SEWAGE WORKS JOURNAL

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Industrial Wastes—Adams

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Sludge Deposits—Fair, Moore and Thomas

Effective Bacteria in Trickling Filters—Butterfield

B.O.D. Dilution Water—Ruchhoft and Committee

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SECOND ANNUAL CONVENTION
New York City, October 9-11, 1941

OFFICIAL PUBLICATION OF THE
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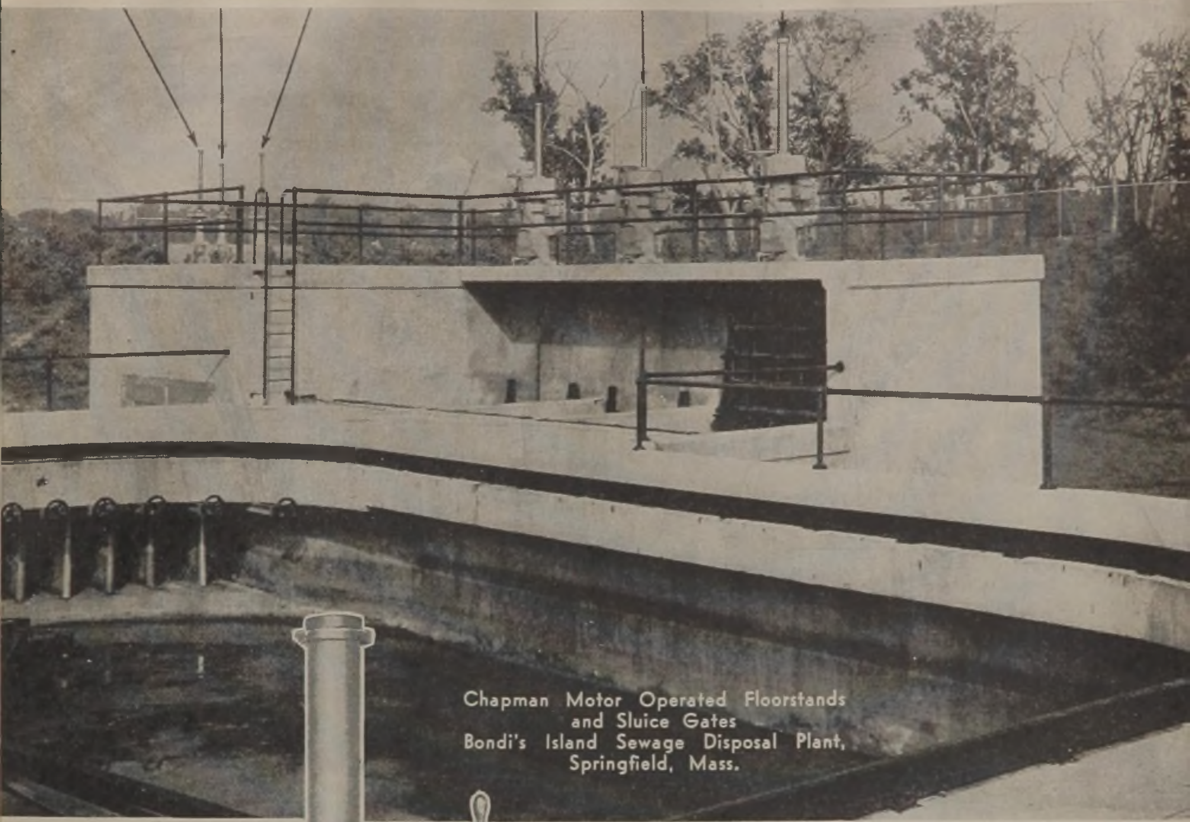

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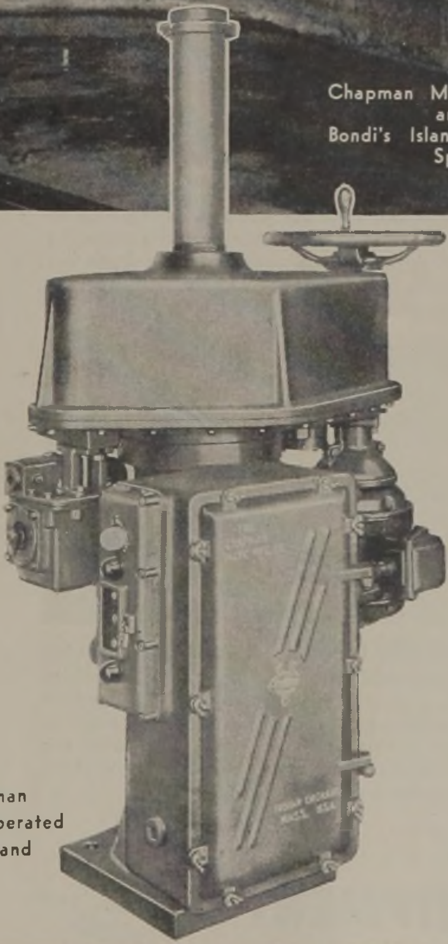

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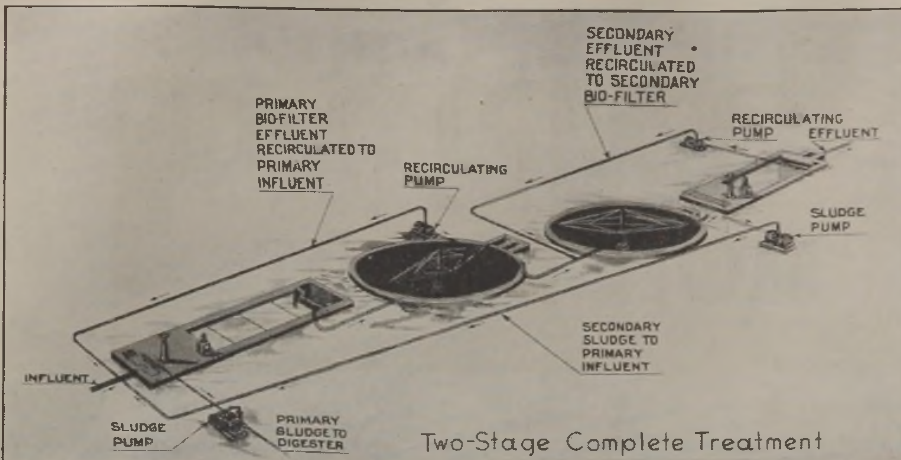

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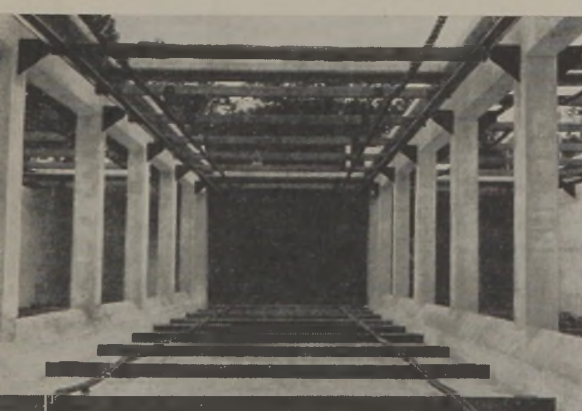

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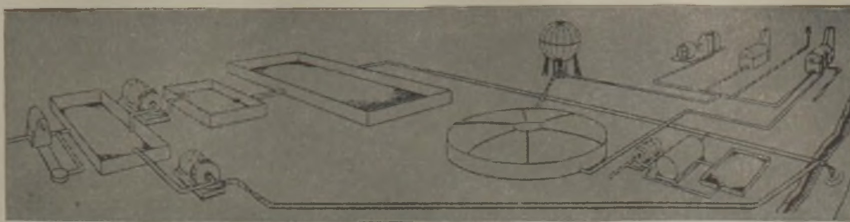

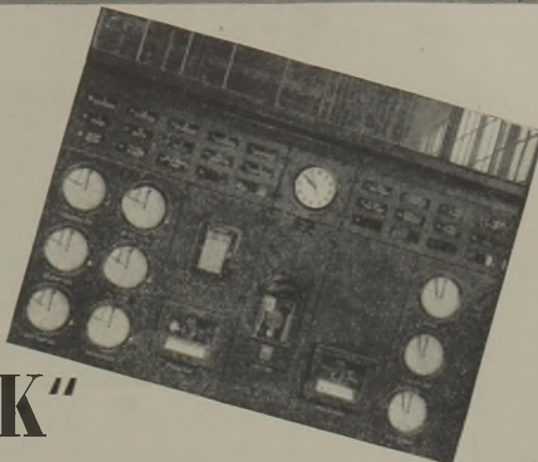

36-inch cast iron pipe being installed by Central Delaware County (Pa.) Authority for an outfall sewer

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Sewage Research

STUDIES OF SEWAGE PURIFICATION

XV. EFFECTIVE BACTERIA IN PURIFICATION BY TRICKLING FILTERS

By C. T. Butterfield and Elsie Wattie

Principal Bacteriologist and Asst. Bacteriologist, U. S. Public Health Service, Stream Pollution Investigations, Cincinnati, Ohio

In studies of the activated sludge process of sewage purification, it was shown [1] that the predominant bacteria in activated sludge belonged to a group represented by zoogleal formations. Subsequently it was demonstrated [2] that these bacteria are the active agents in activated sludge, being capable in pure culture of producing not only activated sludge but also possessing the powers of oxidation and purification inherent to natural activated sludge.

In the trickling filter process of sewage purification, also biological in nature, the fundamental set-up of the process would suggest that the active agents might be the same organisms as those of activated sludge. That is, with both processes the success of the purification depends on the presence of three essential elements, (1) bacterial masses or flocs, (2) food supply for these bacteria, *i.e.* polluting material, and (3) a continuous source of oxygen. The process is also dependent upon a physical means of keeping these three elements dispersed and continuously in contact with each other. In the activated sludge process the contact and mixing is brought about by an agitation of the sludge-sewage mix with compressed air which also provides a continuous source of oxygen. In the trickling filter the sludge mass is held dispersed on a framework of stones, or other material, while the sewage trickles over the surfaces of the sludge. The interstices of this framework provide an ample air reservoir and the circulation of this contained oxygen is aided, in part, by the flow of liquid through the system. With intermittent flow, time is provided for the sludge to utilize the adsorbed substances. Moreover, the successful perpetuation of both processes is dependent on the frequent or continuous removal of excess and, frequently, detrimental by-products. Soluble fractions of such by-products are removed with the effluent in both processes. Suspended matter is removed continuously in the activated sludge process by the withdrawal of excess sludge while in the trickling filter such withdrawals are accomplished by a continuous but moderate unloading and by a periodic sloughing off of the accumulations on the filter stones. With both processes the removal of excess material is aided probably by successive growths of various biological forms. The latter factor is probably more significant in the trickling filter where such biological growths are more varied and more abundant.

While the two processes are fundamentally similar, it does not necessarily follow that the active bacterial agents are the same or even belong to the same group or genus. Consequently, it appeared desirable to study the bacterial flora of trickling filters, to isolate the predominant bacteria in a few instances, to determine the ability of these organisms in pure culture to carry on the trickling filter process, and if such bacteria appeared to be similar to those obtained from activated sludge, to make a comparative pure culture study of the two types employing both activated sludge and trickling filter set-ups. Consideration is now given to the results of studies which may clarify these questions.

Operation of Experimental Unit

An experimental trickling filter, 30 in. square and 6 ft. deep, constructed in three equal sections to allow for the collection of samples, served as an immediate source of material for this study. The filter was fed with settled natural sewage in standard fashion (in intermittent cycles), usually at a rate of 3 million gallons per acre per day continuously throughout the 24-hour period. The sewage employed was from Third Street sewer, Cincinnati, Ohio, which carries principally a domestic sewage from a residential section.

From the start of the flow of sewage through this filter, frequent macroscopic and microscopic examinations (the latter of both wet and dry stained preparations) were made of composite samples of material scraped from the stones of the filter. Results of these examinations indicated a very marked similarity between the growths on the stones of the trickling filter and the growths of activated sludge previously studied and reported.[1] This agreement was particularly apparent in the bacterial section of the biological elements involved. With regard to biological forms, other than bacteria, the presence of flies and fly larvae (which are never found in activated sludge) and of certain varieties of worms (only rarely observed in activated sludge) in the growths of the trickling filter have been noted. These observations have been confirmed repeatedly by the results of a study of the material on stones obtained from two municipal trickling filter plants.

Pure Culture Isolations

As soon as this trickling filter had developed a normal purification rate, as measured by the reduction in the B.O.D. of the sewage passing through the filter an intensive bacteriological study was instituted of the growths which had developed on the stones. This study involved the isolation, in pure culture, of the predominant bacterium present in the growths and in some instances an attempt to determine the relative number of such bacteria per ml. of growth. In making these observations, two methods were followed. With both methods a number of stones, with their adherent growth, were selected at random from various sections of the filter. After a gentle preliminary washing with sterile dilution water to remove extraneous and loosely attached material and organisms, the adherent growths were carefully scraped from the stones with sterile instruments and the removed material accumulated in a sterile petri dish. From this point one of the following two methods were applied.

Method No. 1.—The accumulated growth was mixed thoroughly, a one-tenth ml. portion was withdrawn, and examined carefully under low power magnification. Typical massed bacterial formations, which appeared to represent the predominant type of bacteria in the mixture, were selected, picked with sterile capillary pipettes and carefully washed by passing them, with appropriate agitation, through a series of sterile dilution waters. When these massed formations of bacteria had been presumedly washed relatively free of extraneous bacteria and adherent material, the bacteria in the masses were dispersed by pressure between two sterile glass surfaces. Simultaneously, sterile dilution water was added and a fairly thorough separation of the clumped bacteria was obtained. The organisms, thus dispersed, were planted in serial dilution in tubes of broth and synthetic sewage. The tubes were incubated at 20° C. and examinations were made at 24-hour intervals for 96 hours. Usually growth occurred in all dilutions up to and including the 0.00001 dilution and all growths above the 0.01 dilution appeared to be pure and of the same type of organism. Isolations made from the highest dilutions were subjected to additional purification and held for further study.

*Method No. 2.**—The accumulated growth, referred to above, was mixed thoroughly and a one ml. or larger portion was removed and placed in a one-ounce sterile ground-glass stoppered bottle with glass beads. Sterile dilution water was then added to make 10 ml. and the mixture shaken at full speed in the shaking machine for 10 minutes. Immediately afterward the now finely divided mixture was diluted further and planted in serial dilution in tubes of broth or synthetic sewage. Tubes thus inoculated were incubated at 20° C. for 96 hours. Growth usually occurred in all dilutions up to the 0.00001 or 0.000001 dilution and judging from microscopic observations all growths from tubes above the 0.01 to the 0.001 dilution contained pure cultures. To insure the purity of these cultures transfers were made from the highest dilutions showing growth. After these transfers had been incubated for 6–8 hours (*i.e.* after some growth had occurred but before sufficient

* Method No. 1 outlined above was the procedure followed in the original work with activated sludge as reported in reference (1). Shortly after this article appeared a fair and just criticism was voiced to the effect that this method of selection of the portion of sludge for examination introduced a personal equation in the selection which might materialy affect the result. That is, a mass might be selected which did not represent the predominant organism in the mixture. However, this presumption does not appear probable when it is considered that the worker responsible for the selection had been making daily intensive microscopical study of the material over a period of several months. A study of means of dispersing bacteria massed in the gross mixture, which may be reported later, resulted in the development of Method No. 2. It should be noted here that since then, the work reported in reference (1) has been repeated employing Method No. 2 without any variation in the type of organism isolated as the predominant bacterium in activated sludge. This Method No. 2 is not presented as a perfect procedure as it has many inherent errors. However, it does avoid some of the errors of procedure No. 1, and the fact that the same type of bacterium is obtained by both methods goes far toward establishing the results presented.

growth had taken place to produce any crowding or clumping of cells), they were planted out in serial dilution on dilute nutrient agar plates. (While these organisms do not grow well on standard nutrient agar they will produce colonies of about 1.0 mm. diameter after incubation for 4 to 6 days at 20° C. on dilute (1–3) nutrient agar.) Selecting plates which contained not more than 20 to 30 colonies per plate, transfers were made from typical colonies. This process of short-time incubation in liquid media followed by planting on solid media was repeated two or three times for each isolation. Colonial appearance, microscopic examination of stained smears and additional chemical tests have indicated the purity of the cultures thus obtained. Such cultures were held for further study.

Four such cultures of the presumedly predominant bacteria in the growths on the stones of the experimental trickling filter have been isolated and subjected to study. In addition, cultures have been isolated from two municipal sewage trickling filter plants.

These four isolations from the experimental filter were made from samples collected at various periods during the year as follows: (1) one in March when temperatures were near freezing and the filter was overloaded, (2) two in June when the temperature was about the average for the year and the filter was being fed at a normal rate of about 3 million gallons per acre per day, and (3) one in August when the highest temperatures of the year prevailed and the flow of sewage to the filter was at a normal rate. The average purification efficiency of the filter for each month in which these cultures were isolated, expressed in terms of the percentage of the 5-day B.O.D. removed, was for (1) 50.4 per cent, for (2) 92.8 per cent, and for (3) 93.9 per cent.

The results obtained while these cultures were being isolated show that these bacteria are present in the filter growth at least to the extent of 300,000,000 per ml. of growth. This figure is cited as representing a minimum number for it is not reasonable to presume that an accurate enumeration was obtained. As it was not possible to make direct counts of the bacteria present in such a mass, recourse was had to procedures which would disperse the bacteria so that plate counts or most probable number estimations based on growth in serial dilutions could be made. To make an accurate enumeration by such a procedure, two assumptions must be made: (1) that all clumps or masses of bacteria were completely broken up, and (2) that no cells were killed, or injured sufficiently to prevent growth, by the dispersion procedure. While the latter assumption cannot be tested, microscopic examination of the treated sample showed definitely that the dispersion of the massed organisms was not complete. Consequently, it is known that the 300 million count given is a low figure and does not represent the maximum number of this type of bacterial cells. In this connection, it is noted that pure culture trickling filter growths free from detritus or any other material (which will be discussed presently) yielded a count of 880,000,000 bacteria per ml. of accumulated growth. The accuracy of this count is subject to the same two assumptions.

Construction and Operation of Pure Culture Filter

The development of apparatus to explore the ability of these bacteria, under pure culture conditions, to reproduce the trickling filter process of sewage purification required considerable time and was accompanied by numerous failures before a fair measure of success was attained. The apparatus employed in the studies here reported is shown diagrammatically in Fig. 1. As the assembled set-up was too large to be sterilized intact, provision was made for a division into sections for sterilization. These sections, Unit A, stock supply of sterile synthetic sewage; Unit B, equalizing reservoir for maintaining approximately a constant pressure on the feed line; Unit C, trickling filter with provision for inflow and outflow of liquid, and Unit D, control device for intermittent flow, are indicated in the figure. Units A, B and C were sterilized by autoclaving with their tubes for subsequent interconnections adequately protected from contamination by cotton packing. Unit D, which did not come in direct contact with the filter or feed material, was not subjected to sterilization.

As far as is known this is the first time that an effort has been made to operate a trickling filter under pure culture conditions. Consequently, a detailed description of the various parts of the apparatus and their function may be of interest. Referring to the designations as given in Fig. 1, the component parts of the set-up may be described as follows: (*a*) five-gallon pyrex carboy, (*b*) sixteen liters of sterile synthetic sewage (for composition, etc., see Reference 2), (*c*) metal collar and clamp arranged to hold rubber stopper with its glass tube outlet firmly in place, (*d*) at this and other points, cotton packing so placed as to prevent the entrance of extraneous bacteria, molds, etc., (d^1) filters of 6 to 12 in. of loosely packed cotton in all air lines, (*e*) screw clamp on rubber hose connection (this clamp was left open during sterilization to allow free exchange of air and steam when carboy was upright, but was closed during the assembling of the apparatus until the time of sampling the synthetic sewage, the connecting of it to Unit B and the starting of the flow through the system, (*f*) pyrex glass tube constant level siphon (this tube must have its lower end beveled to facilitate the flow of air to (*a*) when the level of the sewage in (*g*) drops and sewage begins to flow into (*g*), (*g*) this is a 500 ml. pyrex bottle with side delivery outlet at the bottom, fitted with a two-holed rubber stopper, one hole for inlet sewage tube, the other hole for filtered air intake as sewage is discharged, (*h*) metal screw clamp on rubber tubing, (*i*) to regulate the rate of flow of synthetic sewage, (*j*) pyrex glass tube with constricted tip to aid in regulation of flow, (*k*) pyrex glass cylinder 30 in. long and 2 in. in diameter. (The overall length of tube (*k*) was limited to 30 in., providing for a filter depth of about one-third that of a normal trickling filter, because no greater lengths could be placed in the autoclave and sterilized. For pure culture set-ups such sterilization was essential), (*l*) gravel of ¼ to ½ in. diameter which filled tube (*k*) to a depth of 22 in., (*m*) tight-fitting rubber stopper forced entirely into

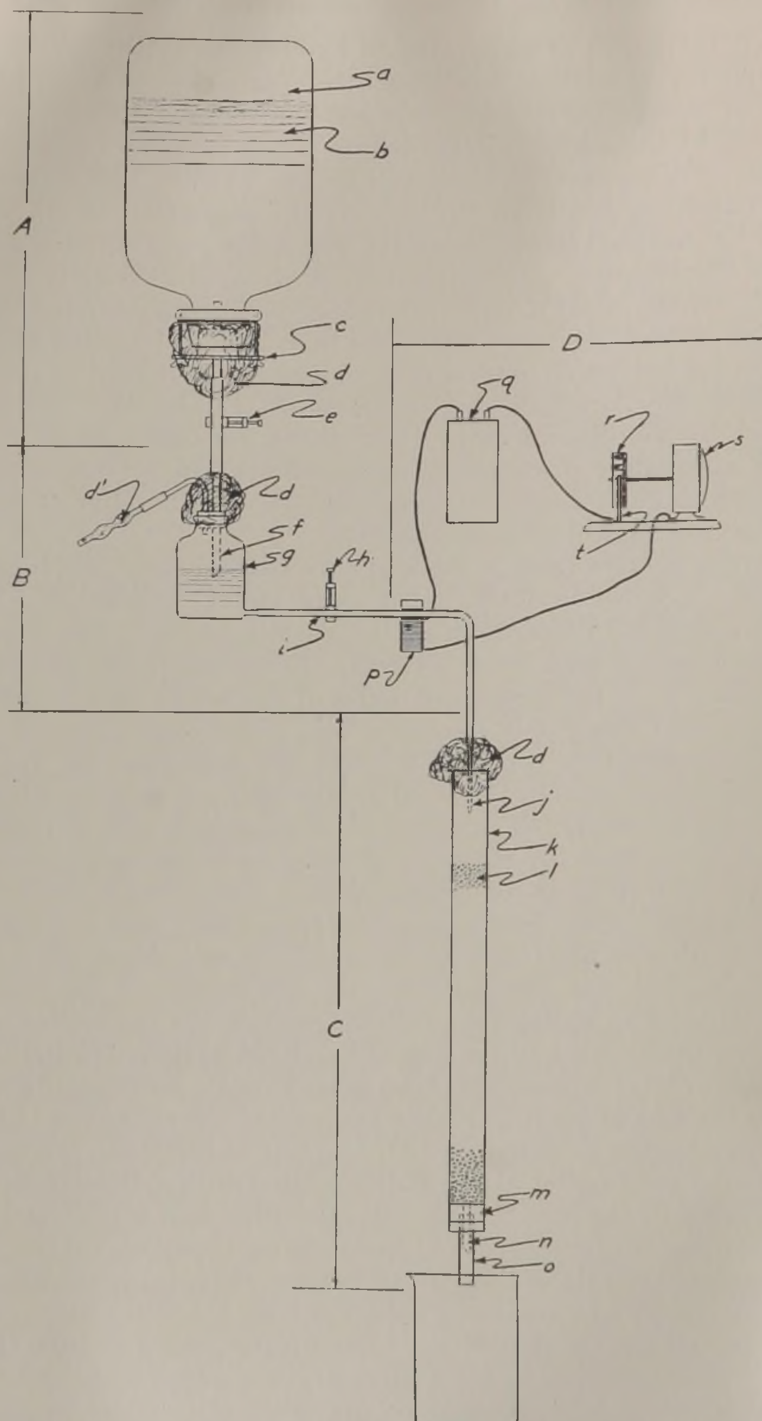


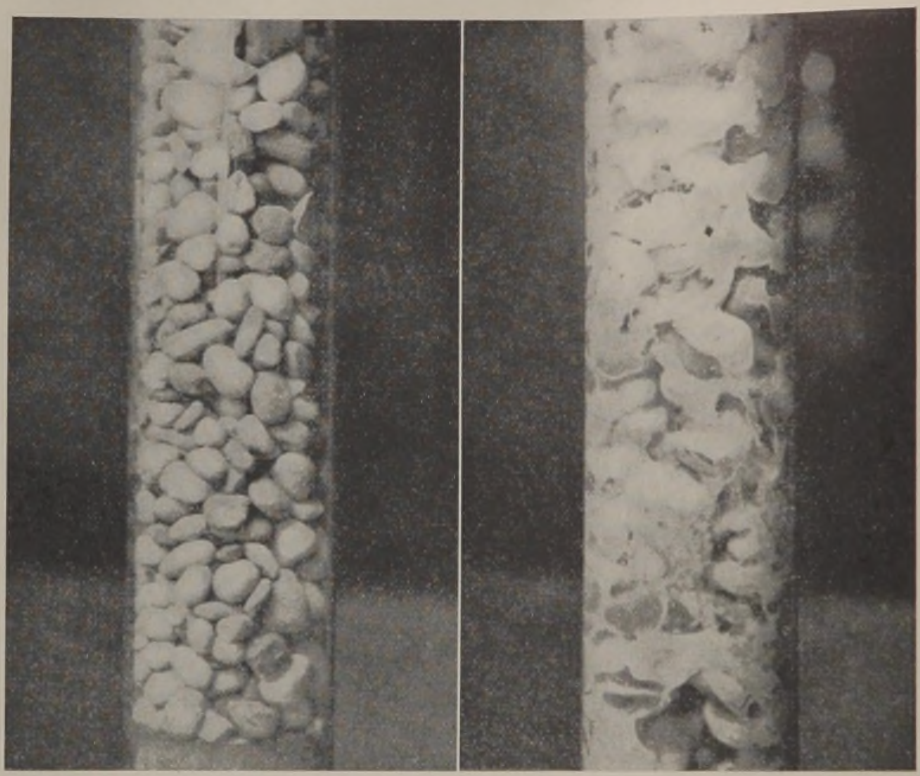
FIG. 1.—Diagrammatic sketch of pure culture trickling filter set-up.

lower end of (k), (n) effluent tube extending through (m) with lower end beveled to aid flow and air-liquid interchange, (o) large glass tube used as a shield for (n), the annular ring of rubber in the rubber stopper between (n) and (o) was left in place to aid in holding tube (o) firm and rigid, (p) an electromagnet which when activated closes on tube (i) collapsing it and stopping the flow of sewage, (q) a 2.0 volt cell connected to electromagnet through a make and break circuit, (r) commutator wheel provided with ten equally spaced contact segments fastened on the extended axis of the hour hand shaft of a clock, thus providing in each one-hour period 10 three-minute periods in which sewage was distributed to the filter at the established rate and 10 three-minute periods in which no sewage flow occurred, variations in the flow and rest periods of the filter may be provided by varying the number and size of contact segments on this commutator (r), (s) the clock which motivated the commutator (r), and (t) a sliding contact for the segments of (r) in the circuit of the two volt cell.

