Indiana, Indianapolis, Indiana. Pp. 31–42. The development of stream pollution control in Indiana is recounted since 1856. Early incidents cited are those prior to the existence of sewer systems. An important decision of the State Supreme Court was made in 1893 concerning the case of an individual's use of a spring for curative bathing and then allowing the water to discharge on the surface. The defendant's right to use the stream as a discharge from his baths was upheld.

In 1901 the State Legislature passed a bill making it a crime to discharge any waste water or waste into a stream so as to pollute it. In 1909 the State Board of Health was given some influencing power for settling nuisance and stream pollution differences. In 1913 the State Board of Health was given the power to order filtration plants for public water supplies. In 1927 the Board of Health was given power to provide for pollution abatement.

In 1935 the Department of Commerce and Industries was given jurisdiction of stream pollution and control and under it was set up a "pollution hearing board." The law is considered a practical one and a considerable improvement over previous legislation. It became ineffective, however, when the Department of Commerce and Industries was abolished in 1941. The present effective act passed in 1943 creates a six-member board with a Technical Secretary required to be a qualified graduate sanitary engineer. The Board has power to bring any appropriate action in the courts, in the name of the state, necessary to carry out the provisions of the act and to enforce laws and orders relating to the laws of water of the state. It has the power to set up stream standards and requires the review of plans and specifications for abatement programs and approval by the Board.

Utilization and Disposal of Industrial Wastes. By Dr. F. W. Mohlman, Director of Laboratories, The Sanitary District of Chicago. Pp. 43–57. The most general problem of industrial wastes in Chicago has been the occasional loss of material such as oil, solvents, sugar, grains or other organic materials which may occur from accident, carelessness, failure of equipment or more often overloading of equipment. The corn products industry has made spectacular waste recovery achievements by the "bottling-up" of its process. In 1922 this company's Argo, Illinois, plant discharged a waste with a population equivalent of 367,000. By 1925 this was reduced to 257,000 or by 30 per cent. By alterations of the process further reductions to 156,000 in 1926 and to 77,000 in 1927 were accomplished. From 1936 to 1943 the average population equivalent has been less than 50,000.

The Sanitary District of Chicago has accumulated much information since 1935 about the waste discharged within the Sanitary District. Three hundred plants have been investigated and the character of their wastes determined. Wastes studied originate from the production of milk, food, meat, as well as fermentation processes, tanneries, paper board and textile plants, laundries, soap and vegetable oil production, coke and tar plants and the production of pharmaceuticals. Also included are wastes from the washing and cleaning of railroad locomotives and trains and a large variety of chemical wastes. Tables give the characteristics of these wastes.

Numerous materials have been found worth salvaging and these have been called to the attention of the industries concerned. Examples are cited showing the savings to the producer in certain cases involving sugar recovery, mineral oil, grease from packing plants and other recoveries. A program for pollution abatement is most effectively attacked on a river valley basis. Recognizing these limitations (1) the control of river water quality to fit specific requirements is impossible, (2) fool-proof treatment plants are impossible and, (3) stream ability to assimilate waste varies with many factors.

Treatment of Wastes Produced in Metallurgical and Metal Working Industries. By William S. Wise, Chief Engineer, State Water Commission, Hartford, Connecticut. Pp. 58–69. Because of the general interest in the treatment of industrial wastes the subject must be approached from two standpoints: (1) abatement of pollution and (2) the recovery of materials. The wastes considered result from the manufacturing process in the following industries:

1. Brass and copper.
2. Iron and steel.
3. Plating (chromium, nickel, cadmium, brass, copper, etc.).
4. Metal working (oils and coolants).

Fabrication of brass and copper products is a major industry in Connecticut. In the process 80 to 90 per cent of the acid and metals are lost in the dilute wash waters during pickling processes and only 10 to 15 per cent is lost in spent pickling liquors. The problem is one, therefore, of handling large volumes of dilute solutions. The waste of one plant has the following yearly average composition:

Sulfuric acid	105 p.p.m.
Copper	24 p.p.m.
Zinc	20 p.p.m.
Chromium (total) ..	20 p.p.m.
Chromate chromium..	9 p.p.m.

A pilot plant for the treatment of this waste consisted of filtration through sand to remove oil and foreign matter; reduction, by sulfur dioxide, of the hexavalent chromium to trivalent form for precipitation; deposition of the copper on brass chips, for re-use in the furnaces; precipitation of the chromium and zinc with lime; filtration, drying and roasting the precipitated sludge with soda ash to oxidize the chromium; leaching out of the chromium as bichromate for re-use; recovery of the zinc as zinc sulfate or as electrolytic zinc. The plant to treat 3,000,000 gal. per day would cost about $200,000 with annual fixed and operating charges $79,000 and the value of recovered by-products $55,000. The processes are being studied continuously to simplify the processes or increase the yield.

In the iron and steel industries the problem is also one of handling spent pickling solutions and dilute rinse waters. The objectionable components are sulfuric acid and copperas. In Connecticut the following methods have been investigated in the treatment of these wastes:

1. Inhibitors in pickling liquors.
2. Removal of iron salts by preferential solution.
3. Bullard-Dunn electrochemical cleaning process.
4. A-C electrolytic process.
5. Ammonium sulfate production and iron oxide.
6. Bassett process.
7. Conversion of copperas to sulfuric acid.
8. Refrigeration process for production of copperas.

9. Evaporation and crystallization of copperas.
10. Treatment with alkaline reagents.
11. Production of ferron.

Plating room wastes consist of spent pickling acids as well as plating solutions and rinse water containing combinations of acids and the various metals used. Most of the metals are toxic even in high dilution. The metals in these wastes are easily precipitated by the usual reagents. Precipitants for this purpose include barium sulfide, sulfur dioxide, sodium sulfide, copperas, scrap iron, sodium sulfites, lead acetate and hydrated barium hydroxide.

Metal working oils and coolants usually contain from two to four per cent miscible oils costing about thirty cents per gal. Bacterial contamination and metal particles are sometimes responsible for the discharge of considerable quantities of these materials. Mechanical clarifying equipment has been used with considerable success as well as a separator operating on the flotation principle.

Earnest cooperation on the part of industry and public officials involved is essential to the success of an industrial waste treatment program.

Sewage Treatment and Industrial Wastes. By Don E. Bloodgood, Associate Professor of Sanitary Engineering, Purdue University. Pp. 70–76. In this paper the writer points out the effect of industrial wastes on the various parts of a municipal sewage treatment plant.

Grit chambers may be adversely affected from the great quantities of inert solids washed from the sugar beets. The volumes may overload ordinary grit chamber handling equipment. Another source of extra solids in the grit chamber is paunch manure from packing plants because of its high specific gravity. Seeds and grains also may reach overload proportions when discharged in the waste of a manufacturing process using grain products.

Coarse bar racks may be affected adversely by packing house wastes and canning plants.

Primary treatment units are sometimes overloaded from large quantities of skins discharged from tomato canning factories as well as oils and greases from many industries. Tanning wastes require a long settling period and a thin sludge is likely to cause difficulty in sludge digestion. Secondary treatment, because of its usual biological nature, may be adversely affected by numerous wastes. Woolen fibers from the waste of a woolen mill have been responsible for sealing the upper layer of trickling filter rock at LaPorte, Indiana. Trickling filters with the usual spray nozzles, too, will suffer from the presence of fats and oils in the sewage as well as clogging materials like tomato skins. Metal plating wastes will probably affect adversely the trickling filter or activated sludge plant operation. Steel mill wastes and milk plant wastes may have a similar effect.

In the treatment and disposal of sludge, difficulties are present by the presence of toxic materials, oil wastes and paper wastes. Pre-treatment by the industry is usually of great relief to municipal sewage plants.

By-Products and Treatment of Brewery and Yeast Wastes. By Dr. Willem Rudolfs, New Jersey Agricultural Experiment Station, New Brunswick, N. J. Pp. 77–82. By-products are actually new products for the specific industry and they may sometimes result in wastes more objectionable than the original wastes. As industries are taxpayers, they are entitled to an equitable share in the waste treatment processes of the community. Extra costs of treatment for which the industry is responsible should be borne by the industry.

The production of useful products from waste is frequently a matter of methods of procedure and economics. Certainly if economical possibilities of recovery exist the cost of waste treatment and disposal is reduced. Established processes of waste treatment, recovery and trend of research are indicated. The utilization of waste in production of by-products is still a field for extensive exploration.

Treatment of wastes is divided among physical (screening, settling and electro-processes), chemical (precipitation aids, neutralization), and biological (utilization of pure cultures and use of crude mixed cultures) methods.

Several examples of waste treatment are described.

Feed By-Products from Grain Alcohol and Whiskey Stillage. By Dr. C. S. Boruff and L. P. Weiner, Hiram Walker & Sons, Inc., Peoria, Illinois. Pp. 83–88. The distillery industry differs from all other industries in that it was technically and legally dead and buried for thirteen years. As a result the industry started from scratch in 1933. The waste problem is now considered a matter of recovery rather than disposal and a profitable business has resulted.

The Hiram Walker plant in Peoria has the most efficient recovery system in the industry. Stillage from screens and presses is evaporated to a syrup of 20 to 30 per cent solids. Centrifuging prior to the evaporation process is very helpful and the evaporation process may be carried to a concentration of 35 to 45 per cent solids. The Hiram Walker scheme for recovering the stillage is described and a flow sheet given. With percentage recoveries increasing and good prices for the products produced, the process is considered highly successful.

Food Canning Waste Utilization. By N. H. Sanborn, National Canners Research Laboratory, Washington, D. C. Pp. 89–95. The canning of fruits and vegetables produced an enormous volume of waste both solid and liquid. Because of the recent shortage and high price of animal fat the possibilities of utilizing cannery wastes has been considered. Because of the low concentration of liquid wastes there is practically no possibility of their utilization. The use of solid wastes has not been practiced more extensively because of (1) the seasonal nature of canning, (2) the perishable nature of the waste requiring immediate conversion, (3) reluctance of the canners to assume added responsibility during the intensive canning season and (4) the questionable financial return.

A consideration of individual vegetables from the standpoint of waste production is given. The returns from processing waste products for the market are satisfactory financially. Dried tomato waste sold for $21.50 per ton in 1941, while in 1943 it was worth $35.50 per ton. This waste has the following approximate compositions: protein, 10 per cent; fat, 3 per cent; crude fiber, 45 per cent; ash, 3 per cent; nitrogen free extract, 33 per cent and moisture, 6 per cent. About twenty-five per cent of the raw tomato tonage appears as waste. Other products produced are completely described. The fruit and vegetable wastes not now used may be considered as an economical loss which warrants the application of time and ingenuity.

In discussion, Mr. D. T. Sherow indicated that in Indiana the major canning wastes come from tomatoes, peas, lima beans, corn and pumpkin. A cooperative waste reclamation plant might be centrally located so as to serve other plants in the area.

The Waste Disposal and Utilization Problems of the Petroleum Industry. By Roy F. Weston, Sanitary Engineer, The Waste Control Laboratory, The Atlantic Refining Company, Philadelphia, Pennsylvania. Pp. 98–125. Thirty-five to forty years ago the gasoline fractions of petroleum were handled and disposed of as dangerous and annoying by-products of waste. Since then billions of cubic feet of natural and refinery gas have been burned as useless by-products. In more recent years technological developments have completely changed this program.