Methods of Developing Growth

In the development of appropriate growths on this experimental trickling filter two methods were tried for the initial seeding of the stones. In method No. 1 a small amount, 10 ml. of a broth culture of the organism under trial, was dropped slowly onto the top stones of the filter and allowed to trickle through. The filter then stood from one to two hours before the flow of sterile synthetic sewage was started. This interval permitted the added bacteria to become somewhat more firmly attached to the stones. Initial flow of sewage for the first day or two was always carried on at a slow rate of less than 1.0 million gallons per acre per day. Such low flows provided ample food for the small numbers of bacteria present and did not produce any violent washing action to carry away bacterial inoculation before growth had become established. With this method one week was required to obtain a satisfactory growth throughout the filter and two weeks were required for the filter to reach maximum efficiency.

With seeding method No. 2 eight liters of sterile synthetic sewage were inoculated with the test organism and aerated at 20° C. for 48 to 96 hours. Under such conditions a heavy, flocculent growth of these bacteria would develop. These 8-liters of growth were passed slowly through the gravel of the experimental trickling filter by means of a sterile siphon, while the filter drainage was carefully regulated by valves. By watching the location of the accumulation of growth added in this manner and making appropriate variations in the rate of flow, a very even distribution of the bacterial masses throughout the filter could be obtained. With this procedure the seeded filter was also allowed to stand for an hour or two after seeding before the initial slow flow of sewage was started. Using method No. 2, as much growth could be obtained in one day on the filter as in a week with method No. 1. Moreover, with method No. 2 maximum efficiencies would be obtained in a week. A photograph of a portion of this experimental filter with and without a fully developed growth of these bacteria in pure culture on the gravel of the filter is shown in Fig. 2. It is noted that the stones and adjoining sections of the retaining walls are covered heavily with growth. This growth is spongy and contains large amounts of moisture. Microscopic examinations indicated that it was composed entirely of bacterial cells. As observed above, this growth mass yielded a minimum bacterial count of 880 million per ml. of moist growth mass.



A B

FIG. 2.—Photograph of sections of pure culture trickling filter. *A.* Unseeded sterile filter. *B.* Filter seven days after seeding.

Testing Procedures

The extent of purification of the synthetic sewage accomplished as it passed through these pure culture trickling filters was measured by comparing the 5-day B.O.D. of the influent with the corresponding 5-day B.O.D. of the filter effluent. These determinations were made in accordance with the Standard procedure. Samples of influent and effluent were put up for this determination in appropriate dilution and seeded. The seed used (one ml. per liter of dilution) in each case consisted of settled domestic sewage after aeration for 24-hours at room temperature.

Rates of flow of the synthetic sewage through these pure culture filters were varied from less than 0.5 to 6.0 or more million gallons per acre per day. In the zone of 1.0 to 3.0 million gallons per acre per day tests made were repeated with greater frequency. These repetitions were made at various times during the life of the filter to provide observations on any variations in growth or in the condition of the filter as it aged. In all cases when a change in rate of flow was made, the filter was allowed to run at the new rate for a period, at least over night, to allow for an adjustment to the new conditions of flow before a test was made.

Results with Pure Culture Trickling Filter

Results obtained in this manner by pure culture trickling filters developed (1) by Culture 87 isolated as the predominant organism in the growth mass on the stones of a trickling filter fed with natural sewage, and (2) by Culture 86, a typical zoogleal bacterium, isolated as the predominant organism in activated sludge, are presented in Table I. The same results are shown graphically in Fig. 3.

Table I.—*Relative Purification Produced by Pure Culture Trickling Filter Growths Developed in an Experimental Trickling Filter*

By *A*: Culture 86, a predominant bacterium in activated sludge, and
By *B*: Culture 87, a predominant bacterium in trickling filters.

Range of Flow in M.G.A.D.	*A*. With Culture 86			*B*. With Culture 87		
	Avg. Flow for Period	No. of Tests Included in Avg.	Percentage of 5-day B.O.D. Removed	Avg. Flow for Period	No. of Tests Included in Avg.	Percentage of 5-day B.O.D. Removed
0.0 to 0.49	0.34	1	71.1	0.39	1	78.6
0.5 to 0.99	0.92	3	52.1	0.75	5	62.7
1.0 to 1.49	1.21	10	57.1	1.22	5	50.0
1.5 to 1.99	1.80	10	49.1	1.78	3	35.8
2.0 to 2.49	2.22	10	43.1	2.25	5	40.5
2.5 to 2.99	2.68	8	38.6	2.73	6	35.6
3.0 to 3.49	3.17	5	32.6	3.28	2	29.8
3.5 to 3.99	3.70	1	22.7	3.78	4	31.0
4.0 to 4.99	4.51	3	23.2	4.51	2	24.5
5.0 to 5.99	5.37	1	14.2	5.00	1	29.2
6.0 to 6.99	6.26	1	16.0	6.07	1	27.6
7.0 to 7.99	7.46	1	21.2			

Three observations may be made regarding the results presented. First, a marked purification of the synthetic sewage occurs as it passes through the filter. Second, there is a definite correlation between the rate of flow and the extent of purification. And third, the purification accomplished by the two pure culture systems is quite similar. That is, judging from the results obtained, these two organisms, one predominant in trickling filters, the other in activated sludge, may be used interchangeably in pure culture trickling filters without apparent variation in purification efficiency. Certain conditions affecting these observations will be considered.

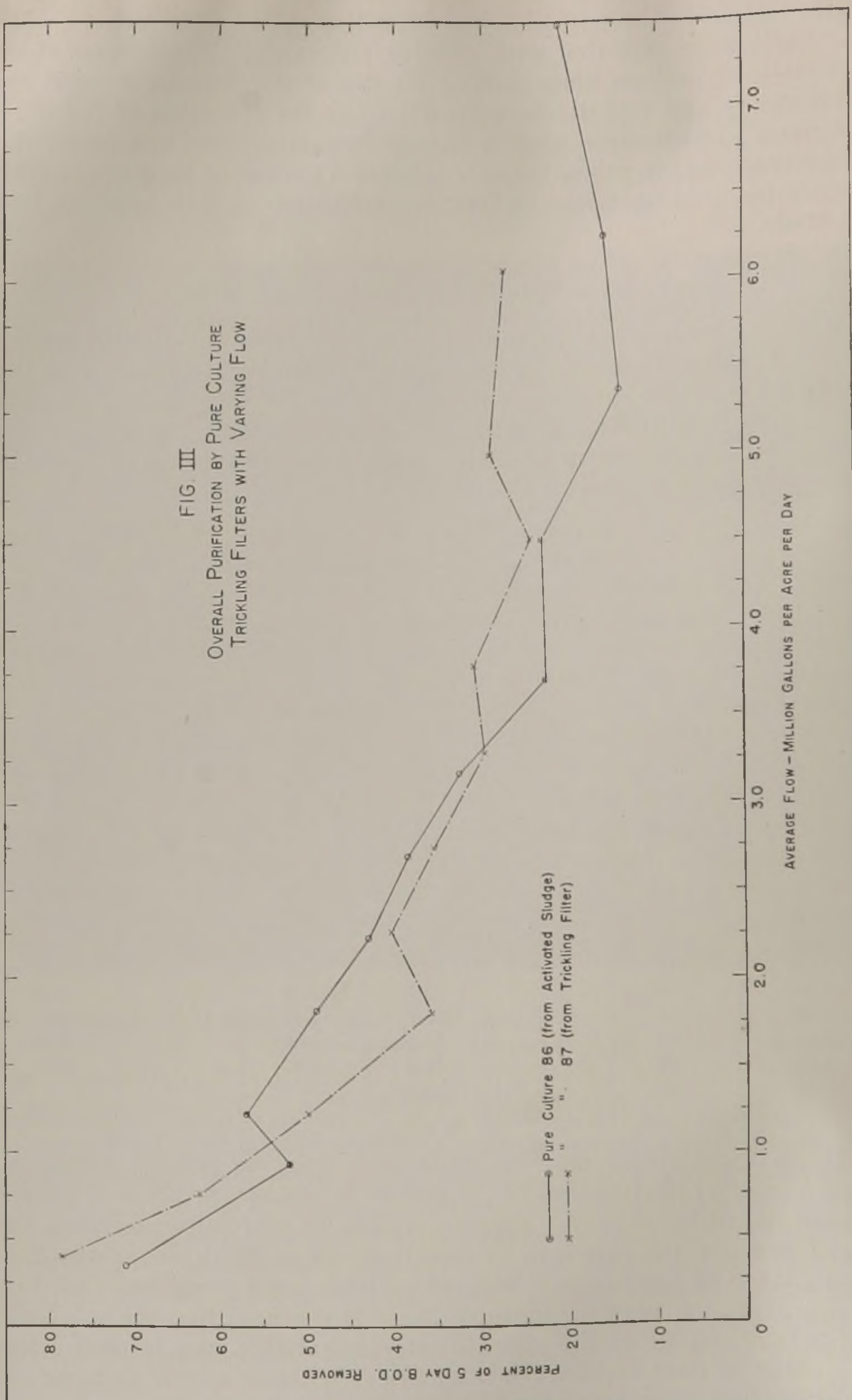


FIG. III
Overall Purification by Pure Culture
Trickling Filters with Varying Flow
Pure Culture 86 (from Activated Sludge)
" " 87 (from Trickling Filter)
Percent of 5 Day B.O.D. Removed
80
70
60
50
40
30
20
10
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
Average Flow—Million Gallons per Acre per Day

FIG. 3.

With regard to the overall purification accomplished by these pure culture trickling filter systems, it was planned at the start of the work to make direct comparison of the results obtained with those observed in plant size units operated under natural conditions with all the flora and fauna of domestic sewage. The requirements for a pure culture set-up established limits which prevented such a direct comparison. For instance, as noted above, the depth of gravel in the pure culture filter was limited to 22 in. by the sterilization facilities, while the depth of stone in a normal filter is about 60 to 72 in. Correspondingly, the time of flow through the stones of the pure culture filter was less than one minute (about 55 seconds) while flow through a normal filter requires 3 to 4 minutes.

Consequently, the extent of purification in a similar filter fed with raw domestic sewage containing all of its normal flora and fauna was determined. In each case the purification with the pure cultures approached that observed with a similar filter containing the normal flora and fauna.

While definite evidence is not available to show that the extent of purification in a trickling filter varies directly with the depth of the filter or with the time the sewage is in contact with the growth on the filters, presumptive evidence suggests that this is the case. Therefore, the purification accomplished by the filter of 60 to 72 in. depth might be assumed to be about three times as great as that observed with a 22 in. filter. That is, on this basis, the purification of about 33 per cent observed with the 22 in. filter at a flow of 3 million gallons per acre per day would be expected to be 90 to 100 per cent with a filter of normal depth. Or considered from another angle, the 22 in. filter flowing at a rate of one million gallons per acre per day might be expected to accomplish the purification of a normal depth filter flowing at a rate of three million gallons per acre per day. On the latter basis, the percentage of the 5-day B.O.D. removed would be in the range of 50 to 60 per cent. With such allowances the degree of purification accomplished by these pure culture filters would be of almost the same order of magnitude as observed in a normal filter. Thus the purification accomplished by the pure culture trickling filters developed by the predominant bacteria isolated from a natural activated sludge equalled that accomplished by a similar trickling filter developed by the predominant bacterium in a trickling filter.

Pure Culture Trickling Filter Operated as Contact Filter

At the conclusion of each run when the pure culture filter was operated as a trickling filter, it was operated for a time as a contact filter to compare the purification brought about by these two methods. To carry out this procedure the outlet (*n*) of the filter (see Fig. 1), was closed by attaching a short piece of sterile rubber tubing with a clamp. The filter was then slowly filled to the top level of the stones and allowed to stand thus for one hour. The effluent was then slowly drained off and the filter allowed to rest for at least three hours before the test was repeated. The degree of purification was determined by comparing the 5-day B.O.D. of the influent with the corresponding B.O.D. of the effluent. This test as a contact filter was repeated seven times using synthetic sewage, eleven times with sterilized natural sewage, and five times with raw natural sewage. The latter tests were conducted on the same day at the end of the run so that the additional inoculum introduced with the raw sewage would not have time to develop sufficiently to affect the results materially. The averages of the results obtained from these runs as a contact filter are given in Table II.

TABLE II.—*Pure Culture Trickling Filter (Culture 86, Table I) Operated as a Contact Filter with Various Feeds*

Nature of Influent	Number of Tests	Average Contact Period	Per Cent of Purification as Measured by 5-day B.O.D. of Influent and Effluent
Synthetic Sewage	7	1 hr.	28.2
Sterilized Natural Sewage	11	1 hr.	51.3
Raw Natural Sewage	5	1 hr.	61.1

The amount of sewage required to fill this unit as a contact filter was a quantity which would provide an hour's flow at a rate of about 3.35 million gallons per acre per day. Consequently, as the sewage was held in contact for one hour the extent of purification may be compared with the trickling filter results when operated at 3.35 million gallon rate. This rate of operation as a trickling filter (see Fig. 3) had given an average reduction of the 5-day B.O.D. of about 30 per cent. The purification accomplished by the contact process, with synthetic sewage in which all components are in solution, is approximately the same as the average obtained by the sprinkling procedure. However, the purification accomplished by this process with sterilized natural sewage and with raw sewage is considerably greater than with synthetic sewage. This may be explained by assuming for the contact method a 100 per cent wetting of all of the active biological surfaces while with the sprinkling method some of the surfaces may escape such contact. The more reasonable explanation is, that with natural sewage, sterilized or raw, a considerable portion of the 5-day B.O.D. is contained in colloidal and suspended matter. This fraction would be removed effectively by the filter, while in synthetic sewage no such suspended solids were present. It was not possible to make these observations satisfactorily with natural sewage on the pure culture trickling filter as the particles present in the sewage interfered with the establishment of a continuously uniform flow at the low rates required.

Results with Pure Culture Activated Sludge

Using the same pure cultures, No. 87 isolated from a trickling filter, No. 86 isolated from activated sludge, and a new culture, No. 103, isolated from a trickling filter, pure culture activated sludges were developed and their overall purification efficiency using synthetic sewage

TABLE III.—*Overall Purification by Pure Culture Activated Sludges Developed by Bacteria Isolated from Various Purification Systems*

Designation	Cultures Used	Source of Culture	Amount of Sludge in P.P.M.	No. of Tests Made	Per Cent of 5-day B.O.D. Removed after Aeration of:			
					1 hr.	3 hrs.	5 hrs.	24 hrs.
A	86	Activated Sludge	877	4	34.9	52.0	62.2	61.0
B	87 and 103	Trickling Filter	760	4	43.4	66.7	75.8	80.3
C	1, 4 and 9	Activated Sludge	1793	5	34.6	78.1	82.1	88.8
Average of *A* and *C*					34.8	65.0	72.2	74.9

was determined by the methods described in reference (1). The results obtained from these tests are presented in Table III.

For purposes of comparison, the average results from a previous similar study [2] with activated sludge bacteria, zoogleal cultures Nos. 1, 4 and 9, are included in this table. This gives an opportunity to compare the results obtained with the older pure culture sludges (with a much heavier growth, 1793 p.p.m. vs. 877 p.p.m. of suspended solids), with the newer sludge developed with Culture 86.

The amount of purification accomplished by the pure culture activated sludges produced by Cultures 87 and 103, isolated as the predominant organisms of trickling filters, exceeds that accomplished by the activated sludge produced by Culture 86, isolated from activated sludge, but does not equal the earlier results obtained with activated sludge Cultures Nos. 1, 4 and 9. It must be noted, however, that these previous sludges were developed until they contained a much larger number of bacteria as measured by the amount of sludge produced. The average overall purification accomplished by pure culture sludges produced by activated sludge bacteria Cultures 1, 4, 9 and 86 (that is, the average of A and C as given in Table III) approximately equals that accomplished by the activated sludges produced by trickling filter bacteria, Cultures 87 and 103. Thus it is observed that the predominant bacteria of a trickling filter can produce a pure culture activated sludge which functions at least as effectively as a similar sludge produced by the normal activated sludge bacteria.

Results with Bacteria-Only, Trickling Filters and Activated Sludges Developed by Several Strains of Zoogleal Bacteria

Detailed studies of the characteristics of the zoogleal bacteria isolated from activated sludges and from trickling filters, which may be presented in a future paper, have yielded interesting information. For instance, the various strains were identical, with regard to certain major characteristics. They were all aerobic, gram-negative rods, producing capsules, not forming chains, forming zoogleal flocs or huge colonies in liquid media under aeration, and failing to ferment the ordinary sugars with gas production. They differed in certain minor characteristics such as the digestion of casein, the production of indol, and the utilization of nitrates.

These differences in activity suggest that while the extent of purification produced by sludges developed by these bacteria, each in pure culture, was approximately the same, the substances utilized by the various sludges may have varied in quality if not in quantity. This suggests further that a bacteria-only activated sludge or trickling filter produced by the combined growths of several of these strains of bacteria would bring about a more complete purification. If these bacteria were the active agents, this purification would approach more uniformly, even with a feed whose constituents varied, the purification produced by a normal trickling filter, or activated sludge.

Accordingly, an experiment was carried out to determine the purification accomplished by a bacteria-only growth in a trickling filter and in activated sludge when the bacteria involved were a mixture of pure strains of zoogleal organisms. Nine pure culture strains were selected for this purpose; Cultures Nos. 53, 83, 85, 86 and 88 which had been isolated from activated sludges, and Cultures Nos. 87, 100, 102 and 103, which had been obtained from the growths on the stones of trickling filters. In producing such growths each of nine flasks containing 100 ml. of broth was inoculated with one of these strains in pure culture. They were held at 20° C. for 48 hours. By this time all nine flasks had developed a heavy flocculent growth. The entire contents of each of the nine flasks were then introduced into an aeration bottle containing eight liters of synthetic sewage, and aeration was started with storage at 20° C. While it was not possible to follow the relative growth of each of the nine strains present in the aeration bottle, it was felt that the massive initial inoculation employed would give each strain an excellent opportunity to be well represented in the final growth subjected to test. Sludges produced in this manner will be referred to as "mixed pure culture" growths.

The 8-liter portion of synthetic sewage, thus inoculated and incubated at 20° C. under aeration, was fed daily with fresh synthetic sewage by the fill-and-draw method. That is, once daily, aeration was stopped, the bacterial sludge was allowed to settle for 30 minutes, five liters of clear supernatant were removed under aseptic conditions with a sterile siphon, five liters of sterile synthetic sewage were added, and aeration was resumed. When necessary, adjustments were made with sterile solutions to keep the hydrogen-ion concentration in the range of pH 6.6 to 7.4. After a period of about 30 days, when bacterial sludge had developed to the extent of about 1500 p.p.m. in terms of suspended solids (dry weight at 105° C.) the eight liters were thoroughly mixed and divided into two equal portions. The sludge of one portion was transferred at once to a sterile trickling filter set-up, using method No. 2 above, for observations on its efficiency in purifying synthetic sewage under these conditions. (For results see Table IV, Experiment 1–X.) Tests were made on the purification accomplished with various rates of flow during the next seven days. The other portion of this "mixed pure culture" activated sludge was continuously maintained as an activated sludge with daily feedings as described above. Tests were made of its purification efficiency, as an activated sludge, on the first (Experiment 1–A), third (Experiment 1–B) and seventh (Experiment 1–C) day of feeding from the time the portion was withdrawn to start the trickling filter set-up. (See Table V for results.)

After the sludge of 1–X had been in service for thirteen days as a trickling filter sludge, it was completely removed from the stones with aseptic precautions and put on test at once as an activated sludge. The results from this test with this sludge, 1–X, are presented in Table V. It is noted that in this experiment practically none of the bacterial sludge was lost either as it was added to or removed from the trickling filter set-up. This is shown by approximately the same suspended solids content for portions 1–C and 1–X.

These observations with activated sludge and trickling filter purification by "mixed pure culture" growths were repeated under identical procedures in Experiment Nos. 2–A, 2–B and 2–X. The only variation noted in Experiment 2 is that apparently about one-third of the bacterial sludge was lost either in transferring the portion of sludge to, or removing it from, the trickling filter. This is shown by the variation in suspended solids content; 1666 for 2–B and 904 for 2–X. The results obtained in these two experiments, with averages, are presented in Tables IV and V.

Discussion of Results

Considering first the findings from the trickling filter studies, it is noted, as has been observed in the preceding experiments with pure culture trickling filters, that excellent results were obtained until partial or complete ponding of the filter occurred. Correction of this difficulty, by stirring the gravel in the ponded area, usually, but not always, restored normal operation after a few days. It is assumed when normal results were not obtained again that the ponding action had blocked off certain portions of the growth in the filter even though an apparently normal resumption of flow had occurred. Such an effect might materially reduce the opportunity for contact between some of the bacterial masses and the inflowing bacterial food and at the same time would have a tendency to create anaerobic areas.

Comparing the results presented in Table I with those in Table IV, it is at once apparent that in the trickling filter set-up the "mixed pure culture" growth was more effective than the growth of any one pure culture. This difference was definitely in the favor of the "mixed pure culture" growth when the rate of flow was approximately three million gallons per acre per day. However, when the flow was near the rate of one million gallons per acre per day, the increased efficiency of the "mixed pure culture" growth was the more marked. This latter rate of flow as was noted above is probably about the optimum for shallow filters of the depth required for the production of a set-up under pure culture conditions. Thus the results obtained with the "mixed pure culture" growth, reaching a maximum efficiency of removing approximately 90 per cent of the 5-day B.O.D. of the influent, approach very closely the conditions of a normal trickling filter. This suggests very definitely that these bacteria are the active agents in this purification process.

The results presented in Tables III and V provide for a similar comparison when the growths of these same organisms, in pure culture, and in "mixed pure culture," are used as an activated sludge. Again it is observed that the "mixed pure culture" growth is the more effective. The maximum difference, about 40 per cent, is found in the averages for the results obtained at the one-hour aeration period. The differences observed at the 3, 5 and 24-hour aeration periods were considerably less

TABLE IV.—*Purification Accomplished by a Trickling Filter Developed by the Growth of a Mixture of 9-Pure Cultures of Zoogleal Bacteria*

Experiment 1–X*				Experiment 2–X†			
Hours from Start	Rate of Flow M.G.A.D.	% of 5-day B.O.D. Removal	Remarks	Hours from Start	Rate of Flow M.G.A.D.	% of 5-day B.O.D. Removal	Remarks
20	0.74	80.6		48	0.87	65.2	
44	1.78	78.0		72	1.47	66.6	
48	2.13	88.0		74	1.43	66.9	
68	2.88	86.6		76	1.43	66.2	
70	1.09	89.4		96	3.72	23.6	Flow suddenly increased at sampling period
72	0.93	91.2		98	1.36	27.9	
117	1.10	77.6		120	1.02	58.1	Ponding observed at intervals
119	0.68	84.2	Rate increased as soon as sampled	124	1.12	58.0	
121	4.14	44.6		144	0.88	54.5	
140	5.04	31.3		148	1.02	68.5	
142	3.41	12.8	Ponding complete. Filter stones stirred up	168	1.12	61.4	
164	2.89	70.2		216	1.80	28.4	Ponding complete Filter stones stirred up

* See Table V for purification accomplished by aliquot portions of the same mixed bacterial growths under conditions of activated sludge operation. Test 1–A made at 20-hour period, 1–B at 68-hour period, 1–C at 164-hour period, and 1–X with sludge washed from the growth on the stones of this filter.

† See Table V for purification accomplished by aliquot portion of the same mixed bacterial growths under conditions of activated sludge operation. Test 2–A made at 72-hour period, 2–B at 168-hour period, and 2-X with sludge washed from the growth on the stones of this filter.

Table V.—*Purification Accomplished by Activated Sludge * Developed by the Growth of a Mixture of 9-Pure Cultures of Zoogleal Bacteria*

Experiment No.	Amount of Sludge P.P.M.	Percentage of 5-day B.O.D. Removed after Aeration for:				Percentage of 5-day B.O.D. Oxidized after Aeration for:			
		1 hr.	3 hrs.	5 hrs.	24 hrs.	1 hr.	3 hrs.	5 hrs.	24 hrs.
1–A †	1536	34.3	40.8	86.4	90.7	—	—	—	—
1–B	1628	64.9	82.1	83.9	88.7	—	—	—	—
1–C	1558	53.7	77.7	81.2	81.5	38.4	62.2	67.9	84.6
1–X	1598	57.9	84.8	79.8	81.4	23.6	43.0	52.9	63.6
2–A	—	67.7	83.5	89.2	87.3	—	—	—	—
2–B	1666	50.5	85.1	89.7	85.1	23.3	43.7	48.6	59.7
2–X	904	31.2	64.3	65.4	71.0	15.5	34.7	42.5	58.5
Avg. 1–A, 1–B, 1–C, 2–A, and 2–B		54.2	73.8	86.1	86.7	30.8	52.9	58.2	72.2
Avg. 1–X and 2–X		44.6	74.6	72.6	76.2	19.6	38.8	47.7	61.0

* Sludges produced by the mixed growth of nine pure cultures of zoogleal bacteria, Cultures No. 53, 83, 85, 86, 87, 88, 100, 102 and 103.

† Sludges 1–A, 1–B, 1–C, 2–A and 2–B produced and continuously maintained under aeration as an activated sludge. Sludges 1–X and 2–X developed as an activated sludge for about 30 days as an aliquot portion of 1–A and 2–A, then at the time tests of 1–A and 2–A were made sludge portions 1–X and 2–X were put on sterile trickling filters and used as a trickling filter for 13 days, then growth on stones of filter was washed off and tested at once as an activated sludge in 1–X and 2–X.

but the "mixed pure culture" sludge consistently produced a higher percentage of B.O.D. removal.

In the averages presented in Table V an interesting difference is observed between the purification produced by sludges 1–A, 1–B, 1–C, 2–A, and 2–B (which had been produced and continuously maintained under aeration as an activated sludge) and the purification brought about by sludges 1–X and 2–X (which while originally produced as an activated sludge had been in service on a trickling filter for the thirteen days immediately preceding these tests). With but one exception the sludges continuously maintained as activated sludges, produced the higher degree of overall purification. The one exception, the 3-hour period, was probably caused by one unusually high result in Experiment 1–X, at the 3-hour aeration period. This difference between the activity of the two diversely treated sludges was more marked when measured by the portion of the 5-day B.O.D. oxidized * during the various aeration intervals. The "mixed pure culture" sludge in each

* It may be pertinent to distinguish here the differences between the terms B.O.D. removed and B.O.D. oxidized, which are explained in detail in reference (2). When an activated sludge or a trickling filter is fed with sewage the initial but continuous step in the purification process is adsorption followed by oxidation and by synthesis of the adsorbed material into new bacterial protoplasm through growth and reproduction of cells. The B.O.D. removed is a measure of the overall, or total, purification produced by the combined activities of adsorption, oxidation and synthesis. The B.O.D. oxidized includes only that portion of the overall purification which has been produced by actual oxidation.

instance produced a greater amount of oxidation, the greatest difference being observed during the first hour of aeration.

This difference in activity between the activated and trickling filter sludges is probably brought about by the condition of the sludges. The sludges which had been maintained under continuous conditions of activation were fed by the fill-and-draw method. At the time of test, 24 hours had elapsed since the last feeding and these sludges were probably relatively free of adsorbed material. The other sludges used in trickling filters immediately prior to these tests under conditions of activated sludge operation, had been fed continuously up to the time of removal from the filters. These sludges were probably moderately loaded with adsorbed material when aeration was started. Their gradual improvement in purifying power at each subsequent aeration interval supports this assumption.

Perhaps the most interesting observation made in this study of the bacteria of trickling filters is that the zoogleal organisms found to be predominant in trickling filters and in activated sludge floc may be used interchangeably in pure culture set-ups without any material variations in the purification efficiency obtained. This interchangeability in pure culture trickling filters is shown quite definitely in the results presented in Table I and in Fig. 3. The same interchangeability in purification by the activated sludge process is shown in the results of Table III.

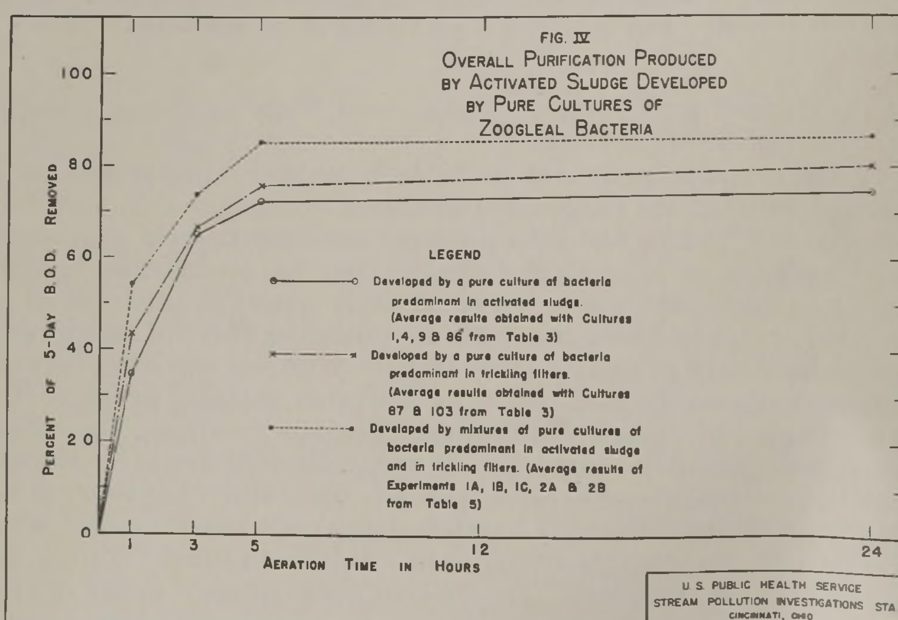


FIG. 4.

This interchange function of these zoogleal bacteria in activated sludge is shown more clearly in Fig. 4. Here the average purification accomplished by activated sludges, each developed by a pure culture of zoogleal bacteria isolated from natural activated sludge, is contrasted with the purification obtained with activated sludges developed by a pure culture isolated from a normal trickling filter. In the average for sludges developed by bacteria isolated from activated sludge, nine experiments are included, two with Culture No. 1, one with Culture No. 4, two with Culture No. 9, and four with Culture No. 86; while four experiments, two with Culture No. 87 and two with culture No. 103, are included in the average for sludges developed by bacteria isolated from normal trickling filters. Remarkable agreement at all aeration intervals is noted between the purification accomplished by the pure culture activated sludges developed by the zoogleal bacteria from the two sources, activated sludges and trickling filters. Moreover, the slight difference in purification noted, which is within the limits of variation observed between different cultures, favors the activated sludges developed by bacteria isolated from trickling filters.

The results obtained with the mixture of nine pure cultures of these zoogleal bacteria, four isolated from trickling filters and five from activated sludges, are also shown in Fig. 4. It is noted that this ''mixed pure culture'' sludge produced a more extensive purification at each aeration interval, with the greatest change taking place during the first hour.

Summary

The isolation in pure culture of the predominant bacteria found in the growths on the stones of experimental and municipal trickling filter sewage plants is reported. These bacteria are present at least to the extent of 300 million per milliliter of filter growth. The organisms thus isolated and studied are zoogleal in nature and are similar to the predominant bacteria found in activated sludge.

The construction, method of inoculation, and operation of a trickling filter unit under pure culture conditions is described in detail.

These bacteria isolated in pure culture, when applied to this trickling filter unit, produced a growth on the stones of the filter which simulated a normal trickling filter both in appearance and in purification properties.

The predominant bacteria of activated sludge in pure culture are shown to have the same ability to produce adherent growths on the stones of a filter which in gross appearance and in purifying power simulate a normal trickling filter.

Conversely, it is demonstrated that the bacteria isolated as the predominant organisms in a trickling filter will in pure culture produce a floc of the same general appearance as activated sludge. That is, these trickling filter bacteria also have the ability to grow in a liquid medium in a massed floc or colony which binds itself together tenaciously enough to remain intact under the agitation of the aeration required to keep it suspended and to maintain aerobic conditions. This pure culture activated sludge during a 5-hour aeration interval removed about 76 per cent of the 5-day B.O.D. of polluted waters.

A mixture of nine pure cultures of these zoogleal bacteria, in both trickling filter and in activated sludge set-ups, was more effective than any one strain in pure culture. The extent of purification brought about by such a mixture was equivalent to that produced by a trickling filter or by an activated sludge containing all of the flora and fauna of normal sewage.

The results obtained show that the predominant zoogleal bacteria of trickling filters and of activated sludges may be used interchangeably without impairment of purification efficiency and these results also indicate very definitely that the members of this group of bacteria are the active agents in purification by biological processes and suggest that the maintenance of conditions favoring their growth would expedite such purification procedures.

Acknowledgment

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EFFECTS OF DILUTION WATER ON B.O.D. OF WASTE SULFITE LIQUOR

By George Martin and E. P. Miller

Sewage Works Superintendent and Chemist, Green Bay Metropolitan Sewerage District, Green Bay, Wisconsin

Numerous articles have been written in the past few years calling attention to the problem of industrial waste and pointing out that in many cases the industrial waste is so enormous in comparison with domestic waste that it completely overshadows the latter. Where such conditions exist the building of sewage treatment plants seems almost useless if the industrial waste is completely forgotten and allowed to flow untreated into rivers or other surface waters. Such has been the case in the Fox River Valley in Wisconsin where the industrial waste from four sulfite mills has a population equivalent twenty times as great as that of the domestic waste. Here the problem has not gone entirely unchallenged for the Green Bay Metropolitan Sewerage District has undertaken an investigation of the possibilities of biological treatment of the waste. In addition to this the District, in co-operation with the State Board of Health, recently completed and published their report on an extensive sanitary survey of the polluted areas in and about the City of Green Bay, a report that necessarily dealt largely with waste sulfite liquor and its pollutional effects. A direct effect of this work was the arousing of interest among the sulfite mill officials to the extent that an organization was formed by these mills to establish a research program to study methods of treating their waste.

For the past several years considerable work has been done by the Green Bay Metropolitan Sewerage District in studying the problem of waste sulfite liquor. About two years ago the question arose as to whether or not the Green Bay sewage treatment works could take the effluent from a lime-precipitated waste sulfite liquor treatment plant and what the B.O.D. would be of the combined effluent. To determine this we ran a series of tests and found that there was an enormous increase in B.O.D. and that slime growths increased to such an extent that trouble was anticipated. In fact, the five-day B.O.D. of the combined wastes increased from about 200 p.p.m. to 950 p.p.m., indicating that the B.O.D. of the lime precipitated waste sulfite liquor effluent was approximately 4,700 p.p.m., which results were quite surprising as they were about eight times as high as those which had previously been reported. This increase in B.O.D. due to the mixing of sewage with the lime precipitated waste sulfite liquor indicated that the sewage furnished certain essential material necessary for the promotion of bacterial growth whereas the previous B.O.D. tests had been run with samples of waste diluted with standard bicarbonate water which lacks these essentials. All this led to further study and a search of the literature proved that this same phenomenon had been encountered by Lea and Holderby working with various industrial wastes.[1] These first observations were later followed by the work of Lea and Nichols,[2] in which the use of a supplemented dilution water containing comparatively large amounts of nitrogen and potassium was proposed.

Additional work on this particular problem of waste sulfite liquor was undertaken during the winter of 1938 and the results show that a large difference in B.O.D. was obtained for the same waste sulfite liquor when mixed with standard, supplemented, and river dilution waters. This was followed by a further study of the problem in order to arrive at more definite conclusions as to a satisfactory dilution water for waste sulfite liquor and to determine the effect of the waste on various surface waters.

Waste sulfite liquor is unusual in that it is a waste in which all the solids present are in solution or in such a state of colloidal dispersion as to approach true solution. Therefore, the B.O.D. is the only criterion of the pollution characteristic of the waste (authorities having denied any possible toxic effect of the waste at the low concentrations generally found in flowing streams[3]) and the method employed in determining this value is of great importance.

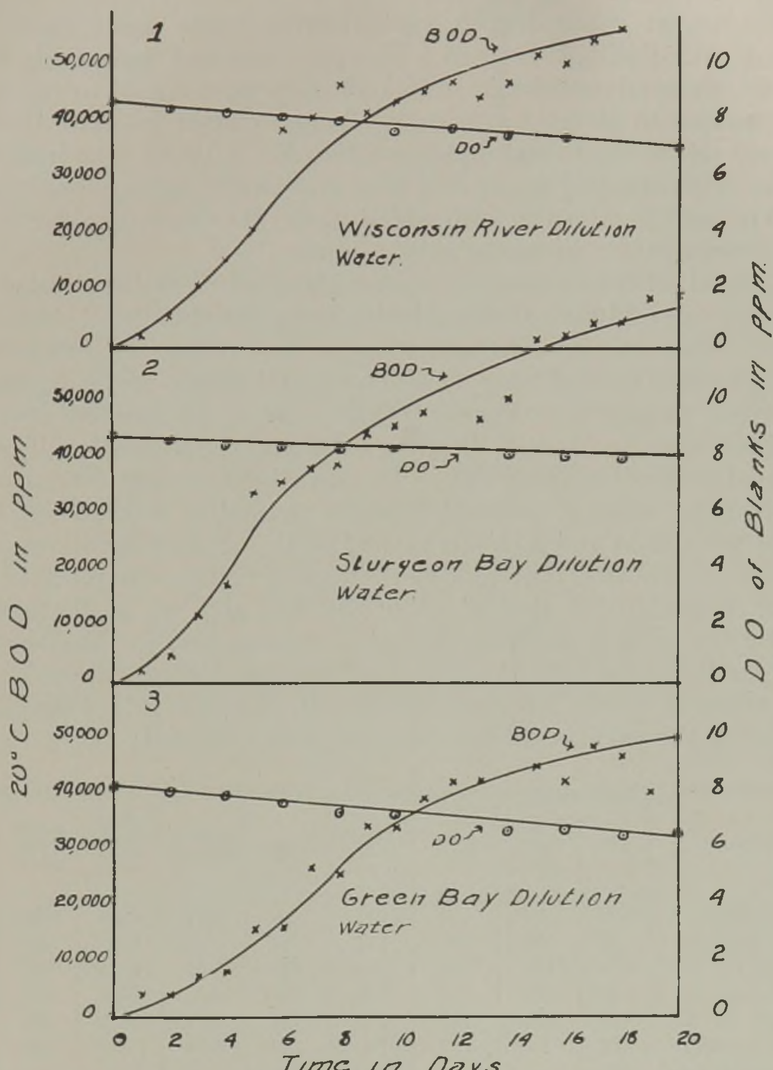
The two main constituents of waste sulfite liquor are lignin, present in the form of calcium ligno-sulfite, and carbohydrates, with the lignin accounting for 50 to 60 per cent of the total solids and the carbohydrates 20 to 30 per cent. These two substances are far apart in their relative availability as bacterial food, the carbohydrates being present largely in the form of readily available sugars and the lignin in a colloidal state necessitating an initial breakdown to true solution before being available for bacterial assimilation. It also may be well to mention here that the waste is almost completely lacking in both phosphorus and nitrogen.

In order to make this study fairly representative a number of five-gallon samples were obtained from the following Wisconsin rivers and other surface waters:

1. Wisconsin River one-half mile above Brokaw
2. Sturgeon Bay Ship Canal
3. Green Bay at Mouth of Fox River
4. Fox River just above DePere Dam
5. East River above the City of Green Bay

As these waters all had an initial B.O.D. of from 2 p.p.m. to 10 p.p.m., it was necessary to allow them to age until this demand was almost satisfied, that is, until the demand was low enough to allow at least 5 p.p.m. of dissolved oxygen at the end of a twenty-day incubation period. This required about thirty days for the twenty-day B.O.D. determinations whereas ten days aging produced a satisfactory water for five-day B.O.D.'s.

In addition to aging, these waters required some treatment before being use. As the suspended solids were quite high, a period of quiescent settling of several days was allowed, after which the clear supernatant was decanted. This decanted water was then aerated every five to six days to keep the water as near saturation as possible. The fortified and bicarbonate waters were seeded with 1 ml. per liter of clarified sewage for the twenty-day runs, whereas for the shorter runs the fortified water was seeded with 10 ml. per liter of fresh river water.



The natural waters were not seeded after aging except for the ten-day runs on samples No. 3 and No. 4 which were seeded with fresh Fox River water.

Because of the large B.O.D. of waste sulfite liquor it was necessary to dilute the waste before adding to the B.O.D. bottles. In doing this it was found that greater accuracy could be obtained when the original waste was diluted so the same volume could be added to the B.O.D. bottles over the dilution range. As the concentration of the waste after diluting in the B.O.D. bottles varied from 1 in 3,000 to 1 in 25,000, it can be readily seen that the method and accuracy of these dilutions plays an important part in obtaining correct results. Therefore, the following procedure was adopted:

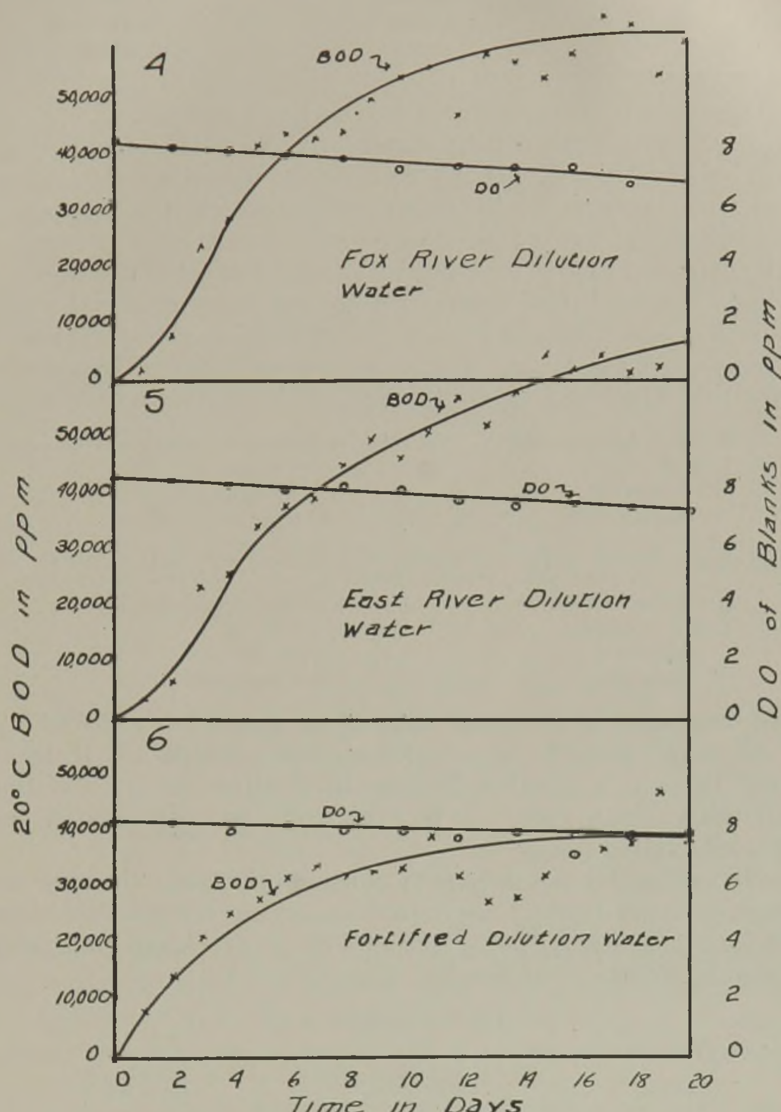
1. 10 ml. of concentrated waste sulfite liquor were made up to 1,000 ml. with distilled water in a liter graduate and thoroughly shaken.
2. 10 ml. portions of this initial dilution were added to the 300 ml. B.O.D. bottles to give a waste sulfite liquor concentration of 1 in 3,000.
3. 500 ml. of the initial dilution (Step No. 1) were then made up to 1,000 ml. with distilled water in a liter graduate. After thorough shaking, 10 ml. of the mixture were added to the B.O.D. bottles for the next lower concentration of waste sulfite liquor.
4. 500 ml. of the dilution from step No. 3 were further diluted in the same manner and 10 ml. of this dilution were added to the B.O.D. bottles. This procedure was repeated until the entire dilution range was covered.

This method proved very satisfactory, and gave a uniform procedure with small chance for error. B.O.D.'s were determined every day throughout the run for each dilution water and the corresponding blanks were analyzed every other day. The dissolved oxygen determinations were made by using a modified Winkler method in which 2 ml. of each reagent were used and a thirty second period of shaking allowed. Numerous tests showed that this method gave results comparable to the alkaline hypochlorite method after the first day of incubation. Apparently the sulfites and polythionates are oxidized in this period and no longer interfere with the dissolved oxygen determinations.

In order to better interpret the B.O.D. data the following chemical analysis of the various dilution waters were obtained:

Sample	pH	Total Hardness	Alkalinity	Total Solids	Ash	Ammonia Nitrogen	Total Organic Nitrogen	Soluble Phosphorus	Total Phosphorus
Wisconsin River	8.10	56	50	102	65	0.17	0.21	.02	0.02
Sturgeon Bay	8.32	120	120	157	95	0.10	0.56	.01	0.02
Green Bay	8.15	172	154	259	143	0.09	0.92	.00	0.01
Fox River	8.32	168	158	239	143	0.10	0.60	.09	0.12
East River	8.10	510	404	663	428	0.11	0.70	.02	0.03
Fortified Water	8.00	—	146	160	147	0.60	—	.03	0.03
Bicarbonate Water	8.05	—	—	210	210	—	—	—	—

Of the above data, those of greatest interest are the nitrogen and phosphorus figures, because on their presence depends to a large extent the degree of bacterial activity. A rather interesting fact was noted in the complete lack of soluble phosphorus in the Green Bay sample, although the Fox River sample was comparatively high in this substance. Two large sulfite mills dump their waste between these two sampling stations and apparently the soluble phosphorus is either used up by the tremendous bacterial activity occurring under the conditions of a large food supply and favorable conditions for growth or the phosphorus is rendered insoluble by the large amount of calcium in the



waste liquor. In either case the fact that the soluble phosphorus is completely removed is of great importance because of the change in bacterial activity that is caused and the consequent slowing down of the rate of purification of the stream. That the rate of activity is markedly lower is shown by a comparison of the two curves for Green Bay and Fox River dilution waters.

Type of Dilution Water

Days	Fox River P.p.m. B.O.D.	Green Bay P.p.m. B.O.D.
2	7,500	4,500
3	17,000	7,500
4	29,000	11,000
5	35,000	15,000
6	42,500	19,000

This data is shown graphically on curves No. 3 and No. 4.

The waste liquor therefore apparently does considerable damage in excess of its high B.O.D. by completely upsetting the balance of essential mineral elements in the water into which it is dumped. The bicarbonate water, having no phosphorus or nitrogen present, could hardly be expected to give any indication of the effect of the waste sulfite liquor under natural conditions. Its use for any industrial waste low in phosphorus and nitrogen is worse than useless, giving erroneous results which are misleading. For example, one type of treatment produced the following data by using standard bicarbonate dilution water:

W.S.L. before treatment	3,162 p.p.m. five-day B.O.D.
Treated effluent	548 p.p.m.
Reduction	2,614 p.p.m.
Reduction	82.6 per cent

By using East River dilution water the following data was produced:

W.S.L. before treatment	24,200 p.p.m. five-day B.O.D.
Treated effluent	18,500 p.p.m.
Reduction	5,700 p.p.m.
Reduction	23.6 per cent

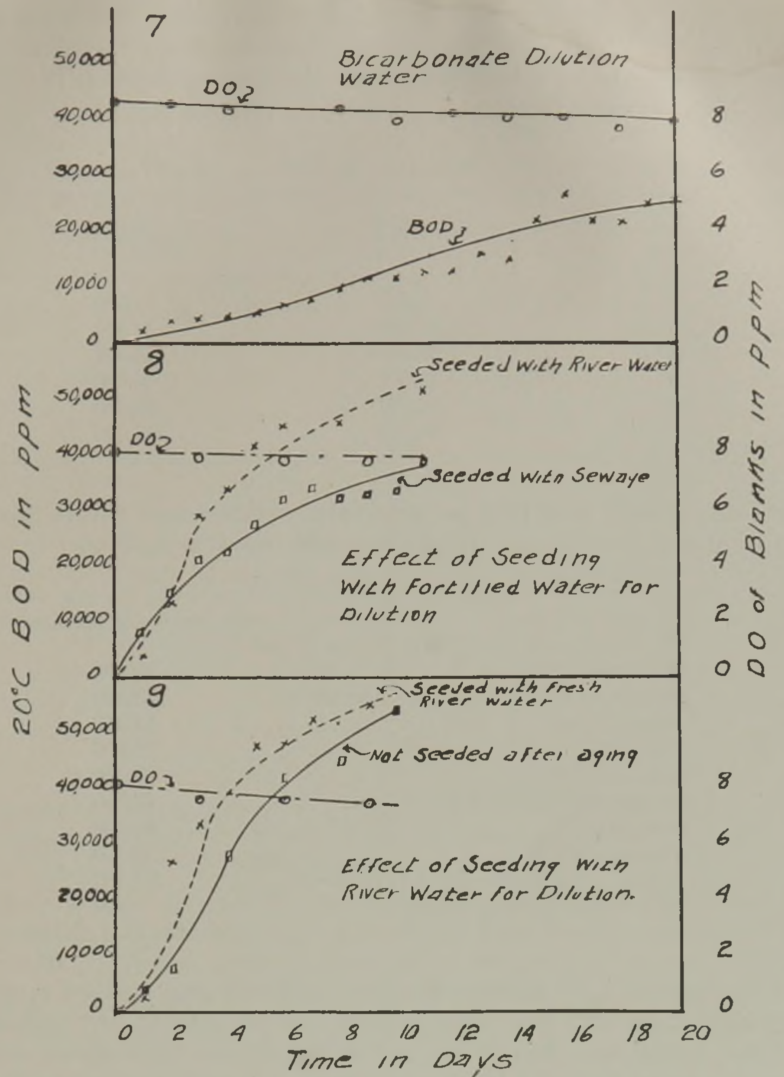
This wide variation in the percentage of reduction from 82.6 to 23.6 per cent is the result of only one set of data, but nevertheless it does illustrate that there is a great difference in dilution waters and that the effect of the various waters is not the same on both treated and untreated waste sulfite liquor.

Bicarbonate water not only runs consistently lower than the natural dilution waters but is much more erratic, giving results that cannot be checked in consecutive runs. A comparison of bicarbonate and Fox River waters follows (Curves No. 4 and No. 7):

Type of Dilution Water

Days	Fox River P.p.m. B.O.D.	Bicarbonate P.p.m. B.O.D.
2	7,500	3,500
3	17,000	4,500
4	29,000	5,000
5	35,000	5,500
6	42,500	6,500

The fortified water of Lea and Nichols, using clarified sewage for seeding, gives results that are more nearly comparable to the natural dilu-



tion waters but are still low in most cases. However, upon seeding the fortified water with natural surface water the results compare much better. (Curves No. 4, No. 8, and No. 9.)