The wastes of the petroleum industry are classified as oil production wastes (drilling muds, salt water, free and emulsified oil, tank bottom sludge and vented natural gas). Refinery wastes include:

1. Free and emulsified oil from leaks, spills, tank draw-off, etc.
2. Waste caustic, caustic sludges, alkaline waters, etc.
3. Acid sludges and acid waters.
4. Emulsions incident to chemical treatment.
5. Condensate waters from distillate separators and tank draw-off.
6. Tank bottom sludges.
7. Coke from equipment tubes, towers, etc.
8. Acid gases.
9. Waste catalysts, filtering clays, etc.
10. Special chemicals from by-product chemical manufacture.
11. Cooling water.
12. Sanitary wastes.

The use and possible future uses of all these wastes are given.

Marketing and transportation wastes result from leaks and spills, oil from equipment maintenance and repair parallel washing wastes and sanitary wastes. Their reduction is dependent upon proper operation and management.

A bibliography of 137 references is appended.

Industrial Wastes and Fish Life. By M. M. Ellis, Senior Aquatic Physiologist, U. S. Fish and Wildlife Service, University of Missouri, Columbia, Missouri. Pp. 126–134. The evaluation of fisheries must include the sport fishing as recreation as well as commercial fishing for food production with due consideration of all interests. The production of fish in streams may be considered in a similar light to the production of a manufactured article. A breakdown in the process may result in a great loss. If stream quality is degraded, even for a short time, many fish may die from what may seem like a trivial breakdown at the plant.

From the standpoint of the fish, industrial wastes may be classified in these five major categories:

1. Suspensoids which blanket or cover the stream bottom and submerged objects in the stream;
2. Substances which have an oxygen demand or oxygen consuming power;
3. Compounds which alter the relative acidity or alkalinity (pH) of the water;
4. Materials which increase or change the salinity of the water, and
5. Substances which are specifically toxic.

Settleable solids are a potentially serious pollution hazard because of their blanketing the stream bottom with inert material. Such items may include wood fiber, sawdust, paper pulp, rock powder, mine slimes, mud from various washing operations, oil wastes, tars, unreduced sewage and other inert materials. Frequently only a thin film of such materials is necessary to kill the bottom fauna in an otherwise healthful stream. Utilization has been partly responsible for a reduction of these materials.

The effect of substances having an oxygen demand is most readily appreciated by sanitary engineers. These values are not themselves in conclusion, however, and must be considered as only a part of the information on a polluted stream. Experiments have indicated that fish will survive in high concentration of wastes if aeration is practiced to maintain the dissolved oxygen level at 5 p.p.m. or above. Stream pollution studies should be based on extremes rather than average conditions because it is the extreme condition which may prevail for only a few minutes that will kill fish life. The criteria for fish life should be based on successful growth maintenance and reproduction rather than simply survival of the fish. The observation that fish were found living in polluted water with only 2.5 to 3 p.p.m dissolved oxygen is frequently made. While they do exist at these oxygen levels, physiological and biochemical studies of such fish show that they are not prospering and at these times are much more susceptible to effect of acids and metallic poisons.

Fish and the common aquatic organisms prefer pH values of 6.5 to 8.4. pH values below 5.0 or greater than 9.0 are definitely detrimental or even lethal. Changes in these values within a few hours coupled with a slight increase in temperature or lowering of the dissolved oxygen can be fatal to various warm water fishes and trout.

Changes in salinity as reflected by the specific conductance of a stream water have been found critical. At the present time industry is utilizing its waste or making sincere efforts to rectify objectionable effluents more than ever before.

Industrial Wastes and Stream Pollution. By Joseph L. Quinn, Jr., Indiana State Board of Health, Indianapolis, Indiana. Pp. 135–137. While Indiana is classed as an agricultural state, it also has many industries concerned with waste utilization and stream pollution. Fifty-six and five-tenths per cent of the people normally have access to municipal water supplies and receive their water from potentially polluted streams. Municipal sewage treatment plants and industrial waste treatment plants are considered the answer to the problem.

In addition to these formal papers the meeting included a symposium of milk wastes with Dr. H. A. Trebler, presiding; on distillery, starch, and brewery wastes with Mr. H. W. Streeter presiding; on food canning wastes with Mr. L. F. Warrick presiding; on refinery, steel mill, and mine wastes with Dr. F. W. Mohlman presiding; on sewage treatment with Mr.

D. P. Backmeyer presiding; on pulp and paper wastes with Dr. Harry W. Gehm presiding; on water treatment with Dr. W. E. Howland presiding; and on meat packing plant wastes with Mr. R. E. Bragstad presiding.

RALPH E. FUHRMAN

The Treatment of Textile Wastes at Huddersfield (England). BY H. H. GOLDTHORPE. Lecture before the Joint Meeting of the Country Textile Society and the Midland Branch of the Institute of Sewage Purification . . . January 26, 1946.

The sewage treatment plant at Huddersfield receives a flow of about 14.4 m.g.d. from a population of 133,000. The sewage is made up of about equal volumes of domestic sewage, chemical trade wastes and textile wastes. A charge of about 2 cents per 1,000 gal. is made for treatment of the wastes if the factory is located within the city or 4 cents if it is outside.

The domestic and textile sewage and the chemical waste which reach the plant through separate sewers are settled separately before they are combined for biological treatment. Waste acid (less than 30 per cent H_2SO_4) from the chemical plants is delivered free to lead lined tanks at the sewage plant and is used to acidify the alkaline domestic and textile sewage to pH 4.5 as it enters the settling tank. At this pH, a voluminous rapid settling floc is produced, leaving a fairly well clarified effluent. In this way, about 1,000 tons of acid calculated as 100 per cent sulfuric acid are absorbed from the chemical plants each year and another 300 tons are used for conditioning the textile sludge.

The slightly acid chemical waste is treated with lime to bring the pH to 8.3 so as to remove iron, colloidal matter and some color. About 650 tons of lime are purchased each year.

Chemical precipitation and sedimentation reduce the oxygen consumed from permanganate (4 hours) from 200 to 100 p.p.m. in the domestic and textile sewage and from 400 to 350 p.p.m. in the chemical waste.

Experimental studies indicate that after neutralization the domestic and textile sewage can be treated as a medium strong sewage by any of the usual biological methods. The chemical waste, however, is best purified on percolating beds. When the combined waste is treated on percolating beds at a rate of 90 gal. per cu. yd. per day the B.O.D. is reduced from 200 p.p.m. to 20 p.p.m. This effluent meets the requirements of the Royal Commission. Preliminary experiments indicate that double filtration at a primary rate of 720 gal. per cu. yd. per day followed by secondary filtration at 240 gal. or an overall rate of 180 gal. may be satisfactory.

At the present time, the sludge from the domestic and textile sewage is treated with sulfuric acid to bring the pH to 2.7 and then pressed. Grease is extracted with benzene and the sludge cake is dried in a rotary drier for use as a fertilizer. The press water is returned to the domestic and textile sewage. The chemical and biological sludges are lagooned.

G. P. EDWARDS

Dewatering of Sewage Sludge by Coagulation and Vacuum Filtration.* Part I. Laboratory Experiments. BY J. M. WISHART, C. JEPSON AND L. KLEIN. Report of the Rivers Committee of the Manchester Corporation.

At the Davyhulme Works in Manchester, England, the sludge, part of which is digested, is disposed of at sea, or by broadcasting over land. The sludge consists of about equal parts by weight dry solids of primary and excess activated sludge. Since the 8,000 dry tons of excess activated sludge will be greatly increased when the new proposed activated sludge plant is constructed, an examination of the possibility of preparing fertilizer from the activated or mixed sludges seemed desirable.

Laboratory experiments confirmed the conclusion of other workers that ferric chloride is the best coagulant for activated sludge. Other coagulants tried were in order of efficiency: chlorinated copperas, ferric sulfate, aluminum sulfate and chromium alum. The sulfate ion seems to have an inhibiting effect on the coagulation of sludge. The large amount of ferric chloride required for optimum coagulation

* Published by Henry Blacklock and Co., Ltd., Printers, Albert Square, Manchester, England.

of activated sludge, 8 to 10 per cent on a dry basis, is higher than for most American sludges and may be caused by the presence of a large volume of industrial waste.

The main factors affecting coagulation and vacuum filtration of sewage sludge, especially activated sludge, are the condition, age, alkalinity and density of the sludge. Well aerated activated sludge in good condition requires less ferric chloride for coagulation than sludge in poor condition and stale sludge requires more ferric chloride and filters at a lower rate than fresh sludge. Aeration of fresh or stale sludge for one to two hours reduces the amount of ferric chloride needed for coagulation of activated or mixtures of activated and primary sludges as it decreases the alkalinity and oxidizes some of the reducing compounds which consume ferric chloride. Elutriation of sludge with tap water, sewage effluent acidified to pH 4 or 5, chlorinated sewage effluent or filtrate from sludge coagulated with ferric chloride reduces the amount of ferric chloride needed for sludge conditioning. Concentration of activated sludge, especially if followed by aeration decreases the amount of ferric chloride required and increases the rate of filtration. The storage of sludge for periods of more than a half hour after coagulation has an adverse effect on vacuum filtration. Probably because of the difference in the condition of the activated sludge obtained from 3 separate plants treating the same sewage, different results with regard to coagulation and vacuum filtration were observed.

The bulletin contains 51 pp., 35 tables, 15 graphs and 14 sections. The latter are as follows: (1) Summary of work done by others, (2) experimental technique, (3) coagulation of activated sludge by chemicals, (4) fresh and stale activated sludge, (5) adjustment of pH value before coagulation, (6) activated sludge containing different amounts of solid matter, (7) aeration before coagulation, (8) storing coagulated sludge before filtration, (9) different sludges and mixtures of sludges, (10) effect of elutriation before coagulation, (11) activated sludge from different activated sludge plants, (12) composition of sludge cake, (13) discussion of results, and (14) summary.

G. P. Edwards

Development in the Treatment of Sewage and Allied Wastes. By A. E. Berry. *Engineering Contract Record,* 58, No. 2, 64–66, 174–183 (1945).

New municipal construction in the sewage works field has been practically at a standstill during the war. For this reason operating problems have been magnified at existing works to care for increased war-time loads. Limited research under this pressure has been continued.

The committee on water and sewage works development with its "Blueprint Now" program has kept postwar planning in the foreground. States have aided in permitting the setting up of postwar reserve funds and state financial assistance for planning. The program for Ontario has been estimated at $40,000,000 for water and sewerage projects. Three-fourths of this amount is expected to be used for new sewer systems and sewage treatment facilities. In Britain planning has been active and both the Institute of Sewage Purification and the Institution of Sanitary Engineers have advocated that sewerage services should be put on a regional basis.

A review of the United States Public Health Service inventory of public sewerage needs is given.

The sewerage improvement programs of New York, Boston, Los Angeles, Philadelphia, Norfolk, Chicago and other United States cities are briefly described.

Of the industrial wastes, grease and oils have been serious offenders, as it is found in almost all sewages and to a greater degree in wastes from industrial establishments.

Current practices in the treatment of packing house, paper, synthetic rubber and textile wastes are given.