Type of Dilution Water

Days	Fortified Seeded with Sewage P.p.m. B.O.D.	Fortified Seeded with Fox River Water P.p.m. B.O.D.	Fox River P.p.m. B.O.D.
2	14,000	12,500	7,500
3	18,500	24,000	17,000
4	22,000	32,500	29,000
5	25,000	37,500	35,000
6	27,500	41,000	42,500

As the initial runs using natural surface waters were not seeded after aging, a few runs were made using fresh water from the same source for seeding with the effect of increasing the rate of the B.O.D. A comparison of the results thus obtained follows (Curve No. 9):

Type of Dilution Water

Days	Fox River No Fresh Seed P.p.m. B.O.D.	Fox River Fresh Seed Added P.p.m. B.O.D.
2	7,500	12,500
3	17,000	32,500
4	29,000	41,500
5	35,000	46,000
6	42,500	49,000
11	55,000	55,000

The five-day B.O.D.'s of 13.2 per cent total solids waste sulfite liquor obtained by using the various dilution waters were as follows:

Water	Five-Day B.O.D., p.p.m., 20° C.
Wisconsin River	22,500
Wisconsin River (Fresh Fox River Seed)	37,500
Sturgeon Bay	27,500
Green Bay	15,000
Fox River	37,500
Fox River (Fresh Fox River Seed)	46,000
East River	30,500
Fortified Water	25,000
Fortified Water (Fresh Fox River Seed)	37,500
Bicarbonate Dilution Water	5,500

An average of 2,500 gallons of waste sulfite liquor having a strength of approximately 13.8 per cent is made per ton of air dry pulp manufactured. Using this information and the above data along with the population equivalent of 0.167 lbs. of five-day B.O.D. per capita per day, the following values were calculated:

Water	Population Equivalent of a 100-Ton Sulfite Mill
Wisconsin River	283,000
Wisconsin River (Fresh Fox River Seed)	471,000
Sturgeon Bay	346,000
Green Bay	188,500
Fox River	471,000
Fox River (Fresh Fox River Seed)	579,000
East River	384,000
Fortified Water	314,000
Fortified Water (Fresh Fox River Seed)	471,000
Bicarbonate Dilution Water	69,000

In the determination of the B.O.D. of surface waters polluted with waste sulfite liquor to such an extent that dilution is required to obtain the B.O.D. data, it was found that considerably lower results were obtained when using standard bicarbonate water in comparison to a natural dilution water. Apparently dilutions of even two parts of standard bicarbonate water to one part of a polluted sample so upset the essential mineral balance that the biochemical activity is greatly reduced. The data obtained on 2:1 diluted samples follows:

B.O.D. of Green Bay Water at Mouth of Fox River, 1/24/40

Days	Bicarbonate Dilution Water P.p.m. B.O.D.	River Dilution Water P.p.m. B.O.D.
2	3.3	9.9
5	7.5	16.2
7	8.4	21.0
10	12.6	19.8
15	15.0	26.4
17	15.7	27.0
B.O.D. of Green Bay Water at Mouth of Fox River, 2/2/40		
3	7.2	12.0
5	9.0	16.2
7	11.7	16.8
10	14.1	19.2
14	17.1	23.1
20	16.2	28.2

The results using the river dilution water are nearly 100 per cent higher than those obtained with the standard dilution water. Further proof of the inaccuracy of the standard dilution water is evidenced by the fact that no increase in B.O.D. is shown between the sampling station above the two Green Bay sulfite mills and below their outlets, whereas using river dilution water, an increase between these two points of 12 p.p.m. in B.O.D. was observed. This increase for the flow of the Fox River is equivalent to a population load of 1,000,000 people.

Conclusions

In the study of the B.O.D. of a waste such as waste sulfite liquor it is advisable to use as dilution water the water into which the waste is to be dumped. The water should be aged a sufficient length of time to satisfy most of the B.O.D. originally present—ten to twenty days should suffice—keeping it well aerated during the aging period. The water should be seeded with fresh water from the same source with an amount of about 10 ml. per liter.

In the study of the pollutional results of waste sulfite liquor it is hardly sufficient to draw conclusions based on any particular proportion of the B.O.D. curve; that is, the five-day B.O.D. may or may not be a large percentage of the total B.O.D. The only satisfactory method is to determine a ten to twenty-day curve on the waste and to interpret the pollutional load from this curve.

When it is necessary to obtain the B.O.D. of a water polluted with waste sulfite liquor, aged dilution water from the same stream should be used if results of value are to be obtained.

Waste sulfite liquor apparently exerts a great influence upon the natural balance of the essential mineral element by completely effecting the removal of soluble phosphorus.

The actual population equivalent of a 100-ton sulfite mill will vary with the surface water into which it is dumped. These values will range from 283,000 to 579,000.

The population equivalent of the load added by the Green Bay sulfite mills was checked by a series of samples and proved to be slightly over a million, a figure that checks with the calculated data using the B.O.D. of waste sulfite liquor obtained with Fox River dilution water.

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2. *This Journal*, 8, 435 (1936).
3. "Water Pollution Studies in Wisconsin, Effects of Industrial (Pulp and Paper Mill) Wastes on Fish." By Arch E. Cole.

REPORT ON THE COOPERATIVE STUDY OF DILUTION WATERS MADE FOR THE STANDARD METHODS COMMITTEE OF THE FEDERATION OF SEWAGE WORKS ASSOCIATIONS

By C. C. Ruchhoft

Prin. Chemist, U. S. Public Health Service, Stream Pollution Investigations, Cincinnati, Ohio

A meeting of the Standard Methods Committee of the Federation of Sewage Works Associations was held at Chicago, October 4, 1940. At this meeting it was decided to make a cooperative study of dilution water to be used in the 5-day B.O.D. determination. Though it was generally agreed that mineralized phosphate buffered water of the type proposed by Theriault[1] was desirable, there was some objection to recommending such a water as a standard without further study. A brief set of instructions for making the study was prepared and sent to members of the Committee who were interested. Some of these found it impossible to take part in the study, and consequently a few cooperators from outside the original Committee were found.

The men who cooperated in the study are as follows:

E. Hurwitz, Southwest Treatment Plant, San. Dist. of Chicago, Ill.
Dr. W. D. Hatfield, Decatur Treatment Plant, San. Dist. of Decatur, Ill.
W. S. Mahlie, Sewage Treatment Plant, City of Fort Worth, Texas
R. K. Lewis, Sewage Treatment Plant, City of Indianapolis, Ind.
E. F. Eldridge, Engineering Experiment Station, Mich. State Coll., E. Lansing, Mich.
F. W. Gilcreas, Division of Laboratories, New York State Dept. of Health, Albany, N. Y.
Dr. Gail P. Edwards, Wards Island Plant, New York City, N. Y.
G. R. Barnett, Peoria Laboratory, San. Dist. of Chicago
R. R. Powell, U. S. Public Health Serv. Hospital Sewage Treatment Plant, Lexington, Ky.
J. F. Kachmar and O. G. Pettijohn, U. S. Public Health Service Stream Pollution Invest. Station, Cincinnati, Ohio

Procedure of Study

In this study it was desired to obtain comparative 5-day B.O.D. results upon a wide variety of samples, using standard sodium bicarbonate water and the mineralized phosphate buffered (Formula C) water in parallel. It was suggested that the cooperators could collect important data with a small amount of additional work with the Formula C water, but with no other change in their routine laboratory B.O.D. practice. Several of the routine samples which were regularly put up in bicarbonate dilution water were also diluted with Formula C water on one or two days each week. Several of the cooperators put up their samples in both dilution waters every day. The same procedures in making dilutions, seeding (when necessary), incubation, and in the dissolved oxygen determinations were followed upon the samples diluted with both waters. The following instructions for preparing the dilution waters to be studied were sent to all investigators:

1. The sodium bicarbonate water should be prepared with well aerated good quality distilled water, using 0.3 g. per liter of C.P. sodium bicarbonate following the precautions given in the Eighth Edition of Standard Methods (page 155—1.1).

2. The phosphate buffered Formula C water should be prepared as follows: The four stock mineral solutions required are prepared by dissolving the C.P. salts in liter quantities of distilled water:

(*A*) Ferric chloride—.25 g. $FeCl_3 . 6H_2O$
(*B*) Calcium chloride—11. g. $CaCl_2$ (Anhyd.)
(*C*) Magnesium sulphate—10. g. $MgSO_4 . 7H_2O$
(*D*) Phosphate buffer stock solution. Dissolve 34 g. of potassium acid phosphate (KH_2PO_4) in about 500 ml. of distilled water. Add 1 N sodium hydroxide (40 g. NaOH per liter) until a pH of 7.2 is reached. About 175 ml. of 1 N NaOH will be required. The mixture is then diluted to one liter.

The following amounts of each of the above stock solutions are added to distilled water (same quality as used for bicarbonate dilution water) to prepare the Formula C dilution water:

A. 0.5 ml. per l. or 8.0 ml. per 16-liter carboy,
B. 2.5 ml. per l. or 40.0 ml. per 16-liter carboy,
C. 2.5 ml. per l. or 40.0 ml. per 16-liter carboy,
D. 1.25 ml. per l. or 20.0 ml. per 16-liter carboy.

After almost 800 samples had been studied, the trends with Formula C and bicarbonate water had been rather definitely established. Nichols [2, 3, 4] has advocated the addition of nitrogen in an available form to all dilution waters to ensure the requisite quantities of this element for metabolic needs when carbonaceous wastes, such as paper mill waste, are under examination. In the latter part of this study, therefore, the results with the Formula C water fortified with ammonium sulfate were compared with bicarbonate or Formula C water without the addition of nitrogen. For this part of the study the following instructions were sent out for preparing the ammonia-supplemented mineral dilution water from two stock solutions.

Stock Solution A.

$CaCl_2$ anhyd. (C.P.)	3.0 g.
$MgSO_4 . 7H_2O$	3.0 g.
$FeCl_3 . 6H_2O$ (1% solution)	1 ml.
Distilled water to make	1000 ml.

For best results these salts should be added in the order given.

Stock Solution B.

Dissolve 34 g. of KH_2PO_4 in about 500 ml. of distilled water. Add 1 N sodium hydroxide solution (40 g. NaOH per liter) until a pH of 7.2 is reached. About 175 ml. of 1 N NaOH will be required. Then add 1.5 grams of $(NH_4)_2SO_4$ and dilute to 1 liter.

To make the nitrogen-supplemented mineral dilution water, add 10 ml. of stock solution A and 1.25 ml. of stock solution B to each liter of a good grade of distilled water.

This makes a mineralized buffered dilution water containing 94.13 p.p.m. of total solids in the following proportions:

$FeCl_3$	.06 p.p.m.
$CaCl_2$	30.00 p.p.m.
$MgSO_4$	14.70 p.p.m.
$KNaHPO_4$, KH_2PO_4	47.50 p.p.m.
$(NH_4)_2SO_4$	1.87 p.p.m.
Total	94.13 p.p.m.

The above procedure seems advantageous because only two stock solutions are required. However, neither the one per cent ferric chloride solution used for preparing stock solution A, nor stock solution A keeps very well because of a tendency of the ferric chloride to hydrolize in these concentrations. It is believed, therefore, that the original procedure employing four stock solutions is preferable. In either case, however, when the water is to be supplemented with nitrogen, the ammonium sulfate should be added to the stock phosphate buffer solution.

Analytical Data

In this study a total of 1123 samples were diluted in the waters being compared. These samples included river water and sewage in all stages of purification from a variety of treatment plants. The numbers and kinds of samples compared from all laboratories are shown in the following table.

Of these 1123 samples, 785 were compared in the mineralized phosphate buffered (Formula C) water and standard bicarbonate water, 277 were compared in nitrogen-supplemented Formula C water and standard bicarbonate water and 61 were compared in the Formula C water with and without supplemental nitrogen.

Comparative B.O.D. in Formula C and Bicarbonate Water

The comparative data on B.O.D. in the Formula C and bicarbonate waters are presented in Tables I, II and III for raw and primary effluent sewage, completely treated effluents and miscellaneous samples, respectively. Percentage B.O.D. deviation frequency curves for these data are plotted in Figs. 1 and 2.

The data in Table I indicate that the mean B.O.D. obtained on raw and settled sewage was generally slightly higher in Formula C water

Total Number of Samples Compared in the Dilution Waters

Laboratory Contributin	Raw Sewage	Primary Effluent	Aeration Effluent	Activated Sludge Effluent	Filter Effluent	Final Effluent	River	Total
Chicago South West Plant	3	31		35			5	74
Decatur Plant	150					149		299
Fort Worth Plant	58	49	49	34†	49	53		292
Indianapolis Plant	11	21	11	11			42	96
Michigan Eng. Exp. Station	10*							10
New York State Bd. of Health	7	2				4		13
Ward's Island, New York City	51	51		31				133
San. Dist. of Chicago, Peoria, Ill.							69‡	69
U. S. P. H. S. Hosp., Lexington, Ky.	22	20		17				59
U. S. P. H. S. Stream Poll. Invest. Sta., Cincinnati, O.	41			20	17			78
Totals	381	146	60	148	66	206	116	1123

* Beet sugar factory wastes.

† The results on these samples are not included with the activated sludge data. This is because these B.O.D. results are so high that they are not comparable with the other activated sludge effluent data.

‡ Forty-one (41) of these samples are river water containing glucose.

than in bicarbonate water. The mean deviations between the Formula C and bicarbonate dilution water data in this table varied from 7.0 to 39.9 p.p.m. and the standard deviation varied from $\pm$ 4.4 to $\pm$ 18.7 per cent. Both the mean deviation and standard deviation seem to be slightly lower for primary treated sewage than for raw sewage. The deviation frequency curve for the raw and settled sewage samples (Fig. 1) follows an approximately normal frequency distribution except for a shift of the maximum point of the curve to the right of the y axis. This shows that the Formula C water usually gave slightly higher results on this series of 399 raw and primary treated samples.

Table II, which summarizes the results for filter effluent, activated sludge effluent and final effluent samples indicates that the variations between the results obtained in these dilution waters depend to a considerable extent upon the kind of sample under examination. The poorest checks and greatest mean percentage deviation and standard deviation are obtained on activated sludge effluent samples. With these samples higher results are usually obtained with bicarbonate water. This is well illustrated by the frequency curve of B.O.D. deviations for activated sludge samples in Fig. 2. This figure shows a skew frequency distribution and indicates the great tendency for the B.O.D. of these samples to be higher in bicarbonate water.

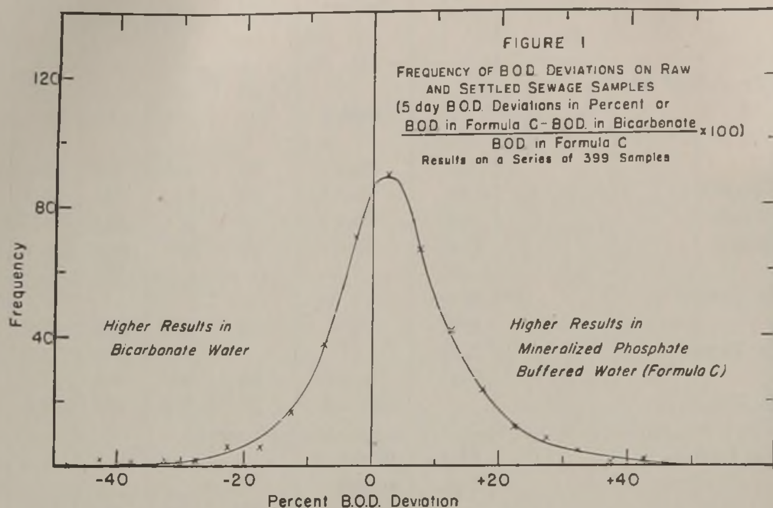
The data for final effluent samples from sprinkling filter plants summarized in Table II shows lower standard deviations ($\pm$ 7.9 to $\pm$ 26.4

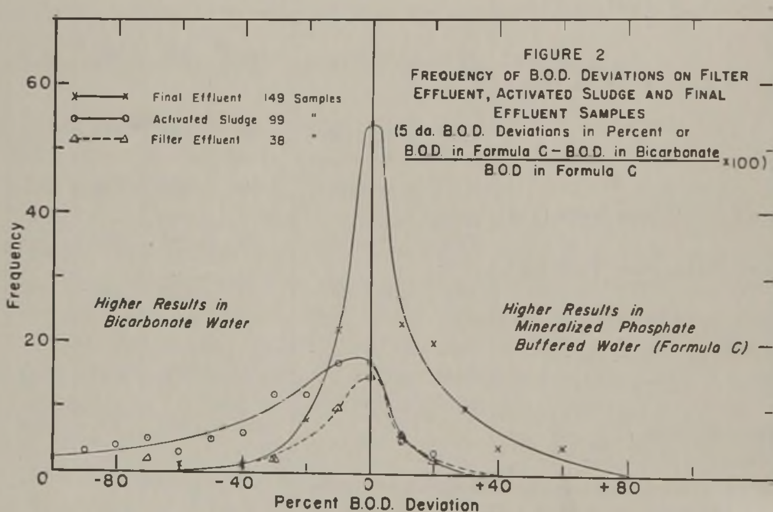
TABLE I.—*Summary of Comparative B.O.D. Data Obtained on Raw Sewage and Primary Effluent Samples with Formula C and Bicarbonate Dilution Water*

Laboratory Contributing	Month 1940 and 1941	Description of Samples	No. of Samples Compared	Mean 5-day B.O.D., P.P.M.		Mean Deviation, P.P.M. ±	Standard Deviation in Per Cent ±
				Formula C	Bicarbonate		
Southwest Treatment Works, Chicago, Ill.	—	Settled	28	158	147	20.5	18.7
Decatur, Illinois	Oct.–Nov.	Raw	36	252	215	39.9	17.1
Decatur, Illinois	Dec.	Raw	30	254	227	19.9	8.7
Decatur, Illinois	Jan.	Raw	30	256	234	21.5	10.4
Decatur, Illinois	Feb.	Raw	27	287	295	19.2	10.5
Fort Worth, Texas	Nov.–Feb.	Raw	31	258	250	17.6	9.7
Fort Worth, Texas	Nov.–Feb.	Pri. eff.	22	207	207	7.7	5.2
Fort Worth, Texas		Sec. eff.	28	216	214	7.0	4.4
Indianapolis, Indiana	Mar.–Apr.	Screened settled clar.*	31	249	249	13.0	6.1
Lexington, Ky. U. S. P. H. S. Hospital	Jan.–Mar.	Raw	22	356	347	48.4	17.7
Lexington, Ky. U. S. P. H. S. Hospital	Jan.–Mar.	Pri. eff.	20	222	245	21.2	15.3
New York State		Raw and settled	6	280	258	34.7	—
Ward's Island Plant, New York City	Nov.–Feb.	Raw	31	184	180	16.8	13.0
Ward's Island Plant, New York City	Nov.–Feb.	Pri. eff.	31	199	199	12.7	9.5
Stream Pollution Invest. Station, Cincinnati, O.	Jan. 1941	Raw	29	263	249	25.3	17.0
On all of above samples	—	—	402	240	231	20.9	12.6

* Eight (8) plain aeration effluent samples are included in this group.

per cent) and does not indicate any tendency for higher B.O.D. results in bicarbonate water. An examination of the frequency curve for these data (also shown in Fig. 2) indicates a more normal frequency distribution but with a slight tendency for more frequent high results in Formula C water. The frequency distribution for sprinkling filter plant final effluent samples lies between the raw sewage samples and the activated sludge effluent samples frequency distribution. However, it resembles the raw sewage sample B.O.D. deviation frequency distribution much more nearly than the activated sludge frequency distribution. Though there were only 38 filter effluent samples compared, hardly enough for a satisfactory frequency curve, these results also are summarized in Table II and the deviation frequencies are plotted in Fig. 2.





The beet sugar factory waste data in Table III indicate that higher mean B.O.D. results can be expected with Formula C water than with bicarbonate water on this kind of sample. The mean deviation was 128 p.p.m. and the standard deviation 16.2 per cent. The river water data also summarized in Table III are quite variable, depending apparently upon the stage of purification reached in the river. There are hardly enough data to warrant any conclusion, except that bicarbonate water may tend to give higher results when the river water is approaching nitrification as at Peoria and Indianapolis.

TABLE II.—*Summary of Comparative B.O.D. Data Obtained on Filter Effluent, Activated Sludge Effluent and Final Effluent Samples with Formula C and Bicarbonate Dilution Water*

Laboratory Contributing	Month 1940 and 1941	No. of Samples Compared	Mean 5-day B.O.D.		Mean Deviation, P.P.M. ±	Standard Deviation in Per Cent ±
			Formula C	Bicarbonate		
Filter Effluent Samples						
Fort Worth, Texas	Nov.–Feb.	21	37.1	37.1	1.5	7.0
Stream Pollution Invest. Sta.	Jan. 1941	17	30.8	31.8	4.5	34.0
Activated Sludge Effluent Samples						
Southwest Treatment Wks. Chicago	—	29	10.9	15.9	5.1	61.0
Indianapolis, Indiana	—	8	4.6	6.6	2.2	47.5
Lexington, Ky. U. S. P. H. S. Hospital	Jan.–Mar.	17	16.6	26.4	10.6	85.0
Ward's Island Plant, New York	Nov.–Feb.	31	8.6	11.2	2.7	41.7
Stream Pollution Invest. Sta.	Jan. 1941	14	14.4	14.2	.8	11.5
Final Effluent Samples						
Decatur, Illinois	Oct.–Nov.	35	25.1	20.7	5.6	26.4
Decatur, Illinois	Dec.	27	26.7	25.2	2.5	15.8
Decatur, Illinois	Jan.	31	25.7	23.7	2.7	13.4
Decatur, Illinois	Feb.	28	27.0	28.9	2.3	12.1
Fort Worth, Texas	Nov.–Feb.	25	24.4	25.4	1.1	7.9
New York State	—	3	65.0	61.0	10.0	—
All filter effluent samples		38	34.3	34.8	2.9	25.9
All activated sludge effluent samples*		99	11.1	15.2	4.5	54.6
All final effluent samples		149	26.6	25.3	1.2	17.3
All of above three groups		286	22.2	23.1	3.6	35.8

* Fort Worth not included in this group.

Comparison of Ammonia Supplemented Formula C Water and Bicarbonate Water

A summary of the results obtained with the Formula C water supplemented with ammonium sulfate and standard bicarbonate water is presented in Table IV. It will be noted that the B.O.D. agreement on raw sewage and primary treated samples seems to be good. Both the mean and standard deviations obtained on a series of 120 raw and settled sewage samples in these waters are lower than were obtained in the longer series of such samples in Formula C and bicarbonate

TABLE III.—*Summary of Comparative B.O.D. Data Obtained on Miscellaneous Samples with Formula C and Bicarbonate Dilution Water*

Laboratory Contributing	Month	No. of Samples Compared	Mean 5-day B.O.D.		Mean Deviation, P.P.M. ±	Standard Deviation in Per Cent ±
			Formula C	Bicarbonate		
Beet Sugar Factory Waste						
Michigan Engineering Exp. Sta.	—	10	820	694	128	16.2
Glucose in Illinois River Water*						
Peoria Lab., Sanitary Dist. of Chicago	1941 Jan.–Feb.	41	4.88	4.78	0.22	5.5
River Water						
Southwest Treatment Wks. Chicago	—	5	41.8	40.0	2.2	—
Indianapolis, Indiana	—	32	13.1	15.3	2.4	55.0
Peoria Lab., San. Dist. of Chicago	—	28	2.3	2.4	.3	17.7
All river water samples		65	10.7	11.6	1.5	39.9

* These samples contained from ½ to 10 P.P.M. of glucose.

waters. The B.O.D. deviation frequency distribution for this series of 120 samples, while not shown, is very similar to Fig. 1. The results obtained with all other kinds of samples are also shown in Table IV. The results, while not sufficiently numerous for frequency distribution plotting, seem in general to be similar to the results on Formula C and bicarbonate water already discussed. It is interesting to note that the mean B.O.D. for this series of 35 activated sludge effluent samples was again slightly higher in the bicarbonate water, even when the Formula C water was supplemented with ammonia. The skew frequency distribution and the much higher standard deviation were evident again in these activated sludge effluent results.

A summary of the comparative B.O.D. data obtained in Formula C water with and without supplemented ammonia is given in Table V for 31 raw sewage and 30 final effluent samples from Decatur. On both raw sewage and final effluent samples the ammonia fortified water gave slightly higher mean results. A lower mean deviation (8.4 p.p.m.) was obtained than in either of the other series of raw sewage samples. The standard deviation was 10.1 per cent, an intermediate value between those obtained on the other two series. On the final effluent the mean deviation was 2.2 p.p.m. or slightly higher than was obtained on the other series of samples. The standard deviation was 12.4 per cent, which was again intermediate between that obtained in the first two series of samples. A condensed summary permitting a comparison be-

TABLE IV.—*Summary of Comparative B.O.D. Data Obtained on Various Samples with Formula C Water Supplemented with Ammonium Sulfate and Standard Bicarbonate Water*

Laboratory Contributing	Description of Samples	No. of Samples Compared	Mean 5-day B.O.D.		Mean Deviation, P.P.M.	Standard Deviation in Per Cent ±
			Formula C + $(NH_4)_2SO_4$	Bicarbonate		
Ward's Island, New York City.........	Raw sewage	32*	191	190	15.3	10.9
Fort Worth, Tex.	Raw sewage	27	305	310	16.8	7.8
Indianapolis, Ind.....	Raw sewage†	9	291	279	14.3	5.7
Ward's Island, New York City.........	Settled sewage	25‡	162	157	10.6	9.9
Fort Worth, Tex.	Settled sewage	27	207	208	5.5	3.3
All raw and settled sewage samples...		120	222	219	12.4	8.3
Fort Worth, Tex.	Aeration eff.	30§	191	189	4.8	3.6
Fort Worth, Tex.	Secondary tank eff.	28	188	186	7.5	5.0
Fort Worth, Tex.	Filter eff.	28	43.8	43.9	2.4	7.3
Fort Worth, Tex.....	Final eff.	28	28.1	27.9	1.1	5.9
Ward's Island, New York City.........	Activated sludge eff.	33‖	10.2	11.7	2.2	35.0
Indianapolis, Ind. ...	River water	10	20.6	22.0	2.0	12.6

* This group includes 3 samples from the Sanitary Dist. of Chicago Southwest Plant, 8 from the Stream Pollution Investigations Station and 1 from the New York State Board of Health.