Activities to abate stream pollution, greatly lagging because of the war, are a postwar need. Work in the United States by the Sanitary Water Board of Pennsylvania, the Interstate Sanitation District, is given as an example of improvements in stream sanitation.

Maintenance of sewage treatment plants and equipment has been made more difficult during the war because of restrictions and shortages. Standards of safety have been maintained regardless of this condition and much attention has been given this phase of plant operation.

Progress in sewage treatment processes is exemplified by the development of the high-rate trickling filter and refinements in the activated sludge process. There has been practically no opportunity for the development of treatment equipment during the war. Progress is noted in fields of sewage chlorination and sludge disposal. In sludge disposal the trend to more digestion is observed as well as improved methods of heating tanks, control of supernatant liquor, sludge gas use, elutriation and dewatering.

Sewage works financing has been aided by the increased use of sewer rental laws and the adoption of rate charges for industrial wastes. The year 1944 is considered as one of progress and of preparation for future developments.

RALPH E. FUHRMAN

Some Aspects Concerning the Sewerage of Rural Areas. BY N. CAMPBELL LITTLE. *Journal of the Institution of Sanitary Engineers,* **44**, Part 4, 167–201 (1945).

In conformity with the Rural Water Supplies and Sewerage Act of 1944 there is to be provided a supply of water in pipes for every rural locality. The government is to help pay for the cost of sewerage or sewage disposal where the need for such is due to anything done to supply or increase the supply of water in the locality concerned. It would seem that the need for sewerage facilities would go hand in hand with the provision of a water supply, since satisfactory use of water can only be made when sewers and drains are available.

In most rural districts the drainage and sewage disposal facilities are meager. In some localities sewer ditches are used. Some villages have covered these sewer ditches when they gave rise to serious nuisance. These are usually at a shallow depth with flat floors and are not self-cleansing at low flows. In dry periods solids are deposited and they become very foul.

There are many types of sewage disposal works in rural areas. Plants for individual houses usually include a septic tank or cesspool or a septic tank with a small filter. Private installations for large mansions usually include a septic tank and a circular filter. Rural District Councils, where organized, may provide disposal works or provision for treatment on land or discharge to a sea outfall. Some rural areas are enabled to discharge sewage to the system belonging to a larger municipal authority or joint sewerage board.

In some rural areas sewage disposal works were constructed for war-time requirements. Careful study should be made of these plants before they are taken over for use by a local authority to be certain they can be used without enlargement or extensions.

In planning sewerage schemes use should be made of existing maps. It seems feasible to plan facilities only for concentrated building developments in villages and hamlets, and to include in the scheme only those isolated houses and farms that may be within reasonable distances of sewers. It will be found best, in general, to abandon old existing sewers and use them for storm flows when developing a more complete sewerage system. When drainage from farm buildings is to be connected to a rural system appropriate increase in the capacity of the treatment works must be provided.

An estimate of the population to be served may be difficult, since no one can say what the trend will be in the postwar period. A figure based on the present population plus an allowance for an increase due to housing proposals should be reasonable. The flow to be handled should not be based on a figure of less than 25 gal. (Imp.) per capita per day. Estimates of total dry weather flow should include known trade waste flows and allowances for infiltration into the system.

A separate system of sewers is preferable. When designing the layout of sewers in a built-up rural area it may be found best to locate the sewers at the back of the houses rather than in the roads. This will usually mean shorter house connections and will avoid cost of restoring road surfaces.

Where pumping stations are necessary certain minimum figures should be observed. No pumps smaller than 3-in. and no discharge mains smaller than 4 in. should be used. Bar screens with 2-in. openings should be provided ahead of the pumps. Pumps should be located in a separate compartment and should be at a self priming level. A sump with a capacity equal to one-half hour dry weather flow should normally be sufficient. During storm flows or periods of excessive flows the suction chamber may overflow to a second chamber, from which flows in excess of six times the dry weather flow may be discharged to the nearest stream. A flap gate may be provided to drain the second chamber to the suction sump.

In the design of treatment works for rural projects liberal capacities should be provided for tanks, filters and other units. The area may develop to a greater extent than anticipated and variations in flow are likely to be extreme. While works consisting of septic tanks and land irrigation may appear attractive because of the low cost there are certain considerations to be remembered. Land irrigation requires careful attention and it is not desirable to have such areas close to populated areas. Irrigation areas are also a source of contamination for underground water supplies. Probably the better treatment layout for small plants is that comprising sedimentation tanks and filters.

Wherever possible neighboring villages and hamlets should discharge to a single disposal works because of several possible advantages. Where this is possible the number of effluent outfalls to a stream is reduced and variations in the character of the sewage due to trade wastes or other causes are more readily balanced. Furthermore, sewage treatment and sludge disposal can be more efficiently and economically carried out at a centralized works.

While a centralized plant for several communities is desirable, a regional scheme may be adopted to provide combined management and supervision of all works within the area. Thus a competent staff could be organized to inspect the smaller plants at regular intervals and maintain them in satisfactory operation.

The paper is discussed by twelve members. One discussion, in regard to pumping stations, suggested that the minimum diameter of sewage pumps should be 4 in. rather than 3 in. Use of comminutors rather than screens ahead of the pumps was also suggested. To overcome possible odor complaints it was urged that new plants be provided with unheated digestion tanks.

T. L. Herrick

Public Health in India. By F. C. Temple. *J. of the Institution of Sanitary Engineers,* **44**, 202–209 (Oct., 1945).

This paper describes water supply systems and sewerage systems of various cities in India.

At the beginning of the century the cities of Calcutta, Bombay and Madras were the only towns having skeleton systems for both water supply and sewerage. Very few houses were connected to either system. At Madras sewage was discharged to a stretch of sand dunes. This was very unsatisfactory as the water drained away rapidly, leaving a sticky putrefactive mass on the surface. At Bombay a very flat system of large sewers led to a screening and pumping plant which discharged the sewage to sea. Ejectors were used in certain districts to lift sewage to the system. Odor conditions were bad within a mile of the pumping station due to the septic condition of the sewage.

It is of interest to note that at Bhagalpur, where the water supply is pumped from the Ganges, that the river changes its course from time to time and moved anything up to seven miles away from the station intake. At such times a portable engine and pump was used, and the water discharged to the waterworks through a trough made up from corrugated metal sheets. Wells were resorted to when the piped supply fell below about 3 gal. (Imp.) per capita per day.

Considerable progress in the development of water supplies was made between 1910 and 1920. Further expansion followed after 1920.

At Bombay various modifications have been made to the sewerage system. Sewage treatment works have been provided for some districts. At one plant heated digesters were installed. Use of heat would appear unnecessary for most of the year the sludge temperature would be naturally higher than the optimum for controlled digestion.

In general, sewage treatment is developing gradually. The first good sized activated sludge plant (100,000 Imp. gal. per day) was built at Jamshedpur in 1920.

T. L. Herrick

Rangoon's Water Supply Back to Normal. By A. B. Cooper. *J. Institution of Sanitary Engineers,* 44, 210–211 (Oct., 1945).

This paper describes briefly the task of restoring the water supply system of Rangoon to normal peace-time capacity.

T. L. Herrick

The Sewerage Problem in Liberated Rangoon. By A. B. Cooper. *J. Institution of Sanitary Engineers,* 44, 212 (Oct., 1945).

The Japanese had made no attempt to sabotage the sewerage system of Rangoon. However many of the sewers were very badly damaged due to bombing. All manhole covers had been removed, presumably for munitions purposes. Many of the manholes had become choked with rubbish and bomb debris.

Most of the 40 ejector stations for low lying areas were found out of action, though the central compressor station was undamaged. These stations were rapidly restored to service, half of them being in serviceable condition within two months after the city was liberated.

T. L. Herrick

Presidential Address. Institute of Sewage Purification. By John Hurley (1945).

Emerging from the hardships of the war, Hurley points out the urgent need of rehabilitation of sewage works in Great Britain, despite the handicap of insufficient staff and a low level of salaries. However, the outlook for research is inspiring.

Heretofore the Institute membership was largely composed of persons actually in charge of sewage disposal works. A wider scope of membership is now sought, with local branches. As Examination Secretary, Hurley believes an orderly examination scheme for corporate members is desirable, after at least three years' full time experience on a sewage works.

During the war period research was checked. Cooperation with other bodies is now welcome. Standards of sewage effluents and methods of analyses should be set up and universally followed, to permit comparison.

Amendments to the Public Health (Drainage of Trade Premises) Act, 1937, are in order.

The disposal of and treatment of storm water requires consideration.

Reorganization of sewage disposal on a regional system based on drainage areas is much discussed, but far from accomplished, although creation of rivers boards more widely would be helpful. Such boards at present are a law unto themselves and need reorganizing, with executives possessing knowledge of sewage treatment, industrial wastes, and stream examination.

In a sewage works design, more alternatives are available. In a choice, full account should be taken of local circumstances. Rural sewage disposal is of growing importance, and more attention should be given to the design of small works. Covered tank and filter installations will prevent sabotage of small sewage works.

Hurley urges the younger men to recognize the purpose and significance of their work, and its place as a public service. A spirit of service must be sustained.

Langdon Pearse

A National Policy for Trade Effluents. By J. Hurley. *Institute of Sewage Purification* * (November 29, 1945).

Hurley reviews the situation which resulted in the Public Health Act, 1937, in Great Britain and indicates that the war blocked its application. In the meantime comment, both favorable and unfavorable, has been made. Particularly irritating is the recognition of prescriptive rights of discharge, whereby an industry could continue to impose the treating of its sewage on the municipality, if it had done so prior to March 3, 1937, providing the old payments (if any) are continued. Beside the difficulty of establishing the practice in 1937, and the rise in cost of service, other anomalies arise, of which the focal point is the lack of any uniform industrial waste effluent policy for the country as a whole.

Hurley does not believe that the Act can ever achieve satisfactory results, as now constituted. He proposes a uniform national scheme embodying—

* A preprint.

1. Provision for the manufacturer to discharge liquid waste to the public sewers, subject to reasonable conditions and payment.
2. Pre-treatment of the waste at the factory should be kept to the minimum, with moderate expense.
3. Conditions of pre-treatment and payment should apply to the whole country.
4. An industry should not be compelled to use such service, if it can turn out a satisfactory effluent.
5. The scheme should apply to all trade wastes discharged to the sewers, whether through old or new connections.
6. The scheme should discourage the location of industries in districts incapable of accepting industrial wastes in the public sewers and of giving adequate treatment thereto.

To accomplish this, prescriptive rights of discharge should be abolished. Every manufacturer should contribute to a central fund controlled by a central authority, an amount based only upon the character and volume of his trade effluent. From this fund the municipalities (local authorities) would be reimbursed for the expenditure in treating industrial wastes, in proportion to the amount of treatment, where full, partial, or negligible. A standard should be set up for pre-treatment and composition of each class of waste, with a uniform country-wide charge for each.

Hurley then discusses along general lines the specifications for pre-treatment, the grading of trade effluents, price fixing, and payment to sewage authorities. He urges early cooperation in projected industrial development between the sewage expert and the industry. Such a scheme would need revision of the Act. It should not prove harsh on either the manufacturer or the local authority.