† These include screened, settled and clarified sewage samples.

‡ This group includes 3 samples from the Sanitary Dist. of Chicago Southwest Plant and 2 from the New York State Board of Health.

§ This group includes 6 samples from the Sanitary Dist. of Chicago Southwest Plant, 1 from the New York State Board of Health and 6 from the Stream Pollution Investigations Station.

‖ This group includes 3 samples from Indianapolis, Ind.

tween the results obtained in these three series of samples in the three pairs of dilution waters is presented in Table VI. In the B.O.D. determination, checks within 10 per cent on duplicate determinations are usually considered as satisfactory. The percentage of the comparative results agreeing within 10 per cent are shown in this table; and with Formula C and bicarbonate waters vary from 24 per cent on activated

TABLE V.—*Summary of Comparative B.O.D. Data Obtained on Raw Sewage and Final Effluent Samples with Formula C with and without Ammonium Sulfate*

Laboratory Contributing	Description of Samples	No. of Samples Compared	Mean 5-day B.O.D.		Mean Deviation, P.P.M.	Standard Deviation in Per Cent ±
			Formula C + $(NH_4)_2SO_4$	Formula C		
Decatur, Illinois.....	Raw sewage	31*	308	304	8.4	10.1
Decatur, Illinois.....	Final eff.	30†	27.2	25.5	2.2	12.4

* This group includes four (4) samples from the Stream Pollution Investigations Station.

† This group includes two (2) samples from the Stream Pollution Investigations Station.

TABLE VI.—*Condensed Summary of Comparative B.O.D. Data.*

Description of Samples Compared	Number of Samples Compared			Mean B.O.D. in P.P.M. (In Formula C Water)			Mean Deviation in P.P.M.			Percentage of Results Agreeing Within 10 Per Cent			Percentage of Times that Formula C Water Gave Equal or Higher Results			Standard Deviation in Per Cent		
	A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Raw and settled sewage....	402	120	31	240	222	304	20.9	12.4	8.4	76	85	74	72	66	39	12.6	8.3	10.1
Filter effluent............	38	28	—	34.3	43.8	—	2.9	2.4	—	66	86	—	50	50	—	25.9	7.3	
Activated sludge effluent....	99	33	—	11.1	10.2	—	4.5	2.2	—	24	24	—	17	18	—	54.6	35.0	
Final effluent.............	149	28	30	26.6	28.1	25.5	1.2	1.1	2.2	57	86	60	62	71	30	17.3	5.9	12.4
River water..............	65	10		10.7	20.6		1.5	2.0		49	50		31	50		39.9	12.6	
Beet sugar wastes..........	10			820			128			30			90			16.5		

A. Comparative data with Formula C and bicarbonate water.
B. Comparative data with Formula C plus $(NH_4)_2SO_4$ and bicarbonate water.
C. Comparative data with Formula C and Formula C plus $(NH_4)_2SO_4$.

sludge to 76 per cent on raw sewage. When Formula C water fortified with ammonia is compared to bicarbonate water the checks within 10 per cent were 85 to 86 per cent for final effluents, filter effluents and raw sewages, but fell to 50 per cent on river water and to 24 per cent on activated sludge effluents. Very similar values were obtained for the percentage of results checking within 10 per cent when Formula C water and Formula C water with ammonium sulfate were compared on raw sewage and final effluents. It is notable that the percentages of comparative results checking within 10 per cent are in good agreement in the A and B columns. This indicates that the Formula C water, whether supplemented with ammonia or not, will give results which bear essentially the same relation to the bicarbonate results.

The percentage of times that the Formula C water gave results equal to or higher than the bicarbonate water are also shown in Table VI. These data show that the Formula C water, either with or without supplemental ammonia, can be expected to give equal or higher results from 66 to 72 per cent of the time on raw or primary treated sewages, from 62 to 71 per cent of the time on final effluents, about 50 per cent of the time on filter effluents and only 17 to 18 per cent of the time on activated sludge effluents. Again there is a great similarity in the comparative data obtained whether the Formula C water contained ammonia or not.

When the Formula C waters with and without ammonia are compared, equal or higher results are obtained in the Formula C water without ammonia only 30 per cent of the time on final effluents and 39 per cent of the time on raw sewage. These data therefore indicate that slightly higher results can be expected in the ammonia-supplemented water. This is not in perfect agreement with the indirect data in columns A and B.

Summary

A comparative study of the 5-day B.O.D. results obtained in a mineralized phosphate buffered water, with and without ammonia, and in the standard bicarbonate water, has been made. A summary of the data obtained and the deviation frequency distributions have been presented. The relationship between the results obtained in the mineralized phosphate buffered (Formula C) water and in the present standard bicarbonate water is not altered by the addition of the small amount of ammonium sulfate to the mineralized phosphate buffered water that is recommended as a supplemental source of nitrogen. In general, slightly higher 5-day B.O.D. results can be expected in strong industrial wastes, raw and primary treated sewage and in effluents from sprinkling filter plants in the mineralized phosphate buffered water. Effluents from activated sludge plants, on the other hand, can be expected to give higher results in bicarbonate water, also when the phosphate buffered water is supplemented with ammonia. Normal deviation frequency distributions were obtained on raw sewage and primary effluents, while a skew deviation frequency distribution was obtained on activated sludge effluents. The standard deviations between the results in the

mineralized phosphate buffered water and the bicarbonate water were as follows:

	Per Cent
Raw and settled sewage	12.6
Final effluents (sprinkling filter plants)	17.3
Filter effluents	25.9
River water	39.9
Activated sludge effluents	54.6

On the basis of this study it is believed that the mineralized phosphate buffered dilution water is superior to the bicarbonate water for the determination of 5-day B.O.D. in sewage treatment practice, where the efficiency of a treatment process is to be followed. Whereas the ammonia-supplemented mineralized phosphate buffered water is superior for the determination of B.O.D. on nitrogen deficient wastes and is entirely satisfactory for sewage and sewage effluents (it having been shown to give lower B.O.D. values than bicarbonate water on activated sludge effluents) it is recommended that a mineralized phosphate buffered water supplemented with the amount of ammonium sulfate used in this study be adopted as standard. Because the description of the water as a mineralized phosphate buffered nitrogen supplemented water is too long and the name nitrogen supplemented Formula C water seems undesirable, it is suggested that this water be called the Theriault-Nichols dilution water.

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CHEMICAL COAGULATION OF SEWAGE *

XIII. INERT MATERIALS

By Harry W. Gehm

Assoc., Dept. Water and Sewage Research, New Brunswick, N. J.

Early in the practice of chemical treatment of sewage, more or less inert materials were added in a finely divided state to produce or aid coagulation. The theory behind the use of these materials was that they would settle rapidly on account of their relatively high specific gravity and carry with them a portion of the finely divided sewage solids. It was also believed that when incorporated in a hydrous floc, formed in sewage by the addition of a coagulant, they would render the floc particles heavier, hence more readily settleable and productive of a more dense sludge.

Some of the materials used in early practice were marl, peat, clay, chalk and limestone (1). Milled paper was employed in one of the processes used recently in this country (2). Laboratory and plant trials have been made with activated carbon (3) and silica. Paper rapidly fell into disuse because the benefits derived did not justify the expense involved. In general, none of the materials employed have shown much promise of improving present methods of chemical coagulation of sewage.

At present some new inert materials, industrial residues, are available in different localities at very low costs. Some of these might prove more effective than the materials formerly tried. There are also some materials on the market which could possibly be effective, because of some inherent properties. In the former group are spent tan bark, flue dust, sludge ash and iron oxide waste from copperas roasters. In the latter category such materials as bleaching clays, activated carbon, bentonite and diatomaceous earth may be included.

This paper deals with experiments made with various materials in respect to their effect on clarification and sludge volume when used alone and in conjunction with chemical coagulants.

Procedure

The general methods employed were identical to those reported in former papers of this series (4) (5). The inert materials used were weighed and added to the sewage prior to treatment with the coagulant. The range of dosage included amounts exceeding practical quantities in order that any effect, even if small, could be demonstrated. All of the waste material was ground to pass a 200 mesh sieve, while the commercial products were applied as received. In these experiments 0, 50, 100, 500, 800 and 1,000 parts per million of the inert material were added

* Journal Series Paper, N. J. Agricultural Experiment Station, Dept. Water and Sewage Research, New Brunswick, N. J.

to each of six one-liter portions of sewage with rapid stirring to insure dispersion. The samples were flocculated thirty minutes and settled for two hours. Clarification was evaluated by measuring turbidity remaining in the supernantants. The sludge volume was measured directly. This procedure was repeated for each dosage of coagulant used with six other one-liter portions of the same sewage. The procedure was identical for each inert substance with the exception of the coagulant dosage, which was varied according to the requirements of the sewage. Domestic sewage only was selected for this work.

By-products

Spent Tan Bark.—This material consists of the residue remaining after tan bark has been leached in the manufacture of tannic acid. The residue consists mainly of cellulosic and ligneous materials and a small quantity of residual tannin and tannic acid. This material was selected because tannins have been shown to have concentrating and dewatering action on sewage sludge.

It was found that the finely divided spent tan bark dispersed well in sewage. Rather than aiding clarification, however, it was found to be detrimental. Figure 1 *A* shows that 100 p.p.m. either prevented clarifi-

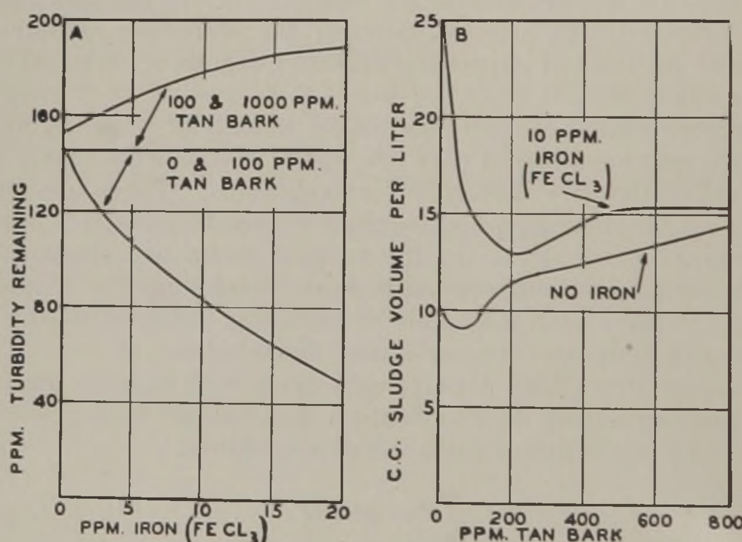

Fig. 1.—Effect of tan bark on clarification and sludge volume.

cation entirely, when ferric chloride was applied, or added turbidity which was not removed by the coagulant. In either case the turbidity in the supernatant with and without ferric chloride treatment remained the same. Dosages of tan bark up to 1,000 p.p.m. yielded supernatants of lesser clarity than obtained when the sewage was flocculated and settled without the addition of chemicals.

Tan bark can influence strongly the compacting qualities of a chemical sludge. As shown in Fig. 1 *B*, tan bark increased the sludge volume when no coagulant was applied. When ten parts per million ferric chloride as iron were applied, 100 p.p.m. of tan bark reduced the volume 40 per cent, while 200 p.p.m. reduced it over 50 per cent. Higher dosages of tan bark effected no further reduction.

Flue Dust.—The addition of flue dust to sewage prior to coagulation with ferric chloride improved clarification somewhat. With 100 p.p.m. of dust, clarification increased 8 per cent, and with 1,000 p.p.m., 22 per cent, when sufficient coagulant was added to give a high degree of clarification. The effectiveness of the dust in aiding clarification was generally in proportion to the coagulant dosage. With no coagulant no clarification was produced by the flue dust itself. The results are illustrated in Fig. 2 *A*.

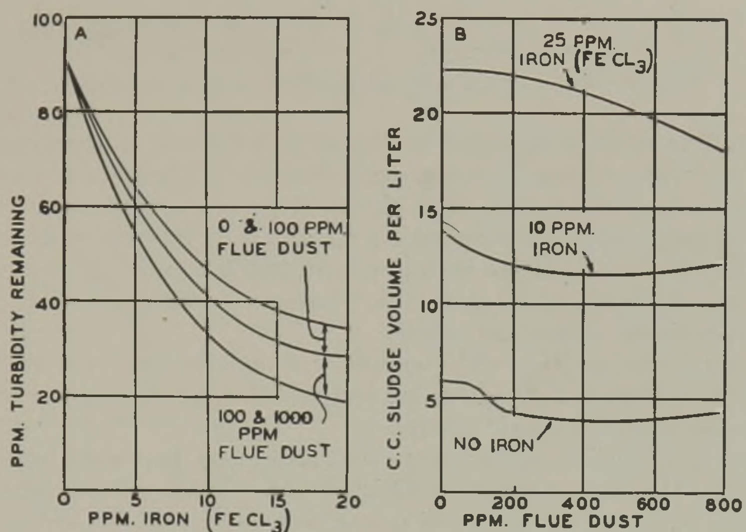

FIG. 2.—Effect of flue dust on clarification and sludge volume.

Flue dust did not appear to be particularly effective in decreasing the sludge volume. Inspection of Fig. 2 *B* shows that significant reductions in sludge volume occurred only when 400 p.p.m. or more of dust was applied, and the sewage was treated with a coagulant dosage sufficient to give almost complete clarification (25 p.p.m. of iron).

Iron Oxide.—Iron oxide (Fe_2O_3), despite its high specific gravity, dispersed and remained in suspension during flocculation surprisingly well. However, when very large dosages were used (500 p.p.m. or more) some of this material settled immediately. With 50 p.p.m. of the oxide and dosages of ferric chloride sufficient to give partial clarification, increases in turbidity removal were noted as high as 13 per cent which could be attributed to the oxide. With a sufficient dosage of ferric chloride to give good clarification no added clarification was attained. The results are graphically shown in Fig. 3 *A*.

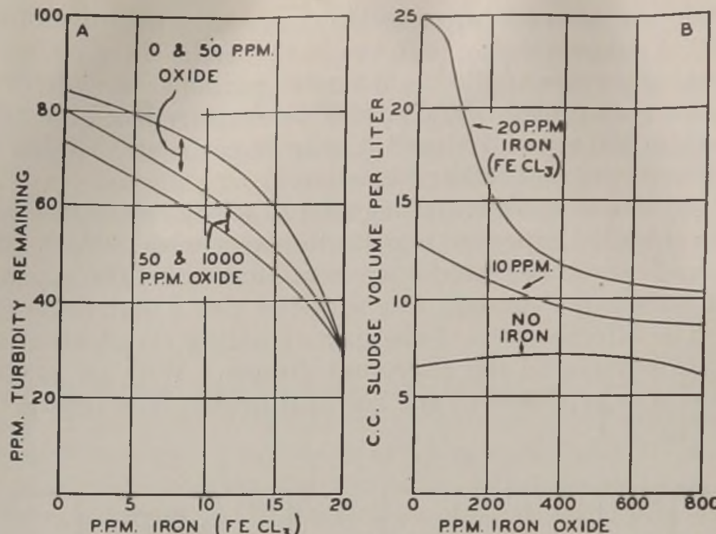

FIG. 3.—Effect of iron oxide on clarification and sludge volume.

The effect of this material on the sludge volume was marked when the sewage was coagulated with ferric chloride. Figure 3 *B* shows that the effect was greater with high chemical dosages. When the demand dosage of ferric chloride was added (20 p.p.m.), 100 p.p.m. of oxide reduced the volume of sludge by 8 per cent, 200 p.p.m. by 28 per cent and 400 p.p.m. oxide about 50 per cent. Larger dosages of oxide did not have appreciable additional effect.

Digested Sludge Ash.—The ash used was collected from an incinerator in which digested sludge is burned completely, leaving a very finely divided ash free of organic matter.

In the clarification experiments the sludge ash appeared to give definite aid to the ferric chloride (Fig. 4 *A*). While demonstrating no clarifying power of its own, 100 p.p.m. ash decreased the dosage of coagulant necessary for complete clarification by 33 per cent. Larger

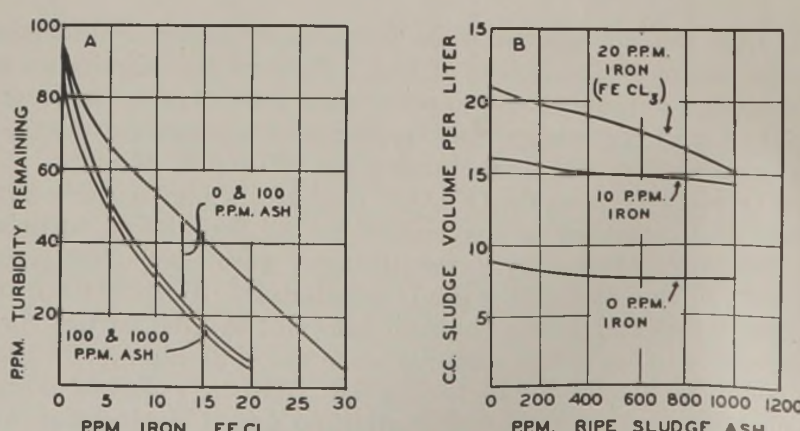

FIG. 4.—Effect of ripe sludge ash on clarification and sludge volume.

quantities of the ash did not cause an appreciable further reduction in the coagulant demand.

The results on sludge volume experiments in Fig. 4 *B* demonstrate that the ash was effective in reducing the sludge volume only when applied in large dosages to sewage treated with higher dosages of ferric chloride. For instance, 100 p.p.m. reduced the volume 4 per cent, while 1,000 p.p.m. reduced it about 30 per cent.

Industrial Products

The second group of materials investigated were those which have been shown to be effective for other purposes in water or sewage treatment. These materials were obtained as manufacturers' samples. Experiments with these substances followed the same general pattern as those made with the waste products.

Activated Carbon.—A finely divided common brand of activated carbon was used in these experiments. The inability of this material to aid materially in the clarification of sewage is shown in Fig. 5 *A*. No

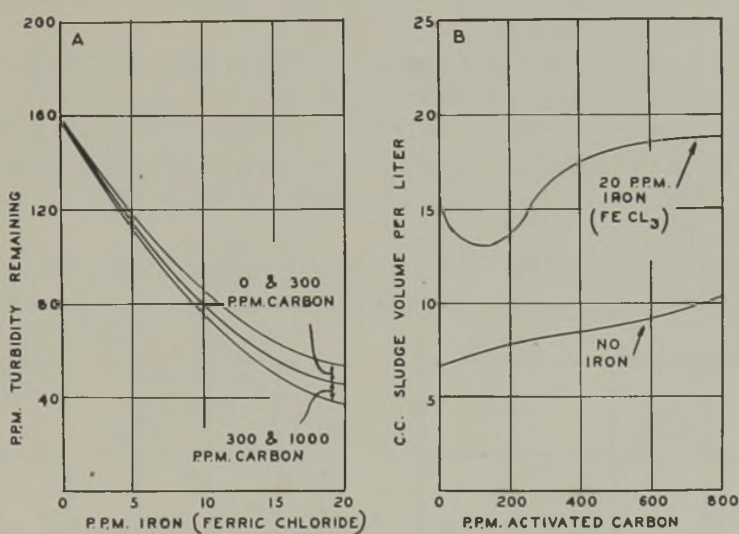

Fig. 5.—Effect of activated carbon on clarification and sludge volume.

marked improvement in the removal of turbidity was evident either with or without the use of a coagulant, even when 1,000 p.p.m. was applied.

As could be expected the sludge volumes obtained were not materially affected by the carbon. Dosages up to 200 p.p.m. in conjunction with the demand dosage of ferric chloride reduced the volume slightly, while higher dosages increased it considerably (Fig. 5 *B*).

Bleaching Clay.—The type of clay used in water coagulation was selected for these experiments. This substance dispersed exceedingly well and settled readily with the settleable solids after flocculation. Clarifying power, however, was not demonstrated to any appreciable

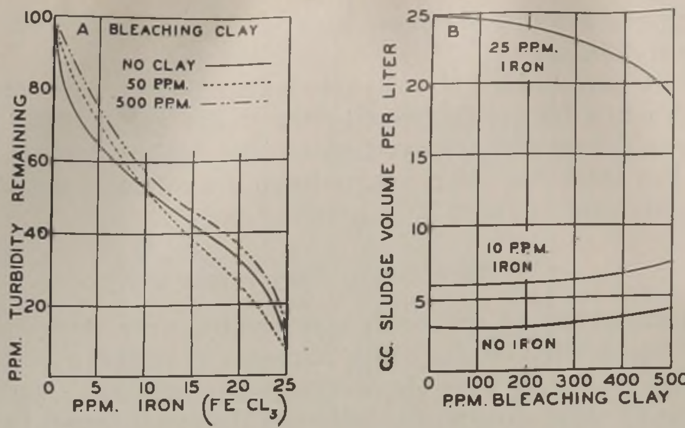

FIG. 6.—Effect of bleaching clay on clarification and sludge volume.

extent (Fig. 6 *A*). This substance had the property of changing the character of the floc to a remarkable degree. As little as 50 p.p.m. applied prior to ferric chloride treatment produced a small dense floc which settled very rapidly.

Activity of the clay in reducing sludge volume was slight, except when excessive quantities were used. Figure 6 *B* shows that 500 p.p.m. of bleaching clay was required to effect a 20 per cent reduction in sludge volume when the coagulant dosage was sufficient to give complete clarification. Reductions in volume accomplished by smaller dosages were insignificant.

Diatomaceous Earth.—The low priced variety of this material was used in these experiments. Summarized data are shown in Fig. 7 *A*.

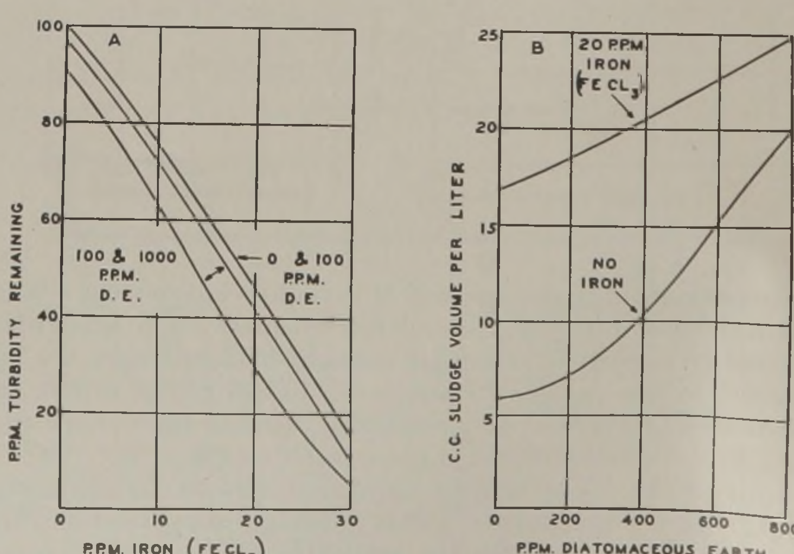

FIG. 7.—Effect of diatomaceous earth on clarification and sludge volume.

Application of even 1,000 p.p.m. of this material showed little effect on clarification, increasing the turbidity removal less than 10 per cent.

The application of diatomaceous earth materially increased the volume of sludge collected, whether a coagulant was employed or not (Fig. 7 *B*).

Bentonite.—To obtain good dispersion, a suspension of commercial bentonite in water rather than the dry substance was employed. Time is required for the bentonite to absorb water and assume a gel form in which it is supposed to have its most effective coagulating properties. Otherwise the experimental method was the same as it was for the other substances. It was found that 100 p.p.m. of this material had a slightly beneficial effect on clarification. Increasing the dosage to 800 p.p.m. had a small additional beneficial effect, but the degree of additional clarification was not appreciable. However, the same degree of clarification could be obtained with 30 per cent less ferric chloride when 800 p.p.m. of bentonite was used as shown in Fig. 8 *A*.

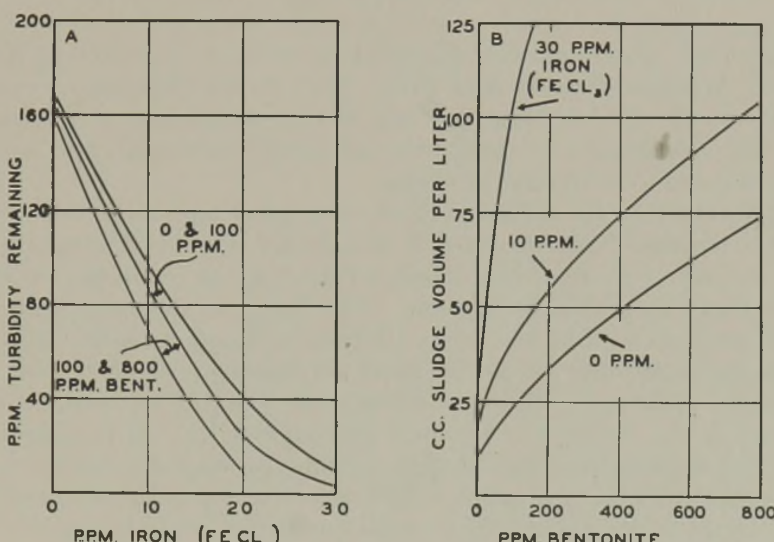

FIG. 8.—Effect of bentonite on clarification and sludge volume.

The curves in Fig. 8 *B*, showing sludge volumes produced at varying dosages of bentonite and ferric chloride, indicate increased sludge volume, particularly when the coagulant was applied. Even partial dosages of ferric chloride at a bentonite concentration of 100 p.p.m. gave high sludge volumes. When the demand dosage of ferric chloride was applied with 100 p.p.m. of bentonite, the volume after two hours settling was nearly four times greater than when no bentonite was used.

Discussion

None of the waste materials used in these experiments, with the possible exception of sludge ash, showed promise of being particularly useful in practice as aids in clarification and accelerants in sludge compacting. Tan bark speeded compacting but prevented clarification; flue dust aided clarification slightly, but was not particularly effective in compacting the sludge; and iron oxide helped compacting but aided clarification only when a partial dosage of coagulant was applied.

Digested sludge ash, applied at the rate of 100 p.p.m. lowered the coagulant demand 33 per cent and accelerated sludge compacting to a small degree. Whether the decrease in coagulant demand was due to soluble or insoluble matter in the ash, or both, was not determined. The ash contained some calcium oxide, which substance could affect the results. It is extremely doubtful, however, if sufficient CaO were present to account for the results obtained.

The addition of 100 p.p.m. of ash in a plant would necessitate the reuse of ash, because a million gallons of sewage may produce only from 300 to 750 pounds instead of 830 pounds per million gallons treated. Whether the ash would be effective on second passage is questionable and whether the saving in coagulant effected would warrant the necessary equipment and operation is doubtful.

In general the commercial materials were no more effective than the wastes. Activated carbon had little effect on clarification or compacting; the merit of bleaching clay lay in the production of a somewhat better floc; diatomaceous earth was practically valueless; and bentonite produced excessive volumes of sludge.

It appears that the addition of various inert materials to sewage as an aid to chemical clarification is not justified as a general practice. There seems to be no need to supply nuclei for floc formation in sewage because there are sufficient present. The fact that the coagulant affects the dissolved as well as the finely divided suspended matter of sewage reduces the possibility of aid by inert substances. Replacement of coagulant by chemically inactive substances capable of absorption requires excessive dosages to produce desired results. It is, therefore, a matter of clarification and sludge volume production, which in turn affect operation and economics. The acceleration in the compacting of sludge would be advantageous if small quantities could be employed for effective results. However, in most cases the quantity of inert matter necessary is too great to be practical. Moreover the addition of large quantities of inert substances means their handling through the plant units. This adds expense and in some cases attending difficulties. It may be possible that certain inert materials could be treated or activated in some manner to make them more effective.

Summary

Laboratory experiments with wastes from industrial processes (tan bark, flue dust, iron oxide and sludge ash) and inert commercial products (activated carbon, bleaching clay, diatomaceous earth and bentonite) to determine their effect on clarification of sewage and compacting of sludge show that:

(1) Inert materials are in general of little value in aiding the process of chemical treatment of sewage.

(2) Such substances can accelerate the compacting of chemical sludge but in general too great a quantity is necessary to produce the desired results.

(3) Digested sludge ash gave the best overall results of all materials tried.

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A SUGGESTED PROCEDURE FOR THE DETERMINATION OF GREASE

By Harvey F. Ludwig

Engineering Assistant, East Bay Cities Sewage Disposal Survey, Berkeley, California

This discussion summarizes observations made in the laboratories of the East Bay Cities Sewage Disposal Survey on various methods of extracting grease from domestic sewages and industrial wastes. A new procedure is suggested for the determination of grease which eliminates the necessity of evaporating the sample to dryness, and which is believed to be sufficiently dependable and simple for most sewage testing work.

Routine Tests by the East Bay Cities Sewage Disposal Survey.— The routine testing work of the survey included laboratory grease analyses of some 300 composited samples of domestic sewages and of wastes from numerous industries. The test procedure adopted for this work is a modification of the dry extraction procedure of Standard Methods, as used by the Richmond-Sunset Sewage Treatment Plant of San Francisco, California. This procedure comprises acidifying the sample with hydrochloric acid, evaporating to dryness with the water-bath and drying oven, and extracting the grease by rubbing the solvent into the residue with a glass rod. The solvent containing the dissolved grease is filtered, the filtrate evaporated on the water-bath, and the residue dried, cooled, and weighed. Chloroform was used as the extracting agent. This procedure was selected because it is simple, and because it was thought to be sufficiently accurate for the purposes of the survey.

It became apparent, however, during the progress of the work, that the adopted procedure had serious shortcomings as an analytical test. Duplicate determinations sometimes did not check. Further, in some of the industrial wastes analyses, chloroform-soluble substances were extracted which had little or no grease-like properties. This was particularly true of those wastes from paint and chemical manufacturing industries, from which crystalline substances were frequently obtained.

A number of synthetic samples were prepared by adding known weights (about 100 mgm.) of various fatty acids (stearic, palmitic, lauric, and myristic) to 500 c.c. portions of sewage of very low grease content (5 p.p.m.). The fatty acids were dispersed by heating and agitating the mixture. Following the dispersion about 500 p.p.m. $CaCl_2$ was also added. These modified sewages were then analyzed for grease by the routine dry-chloroform procedure described, and it was found that only a variable fraction of the added fatty acids could be recovered. It was observed during filtration of the solvent containing the extracted substances that these substances tended to crystallize along the top edge of the filter paper. Further, the residue obtained by evaporating the filtrate was hard and glassy, and redissolved in chloroform only with difficulty. It is concluded from these observations that when the acidified sample is evaporated to dryness in the presence of an appreciable concentration of calcium or other polyvalent cations, the fatty acids will be transformed into soaps of these cations which are only slightly soluble in the extracting agent. When a Soxhlet extraction is made, as in Standard Methods, it is probable that all the fatty acids may be recovered; but even in this case the residue will contain a variable amount of calcium and other polyvalent cations.

Proposed Grease Test.—In order to overcome these difficulties it seemed desirable to eliminate the operation of evaporating the sample to dryness, and accordingly a wet-extraction procedure was studied. The procedure used was as follows:

1. Acidify a 500 or 1000 c.c. sample with hydrochloric acid (add about 10 c.c. of 1:1 HCl, or make red to methyl orange), and boil for about 15 minutes or until the fats and oils have collected in a surface film.
2. Place beaker in refrigerator for several hours (over night), allowing the grease to solidify into a solid or very viscous mass.
3. Filter, washing the beaker and filter paper with cold water. Return filter paper to beaker, and place in drying oven for about 15 minutes, to remove moisture and to warm the grease so that it will be readily soluble in the solvent.
4. Extract the grease by use of a Soxhlet apparatus or, more simply, by direct solution. In either case add enough solvent to wet the filter paper thoroughly. Using a glass rod swab the sides of the beaker with the filter paper, and transfer the paper and solvent to either the Soxhlet thimble or to a small beaker. Rinse the large beaker with small portions of solvent to insure complete transfer.
5. In the case of direct solution, stir the contents of the small beaker, and refilter the supernatant into a weighing receptacle. Add more solvent and repeat the washing to insure complete transfer of the grease. Generally about three washings will be adequate. The solvent containing the dissolved grease is evaporated on the water-bath, and the residue is dried, cooled, and weighed.

By this procedure soaps and fatty acids will be recovered as fatty acids. Triglycerides will be recovered as triglycerides, as these are not broken down by acidification. In Step 1 of the procedure, the operation of boiling insures complete reversion of the insoluble soaps to the fatty acid form. It is the experience of soap chemists that in a cold process there will be incomplete reversion even under highly acid conditions. The operation of boiling also concentrates the grease at the surface; and, if desired, a large portion of the underlying solution may be drawn off.

The separation of the grease from the liquid medium by filtration in Step 3 is based on the assumption that in Step 2 the grease materials will either solidify or become too viscous to pass through the filter paper. There may be present low titre fatty acids or light mineral oils which in the pure state would not be retained by the filter paper. In practice, however, there will generally be present some high titre fatty acids, and as a result all the fats and oils present will tend to solidify in a single mass. There is the possibility that very volatile mineral oils may not enter into this solidification and thereby be lost; however, it is questionable as to whether it is desired to recover these oils. It might be argued that those fats and oils which are retained by the filter paper under the conditions defined are fairly representative of that fraction of the total fats and oils which has true sanitary significance.

In addition to the fats and oils which are extracted by this procedure, there will also be present in the residue any solvent-soluble non-grease materials which are retained by the filter paper in Step 3. The error due to these materials should be appreciably less by this procedure than by dry extraction procedures or by wet extraction procedures in which the solvent is added directly to the sewage sample.

This boiling-freezing procedure was tested on synthetic samples prepared as previously described, using stearic, palmitic, lauric, myristic, and oleic acids, and ordinary motor lubricating oil. In all cases practically complete recoveries were obtained. The oleic acid and lubricating oil did not solidify, but were sufficiently viscous to be retained by the filter paper.

The method was then applied to ten different samples of primarily domestic sewages, in conjunction with the routine dry extraction procedure, using the same number of extractions with the same volumes of solvent for both methods. These results are tabulated:

Sample No.	Procedure (1): Dry Extraction, Without Soxhlet, P.P.M.	Procedure (2): Boiling-freezing, Without Soxhlet, P.P.M.	Percentage (1) of (2)
1	69	78	88
2	168	199	84
3	23	27	85
4	64	80	80
5	41	48	85
6	37	38	98
7	59	67	88
8	150	146	103
9	57	59	97
10	180	179	100
Mean	—	—	91

The data indicate that for domestic sewages the weights obtained by the dry extraction procedure are somewhat less than those obtained with the boiling-freezing procedure. It is regretted that Standard Methods Soxhlet extractions were not made for these same samples.

Summary

When an acidified sewage sample is evaporated to dryness, the fatty acids may revert to calcium and magnesium soaps, which are only slightly soluble in chloroform or similar extracting agents. Complete recoveries are possible, under these circumstances, only by continuous extraction, as with a Soxhlet apparatus.

A boiling-freezing procedure, which eliminates the necessity of evaporating to dryness, is suggested for the determination of grease. The boiling is necessary to insure the complete reversion of soaps to fatty acids, and also serves to concentrate the grease in a surface layer. Low temperatures are then employed to change this grease to a solid or very viscous form; it may then be separated from the liquid medium by filtration. It is believed that the method is sufficiently simple for general testing work.

The method was tested on synthetic samples prepared by adding fatty acids and a lubricating oil to sewage of low grease content, and the recoveries were practically complete. It is believed that the residue obtained by the method will include practically all the grease materials of sanitary significance. The residue may also contain some solvent-soluble non-grease materials, but this error will be eliminated to the extent by which these materials are not retained by the filter paper in the operation of separating the water from the solidified grease.

Acknowledgment.—Charles Gilman Hyde, Harold Farnsworth Gray, and A. M. Rawn constitute the Board of Consulting Engineers for the East Bay Cities Sewage Disposal Survey. R. R. Ribal is Principal Assistant Engineer. The author is indebted to these gentlemen for the suggestions and assistance which they provided. (See paper by Okun, Hurwitz and Mohlman.[1])

[1] This JOURNAL, May, 1941.

Plant Operation

CURRENT DEVELOPMENTS AND TRENDS IN SEWAGE TREATMENT *

By A. J. Fischer

Development Dept., The Dorr Company, Inc., New York, N. Y.

Future trends in sewage treatment will be largely influenced by current developments. These to a great extent are concerned with improvements of equipment and processes that have been introduced during the past decade. Most of these have been publicized in the technical literature—a few perhaps too optimistically. Wide acceptance of new ideas, however, is generally a slow process and usually follows laboratory or pilot plant work, a representative full plant scale demonstration, and then the evidence of satisfactory operation of a number of typical installations.

Due to differences in sewage characteristics, the fact that a certain process works satisfactorily in one city or locality does not necessarily mean that it will be universally successful. Likewise, an occasional failure should not condemn a process or device, as there may be extenuating circumstances affecting occasional plants. Sanitary engineers and public health bodies are as a rule conservative in evaluating new ideas because of the large number of questionable proprietary processes that have been proposed in the past. Such conservatism is, however, often extreme and in many instances retards worthwhile developments. The caution being taken in accepting high rate filters in some sections is an example of this ultra-conservatism.

On the other hand it is recognized that sewage treatment runs in cycles, and that these cycles are usually stimulated by intensive commercial activity along certain lines. The trend away from activated sludge treatment toward chemical precipitation, and then to high rate filters exemplifies this cyclic trend. This commercial stimulation is of benefit to the science of sewage treatment and has been responsible for a considerable portion of the major developments in modern sewage treatment practice. But, this activity often requires a brake, otherwise plants may be overburdened with unnecessary equipment that would be costly to operate, or a treatment process may be adopted that is inadequate to meet the local requirements. Just because sludge incineration is satisfactory for Chicago or Buffalo is no reason why it should be adopted elsewhere where the sludge may be more economically hauled to dumps or used as a fertilizer. Similarly chemical precipitation may

* Presented at the Thirteenth Annual Meeting of the California Sewage Works Association, San Diego, Sept. 16, 1940.

be adaptable in some plants where only seasonal treatment is required and where extremely low B.O.D.'s are not necessary, but may be entirely out of place where requirements are more exacting.

Regardless of how or by whom a process or particular piece of equipment is introduced in the sanitary field, it will not survive if it cannot show definite advantages. These advantages may be tangible, in that better results are secured or that savings in installation or operating costs will result. Or they may be intangible in that greater ease of operation, a better appearance, or elimination of odors, etc. are obtained. These intangible advantages often seem remote from the dollar sign, but nevertheless they are very real.

With these facts in mind, a more concise evaluation of past and current developments and their effect on future trends in sewage treatment may be obtained.

Considerable progress has been made in unit operations and in processes or flow sheets comprising combinations of these unit steps. Of the former, the advances made in screening, aeration, trickling filters, effluent filters, digestion and various methods of sludge dewatering are outstanding. Likewise, major process developments have dealt with raw sewage flocculation, high rate filtration and sludge elutriation. Noteworthy work is also being done on improvements in grease removal, sedimentation, chemical treatment and sludge drying. Time would not permit a detailed discussion of all of these phases of sewage treatment. Moreover, in view of the excellent review presented by Dr. Mohlman in the February, 1940, issue of *Water Works and Sewerage,* such a detailed discussion would be superfluous in certain of its aspects. The intention here is rather to present the writer's opinions regarding the possible future outlook of sewage treatment in relation to past and present developments and present trends.

Screening

At an overwhelming number of plants being designed or under construction, sewage screenings will be ground and returned to the raw sewage. In the United States "Comminutors" are being used extensively for small plants, while separate screens and shredders appear to be favored for the larger installations. In England and Holland, where most of the sanitary activity in Europe has been going on since the outbreak of the war, a shredder pump known as the "Gargantua" disintegrator is being widely used, mostly in connection with mechanically cleaned bar screens. Figure 1 shows the vertical type of this unit. One form of this disintegrator is capable of delivering the ground screenings against high heads. Such an arrangement would be ideal for the preferable introduction of the screenings directly into a digester. Unfortunately, however, a large volume of liquid is necessary to convey the screenings through the unit, and therefore this procedure is not practical.

Regardless of the type of screenings shredder employed, it appears that the quantity of scum in the subsequent settling unit is increased when the ground screenings are returned to the sewage. Greater digester scum difficulties have also been reported. Overloading of sepa-

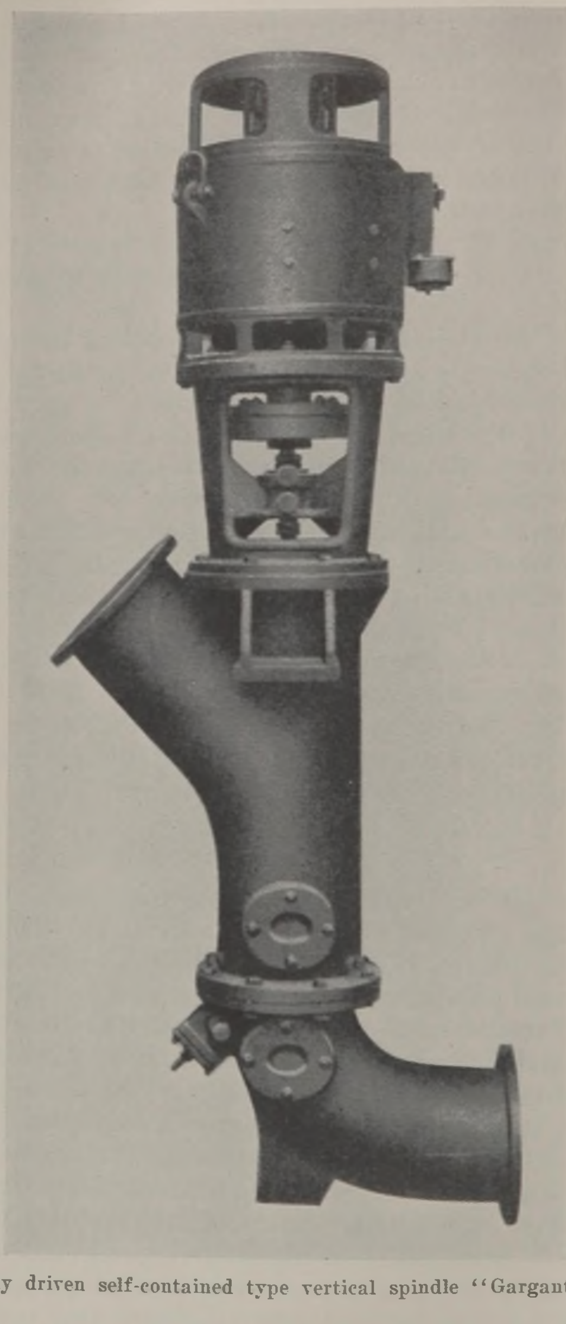

FIG. 1.—Electrically driven self-contained type vertical spindle "Gargantua" disintegrator.

rate shredders is often encountered when a screen rake dumps its load. The operation of the screen rake, conveyor and shredder may be regulated by an interlocking timing device.

Grit Removal

Mechanical removal and washing of grit is being and should be more generally adopted in both small and large plants. Area rather than velocity is now considered the most important factor in grit chamber design. Proportionate flow weirs are unsatisfactory in regulating velocities in grit channels because although they maintain a constant average velocity, a relatively high velocity is set up along the channel floor. This velocity is often of such intensity that settling fine grit is carried out over the weir of the collecting channel.

Well washed grit is satisfactory for use as fill, for roadway surfacing around plants and as a substitute for sand in replenishing sludge drying beds.

Grease Removal

Pre-aeration of sewage for grease removal is now generally restricted to plants receiving considerable quantities of industrial waste such as packinghouse waste. The use of chlorine for increasing the separation of grease is being tried at a number of plants. To date there is no conclusive proof available that chlorine is beneficial in this step.

Regardless of the efficiency of grease separating tanks built to date, a considerable portion of the grease separated from sewage is released in the primary sedimentation tank. Efforts are now being made to secure an almost complete separation in specially designed skimming units.

Outside of California, where grease and scum problems are more acute, than in other sections of the country, it is questionable whether grease skimming will be adopted in the future except possibly in a few large plants, chiefly of the activated sludge type.

Clarification

Research work on clarification has been mainly along the lines of improving feed distribution and effluent take-off. A number of model tests based on hydraulic similitude have been made wherein dye detention periods were observed. Such tests while interesting are of little direct value in determining the effectiveness of a settling tank for removing solids. Tank surface area and not detention period is the chief factor that influences clarification. This is true in raw sewage as well as activated sludge settling. The present tendency is to use design overflow rates of not more than 800 gal./sq. ft./24 hrs. in small plants for all classes of settling. Overflow rates not exceeding 1200 gal./sq. ft./24 hrs. are frequently used for large plants.

Two-stage primary settling, such as is being practised at Mogden, England, has been found to be only slightly better than single-stage settling. In other English plants two-stage settling of activated sludge has been likewise found to be ineffective as far as the clarity of the effluent is concerned. However, a more readily settleable activated sludge has been obtained by returning only coarser sludge that settled in the first tank.

Raw Sewage Flocculation

It has been amply demonstrated and is now an accepted fact that mechanical flocculation will increase the efficiency of raw sewage clarification. Table I shows some typical plant results. At Ypsilanti, Cedar Rapids and Los Angeles, results directly comparable with plain settling were obtained. Tests have been made and are still under way to determine the effect of the addition of various types of sludge to raw sewage ahead of flocculation.

Table I.—*Plant Results—Raw Sewage Flocculation*

Plant	Detention, hrs.		Clarifier Overflow Rate	Suspended Solids, p.p.m.		Per Cent Removal	Remarks	Source
	Floc.	Clar.		Raw	Settled			
Ypsilanti, Mich.	0.40	1.87	805	155	66	57.4	Parallel tests	Fischer and Hillman, *Sewage Wks. Jour.*, March, 1940
	0	2.31	790	155	82	47.2		
Cedar Rapids, Iowa	0.67	1.90	662	208	96	53.7	Parallel test	Fischer and Hillman, *Sewage Wks. Jour.*, March, 1940
	0	1.90	662	208	126	39.3	Domestic sewage	
Los Angeles, Calif.	0.50	2.0	—	275	64	76.8	Parallel tests	Smith and Studley, *Sewage Wks. Jour.*, July, 1940
	0	2.0	—	286	91	68.2	Experimental plant	
Denver, Colo.	0.33	2.79	628	145	43	70.0	1939 plant operation	C. P. Gunson, Supt. Denver Sew. Disp. Plant, *1939 Operating Report*
	0.33	2.79	628	145	35*	75.8		
Cedar Rapids, Iowa †	0.58	1.67 ea.	733	490	143	70.8	Pre-settling ahead of flocculation and settling	Green and McIntyre, *Water Wks. and Sew.*, October, 1937
	0.50	3.00	440	517	112	78.4	Clarifiers in parallel after flocculation	

* Effluent after filtration through magnetite filters.
† Packing house waste.

Striking results have been obtained where 2.0 per cent activated sludge was added. Results are given in Table II. These results indi-

Table II.—*Effect of Adding Activated Sludge in Raw Sewage Flocculation*

	Floc. Time	Settling Time	Suspended Solids, p.p.m.	Per Cent Removal*
Raw Sewage	0	0	368	—
Raw Sewage	0	60	166	54.8
Raw Sewage	30	30	103	71.5
Raw Sewage + Activated Sludge	0	0	497	—
Raw Sewage + Activated Sludge	0	60	132	64.0
Raw Sewage + Activated Sludge	30	30	44	88.0

* All removals based on raw sewage.

cate distinct possibilities for bio-flocculation wherein a small amount of raw sludge is activated and used as a source of return sludge. At Hilversum, Holland, the return of humus sludge in sufficient quantity to double the amount of dry solids in the feed to a combination type flocculator-clarifier, greatly improved the settling efficiency of trickling filter effluent.

The fragile nature of raw sewage flocs cannot be overemphasized. Great care must be exercised in transferring the sewage from the flocculator to the clarifier. Sudden change in direction, and velocities in excess of 1.5 ft. per second will at least partially undo some of the work accomplished by the flocculation step.

More benefit may be derived from flocculation by increasing removals at normal clarification periods and overflow rates than by attempting to obtain the same removals at lower detentions. Indications are that flocculation to improve the efficiency of raw sewage and trickling filter effluent settling will be used extensively in the future here and abroad.

Chemical Treatment

The boom days of chemical precipitation are over. This does not mean, however, that chemical treatment is a thing of the past, but rather that it has found its proper niche. It still deserves consideration where only seasonal or part-time treatment is required, as an adjunct to biological treatment, where industrial wastes are discharged into the sewerage system, or for odor control.

It still remains a puzzle why alum is superior to ferric salts as a coagulant for some sewages while the reverse is true of others. It is equally strange that pre-settling reduces the coagulant requirements of some sewages while it increases that of others.

Carbonation of highly alkaline sewage has been found to reduce chemical requirements and also aids in subsequent biological treatment. Tests on sewage ozonation have been made and have given some promising indications where iron was present in the raw sewage. This method of treatment has not been carried along far enough, however, to be seriously considered in future plant design.

As a rule chemical treatment cannot compete with biological processes in producing an effluent of low B.O.D. It can, however, produce sparkling clear effluents low in suspended solids.

Aeration

Large activated sludge plants have been of the diffused air type with average aeration periods of five to six hours. Small plants most usually use mechanical aerating devices. A considerable number of the latter have been of the combination type, wherein the aeration and settling compartments are in a single tank. The trend is toward conservatism in establishing design aeration periods in the small plants, a minimum of eight hours being preferred. It is hoped that the days of impossible guarantees regarding power requirements and effluent standards are over in regard to mechanical aerators.

Only two combination paddle-wheel diffused air types of aerators have been installed recently. In both cases the paddles are in the last half of the tank.

Considerable attention has been given to "tapered" aeration. In one form, all the settled sewage is admitted at the head end of the aerator and the air is tapered, while in another the air is held substantially constant along the channel, but fractions of the settled sewage are admitted at various points along the first half of the aeration unit. Both methods have points in their favor. Attempts have been made, however, to mathematically determine exact air distribution, return sludge requirements, etc. Evidence to date indicates that all such formulae are empirical and are not generally applicable. Apparently the safest way to determine air requirements and distribution is by frequent dissolved oxygen tests at various points along the aeration channels. As a rule where about 2.0 p.p.m. of dissolved oxygen is maintained, satisfactory aeration should result. Development work is now under way on an automatic dissolved oxygen recorder. Such an instrument should be of inestimable value to the plant operator.

There has been renewed interest in England regarding pressure aeration, wherein the tanks are covered and a pressure higher than atmospheric maintained above the liquid surface. The theory behind this system is that the increased pressure increases the dissolved oxygen content of the mixed liquor and so increases the aeration efficiency. Claims have been made that detention can be reduced to one-quarter and air requirements to one-eighth. It is very doubtful whether comparative tests would show such advantages. Reports some years ago on a commercial sized unit in Germany were not too enthusiastic.

Should the progress in high rate filters continue at its present pace, the use of the activated sludge process will be restricted chiefly to large plants in the future.

Trickling Filters and High Rate Filtration

The considerable advances in trickling filter and distributor design, and the world-wide acceptance of "high rate" filters indicate that this method of treatment is here to stay. At present two high rate systems are being advocated. These are the "Biofilter" and the "Aerofilter." Biofiltration covers a system wherein filter discharge material is recirculated to a clarifier ahead of the filter. The aerofilter covers a process involving the uniformity of application of the filter feed over the surface of the filter bed.

Another type of filter that has had a more limited use in the United States on packinghouse waste, is the "washable filter" wherein the filter unit is back-washed with air and effluent according to a fixed procedure when it becomes clogged. In England considerable success has been reported on the treatment of milk wastes by "reversible filters," where two filters are operated in series, the sequence of operation being reversed when the primary unit becomes clogged. In England, Germany and South Africa, "enclosed filters" have been built, wherein the filter bed was entirely enclosed, ventilation of the bed being obtained by a suction fan.