In concluding, Hurley urges the necessity of revision of the Act along the lines suggested, believing the time propitious.

LANGDON PEARSE

The Propulsion of Vehicles by Compressed Methane Gas, West Middlesex Main Drainage Works. BY W. PARKER. *Institute of Sewage Purification* * (November 30, 1945).

At West Middlesex, gas from the digestion of mixed sludge yields 457,000,000 cu. ft. per year, with 680 B.T.U. per cu. ft. About 90 per cent of the output is used in gas engines. In 1938 conversion of oil-fired boilers to gas for heating buildings was considered, using about 10,000,000 cu. ft. per year, and the use of surplus gas for propulsion of motor vehicles. By 1942 the necessary plant and equipment had been installed. The first vehicle was operated on methane in April, 1942, and later twelve vehicles, ranging from a staff car to a 5-ton truck, were equipped.

The crude gas is treated to remove a large portion of the CO_2 and to eliminate H_2S, in a low pressure washing tower and an iron oxide purifier. The gas is then stored at 5,000 lb. per sq. in. in storage cylinders, from which it is transferred to smaller cylinders at 3,000 lb. per sq. in. The gas is discharged through a reducing valve into an air-gas mixer and thence into the carburetor of the vehicle by a special inlet.

The plant was designed for a capacity of 6,000 cu. ft. crude gas per hour. The gas is first compressed to 20 lb. per sq. in., then washed and passed through the iron oxide, and through five stages of compression, loading valve, water and oil separator, to the final 5,000 lb. per sq. in. The compressor is a 6-stage machine, belt-driven, with intercoolers. The gas washing tower is of the bubble type, equipped with porous diffuser plates, the water flowing downward. About 750 Imp. (900 U. S.) gal. p.p.m. of water reduced the CO_2 content to 5 per cent.

Determination		Before Washing	After Washing
CO_2	Per cent	33.4	4.8
CH_4	Per cent	64.9	89.2
O_2	Per cent		1.2
H_2	Per cent	1.7	2.6
N_2	Per cent		2.2
H_2S	Grains per 100 cu. ft.	12	0.5
Calorific value B.T.U. net per cu. ft.			822

* A preprint.

About 91 per cent of the original CO_2 and 10 per cent of the original CH_4 are washed out.

Storage cylinders are tested at 7,500 lb. per sq. in., arranged in pairs. The gas content of two cylinders at 60° F. and 30 in. Hg is 13,600 cu. ft. when charged to 5,000 lb. per sq. in.

Vehicle cylinders usually are 8 in. diam. and 6 ft. 3 in. overall length, containing 1.76 cu. ft. Smaller cylinders are sometimes used. The heavier vehicles carry two cylinders, mounted on the running boards. A high-pressure reducing valve cuts the pressure to 15 lb. per sq. in. and a low pressure valve to atmospheric pressure. The gas mixer is mounted on the air intake of the carburetor. It is of the piston type, with both gas and air ports, operating in connection with the accelerator and butterfly valve of the normal carburetor.

The performance figures show a low of 4.25 cu. ft. gas per mile for a light car and from 9.6 to 13.0 cu. ft. per mile for heavier cars and trucks. On an average 173 cu. ft. gas was equivalent to 1 Imp. gal. of gasoline. The vehicle range was from 45 to 80 miles. The equipment has been in use for 3½ years. Details of operation and maintenance are given. At no time did the output reach the 8,000,000 cu. ft. per year originally planned.

The cost of the installation was about $24,000. The conversion of vehicles averaged about $400 each. The annual operating expenses, including labor, maintenance, and power (at 1.2 cents per unit), ranged from 6.6 to 20 cents per 100 cu. ft.

Parker concludes that at Mogden the operation of vehicle transport on compressed CH_4 is sound and practicable, but that the advantage gained was saving in gasoline rather than in money.

For successful operation, the plant must work near its full output; the vehicles must pass the charging point daily and be of the heavier class, employed on local journeys; and charging operations must be staggered to avoid waste of time and equipment. The economics of gas operation rest on the price of gasoline and taxes on fuel.

LANGDON PEARSE

Melbourne and Metropolitan Board of Works. Report for the Year Ended June 30, 1945.

The present population of the 39 municipalities and shires is around 1,200,000. The Board is studying the sewerage requirements for 2,000,000.

The sewage farm has been operated principally in production of beef. The way was cleared by the Commonwealth Government for the sale of cattle so that meat rations were supplied for 115,000 people in Great Britain and Scotland between September, 1942, and June, 1945. During the year 464 acres of land was purchased, bringing the total area in the farm to 24,257 acres.

The operating account for the year ending June 30, 1945, in Australian pounds (approximately one pound equals $3.24), was:

Metropolitan Farm		
Revenue		
Grazing Fees	£ 3,293	
Rent	3,664	
Profit on Sheep	5,161	
Profit on Cattle	54,971	£ 67,089
Expenditure		
Management	1,778	
Sewage Distribution	60,047	
Sundry Trading Expenses	26,673	
Interest	56,415	
Loss on Sundry Trading Operations	706	£145,619
Deficiency being net cost of sewage purification		£ 78,530

On the entire sewerage system, including sewage purification, the financial status is:

Revenue (Taxes and Charges)	£1,107,328
Expense (Management, Maintenance, Interest, and Net Cost of Sewage Purification)	840,501
Surplus to Revenue Account	£ 266,827

LANGDON PEARSE

Report to Honolulu Sewerage Committee upon Sewerage and Sewage Disposal. By Metcalf and Eddy. Volumes I and II, 227 pp. with Appendices (4) and Plates (63), December 31, 1944.

This report covers an investigation of the sewerage and sewage disposal problems in the District of Honolulu, an area 20 miles long and 6 miles wide. Near the northerly boundary mountains rise to a height of 3,150 ft. above the sea. The thickly developed portion lies in the lowlands near the sea. The two principal industries are the raising of sugar cane and pineapples. However, the development of the Army and Navy have curtailed the agricultural areas. The climate is equable, with temperature ranging from 55 to 85° F. The rainfall varies widely with the elevation and location, ranging from 25 in. in Honolulu to 40 or 60 in. within the city, and on the mountain tops, to 300 in. per year.

The sewers are of the "separate" type, started initially in 1899 from plans of Rudolf Hering. Storm water drainage is provided by numerous streams and enclosed drains.

The population has grown steadily, from 22,907 in 1890 to 179,326 in 1940. The estimated population in 1965 is 350,000. The average density of population on the sewered area is 27 persons per acre. However, the density varies from 16.4 to 200 persons per acre in the city.

The water consumption is metered, averaging 133 g.c.d. in 1943, with a maximum daily rate of 203 g.c.d. For the average domestic sewage flow, 60 g.c.d. was estimated. In the industrial area, 6,000 g.a.d. was determined, with 12,000 g.a.d. in the commercial areas in the central business district.

To determine the basis of sewer design, gagings were made, from which the domestic flow of 60 g.c.d. was estimated, with ground water infiltration of 345 g.a.d. during dry weather. The average industrial flow was taken at 6,000 g.a.d. From the central business area (170 acres) the flow was at an average rate of 13,060 g.a.d. and for a smaller area (25 acres) a rate of 16,300 g.a.d. From local business the flow was estimated at 4,000 g.a.d.

Ground water infiltration varied from 2,800 to 14,300 g.a.d. in the early morning. For design purposes the maximum ground water flow was taken at 2,500 g.a.d. in upland areas or new construction, and 4,000 g.a.d. in lowland areas of existing sewers.

In the sewer design a minimum flow should be provided for of 300 g.a.d.

The condition of the existing sewers was determined and their adequacy. Recommendations were made for curing defects in the existing system, and for relief projects and extensions.

The sewage temperature ranged from 74 to 83° F. In making B.O.D. determinations the incubation temperature was set at 25 to 26° C. The sewage varied with the amount of industrial waste, in some areas being high in chlorides. Some of the pineapple cannery wastes ranged from 3,985 to 6,375 p.p.m (5-day at 26° C.) B.O.D., with a pH around 3.80. The population equivalent for the cannery wastes was about 342,000 to the sewers, and 96,000 to a canal. The recommendation was that cannery wastes should be excluded from the sewers as soon as other means of disposal were provided.

A sanitary survey of the waters between Diamond Head and the Kewalo sewer outlets led to the conclusion that there is need of treating the sewage before discharge to the sea, to protect the recreational beaches and waters, which are extensively used. Further, an edible seaweed is eaten raw, as well as certain fish. Although fishing around sewer outlets is forbidden, it is practiced. Besides the raw sewage from a large population, there is a large volume of sewage from naval vessels and shore areas, as well as from army areas. Off the Kewalo sewer outlets, odors and slicks are prevalent. Although slicks traveled around 5,000 ft., in 1944, at no time were sewage solids from Kewalo outlets seen in the vicinity of the Waikiki beaches. Gas-lifted sludge occurred only in the Kapalama Canal. Floating oil is found in certain localities, traceable to gas works or ships, but not at Waikiki. Garbage from ships is sometimes found. Certain areas (other than Waikiki) are unattractive for recreation or bathing. In certain spots fishing should be banned.

The dissolved oxygen content was universally high, sometimes super-saturated. Bacterial analyses (agar; 24 hr. at 37° C. and Coli-aerogenes, lactose broth, 48 hr. at 37° C.) were made and plotted. On certain bathing beaches (other than Waikiki) the Coli-aerogenes per 100 ml. varied from 3 to 55. At times bacterial counts have exceeded 1,000 per ml. and run up to 10,000 per ml. The degree of pollution equals or exceeds several of the standards for safety of waters for bathing at ocean beaches whenever the winds flow towards the beaches from the sewer outlets. A substantial reduction in the degree of pollution by treatment is required. Short-period sedimentation is recommended as adequate. If necessary, chlorination can be added.

The preliminary basis for design is as follows for the year 1963:

Population	330,000
Flow	
Annual average (at 150 g.c.d.)	50 m.g.d.
Maximum rate for design	112 m.g.d.
Sewage characteristics	
Suspended solids	170 p.p.m.
5-day B.O.D.	210 p.p.m.
Equipment includes coarse bar racks, hand cleaned; grit chambers, mechanically cleaned; shredders; by-pass racks; sedimentation (1 hour period; 4 units); sludge digestion, two-stage, 4 units, total capacity	570,000 cu. ft.
Sludge capacity, cu. ft. per lb. of dry solids added per day	12.7

Sludge conditioning and elutriation tanks (2 units; total capacity 8,200 cu. ft.).

Vacuum filters. Filter rate 5 lb. per sq. ft. per hr. dry solids. Filter area required 350 sq. ft. for 120 hr. operation per week.

Sludge dryers to evaporate 121,300 lb. water per day and handle 42,700 lb. dry solids per day.

Sludge gas will be used for heating and drying dewatered sludge cake.

The expected analysis of the dry sludge is in per cent: N, 2.0; potash as K_2O, 0.1; phosphates as P_2O_5, 1.8. This may be of service for soil conditioning or fertilizer, or it may be burned or used for fill.

The estimated cost of construction of the treatment plant is $1,690,000, with an estimated annual operating cost of $95,000. The cost of the intercepting and outfall sewers is an additional $2,951,000. The total estimated cost of all the proposed works, including intercepting sewers, relief, and trunk sewers, is $15,517,000.