From representative data obtained to date, it appears that artificial ventilation of the bed is not required, at least where shallow beds or an adequate underdrainage system is provided. Also shallow beds are far more efficient than deep beds per unit of volume where both low and high rates of filtration are used. Filters should be rated on their capacity to remove B.O.D. rather than on the dosing rate of the applied sewage. Biofilter test data indicates that the B.O.D. loading varies with the strength and characteristics of the sewage. Figure 2 shows B.O.D. re-

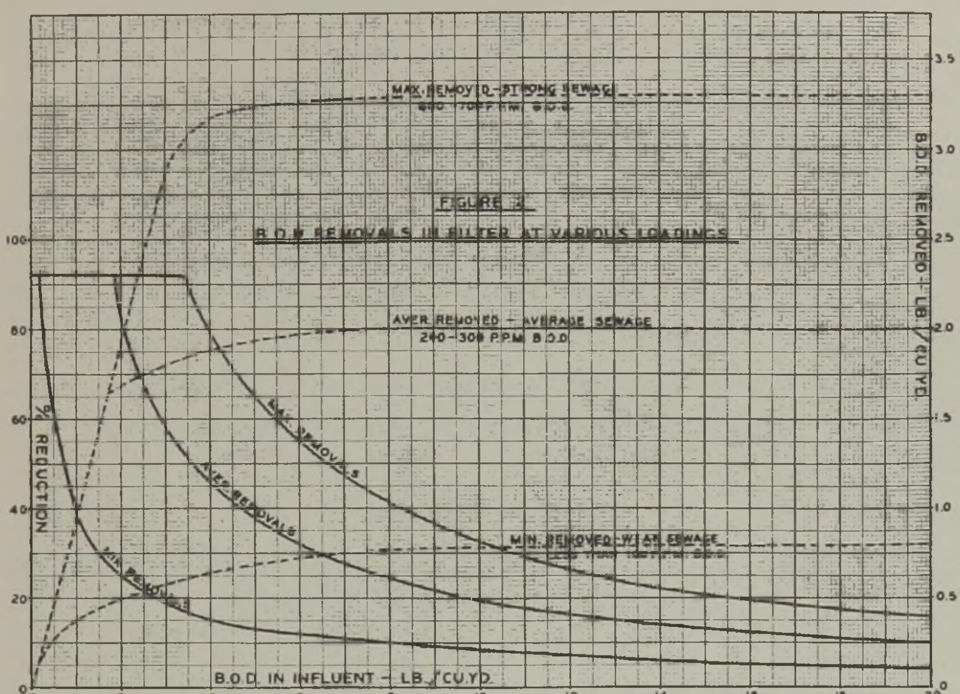

FIG. 2.

movals at various loadings and with different strength sewages for filter beds three feet in depth. It indicates that the removals increase as the strength of the sewage increases. With distillery waste having a B.O.D. of 18,000 p.p.m., removals of 16 lb./cu. yd./day have been obtained. Where very strong sewages are encountered or where a high quality effluent is desired, a two-stage filter system should be employed. Such a system has recently gone into operation at Liberty, N. Y., where the sewage is very strong during the summer months. Although this plant has been operating less than two months, it has been turning out a satisfactory effluent with daytime raw sewage B.O.D.'s of over 500 p.p.m.

Distributors of various designs are now available that assure approximate uniformity of distribution under a wide variation in flow conditions. Provided the maximum permissible B.O.D. loading of the filter is not exceeded, satisfactory operation of the filter may be obtained at dosing rates up to the point where flooding of the bed occurs. With normal sizes of filter stone, this is 100–120 m.g.a.d. It is questionable whether there is any "twilight zone" between dosing rates of 4 to 10 m.g.a.d. where it has been reported that a filter will clog. To date no synthetic material has been produced that can complete economically with crushed rock as a filter medium.

Acceptance of high rate filters for large plants will probably be delayed pending the accumulation of long-time reliable records of small installations.

Effluent Filters

Continued use of effluent filters is predicted where "polished" effluents are desired. Interest is also being given to the direct filtration of raw sewage and trickling filter effluents with and without pre-flocculation. It would appear, however, that at least a short period of preliminary settling will be required in the case of raw sewage. The most recent magnetite filter installation at Liberty, N. Y., is reducing the suspended solids and B.O.D. of the two-stage biofilter effluent from 30 p.p.m. down to less than 15 p.p.m., while the turbidity is reduced from 10 p.p.m. to 5 p.p.m.

Downflow circular magnetite filters have been found to be more satisfactory than rectangular or upflow circular units. Fine sand is preferred with average filter rates of 2.0 gal./sq. ft./min.

Sludge Digestion

Two-stage digestion with flexible piping systems so arranged that the digesters may be operated in parallel is the rule. The question whether or not mixing in a digester is beneficial is apparently still a controversial one. It is rapidly being clarified, however, by an ever increasing accumulation of data that tends to show that stirring is of benefit in increasing gas production and reducing scum. A new type of mixer, first installed at Yakima, Wash., showed that surface scum could readily be pulled from the periphery to the center of a 40 ft. dia. tank and submerged at very low power consumption. The comparative tests at Los Angeles showed the most striking differences in gas production with and without mixing. A survey of long-time plant records compiled by F. G. Nelson has shown that it is difficult to correlate digestion results at different plants. Striking differences in gas production, however, were noted with and without stirring. These differences are shown graphically in Fig. 3.

Interest in thermophilic digestion has been revived by the reports of the Los Angeles tests. Contemplated large-scale operations will be watched with interest.

The digestion of activated sludge continues to be a problem because of the low solids concentration of the sludge after digestion, and the high solids content of the supernatant liquor. Some thought has been given to the elimination or minimizing of overflow liquor by concentrating the sludge ahead of digestion, or to the treatment of the overflow before it is returned to the plant. Upward filtration of supernatant liquor through a bed of ½ in. stone has long been practiced at Birmingham, England. Here the supernatant was heated to 72° F. and returned to the digester for the purpose of heating the digesting sludge. Whether this scheme would work with high solids in the liquor would have to be determined.

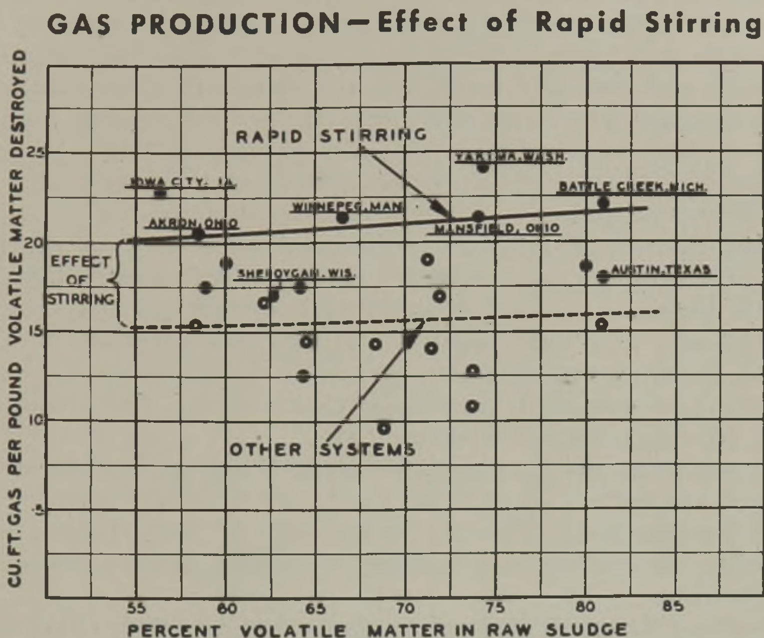

Fig. 3.

The Birmingham sludge heating scheme would not work if higher digester temperatures were required, as the solids contained therein would become colloidal in nature. External sludge heaters are becoming more popular in Europe but have not been widely adopted in this country. Should stage thermophilic digestion become established, it is almost certain that external heaters will be required.

"Dry" digestion or stabilization of raw sludge dewatered on drying beds or by filters or centrifuges is still in the experimental stage. This process is aerobic and thermophilic. It is doubtful whether it will prove commercially attractive in the near future.

Sludge Dewatering

The vacuum filter is still the preferred device for dewatering sludge. In small or medium sized plants, however, unless unusual conditions prevail, the use of anything but sand drying beds for dewatering digested sludge is questionable.

Sludge elutriation is being used to a greater extent. Its use is well justified on digested mixed sludges which ordinarily require very heavy doses of conditioner. The general inclination is away from primary raw, or raw mixed sludge filtration in favor of first digesting the primary sludge fraction. A plant is at present under design for Colne Valley, England, where the primary raw sludge will be digested, elutriated and then mixed with thickened activated sludge ahead of the filtration step.

In England a method of heat conditioning raw sludge ahead of thickening and dewatering by vacuum filters or filter presses has been developed. In this method the sludge was pressure cooked at 150 lb. Advantages are that no conditioning chemicals are required, and high filter rates and low cake moistures are obtained. Disadvantages are that the process has many complications, is odorous, and produces a separated water high in B.O.D. that would require biological treatment. It is doubtful whether this process would be at all applicable in the United States or find any extended application abroad.

A considerable amount of experimental work has been carried out with centrifuges for the purpose of concentrating activated sludge ahead of digestion, and for dewatering raw and digested sludges for final disposal. For waste activated sludge concentration, it has been conclusively shown that thickeners are more satisfactory and economical than the centrifuges that have been tried to date. Chlorination is of decided advantage in the thickening step.

In dewatering raw and digested sludges the application of centrifuges appears to have limitations, due to the relatively high solids content of the centrifuge effluent. In the case of both sludges, the fine solids in the effluent will resettle when recycled to the raw sewage ahead of clarification.

It has been demonstrated at two plants that raw sludge may be satisfactorily handled without building up an excessive quantity of fines in the circuit or causing an increase in suspended solids in the clarifier effluent. At both plants the plant removals did not exceed 50 per cent and the sludge volatile matter content was normal. In the case of digested sludge, however, fines did build up in the circuit to a point where the recovery of solids in the centrifuge fell below the point of economical operation. Digested sludge or raw sludge that centrifuges with high solids loss in the effluent can be handled, provided the effluent is not returned to the system, or if only part of the total sludge production is centrifuged. A possible application is where existing sludge dewatering facilities are overloaded.

Open circuit test data obtained at Red Bank, N. J., on raw and digested sludges are shown in Figs. 4 and 5. It will be noted that higher recoveries were obtained with the raw sludge.

A continuous type of solid bowl centrifuge, as shown in Fig. 6, such as was used in these tests, has been in operation at Cedar Rapids, Ia., for dewatering digested sludge. The cake is removed continuously from this unit by a spiral conveyor which rotates at a slightly higher speed than the conical bowl.

Sludge Drying and Incineration

Interest in sludge drying is mounting at the expense of incineration. This is due to the present market available for the sale of dried sludge as a fertilizer or as a fertilizer base. Experiences at Chicago and elsewhere should be ample evidence of the fact that where incineration is

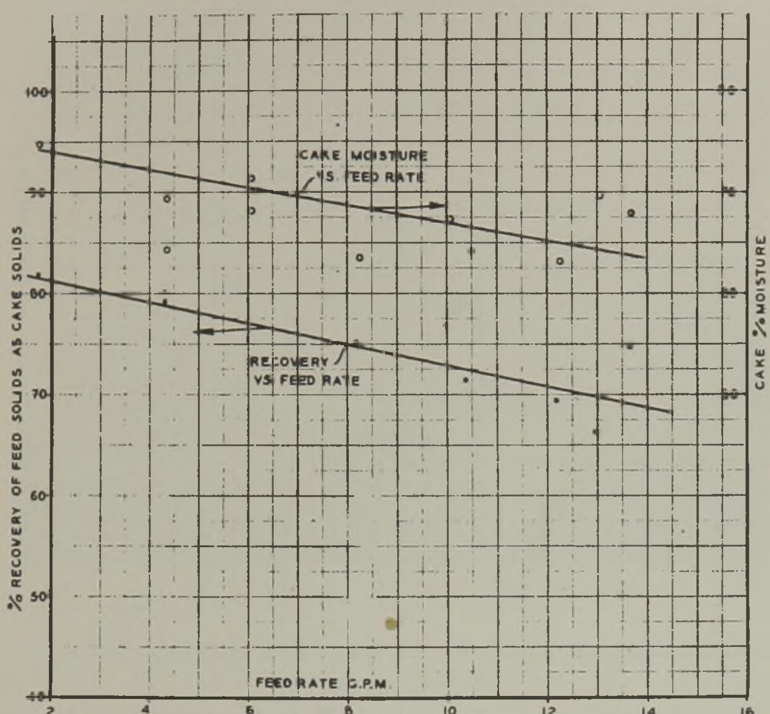

Fig. 4.—Raw sludge, Red Bank, N. J. 18 in. Bird centrifuge open circuit operation feed rate vs. per cent recovery and cake moisture.

Primary clarifier removal = 46 per cent.
Bowl speed = 2000 R.P.M.
Conveyor differential = 12.5 R.P.M.
Bowl volume = 5 gal.

considered justified, provision should be made in the design of the incinerator unit for operating it as a dryer when occasion demands.

All types of incinerators are costly to operate and require close supervision. Their use in small or medium-sized plants should be avoided unless other means of ultimate sludge disposal are not available. However, where a cheap source of fuel such as digester gas is available, drying the sludge for use as a fertilizer may be justified even in small plants.

General Outlook

As no basically new methods of sewage treatment have as yet appeared on the horizon, it is possible that future trends and developments will continue along the lines of improving present unit operations and combining them in various ways. In the United States considerable emphasis will undoubtedly be given to the needs for small plants and improvements to existing installations. The number of new large plants to be built appear to be relatively few.

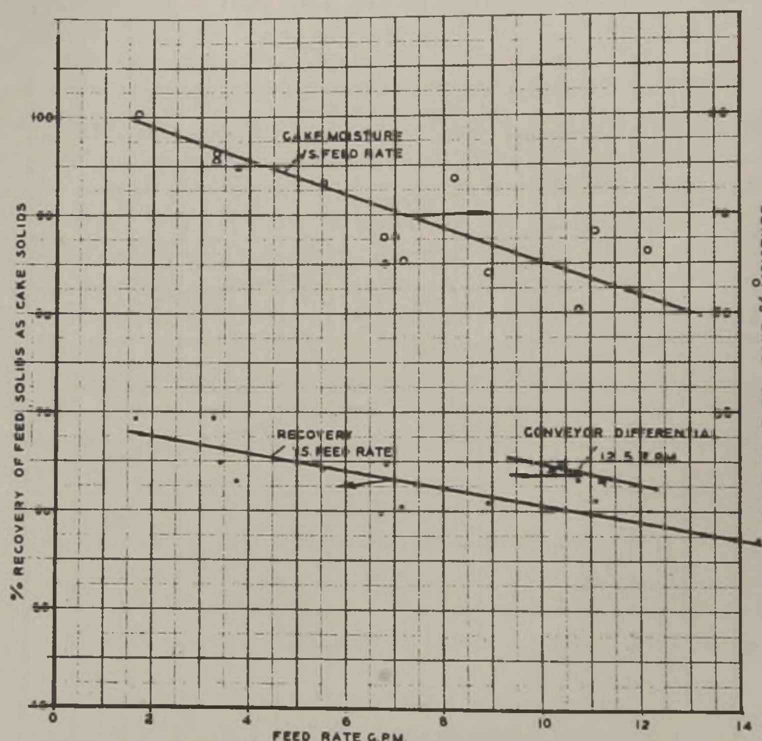

Fig. 5.—Digested sludge, Red Bank, N. J. 18 in. Bird centrifuge open circuit operation feed rate vs. per cent recovery and cake moisture.

Bowl speed = 2000 R.P.M.
Conveyor differential = 25 R.P.M.
Bowl volume = 5 gallons.

The rest of the world seems to be now definitely following our lead in all types of treatment. Progress has been slowed down in Europe due to the war, but latest advices are that public works programs have been instituted in the occupied countries of Central Europe, chiefly in Holland, where plants using raw sewage flocculation, high rate filters, and sludge elutriation and filtration are being designed. In Germany there is a definite swing in opinion away from land disposal back toward biological treatment, but as far as is known, no new plants are at present being projected. The activated sludge process is still the most popular method of complete treatment in England, although considerable interest is being now given to high rate filters. Work on the partially completed activated sludge plants at Paris and Madrid has been resumed. The first modern treatment plant in Portugal, a combination chemical treatment-activated sludge plant at Braga is under construction. In South America a number of modern types of plants have been installed or are contemplated. These include plants with chemical precipitation, high rate filters and stage digestion. In Japan, where activated sludge treatment has been used extensively, all sewage treatment plant construction has been halted, due to the war, but there has been increased activity in India and in South Africa.

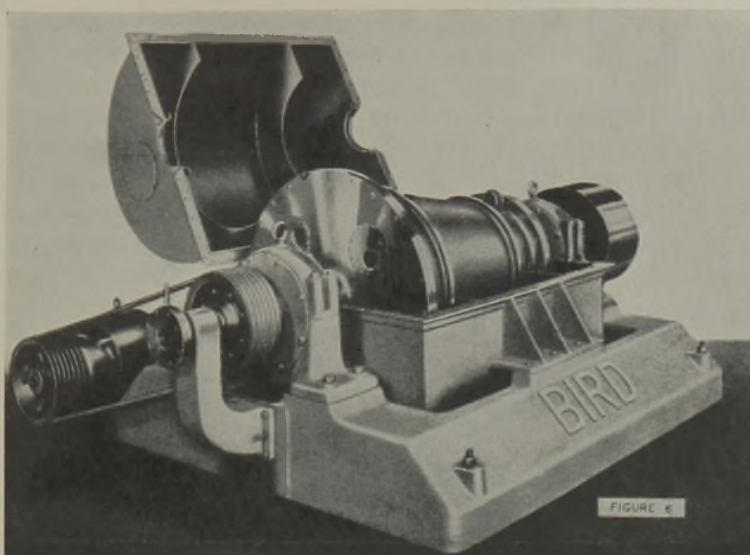

FIG. 6.

Considering all facts at hand, it is apparent that there should be a construction boom in Europe and other foreign countries at the end of the present hostilities, and that a good share of this work will be allotted to sewage treatment plant construction. In this country where we have more direct interests, the general outlook should also be bright and will undoubtedly be bolstered by intensive activity in industrial waste treatment.

DISCUSSION

BY HAROLD FARNSWORTH GRAY

Sanitary and Hydraulic Engineer, Berkeley

Dr. Fischer has presented an excellent exposition of the subject. There are however, a few points on which either an accentuation is desirable, or a different viewpoint may be useful.

He says "cycles are usually stimulated by intensive commercial activity along certain lines. The trend away from activated sludge treatment toward chemical precipitation, and then to high rate filters exemplifies this cyclic trend.'' It may be significant that the patents on activated sludge treatment ran out about the time the trend away from it began, and the trend toward high rate filtration began about the time that several patents were taken out on certain features pertaining to methods of application, recirculation, etc., though the basic idea of high rate filtration is probably not patentable.

The tendency has been for engineers of inadequate experience or training to slavishly follow the current trend in treatment, perhaps as the line of least resistance either to the importunities of equipment representatives, or to the demands of non-technical city fathers for the latest mode or fashion in sewage treatment. In the original manuscript of the Report of the Committee on Sewage Research of the Federation, published in the March, 1938, issue of *Sewage Works Journal,* I wrote (see page 190) ''It is interesting to note that eight of the thirteen new plants on the Raritan River watershed are chemical precipitation plants, which indicates either a special adaptability of this process to that particular situation (perhaps a wide seasonal fluctuation in requirements) or possibly there has been a too slavish aping of the current mode in sewage treatment.'' However, Professor Phelps thought that the last clause of my statement was either tactless or too emphatic, and that part of it was eliminated from the printed report. But as a generalization the criticism had and still has a valid basis.

The current trend needs to be viewed always with the cold eye of suspicion, for fashions come and go, but principles remain. Much of our difficulties in the field of sewage treatment lie in the unwillingness of public bodies, especially in the smaller cities, to support the expense and time and careful study required for really adequate analysis of all the conditions controlling any sewage disposal situation; another contributing factor is the failure of some engineers to appreciate the necessity of making such adequate studies, of selecting the type of treatment process according to conditions rather than of fashions, and of having sufficient backbone to tell the city council, rather than of having the city council tell them.

With regard to screening, I am still unconvinced as to the advisability of returning ground screenings to the influent. If you have once taken the stuff out, why put it back? I feel that this matter deserves the application of better logic, plus some mechanical ingenuity.

Dr. Fischer states ''It is questionable whether grease skimming will be adopted in the future except possibly in a few large plants, chiefly of the activated sludge type.'' I think that here he has failed to visualize the problem of disposal of large volumes of partially treated sewage into oceans, bays and estuaries, where grease removal may be desirable to reduce field visibility or to minimize beach or shore contamination.

My prior remarks concerning a too eager tendency to follow the prevailing mode or fashion in sewage treatment applies with special emphasis to high rate filtration, which Dr. Fischer has reviewed concisely and well. This is most important where large quantities of effluent are returned for dilution or the smoothing out of loadings. The added construction costs for the accessories such as extra settling basins, pumps, and piping, and added power, repair and maintenance costs, need further analysis and comparison. A very sceptical comparison of complete and accurate cost data is much needed here. The speaker is still far from convinced as to the long range economics of high rate filtration, in spite of the rather roseate picture painted in some reports. Furthermore, there seems to be need for a distinction between the functions of rock filters, both standard and high rate, as flocculating devices and as oxidizing devices. There is need for further investigation into these associated but perhaps relatively independent phenomena.

Dr. Fischer's last paragraph regarding a construction boom in sewage treatment seems to me to be overly optimistic. The current hostilities appear to me to be but one active phase in a clash of ideologies which may continue for possibly a century or more before a final settlement is achieved; peace will be merely armed truces as resting periods for recuperation in the main conflict. At the conclusion of the present active hostilities Europe probably will be too broke and too exhausted for much new construction in the field of sanitation, and the forward view is for a marked impairment of the public health as a result. In this country, the continuous piling up of all forms of public debt, even if we succeed in avoiding, for the present, actual war and its end results of panic and depression, will in the not too distant future result in the drying up of all forms of public credit, and the practical cessation of public works construction. It will also curtail industrial activity, and reduce any possibility of expansion in the field of industrial wastes treatment.

ACHIEVEMENTS IN SEWAGE TREATMENT IN NEW YORK STATE DURING THE PAST DECADE*

By Earl Devendorf

Assistant Director, Division of Sanitation, State Health Department, Albany, N. Y.

The increasingly important part being taken by the United States in a complicated and war-torn world has served to subordinate all ordinary functions of local, state, and national government activities and to place emphasis on those functions dealing with national defense. At first thought it might seem, therefore, somewhat out of place to discuss the accomplishments in sewage treatment in New York State on the theory that sewage treatment is an ordinary function of government. It must be acknowledged, however, that the protection of the health and welfare of the nation is of first importance in any program relating to national defense.

Today great emphasis is being placed on the importance of the protection of all public utilities to prevent sabotage that may affect the lives as well as the industries of the nation. The equal importance of sewage treatment becomes apparent when it is considered that the water supplies of about three-quarters of the population of our state are derived from surface water sources, some of which a few years ago were at certain times polluted beyond the ability of safe treatment as based on recognized standards of safe, raw water supplies.

Although the abatement of stream pollution has been one of the main functions of the State Health Department since the passage of the so-called Anti-Pollution Bill in 1903, the efforts to clean up stream pollution in New York State were greatly intensified beginning in 1930. As a result of this intensified program and the opportunity of obtaining Federal aid, more persons are served by sewage treatment plants constructed during the past ten years than were served by plants constructed during the previous thirty years. This intensified program provided for the abatement of stream pollution as rapidly as possible within economic limitations. Moreover the sewage treatment plant program also acted as a means of affording relief of unemployment during the period of the depression and was financed largely with Federal aid at a great saving to the taxpayers. This program was both timely and fortunate from the standpoint of preparing our cities and industries to shoulder their share of the defense program of the nation.

An account of the "Policies and Progress in Sewage Treatment in New York State" was outlined at length in a previous paper which was published in the March, 1936, issue of *This Journal*. Moreover, papers on pollution abatement in the Long Island, Westchester, Metropolitan,

* Presented at the Thirteenth Annual Meeting of the New York State Sewage Works Association, New York City, January 18, 1941.