LANGDON PEARSE

Note: This is an interesting report on a sewage problem in a mild climate. Included is a large amount of detail in tables and charts. L. P.

Research Relating to Sedimentation. By L. B. ESCRITT. *The Surveyor,* 104, 299–300 (June 1, 1945).

The author states that "a considerable amount of research will have to be completed before sufficient knowledge is gained for sedimentation and precipitation tanks to be designed consistently to high standards as regards efficiency, and before designers are agreed on the means by which efficient settlement may be attained."

Although much research has been carried on by individual workers, lack of coordination between investigators and neglect of study of the literature has led to repetition of experiments and omission of necessary inquiries. It is also noticeable that designers are not fully informed on theory and practice in fields other than those in which they themselves are employed. In support of this the author cites the assumption of one designer who assumed that two main factors were involved in the design—a retention period of about three times the period required for quiescent settlement, and over and under baffles equally spaced throughout the tank, thus disregarding Hazen's theory of sedimentation (1904) and the findings of the majority of other experimenters and theorists to the effect that the use of over and under baffles reduces efficiency of settlement and therefore should be avoided.

Hazen postulated that if a sedimentation tank were to be adequate for the settlement of any particular size of particle, the detention period should be such that the particle would be able to fall from the surface of the fluid in the tank to the bottom of the tank at least within the detention period.

Thus, in the case of two tanks of equal surface area but different depth, both the falling time of the particle and the detention period would vary according to the difference in depth: the deeper tank would need to have greater capacity because of the longer settling period, and vice versa. On this line of reasoning Hazen suggested that depth was of little importance, provided the tank were not so shallow as to permit scour and that the efficiency for any rate of flow depended on the surface area—or capacity divided by depth. Data from several sources indicated that the smallest size of particles settled could be related to the ratio of surface area to rate of flow.

The author plots Hazen's data to show that the surface area of a number of tanks is related to smallest size of particles settled according to Stokes' law. The figure shows that the deeper tanks, and therefore, those of larger capacity, are not consistently better than tanks of equal surface area but lesser depth.

The same data are plotted on a detention period—particle size basis indicating the tank depths of all points plotted. On the average the points plotted show that the shallower tanks settle smaller particles than deeper tanks of equal capacity. Therefore he concludes that there appears to be good reason for agreeing with Hazen that surface area is more important than storage capacity.

Hazen's theory, says the author, is ingenious and interesting, but it is inadequate, because it does not take into account the colloids and particles of varied size that can be settled only with the aid of mechanical flocculation or chemical precipitation, and the turbulence of flow which exists in all tanks outside of the ideal conditions of the laboratory.

Practical designers know that the main problem of tank design are the inlet and outlet arrangements. Most tanks have provision for submerged inlets and surface outlets. Thus any suspended solids which pass out of the tank must have risen against gravity. Heavy particles cannot be lifted against gravity without the expenditure of energy. The energy may be derived from convection currents set up by evaporation at the surface of the liquid or from the dissipation of the velocity head at the inlet to the tank. Further, as the settlement of particles from top to bottom of the tank results in a greater intensity of solids in the lower strata than in the upper strata, any vertical currents will carry down comparatively clear water and lift water carrying solids in suspension. This is the reverse of sedimentation.

Aside from the energy dissipated by velocity reduction at the inlet, there is some turbulence created by friction at the sides and bottom of the tank.

Physical and chemical changes take place in sedimentation tanks, due probably to flocculation through turbulence.

Although natural waters and sewages contain particles of many different sizes and characteristics, and although many forces combine to prevent their settlement, a general law appears to be applicable to all sedimentation, either continuous flow or quiescent, which is that as regards the normal proportions and capacities of tanks used in practice, the percentage of suspended matter remaining unsettled varies approximately as a function of the detention period.

Experiments by Holmes and Gyatt (Sew. Wks. J., 1, 318 (1929)) illustrated that in the case of a strong sewage the amount of suspended matter in the effluent varied as the fourth root of the reciprocal of the detention period; while in the case of a weak sewage the remaining solids varied as the fifth root of the reciprocal of the detention period. Thus the importance of detention period can be determined in any case by experiment, and similarly, for any particular tank the maximum rate of flow for any desired degree of efficiency can be found.

K. V. Hill

Are We Backward in Sewage Disposal? By John Hurley. *The Surveyor,* 104, 295–296 (June 1, 1945).

This article attempts to refute the criticism directed against sewage treatment works in England as being badly laid out, insufficiently mechanized and generally behind the latest practice in some foreign countries.

Comparisons of relative standards are difficult to make because the adequacy of a sewage treatment plant has to be gauged in relation to local requirements rather than by fixed and arbitrary standards.

Judging from the viewpoint of effective sewage purification English works do not suffer by comparison with those of other countries. Some instances of stream pollution are admitted but pardonable pride is felt in the results of the treatment provided for heavy concentrations of population on relatively small streams.

However, a comparison between individual sewage works in England with recently installed works abroad indicates a lagging behind in certain directions in England. One reason for this is the age of English plants and the fact that they have been modified, reconstructed and added to from time to time. In such cases it is difficult to secure a pleasing layout or a plant con-forming to the best available practice. The Canterbury plant is cited as an example. Starting with tanks and straining filters in 1868, the earliest section of the present works was constructed at the beginning of this century. Despite additions and alterations from time to time, the problem is still that of utilizing the existing plant as the basis for future development.

Many problems remain to be solved and there are no grounds for complacency. Among them are screening, which at many works is still a filthy and inefficient operation, and the handling of grit. Pollution from discharges of so-called storm water is still a widespread problem. Sludge drying and disposal are problems still unsolved.

In solving these problems and others connected with sewage treatment a broader view of the subject is needed. In the past too little regard has been given to such ugly defects as inconvenient layout, smell, fly nuisance, insufficient mechanization, unnecessarily dirty working conditions and unhygienic dumps of screenings, detritus and sludge. So much attention has been focussed on the production of an effluent of good quality for the benefit of downstream neighbors that little thought has been given to the welfare and amenities of either the workmen on the plant or residents of the immediate neighborhood.

Increased mechanization is needed, to improve operation and efficiency and further to relieve the operator of some of the arduous and nauseating jobs which the workmen of the future will not tolerate.

Certain aspects of sewage disposal deserve special attention from the standpoint of national policy and economy, such as wider utilization of sludge gas, the use of sludge and of sewage in agriculture, and the recovery of by-products from trade wastes. At the present time only a fraction of the sludge gas produced is utilized. The use of sewage sludge for manurial purposes is at last being systematically investigated.

The use of sewage or effluent for agricultural purposes is not necessarily a retrograde step because of the unsavory conditions which existed at some of the early farms due to overloading of the soil. Sewage or effluent could be applied to suit the weather, the land and the crop.

K. V. Hill

Sanitary Engineering in the Republic of Colombia. By Lucio Chiquito. *The Surveyor,* 104, 375 (July 6, 1945).

The characteristics of Colombia, which is a very mountainous country, are described briefly. Elevations vary from sea level to 18,000 feet. There are two principal rivers, the Cauca and the Magdalena, which, after their confluence, flow into the Caribbean Sea.

Water supply is in the developmental stage, with practically all of the capitals of the Departamentos having adequate service. The author predicts that, in the very near future, all towns of over 5,000 population will have modern aqueducts. All items of a water supply project such as pipe, chlorinators, measuring apparatus and the like, are imported. Because of limitations imposed due to the importing of all material and of limited construction funds, it has been the practice to provide a water supply for as many communities as possible first, and to schedule purification works following completion of the supply.

Surface water from rivers and brooks is the main source of supply, with impounding reservoirs used only in Bogota. Underground water has been used only for small communities. Design quantities are predicted upon 250 to 300 liters per capita per day.

During the war, it was possible to import very little construction material. It is hoped to resume construction on a greater scale in the future.

Sewer construction has been more rapid than water construction because of the fact that raw materials are available locally. In 1940 there were many towns with sewer systems of a sort. Only one town had a system designed and constructed under technical supervision. By the end of 1941, there were fifty such systems. In 1943 there were 270 sewerage systems.

Concrete pipes are made in the country, either mechanically or manually. Vitrified pipes are used for systems dealing with dry weather flow. The minimum velocity for dry weather flow is 2.5 ft. per sec.; the minimum diameter pipe used is 8 in. Flush tanks are little used. Storm water overflows are general. In very few cases is it necessary to pump the sewage.

As in the case of the water systems, the sewers are installed first, with treatment plants to follow when possible.

In rural areas, water supply and sewerage are the concern of the corresponding municipality, guided technically by the Secretaria de Higiene of each Departmento. The aim is to supply water as biologically pure as possible and in abundant quantities. Public baths and public wash houses are constructed and children are obliged to bathe at school.

Sewage is treated in septic tanks and discharged through subsurface tile filters. No steps have yet been taken with regard to treating wastes, the industries discharging their wastes freely into the sewers and small streams.

K. V. Hill

The Treatment of Settled Sewage by Continuous Filtration with Recirculation of Part of the Effluent. By E. V. Mills. Paper* presented at a meeting of the Metropolitan and Southern Branch of The Institute of Sewage Purification, Nov. 10, 1945. 14 pp.

Since 1938 large scale tests on the treatment of settled sewage by single filtration and alternating double filtration have been in progress at Minworth. Later one of the four filters became available for further tests and it was decided to use it for tests on continuous filtration with recirculation of part of the effluent.

The filter is 116 ft. in diameter and 6¼ ft. deep, containing an effective volume of 2,173 cu. yd. of medium. The upper 2½ ft. of the filtering medium is ¾-in. round gravel and the remainder is 3-in. broken brick. A four-arm rotary distributor is provided which has a capacity of about 1,000 gal. (Imp.) per minute. Sewage is discharged through jets, most of which are ¾ in. in diameter. Filter effluent is discharged to a humus tank 30 ft. sq. and 28 ft. deep. Humus tank effluent is pumped to the supply pipe leading to the filter.

The filter had been operated until the spring of 1939, treating 60 gal. per cu. yd. per day. It was shut down at that time because of the clogged condition of the medium due to fungus growths. During the summer of 1941 the surface stone was clean but there was a considerable amount of dried film below the surface. The filter was matured by applying settled sewage and later a mixture of settled sewage and returned effluent from June 21 to August 31. Effluents were satisfactory at the end of August. Operating results are given in the following tabulation.

* A preprint.

Period	Rate (1)	Analyses, Parts per Million				
		B.O.D.		Nitrogen as Ammonia		Effluent, Nitrogen as Nitrite plus Nitrate (a)
		Influent	Effluent (a)	Influent	Effluent (a)	
1941–42						
Sept. 1–Nov. 30	200	105	8.5	35	24	7.5
Dec. 1–Mar. 1	210	125	11	26	20.5	8
Mar. 2–May 31	210	150	16	29	25.5	6
1942–43						
June 1–Aug. 31	210	170	13.5	38	15.5	15.5
Sept. 1–Nov. 30	210	160	12	39	19	17
Dec. 1–Feb. 28	210	130	12.5	29	22.5	9
Mar. 1–May 31	210	155	16	37.5	25.5	8
1943–44						
June 1–Aug. 31	245	160	12	37	16	12
Sept. 1–Nov. 30	248	170	13	35.5	19	10
Dec. 1–Feb. 29	247	150	15	33	32.5	3
Mar. 1–May 31	240	175	17	37	36.5	3

(1) Rate of treatment of settled sewage in gallons (Imp.) per cubic yard per day. An equal volume of humus tank effluent was recirculated through the filter.

Note: (a) After one hour of quiescent settling of the sample.

During the winter and spring months trouble was experienced due to ponding and accumulations of obstructive growths below the surface. Forking of the surface at frequent intervals, or scouring of growths below the surface, or a combination of the two methods were effective in correcting ponding. However, ponding was replaced by extensive waterlogging and results were unreliable in the spring. Scouring was accomplished by retarding the distributor and allowing the jets to wash material from the sub-surface medium.

For purposes of comparison, the table below is presented which shows operating results for a single filtration unit and for a unit employing alternate double filtration.

Analyses of Settled Effluents

Period	Single Filtration Unit				Double Filtration Unit						
	Rate (1)	B.O.D., p.p.m.	Nitrogen as Ammonia, p.p.m.	Nitrogen as Nitrite plus Nitrate, p.p.m.	Rate (2)	B.O.D., p.p.m.		Nitrogen as Ammonia p.p.m.		Nitrogen as Nitrite plus Nitrate, p.p.m.	
						I	II	I	II	I	II
1941–42											
Sept. 1–Nov. 30	83	9.0	10.0	26.5	215	10.5	8.5	27.5	17.0	6.5	17.0
Dec. 1–Mar. 1	80	9.5	16.0	16.5	214	19.5	6.0	25.5	23.0	3.5	8.5
Mar. 2–May 31	80	13.0	17.5	19.0	212	22.0	10.0	28.5	25.0	4.0	9.5
1942–43											
June 1–Aug. 31	84	12.5	11.0	28.5	241	17.0	12.0	32.5	25.5	4.0	10.0
Sept. 1–Nov. 30	80	11.5	14.0	25.5	244	18.0	12.0	35.0	28.0	3.5	6.0
Dec. 1–Feb. 28	67	9.0	16.5	20.0	252	16.5	9.5	28.0	25.0	5.0	8.0
Mar. 1–May 31	63	14.0	16.0	24.5	256	20.0	12.0	35.5	29.5	3.0	5.5
1934–44											
June 1–Aug. 31	78	9.5	8.0	30.0							
Sept. 1–Nov. 30	74	7.5	12.0	24.0							
Dec. 1–Feb. 29	65	7.0	19.5	19.5							
Mar. 1–May 31	58	8.5	17.0	24.5							

(1) Rate of dosing in gallons per cubic yard per day.

(2) Rate of dosing of settled sewage in gallons per cubic yard per day, based on total volume of both filters. I. Primary filter effluent. II. Secondary filter effluent.

In general, the recirculating filter more closely resembled in behavior the alternating filtration unit than it did the single filtration unit.

In making a comparison of operating results it is to be remembered that the filter on which recirculation was employed had 2½ ft. of fine medium at the top, whereas the other filters had medium which was uniformly graded from top to bottom.

T. L. Herrick

The Treatment of Settled Sewage in Percolating Filters in Series with Periodic Change in the Order of the Filters. By E. V. Mills. Paper* presented at the Annual General Meeting of the Institute of Sewage Purification, Nov. 29, 1945. 16 pp.

The experimental plant at the Minworth works comprises four filters and four upward flow humus tanks. One unit is operated as a single filtration unit, one is operated with the recirculation of settled effluent, and the other two are operated as a double alternating filtration unit. The following table shows the main features of the four filters.

* A preprint.

	Single Filtration Unit (Filter A)	Recirculation Unit (Filter B)	Double Filtration Unit	
			Filter C	Filter D
Diameter, ft.	122	116	120	110
Effective Area, sq. yd.	1,098	1,043	1,098	1,009
Effective Volume, cu. yd.	2,379	2,173	2,196	2,355
Depth of Medium, ft.	6.5	6.25	6.0	7.0
Nature of Medium	1½-in. to 2-in. pebbles	¾-in. pebbles over 3-in. broken brick	1½-in. to 2-in. brick and pebbles	N. side, ¾-in. to ½-in. broken granite. S. side 1½-in. to 2-in. broken granite
Wall	Open stone	Open stone	Brick, solid	Open stone
Bottom Ventilation	Interior	Interior and through base of wall	Interior and through base of wall	Through base of wall

Note: Drainage tiles are provided over whole area of all filters.

All of the experimental filters were dosed with settled sewage. Results of operation for the single filtration filter and double alternating unit are given in the following table.

During the period from June, 1940, through May, 1941, the double filtration unit was operated at a uniform rate. It was not necessary to reduce the rate during the winter months as was the case with

Period	Rate, Gal. per Cu. Yd. per Day		Biochemical Oxygen Demand, p.p.m.			
				Settled Effluent (*a*)		
	Filter A	Filters C and D together	Influent	Filter A	Filters C and D	
					Primary	Secondary
1940–41						
June 10–Aug. 31	81	163	155	16.5	18.5	19.5
Sept. 1–Nov. 30	74	162	160	14.0	16.0	18.0
Dec. 1–Feb. 28	60	160	145	11.0	20.5	9.0
Mar. 1–May 31	77	162	130	12.0	17.5	9.0
1941–42						
June 1–Aug. 31	78	210	105	11.0	9.0	14.0
Sept. 1–Nov. 30	83	215	105	9.0	10.5	8.5
Dec. 1–Feb. 28	80	214	125	9.5	19.5	6.0
Mar. 1–May 31	80	212	150	13.0	22.5	10.0
1942–43						
June 1–Aug. 31	84	241	170	12.5	17.0	12.0
Sept. 1–Nov. 30	80	244	160	11.5	18.0	12.0
Dec. 1–Feb. 28	67	252	130	9.0	16.5	9.5
Mar. 1–May 31	63	256	155	14.0	20.0	12.0
1943–44						
June 1–Aug. 31	78	240	160	9.5	18.5	11.0
Sept. 1–Nov. 30	74	240	170	7.5	22.5	9.0
Dec. 1–Feb. 28	65	244	150	7.0	21.5	9.0
Mar. 1–May 31	58	235	180	8.5	35.0	14.0

Note: Filters C and D alternated as follows: 1940–1942, weekly, primary effluent settled. 1942–1943, daily, primary effluent settled. 1943–1944, daily, primary effluent not settled.

(*a*) After quiescent settling for one hour.

the single filtration unit, where the rate was reduced from 80 to 60 gal. per cu. yd. per day during December, January and February. Moderate surface ponding occurred on both filters of the double filtration unit in isolated patches. Ponding was very severe on the single filtration unit, necessitating the reduction in rate of application.

It was characteristic of the process of double alternating filtration that most of the work was done in the primary filter. Discharge of effluent of doubtful quality from the primary filter resulted in the rapid deterioration in the condition of the secondary filter. It appears that a good primary effluent is essential for satisfactory operation.

During warmer weather the B.O.D. of the secondary effluent was greater than that of the primary effluent. This is attributed to nitrification during the incubation of the sample.

During the winter of the 1941–1942 period ponding was severe on the double filtration unit. By the end of March the surface of filter C was only slightly ponded but it was so severe on filter D that when treating settled sewage the liquor began to run down the wall in places. The ponding was due to moderately heavy growths of fungus beneath the surface of the filter. Early in April the patches were lightly forked over and they drained immediately. The filters of the double filtration unit recovered their summer conditions more rapidly than did the single filtration unit.

The order of the filters was changed daily during the period from June, 1942, to May, 1943. Heavy subsurface growths appeared in both filters but these accumulations did not seriously hinder the flow of liquid. It was not necessary to fork the surface of the filters. It is of interest to note that during the warmer months of this period B.O.D. of the secondary effluent was not higher than that of the primary effluent. During the winter and spring the quality of the effluent from the primary filter did not deteriorate to nearly the extent that it did during the previous season, when the order of the filters was changed weekly. Furthermore, the condition of the filters was much better during the winter than it was during the winter of 1941–1942. It appears that daily change in the order of the filters gives better results than can be obtained with weekly change.

During the next period, 1943–1944, the order was changed daily and the primary effluent was pumped directly to the secondary filter, without settling. Heavy surface growths did not develop on the filters but considerable amounts of fungus and watery sludge accumulated below the surface in winter. The filters did not recover typical summer conditions as early as in the previous year. Apparently the main effect of treating unsettled primary effluent on the secondary filter was the deterioration in the quality of the primary effluent. It appears that satisfactory results could be obtained by this method if the filters were not too heavily loaded.

T. L. Herrick

Colored TNT Derivative and Alpha-TNT in Colored Aqueous Alpha-TNT Solutions. By C. C. Ruchhoft and Wm. G. Meckler. *Industrial and Engineering Chemistry* (Analytical Edition), **17**, 430–434 (July 15, 1945).

In connection with a study of treatment procedures for alpha-trinitrotoluene (TNT) wastes from shell, mine, and bomb loading plants, a method for determining the concentration of alpha-TNT or TNT derivatives in such waste was developed. Alpha-TNT in aqueous solutions reacts with sodium sulfite and sodium hydroxide to form a colored compound, and the color so formed can be intensified by dilution in a weak sulfite-hydroxide solution. The TNT concentration and the color intensity of the hydroxide and sulfite treated and diluted samples conforms to Beer's law. These reactions form the basis for a simple colorimetric, analytical procedure for the determination of TNT in polluted water and sewage samples. If a spectrophotometer or a photoelectric colorimeter is not available, the method can be adapted to simple direct color comparison with prepared standards. The spectrophotometric procedure requires the determination of extinction values of the colored waste as received at 460 and 505 millimicrons and similar determinations at 505 millimicrons on dilutions after sulfite and hydroxide treatment of the samples. The quantity of colored and alpha-TNT can be estimated from extinction values so obtained by calculation. Analytical data on eight different mixtures of colored and standard alpha-TNT solutions indicate that the procedure can be relied upon to give reasonable estimates of the uncolored alpha-TNT and the colored TNT complex in water containing mixtures of the two.

PAUL D. HANEY

1945 Progress Report on Pollution of Oregon Streams. BY FRED MERRYFIELD AND W. G. WILMOT. *Oregon State College Engineering Experiment Station Bulletin,* Series No. 19, 1–62 (June, 1945).

This bulletin is a report on studies completed during 1944 of the sanitary condition of the Wilamette River and its tributaries and the sewage and industrial waste load imposed upon this river.

The condition of the Wilamette River from Portland upstream to its confluence with the Coast Fork and of the Coast Fork upstream to Cottage Grove, an overall distance of over 200 miles, was studied by intermittent sampling from August 13 to December 5. The data on the dissolved oxygen and B.O.D. in the river throughout this section are presented in curve form. The river is seriously polluted in August and September from Portland upstream to Salem and is polluted locally below the cities of Albany, Corvallis, Eugene, and Cottage Grove. The zones of pollution have rapidly progressed upstream since the 1929 survey, thus indicating the need for early preventative measures. The construction of sewage treatment plants at the various cities and industries creating the pollution is advocated.

Limited surveys of the principal tributaries indicate that severe contamination also exists in the Rickreall, South Yamhill, South Santiam, and Pudding Rivers.

A survey was carried on from July 31 to December 5, to obtain information regarding the various wastes discharged to the section of the river being studied. Samples were collected in proportion to flow over a 24 hr. period bi-weekly at each station throughout the periods of survey. Flow measurements were made with weirs when possible. Where weirs were not installed discharge was estimated from sewer depths and velocities. Apples were used as floats to check the velocity of flow between adjacent man holes.

The average, maximum, and minimum B.O.D.; pH; acidity; chlorides; grease; bacteria; and settleable, total, and suspended solids of the sewage from each of 53 sewers in 21 cities and from 18 industries are shown in table form. No flow records are shown for these wastes; however, the authors state that additional data are available for the city engineers of each city surveyed, and that some estimates of the quantity of industrial wastes were made. Pulp and paper mill wastes and flax retting wastes were not sampled during this survey because they had been adequately covered in a previous bulletin; *Engineering Experiment Station Bulletin No. 7.*

Methods of sampling and analyzing the wastes are described in detail so the bulletin can be used as a guide by the various city engineers cooperating on future surveys in the State of Oregon. A brief discussion is also presented describing the various methods of sewage treatment in general use at the present time, that is, sand filters, trickling filters, and activated sludge.

The advisability of providing for gas recovery from the digestion process so it can be used for heat and power is discussed, and it is pointed out that the quantity of gas produced by sewage sludge may be materially increased in the future when home garbage grinding equipment comes into common use.

PHILIP F. MORGAN

Fourth Annual Report of the Sewage Incinerator Committee, Wausau, Wisconsin, for Year 1944. BY L. MANTEUFEL.

This report covers both sewage and refuse disposal for a town of 27,268 population (as of 1940). The personnel of the sewage treatment plant comprised six full time employees; chief operator, two maintenance men, two operators, and a chemist-clerk. These work 48 hours per week. Accumulative sick leave is granted at the rate of one day per month.

The sewage pumped (22 ft. lift) and treated averaged 2.77 m.g.d. in 1944, with a maximum flow of 7.0 m.g.d. During the year 121.5 kw.h. was used per m.g. An additional 73.5 kw.h. per m.g. was used in operating the treatment plant and incinerator. Only 234 kw.h. were purchased.

The plant comprises bar screen, grit chamber, flocculator, clarifiers, and digestion tanks, with air-drying sludge beds. Chlorination is used for odor control and sterilization. The nearest bathing beach is five miles downstream. There are two gas-driven generators, respectively 35 and 50 kw. The grit averaged 2 cu. ft. per m.g. and the screenings 1.37 cu. ft. per m.g.

Operating Data. 1944

	Suspended Solids, p.p.m.	5-day B.O.D., p.p.m.
Raw Sewage	45 to 409	132 to 300
Effluent	20 to 132	108 to 204

The average removal in per cent was, for suspended matter, 54.5, and B.O.D., 25.

From the clarifiers 778,270 lb. of dry solids were removed, containing 569,920 lb. volatile matter, which, upon digestion, produced 9,451,350 cu. ft. of gas, or 16.65 cu. ft. gas per lb. volatile matter. The two digesters are worked in series. The gas is used in gas engines and for heating the digesters.

In 1944, 1,060 cu. yd. of wet sludge were dried and shredded. Of this, 226.3 cu. yd. of dried sludge were sold for $626.50. 71,200 gal. of liquid sludge were sold for $178.00.

With 7,513,810 cu. ft. gas, 197,280 kw.h. were generated, or an average of 38 cu. ft. per kw.h. The value of the current is figured at two cents per kw.h., the municipal rate. 250,250 cu. ft. gas were used for pumping and 468,000 cu. ft. for water heating and laboratory work.

The operation of the sewage treatment works, incinerator, and city dump cost $42,919.27. This was allocated as follows:

Sewage Plant	$15,882.92
Incinerator	23,678.06
Dump	1,981.93
Garage Construction	1,376.36

In the sewage plant, the expense is distributed as follows:

Gasoline	$ 43.17
Oil and Grease	521.82
Coal	412.63
Water	131.52
Power and Light	4.80
General Expense	1,165.60
Office Expense	226.72
Machine Repairs and Parts	517.23
Pay Roll	11,779.43
Chemicals and Laboratory Supplies	1,080.00

LANGDON PEARSE

The People of the State of California, Plaintiff v. City of Los Angeles *et al.* Defendants.

On January 31, 1946, Judge J. W. Vickers of the Superior Court of the State of California in the County of Los Angeles entered a decree enjoining the defendants (City of Los Angeles *et al*) on and after December 31, 1947, from maintaining without a permit from the State Department of Public Health of the State of California any sewage treatment works or conduits for the discharge of sewage or sewage effluent or impure water, gas, vapors, oils, acids, tar, or any matter or substance offensive, injurious, or dangerous to health in Santa Monica Bay; further, Defendants are enjoined from discharging into Santa Monica Bay any sewage or any matter or substance in any manner, quality, or quantity likely to be offensive, injurious, or dangerous to the public health; further, Defendants are enjoined from maintaining a public nuisance along the beach and in the adjacent shore waters of Santa Monica Bay.

The decree states that a public nuisance shall be deemed to be maintained if—

(1) there is visible on any of the beaches or in the waters of Santa Monica Bay any garbage, fecal matter, sewage grease, solid matter or oily sleek recognizable as of sewage origin, except such oily sleek as may exist at the end of any submarine outfall through which sewage effluent is discharged pursuant to and in accordance with a permit from the State Department of Public Health;

(2) there is any noxious or offensive odor, gases, or fumes of sewage origin in the water or along the beach or shores of Santa Monica Bay;

(3) there is, in the operation of any sewage treatment plant or works, any noxious or offensive odor, gases, or fumes noticeable outside of the tract of land upon which said plant is located;

(4) the quality of water in Santa Monica Bay does not conform with the bacterial standards for salt water bathing beaches as now established by the State Board of Public Health;
(5) or if any other condition or conditions exist or are permitted to exist which under the laws of the State of California constitute a public nuisance.

The decree further orders the immediate installation of additional chlorinating equipment at the Hyperion plant to reduce the bacteria in the sewage to a degree that will be safe for bathing in Santa Monica Bay along the beaches extending southward from the southerly city limits of Manhattan Beach and northerly from Brooks Avenue in Los Angeles.

Prior to April 1, 1946, Defendants shall begin construction of and finish prior to August 1, 1947, a non-leaking submarine tube extending out 5,000 feet.

Prior to July 31, 1946, Defendants are to prepare detailed plants and specifications for a new sewage treatment plant at Hyperion which shall not commit a nuisance as above defined.

Prior to March 1, 1946, Defendants shall begin excavation for the new sewage works.

The Judge summarizes the case in the findings of fact. On January 6, 1923, the State Board of Public Health (hereinafter called State Board) issued a permit to the City of Los Angeles whereby a submarine outfall extending 5,000 feet seaward and the Hyperion plant were built and placed in operation in May, 1925, and operated continuously since. For a long time prior to September 3, 1940, Los Angeles had violated the terms of the 1923 permit by not screening a large portion of the sewage and by by-passing around the screens and discharging directly on the beach at times. Fecal matter, solids, and oily sleek of sewage origin were visible on all the beaches on Santa Monica Bay from State Park Beach to Malaga Cove. Further, the bacterial count exceeded 500,000 per c.c. at Hyperion, and the count of E. Coli exceeded 10 per c.c. on an area along the beach for approximately ten miles, from Brooks Avenue in Los Angeles to Seaside Terrace in Santa Monica. An objectionable odor nuisance existed on the waters and at the beaches. The operations of the sewage works was a menace to the public health and an odor nuisance.

On September 3, 1940, the State Board suspended the 1923 permit and granted a temporary permit, requiring the preparation of plans within a year. As nothing was done, the State Board revoked the temporary permit on May 18, 1942, and further revoked various permits to cities and sanitation districts to connect with the sewage system of Los Angeles.

For some years prior to September 3, 1940, the sewage plant at Hyperion had become obsolete, inadequate for its purpose and unfit and unsafe for use. The submarine tube was broken and leaked badly. The screens removed 10 to 15 tons (dry weight) of sewage solids per day, but the plant discharged into the Bay 150 to 160 tons (dry weight) of sewage solids per day, including "sewage, rags, rubber goods, garbage, feculent matter, offal, refuse, and filth." At Hyperion 8 to 10 tons or more of sewage grease arrives daily, of which only a small part is removed.

Large sleek fields of floating sewage matter form on the Bay. Sewage matter is washed ashore. Both the waters and beaches become so contaminated that the State Board quarantined the beaches from 14th Street in Hermosa Beach to Brooks Avenue in Los Angeles on April 3, 1943, and on October 13, 1945, extended the quarantined area to Seaside Terrace in Santa Monica.

The pollution of the Bay has driven away both sport and surf fish.

The area affected includes 80,000 feet of beach frontage (in which are two State Park beaches), which was visited by 60 million persons in 1942, forty per cent of whom were probably bathers.

On February 14, 1944, Los Angeles engaged Metcalf and Eddy as consulting engineers. They made a report to the Board of Public Works of Los Angeles on April 25, 1944, which advised the continuance of an ocean outfall with discharge one mile offshore, in 60 feet of water, and the construction of a high-rate activated sludge plant to handle 240 m.g.d. of sewage. Of the two sites considered, the Hyperion site was the less costly by one million dollars. The effluent is to be chlorinated, clear, free of most of the grease and at least 75 per cent of the suspended solids. The sludge is to be digested and heat-dried for use as fertilizer or incineration. The plant is to serve approximately 3 million people and cost (including the submarine outfall) 21 million dollars.

The report was accepted May 12, 1944, by the City Council and Board of Public Works, and the City Engineer was ordered to proceed with the plans. Bids for the submarine outfall were scheduled for January 9, 1946.

It was found that six chlorinating machines (each 3 tons daily capacity) could be bought and installed by June 1, 1946, to chlorinate the present effluent and benefit about 3.5 miles of beach.

The necessary financing was arranged in 1944–1945 by Los Angeles. The schedule of feasible dates are:

Chlorinating equipment in operation	June 1, 1946
Submarine outfall in operation	August 1, 1947
Plans completed for treatment plant	July 1, 1946
Treatment plant in operation	December 31, 1947

LANGDON PEARSE

Wisconsin Progress Report on Sanitary Engineering and Stream Pollution Control Activities, 1942–1943. BY L. F. WARRICK. (December, 1944), 13 pages.

This report outlines the fields of activity of the personnel of the Bureau of Sanitary Engineering of the Wisconsin State Board of Health. Investigation and review of plans have been made for 516 water supplies, 527 sewerage systems, 577 industrial wastes, 149 stream pollution problems, 105 recreational bathing places, 83 slaughterhouses, 271 swimming pools, and 27 garbage and refuse disposal dumps. Sixty-one per cent of the state's population is served by 228 sewage treatment plants, 119 of which have only primary treatment, while 78 include trickling filters and 28 have activated sludge units.

Because of the war demands, a number of industrial plants have been greatly enlarged and new ones built. This has required the construction of new milk waste treatment plants and the expansion of some pulp and paper mill waste treatment units during the war period. Some studies on the effect of sodium nitrate addition to canning plant waste lagoons indicate that the sodium nitrate is capable of controlling odors beyond 200 ft. from the lagoons of lima bean and corn packing plants. This is possible when cooling water and silage juice are not added to the lagoon. Studies in cooperation with the United States Public Health Service have been undertaken on food dehydration wastes, metal industries wastes and a new plastic industry's waste. The recommendations for treatment of the industrial wastes were made as the result of stream surveys.

The chemical treatment of lakes and streams to control algae and swimmers' itch has been carried out in connection with a special committee by employing extra help. Greater control of mosquito breeding places will be undertaken as a post war measure to prevent the spread of malaria carried by returning soldiers.

A new bill by the legislature gave the board of health jurisdiction over slaughter houses on July 1, 1943, in regard to slaughtering and slaughter house sanitation. Only about 20 per cent of the state's 400 slaughtering establishments have been examined so far. Rendering plants have also been inspected and licensed.

Examinations of swimming places were limited to routine bacteriological tests. Garbage and refuse dumps were examined as the result of complaints.

The report is very general, giving areas of activity, but no technical or engineering data.

ROBERT S. INGOLS

Pilot Plant Digestion Experiments. BY DAVID BACKMEYER. *Sewage Gas,* 8, 4 (June, 1945), Indiana State Board of Health.

In May, 1944, a series of batch sludge and garbage digestion experiments were begun on a pilot plant scale to determine the proportionate amount of gas produced from garbage. The tests indicated that from 7.7 to 13.5 cu. ft. of gas per pound of volatile solids added or an average of 11.3 cu. ft. may be obtained from digested garbage seeded with supernatant liquor in 15 to 20 days.

G. P. EDWARDS

Items to Consider When Planning Sewage Plant Extensions or Improvements. By J. E. Hupp. *Sewage Gas,* 8, 14 (June, 1945).

When planning sewage plant extensions or improvements it is well to examine the sewerage system to determine whether trouble is caused by excessive ground water leaks, industrial wastes, or septic sewage. Sometimes these causes of difficulty can be readily removed. Good operating records are very helpful to engineers designing additions to a plant and cost records will point out the equipment requiring excessive maintenance.

G. P. Edwards

Clarifiers. By J. B. Kleven. *Official Bulletin* of the North Dakota Water and Sewage Works Conference, 13, 5 (Dec., 1945).

The sewage treatment plant at Grand Forks, N. D., has two circular clarifiers each 35 ft. in diameter and 8 ft. deep at the side wall. The detention period averages about 2 hr. but varies usually between 1.5 and 6.0 hr. during a day. Good removal of suspended solids is obtained at rates as high as 1.1 gal. per sq. ft. per minute (1,580 gal. per sq. ft. per day). The sludge scrapers are operated continuously, but sludge is pumped during four 20–25 min. periods in a day. The effluent weirs are V notched. The concrete in the tanks is in good shape after eight years of service.

G. P. Edwards

BOOK REVIEW

Water Bacteriology. By S. C. Prescott, C.-E. A. Winslow and Mac H. McCrady. John Wiley and Sons, Inc. Sixth edition, 1945. Price, $4.50.

This is a book of 368 pages comprising thirteen chapters as follows:

Previous editions of this authoritative treatise are well-known under the title "Elements of Water Bacteriology." The sixth edition is a comprehensive revision of the preceding one and has been expanded throughout. New chapters on bacteriology of sewage and on shellfish bacteriology have been included.

The book is painstakingly thorough in its coverage of all public health phases of water bacteriology, it being emphasized that the scope is confined to such organisms as may be introduced into water from extraneous sources and are therefore of sanitary significance. Analytical procedures, from sampling practices to the reporting and interpretation of results, are reviewed in detail, making the book a valuable explanatory supplement to the laboratory manual *Standard Methods for the Examination of Water and Sewage.*

With a single exception, the new volume is up-to-date in every respect. The section on standards of bacteriological quality of water presents the 1942 Drinking Water Standards of the U.S.P.H.S., whereas these standards have been superseded by revised regulations approved on February 6, 1946. Access to the manuscript of the ninth edition of *Standard Methods* (now in production) enabled the authors to take account of such revised analytical procedures as may be set forth therein.

The new chapter on sewage bacteriology is highly practical and informative. Here are discussed special analytical procedures in the examination of sewage samples; the occurrence of bacteria in raw sewage and in effluents from presently employed methods of treatment; disinfection practices and a brief review of the part played by bacteria in sewage treatment.

Those interested in the sanitation of shellfish production will find the new chapter on this subject to be most useful, as will pollution abatement authorities who are concerned with waste disposal into coastal waters.

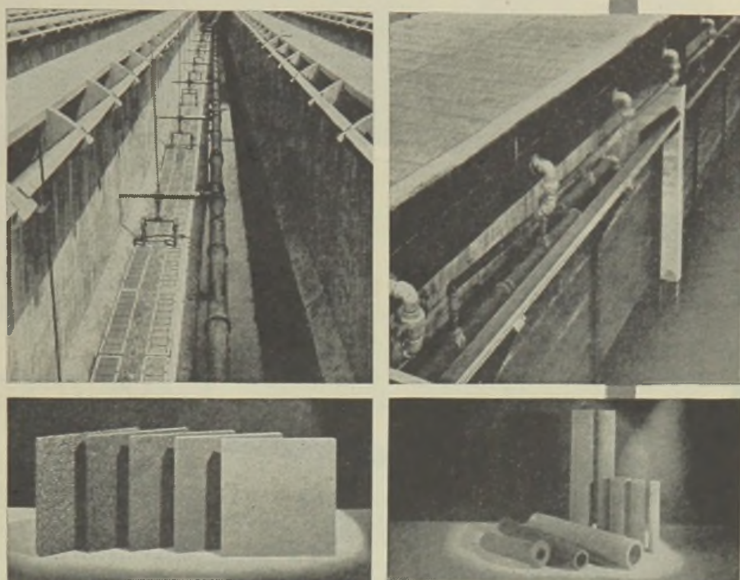
A particularly notable feature of the

book is the unusually comprehensive bibliography. A total of 53 pages is devoted to the presentation of almost a thousand significant references.

The new edition of *Water Bacteriology* is enthusiastically recommended to laboratory analysts, public health officials, sanitary engineers, research workers and students.

W. H. WISELY

Original Woodcut by Lynd Ward



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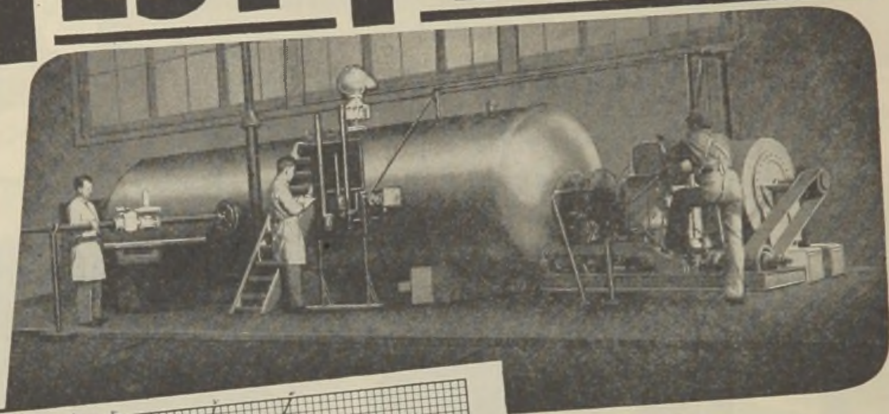

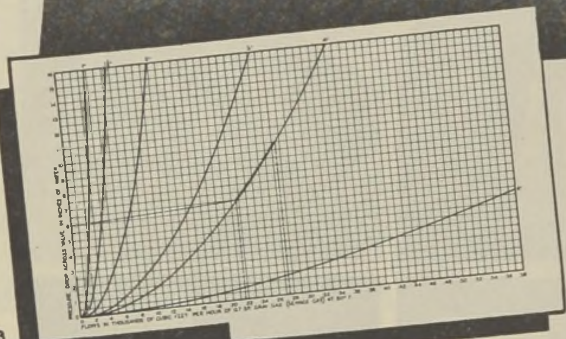

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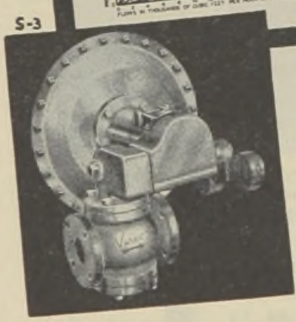
S-3



"VAREC" *Approved* BACK PRESSURE REGULATOR (DOUBLE PORT) Figure No 186.

THE above chart shows actual flow capacities. This regulator will maintain a back pressure to within 5% of the desired predetermined pressure. It is particularly advantageous for installation where dependable, delicate up-stream control is important.

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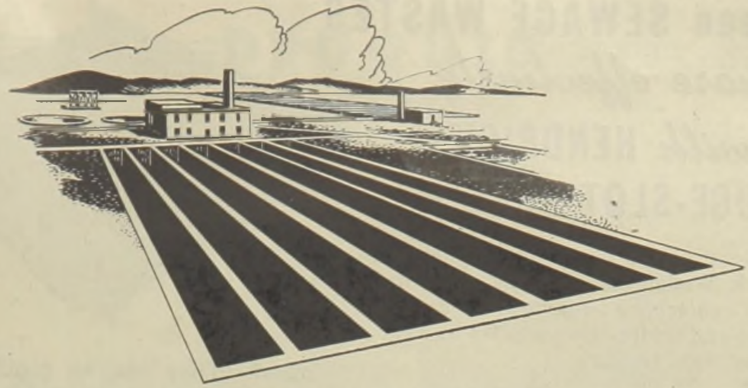

DIRECTORY OF ENGINEERS

(Continued on pages 36 and 37)

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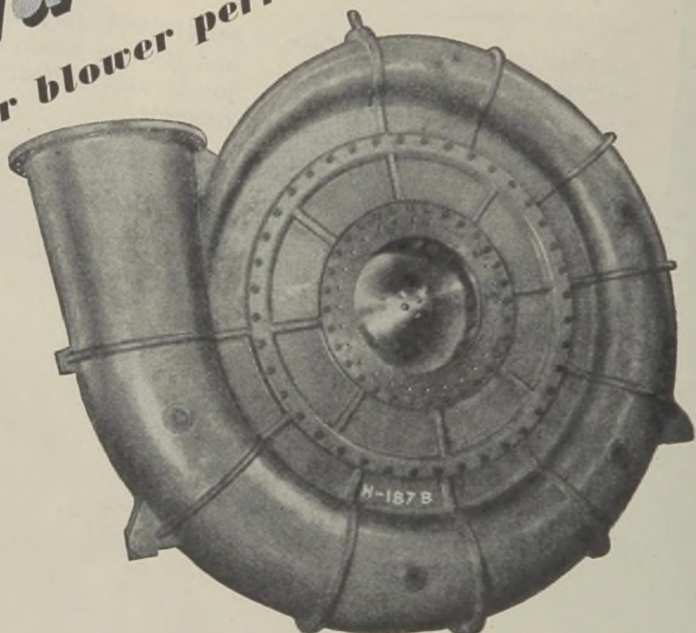

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