TABLE I.—*List of Completed P. W. A. Sewer and Sewage Treatment Projects from 1934–1940*

Municipality	Nature of Work	Estimated Cost
Albany-Schenectady Road District	Sewer system and sewage treatment plant	$ 225,000
Albany	Relocation Beaver Ck. sewer	88,075
Alfred	Improvements and enlargements to treatment plant	36,000
Ardsley	Comprehensive system	190,000
Auburn	Intercepting sewers and treatment plant	830,000
Ballston Spa	Treatment plant enlarged and improved	82,000
Bath	Sewer system and sewage treatment plant	147,000
Belgrave District	Treatment works	115,000
Buffalo	Interceptors and treatment plant	15,000,000
Canajoharie	Sewage treatment works and incinerator	60,000
Canton	Treatment works	44,000
Carmel District No. 1, Lake Mahopac	Sewer system	75,000
Cedarhurst	System and treatment works	460,000
Cedarhurst	Storm drains	15,013
Chatham	Sewer system and treatment plant	225,000
Chappaqua District	System	31,000
Clinton	Sewage treatment plant	50,000
Cobleskill	Sewage treatment plant and incinerator	77,000
Cornwall	System and treatment plant	213,000
Cornwall District	Sewer system and sewage treatment plant	210,000
Cortland	Sewage treatment plant	314,700
Croton-on-Hudson	Storm drains	46,000
Delmar-Elsmere District, Bethlehem Town	Additions to sewage treatment plant and sewer extensions	180,000
Elmira	Sewage treatment plant	359,400
Elmira	Sewer extensions	148,000
Elmira	Intercepting sewers	439,000
Elmsford	Comprehensive system	260,000
Freeport	Improvements to treatment plant	56,000
Garden City	Additions to sewage treatment plant	70,000
Geneva	Treatment works	180,000
Geneva	Mile Point sewage treatment plant	27,500
Glens Falls	Sewage treatment plant	230,000
Goshen	Improvements to treatment plant	52,000
Grand Island District No. 2	Sewer system and treatment plant	40,000
Great Neck	System and treatment works	665,000
Greece Dist. No. 1	Sewer system and treatment plant	1,075,000
Green Acres Dist., Hempstead Town	Sewer system and treatment plant	160,000
Hamburg	Additions to sewage treatment works	59,716
Hastings-on-Hudson	Connections to trunk sewer	22,430
Haverstraw	Interceptors and sewage treatment plant	367,900
Hempstead	Sewer extensions	26,639
Hempstead	Sewer extensions	659,361
Herkimer	Treatment plant and incinerator	80,000
Highland District	System and treatment works	150,000
Highland Falls	System and treatment plant	273,000
Hudson Falls	Sewer system and treatment plant	268,300
Ithaca	Additions to treatment plant	125,000

Table I.—*Continued*

Municipality	Nature of Work	Estimated Cost
Livonia	Sewer system and treatment plant	80,000
Lockport	Interceptors and treatment plant	1,250,000
Lowville	Sewage treatment plant	45,000
Lyons	Additions to sewage treatment plant	60,000
Malone	Intercepting sewers and sewage treatment works	40,000
Manchester	Sewer system and treatment plant	135,000
Maybrook	Completion of system and construction of treatment plant	66,000
Mohawk	Sewage treatment plant	26,600
Mount Morris	Additions to sewage treatment plant	14,364
Newfane District	System and treatment plant	147,000
New York City	Coney Island treatment works	1,900,000
New York City	Ward's Island sewage treatment plant	25,245,000
Niagara Falls	Interceptors and treatment plant	2,575,000
North Collins	Sewer system and treatment plant	88,000
Norfolk District	Sewer system and treatment plant	92,000
North Tarrytown	Interceptors and treatment plant	400,000
Nyack	Interceptors and treatment plant	120,000
*Orchard Park	Sewage treatment plant	268,300
Ossining (2 plants)	Interceptors and treatment plant	300,000
Oswego	Interceptors and treatment plant	160,000
Pearl River District	Sewer system and treatment plant	525,000
Penn Yan	Additions to sewage treatment plant	49,350
Peru	Sewer system and treatment plant	85,000
Pleasantville	Sewer extensions	52,566
Plattsburg	Interceptors and treatment plant	340,000
Port Leyden	Sewer system and treatment plant	60,000
Rensselaer	Sewer extensions	12,606
Riverhead District	Sewer system and sewage treatment plant	459,000
Rockville Centre	Sewer extensions	275,000
Rochester	Treatment works (duplication of Irondequoit plant)	423,000
Rochester	Sewer tunnel	905,000
Scarsdale	Sewer extensions	64,823
Schuylerville	Sewer system and treatment plant	164,000
Sheldrake Dist., Fallsburg Town	Sewer system and treatment works	88,000
Shortsville	Sewer system and treatment plant	160,000
South Fallsburg Dist.	Sewer system and treatment plant	279,000
South Nyack	Sewage treatment plant	50,000
Stella District	System in town of Dickinson	69,000
Stillwater	Sewer system and treatment plant	90,000
Suffern	Sewer system and treatment works	185,000
Tarrytown	Sewage treatment plant	389,400
Tonawanda	Sewage treatment and incinerator	515,600
Tonawanda Dist. No. 2	Additions and alterations to sewage treatment plant	96,000
Walden	System and treatment works	225,000
Watervliet	Sewage treatment and incinerator	354,000
Wallkill	Sewer system and treatment plant	79,000
Warsaw	Sewage treatment plant	80,000
Watkins Glen	Treatment plant	58,000
Westchester County	Saw Mill project trunk sewers	360,000
Westchester County	No. Yonkers trunk sewers	2,085,000

* Under construction.

TABLE I.—*Continued*

Municipality	Nature of Work	Estimated Cost
Westchester County	Blind Brook trunk sewers	209,000
Westchester County	So. Yonkers trunk sewers	928,000
Westfield	Sewage treatment plant	125,000
West Haverstraw	System and treatment plant	155,000
West Long Beach Dist.	Treatment works	50,000
Woodridge	System and treatment works	115,000
Yonkers	Sewer extensions	289,000
Yonkers	Sewer system improvements	38,500
Yonkers	Sewer extensions	403,000
Yonkers	Sewer extensions	571,100
Youngstown	Sewer system and treatment plant	121,000
Total number of projects		108
Total estimated cost		$69,103,143
Storm Sewer Projects Not Included:		
Buffalo	Storm sewer	$ 2,500,000
Buffalo	Filmore-Lovejoy	1,401,108
Tonawanda	Storm sewer (state ditch)	60,018
		$ 3,961,126

and New York City areas presented, respectively, by James L. Barron, Director, Division of Sanitation, Nassau County Department of Health, Seth G. Hess, Chief Engineer-Executive Secretary, Interstate Sanitation Commission, and R. H. Gould, Acting Deputy Commissioner, New York City Department of Public Works, last January before the American Society of Civil Engineers at the Annual Meeting, were published in the May, July, and August, 1940, issues of *Civil Engineering*.

I will endeavor to present a summary review of the achievements in sewage treatment construction in New York State during the past decade, which have been almost exclusively undertaken with Federal aid under the various Federal agencies. Obviously, it would be impossible within the short time available to discuss any details of individual projects, which are recorded in the appended tables.

These records may be summarized as follows:

I. P. W. A. Sewer and Sewage Treatment Plant Construction in New York State, 1934–1940, Inclusive

A total of 111 projects costing a total of some $73,000,000 were constructed in New York State during this period with P. W. A. aid. Included in this program were 68 new sewage treatment plants, 15 reconstructed and enlarged treatment plants, and 29 storm and sanitary sewer projects. The largest projects were the two plants constructed by New York City with P. W. A. aid, namely, Coney Island and Wards Island plants costing some $27,000,000. In addition, New York City has completed and placed in operation the Tallmans Island and Bowery

Bay (part) plants, costing an additional $19,000,000. These plants provide treatment at present of over one-third of the city's sewage, at an estimated cost of $46,000,000 of which about $12,000,000 is the amount of Federal grants received for the two plants (Coney Island and Wards Island) built as P. W. A. projects. The placing in operation of these plants has resulted in reducing materially the pollution and improving the condition of the waters in the New York metropolitan area. Mr. Gould has estimated the cost of additional works to complete the program to be approximately $154,000,000.

Another undertaking of large magnitude was the elimination of the serious pollution of the Niagara River by construction of sewage treatment plants to treat sewage of Buffalo at a cost of $15,000,000 (together with storm relief sewer construction at a cost of $3,900,000); of Tonawanda at a cost of $515,000; of Niagara Falls at a cost of $2,575,000; of Youngstown and Fort Niagara at a cost of $200,000. The placing in operation of these plants has eliminated a serious public health menace to the public water supplies of the cities taking their supplies from this stream.

TABLE II.—*Sewage Treatment Plant Projects Undertaken under T. E. R. A. Program* (1933–1934)

Municipality	Nature of the Work	Estimated Cost
Aurora	Sanitary sewer system and sewage treatment plant	$ 40,915
Ballston	Construction of sludge beds and cleaning of trunk sewer	7,461
Beacon	Sewage treatment plant	119,475
Brighton	Rich's dugway and Allen's Creek disposal plant	21,875
Brockport	Additions to sewage treatment plant	11,929
Glen Cove	Repairs to sewage treatment plant	5,962
Jamestown	Repairs to sewage treatment plant	3,310
Maybrook	Sewer system and manholes	21,967
Oneida	Reconstruction of sludge bed—sewage treatment plant	235
Otsego County Home	Reconstruction of sewage treatment plant	7,858
Rome	Alterations to sewage disposal plant	6,462
Roscoe District, Rockland Town	Sewer system	12,117
Seneca Falls	Repairs to sewage treatment plant	4,671
Syracuse (Hiawatha and Eastwood plants)	Cleaning and repairing	47,601
Webster	Sanitary sewer system and sewage treatment plant	135,196
		$457,042

The completion and placing in operation of the large number of sewage treatment plants constructed under P. W. A. has resulted in greatly reducing the pollution of our New York State waters and eliminating many conditions detrimental to public health which formerly existed as a result of the direct discharge of large volumes of untreated sewage.

TABLE III.—*List of W. P. A. Sewerage and Sewage Treatment Projects Completed or under Construction 1936–1940 Inclusive*

Municipality	Nature of Work	Cost to Date†	Status*
Alden	Sewer system and disposal plant	$463,897	C
Alplaus	Sewer system and disposal plant	21,650	C
Amherst Sewer District No. 1	Emergency pump installation	7,766	C
Arcade	Sewer system and disposal plant	129,731	A
Attica	Sewer system and disposal plant	99,470	A
Auburn	Outfall extension, alterations to weir chamber and construction of a relief sewer at disposal plant	16,682	C
Baldwinsville	Sewer system and two disposal plants	695,114	A
Batavia	Additional sludge lagoon	1,026	C
Boonville	Reconstruction of disposal plant	31,814	C
Brighton	Additions to disposal plant	1,841	C
	Sludge bed ramps at Rich's dugway D.P.—culverts at Allens Creek plant	16,882	C
	Additions to Rich's dugway plant	108,840	C
Brockport	Additions to disposal plant	3,873	C
Camillus	Sewer system and disposal plant	153,308	C
Canisteo	Sewer system and disposal plant	213,988	A
Celoron	Sewer system and disposal plant	227,363	A
Cheektowaga	Construction pumping stations	28,630	C
	Install settling tanks and sludge pump	55,529	C
Colonie, Latham S. D.	Sewer system and disposal plant	37,963	A
Corning	Dike around disposal plant	31,613	C
Dansville	Additions to disposal plant	16,006	A
Falconer	Disposal plant	302,605	C
Franklinville	Additions and reconstruction of disposal plant	21,988	C
Fort Ann	Sewer system and disposal plant	44,982	C
Glen Cove	Additions to disposal plant	98,337	C
Gloversville	Improvements to disposal plant	65,669	A
Greenport	Sewer system and disposal plant	435,495	A
Goshen	Reconditioning disposal plant	2,097	A
Hadley	Sewer system and disposal plant	33,117	C
Honeoye Falls	Sewer system and disposal plant	362,937	C
Ilion	Disposal plant and refuse incinerator	200,284	C
Indian Lake	Sewer system and two disposal plants	117,117	C
Irvington	Trunk sewer and disposal plant	148,277	A
Ithaca	Outfall sewer extension	14,886	C
Lackawanna	Repairs to sewer system and disposal plant	209,972	A
Lake George	Sewer system and disposal plant	131,352	C
Lakewood	Sewer system and disposal plant	439,785	A
Ley Creek, Onondaga Co.	Interceptor and disposal plant	3,361,298	C
Lancaster	Improvements to disposal plant	1,879	C
Mechanicville	Interceptor, pumping stations and disposal plant	207,095	A
Minoa	Sewer system and disposal plant	199,423	C
Newark	Additions to disposal plant	3,334	C
Oakfield	Additions to disposal plant	31,271	C
Olean	Pumping station and disposal plant	229,924	C
Pittsford	Sewer system and disposal plant	322,935	C

TABLE III.—*Continued*

Municipality	Nature of Work	Cost to Date†	Status*
Ripley	Sewer system and disposal plant	111,865	A
Rome	To continue construction of disposal plant started under T. E. R. A.	3,446	C
	Additional work to disposal plant	13,828	C
Roscoe S. D., Town of Rockland	Sewer system and disposal plant	29,441	C
Rotterdam	Sewer system and disposal plant	308,918	A
Royalton Town, Gasport S. D.	Sewer system and disposal plant	28,000	A
Saugerties	Additions and alterations to disposal plant	112,087	C
Saratoga Spgs	Cleaning stones in filter beds	65,558	C
Schenectady	Improvements and additions to disposal plant	48,403	C
Scotia	Disposal plant	70,280	C
South Glens Falls	Interceptor and disposal plant	51,329	C
Spring Valley	Additions and alterations to disposal plant	89,967	A
Springville	Sewer system and disposal plant	102,364	A
Stillwater Town, S. D. No. 1	Sewer system and disposal plant	Just started 1/8/41	A
Syracuse	Rehabilitation of disposal plants	$ 73,480	A
	Chlorination plant	7,830	A
Tivoli	Sewer system, disposal plant	86,193	C
Waterloo	Additions and alterations to disposal plant	6,005	C
West Seneca	Rehabilitation of disposal plants Nos. 5 and 6	21,901	C
Utica	North Side disposal plant	53,940	C
	Total	$10,633,872	

Total number of projects—61

New	34
Reconstruction of old	27
Completed	40
Active	21

* C = Completed.
A = Active as of December 1, 1940.
† Cost as of December 1, 1940.

II. Storm and Sanitary Sewers and Sewage Treatment Projects Constructed under T. E. R. A. Program, 1933–1934

Under the T. E. R. A. Program, 1255 projects of storm and sanitary sewer and sewage treatment plants were constructed at a cost of $16,284,000. Under this program three new sewage treatment plants were constructed and twelve treatment plants were enlarged and improved at a total cost of approximately $500,000.

The greater part of this program consisted of sewer construction which could be undertaken as a means of employment of relief labor without delay from engineering investigations and the preparation of engineering plans.

III. Sewerage and Sewage Treatment Plant Projects Constructed under W. P. A. for 1936–1940, Inclusive

Table III is a list of W. P. A. sewerage and sewage treatment plant projects completed or under construction between 1936 and 1940, inclusive. Under this program 34 new sewage treatment plants have been constructed and 27 treatment plants enlarged and improved. Forty of these projects have been completed and 21 are still under construction. The estimated cost of this work is $10,600,000.

Table IV.—*W. P. A. Sewer Systems Proposed, Active or Completed, 1936–1940, Inclusive*

Municipality	Status	Total Cost*
Belden Center Sewer District	Completed	$ 77,597
Dannemora	Active	40,888
East Greenbush Sewer District No. 1	Completed	226,417
Hartsdale Lawns Sewer District, Town of Greenburgh	Active	144,710
Huntington Estates Sewer District	Active	35,053
Lyncourt Lawns Sewer District, Town of Salina	Completed	401,938
Mattydale Sewer District, Town of Salina	Not released	801,743
Owasco Sewer District	Completed	295,176
Park Hill District	Completed	253,482
West Ellicott Sewer District No. 3	Not released	321,427
West Glen Sewer District	Completed	103,529
West View Sewer District	Completed	70,328
Total		$2,772,288
6 Complete.		
3 Active.		
2 Not released.		

* Actual cost, if completed; estimated cost if active or not released.

In Table IV, 12 projects for sanitary sewer construction proposed or completed with W. P. A. aid are listed. The amount of funds spent to December 1, 1940 on this work is $2,772,000.

In Table V, 14 sewage treatment plant projects are listed which have been submitted to and approved by the Works Projects Administration but work on which has not actually started. The estimated cost of these projects is $4,470,000. In addition, 205 projects covering sanitary, combined, and trunk sewer construction were completed by the W. P. A. from 1936 to 1939, inclusive, on which $5,943,000 was spent. Also, 123 relief, combined, and sanitary sewer extension projects were approved during the year 1940, the total estimated cost of which is $3,680,000.

This summation of W. P. A. sanitary sewers and sewage treatment plant construction gives some indication of the enormous amount of this type of construction work that has been undertaken by W. P. A. in New York State. Many of these projects are of large magnitude, among which may be mentioned the Ley Creek plant at Syracuse built at a cost of over three million dollars; and a million dollar storm relief pressure tunnel trunk sewer in Schenectady. Other unusual types

TABLE V.—*W. P. A. Sewerage and Sewage Treatment Projects Which Have been Proposed or Steps Taken to Initiate*

Municipality	Nature of Work	Total Estimated Cost
Catskill	Intercepting sewers and disposal plant	$ 214,953
East Greenbush Sewer Dist. No. 2	Sewer system and disposal plant	284,742
Elmira Heights	Sewer system and disposal plant	348,650
Horseheads	Sewer system and disposal plant	386,223
Kingston	Intercepting sewers and disposal plant	376,477
Menands	Intercepting sewers and disposal plant	175,085
Mexico	Intercepting sewers and disposal plant	77,392
Newburgh	Intercepting sewers and disposal plant	728,744
Northville	Sewer system and disposal plant	99,475
Oswego	Intercepting sewer	35,906
	Intercepting sewer and sanitary sewers	257,180
Peekskill	Intercepting sewers and disposal plant	
Poughkeepsie	Intercepting sewers and two disposal plants	1,147,000
Salamanca	Intercepting sewers	60,469
Utica	North side interceptor	287,302
Total (14)		$4,469,598

of sewer construction carried out by W. P. A. included a large storm relief sewer tunnel in Rochester, and a trunk sewer and sewage treatment plant project for Irvington, where a large portion of the trunk sewer is constructed as a tunnel.

These larger projects which have been sponsored by local municipalities are the result of sound engineering advice furnished by consulting engineers employed by the sponsoring agencies.

The changing character of the work program carried out in New York State under W. P. A. is well illustrated by the following excerpt from an address given by Mr. Clarence W. Post, Chief Engineer and Assistant Administrator of the State Works Projects Administration, before the New York State Society of Professional Engineers in Albany on March 9, 1940.

In view of the fact that 83 per cent of the W. P. A. workers are doing construction work, we require engineering plans and specifications for all classes except the simplest types of work. Not only must the work be well planned by municipal engineers or their consultants, but also those plans and specifications must be reviewed and cleared for thoroughness and practicability by independent and unrelated boards of engineers. For instance, all matters pertaining to sewage treatment or water supply are routed to the engineers of the State Health Department for conformity with recognized practice; all plans for school buildings and grounds are routed to the engineers and architects of the Department of Education in keeping with sound practice; all plans for river improvements, stream control are routed to the engineers of the War Department for clearance; all plans for dams, bridges, reservoirs are routed to the State Department of Public Works and to the Engineering Review Division, Washington, for approval. We are endeavoring, with the assistance of the State Department of Public Works, to require submission of plans for all rural highway improvements, thereby giving the State, which furnishes part of the money for rural highways, the opportunity to disapprove the utilization of funds on town roads which should be abandoned. The magnitude of the work warrants such a course. The engineer is capable of that responsibility. The public is entitled to that protection.

Summarizing the above our New York State municipalities during the period from 1933 to 1940, inclusive, have constructed 108 new sewage treatment plants, and 54 sewage treatment plants have been modified and enlarged. This work has been undertaken almost exclusively with Federal aid under the various agencies outlined above. The cost of this construction program for sewers and sewage treatment is something over $113,000,000, of which $59,000,000 was Federal aid through the various agencies.

It is to be naturally expected that with the pick-up in employment incidental to the national defense program, the amount of available relief labor will be curtailed. Experience thus far indicates, however, that in the larger cities, at least for the coming year, there will be sufficient unemployed common labor to warrant a continuation of W. P. A. even though on a reduced scale from that experienced during the past year. For the immediate future, at least, the larger municipalities may take advantage of the opportunity of obtaining Federal aid in carrying out needed sanitary sewer and sewage treatment plant construction through W. P. A. There are, in fact, a number of projects of large magnitude which are planned for operation this coming year.

Industrial Wastes

PROBLEMS OF INDUSTRIAL WASTES FROM THE STANDPOINT OF CITY ADMINISTRATION *

By W. T. Knowlton

Sanitary Engineer, Sewer Design Division, Bureau of Engineering, City of Los Angeles

The problems of industrial wastes from the standpoint of the city administration commence when a city is formed. As the city increases in population, these problems increase in importance. In a small residential city, it is doubtful if there are any industrial wastes to be encountered other than those from a laundry and the oil wastes from garages and service stations. When cleaning and dyeing plants are established, and other industries are started that desire to dispose of their waste water, the problem begins to attract the attention of the city administration. Industrial plants that require some means of disposal for their wastes are willing that the city administration shall look after such disposal.

In Vol. III of *American Sewerage Practice* by Metcalf and Eddy, as revised in 1935, industrial waste is defined as waste waters carrying suspended, colloidal, and dissolved matters produced by manufacturing processes and discharged therefrom as being of no commercial value. As the usual custom in cities is to discharge these waste waters into the public sewers, the writer has prepared this paper with special reference to such disposal and the problems produced thereby.

In return for the city providing for the disposal of the industrial wastes, it has been suggested that the industries should bear some part, if not all, of the cost of preliminary treatment of such wastes, when the city finds that such treatment is necessary. Industries cannot in all cases solve the problem of disposal, but they should co-operate with the city in the matter. Each has a part in providing for the welfare of the community.

The problem of industrial waste disposal is very puzzling at times to the city official when he realizes that on one hand the industry is a large corporation paying a generous share of the taxes, while on the other hand this industry is creating a serious condition or nuisance that affects the health of the community, and demands relief.

The technical problems pertaining to industrial waste disposal are more varied and complex than those which have been solved in sewage treatment, and the cost of industrial waste treatment may be as great as that of completing the sewage disposal projects of the nation (1).

* Presented at the Thirteenth Annual Fall Convention of the California Sewage Works Association, San Diego, September 17, 1940.

Kinds of Industries.—In 1904 Los Angeles had 814 industrial plants with a total of 10,000 employees. The number of plants increased to 3,192 in 1937, with 77,000 employees. Among those industries where the liquid wastes have generally been discharged into sewers are fruit, vegetable, and fish canneries, creameries, dairies and ice cream plants, cleaning and dyeing establishments, laundries, overall and rag cleaning plants, breweries, cooperage, soap plants, meat packing and slaughter houses, and the wastes from garages and auto service stations.

Other industries which may have wastes that will affect the sewers are gas works, marble works, oil refineries, chemical works, sugar refineries, bottling works, baking plants, wine plants, moving picture plants, paper plants, poultry dressing houses, and sausage casing factories.

Division of Industrial Wastes into Groups.—As suggested some years ago (2), industrial wastes may be divided into four groups in connection with their disposal.

First: Those wastes which can be discharged into sewers without any preliminary treatment.

Second: Those which require some adjustment of the amount of flow, but no preliminary treatment before disposal into sewers.

Third: Those which can be admitted into sewers after some preliminary treatment of the waste.

Fourth: Those which should not be permitted to be discharged into sewers.

Where the volume of the waste does not materially increase the cost of sewer maintenance or the cost of sewage treatment, and where the waste has no injurious effect on the sewers or sewage treatment, such waste belongs in the first group.

Should the waste discharge into the sewer occur intermittently so as to overtax the sewer capacity, such wastes are in the second group, and the discharge should be controlled at a reasonable and uniform rate over several hours, or at specified periods. An illustration of this discharge is seen where sewer connections are desired from swimming pools and cooling tanks, when there are no storm drains in the vicinity into which such discharge could be made.

The third group includes those wastes which contain acids, oils, grease and other substances that would form deposits in the sewers, or overload the sewage treatment plant. When canneries in this group fail to provide the preliminary treatment required, the sewage treatment plant will frequently show evidence of skins and peelings that should have been intercepted at the plant of the industry.

In the fourth group are those industrial plants which discharge live steam, scalding liquids, volatile inflammable liquids or gases, and unpolluted cooling and condensing water that could properly be carried into a storm drain, if available. The discharge of such wastes in this fourth group should not be put into the sewers unless the sewers are of the combined type which carry both sewage and drainage. Certainly no storm water can be permitted to be discharged into a sewer of the separate type.

The division of the industrial wastes into these four groups shows that, for each application from an industrial plant for a sewer connection, the character, quantity, and rate of discharge of the waste should be known, if possible, and satisfactory arrangements for the waste disposal therefrom should be made before the plant is erected. Occasionally those who are planning the industrial plant have gone ahead with their project, and when the plant was erected, applied for the sewer connection, and then found that the existing sewer was too small.

Amount of Wastes.—The amount of wastes varies with each industry and also among the various plants in the same type of industry. Sometimes the amount of waste in an industry may be less than the amount of domestic sewage therefrom. However, for those industries listed in the first paragraph of Section 2 hereof, the volume of waste is apt to be more than the amount of sewage therefrom, and such conditions affect the capacity of the sewer receiving the waste.

In Los Angeles, laundries and other industrial plants have at times been established in residential districts, which generally have small sewers. This has caused the amount of waste to exceed the available capacity of the small sewer, and thus required the construction of an additional or relief sewer. Due to the much larger amount of solids in industrial wastes than are found in sewage, the disposal of industrial sludge is a problem as difficult and more costly to solve than occurs in sewage treatment. The size of a plant required for the treatment of a million gallons per day of industrial waste is larger and its work more complicated than that required for treating the same volume of sewage.

The volume of liquid waste from various industries in Los Angeles forms an appreciable percentage of the total flow of sewage. An estimate of the volume of laundry waste water gives an average flow of 12 m.g.d., that from meat packing plants and slaughter houses may have an average flow of 8 m.g.d., and that from creameries and dairies may have an average flow of 5 m.g.d. Adding to these wastes, those from breweries, overall and rag cleaning plants, and moving picture studios, will give a total volume of more than 26 m.g.d., which is 20 per cent of the present average flow of sewage discharged into the ocean from the Hyperion screening plant.

Analyses of Wastes. (*a*) *Suspended Solids.*—The suspended solids in sewage may average 250 p.p.m. by weight, but those in industrial wastes may average from 50 to 3000 p.p.m. or more.

In meat packing plants in Los Angeles, the content of suspended solids in the liquid waste may vary from 500 to 3000 p.p.m. Waste rag laundries have shown a variation in such content from 800 to 6000 p.p.m. Overall cleaning plants vary from 500 to 1100 p.p.m. Fish cannery waste has shown a variation from 2000 to 3000 p.p.m.

(*b*) *Grease.*—The content of grease, or ether-soluble matter, in sewage from 16 different cities was found to average 53 p.p.m., or .05 lb.

per capita per day. (3) The average grease content in sewage in Massachusetts was estimated at 97 p.p.m.

The grease content in the fish cannery waste has varied from 400 to 1000 p.p.m. In meat packing plants records from 600 to 900 p.p.m. grease have been noted, while in waste rag laundries grease content in the waste has varied from 600 to 3600 p.p.m.

(*c*) *B.O.D.*—In meat packing plant wastes, the B.O.D. content varies from 600 to 1500 p.p.m. Breweries are next to meat packing houses in such content. A barrel of beer produces wastes whose B.O.D. is equivalent to the sewage of 20 persons.

Harmful Effects of Wastes.—Concrete sewers are subject to deterioration from some industrial wastes, as acid pickling liquids. To prevent such action, the pH value of the waste must not be permitted to fall too much on the acid side of the scale. In Baltimore the city ordinances require that the pH content in the discharge from industrial plants shall not be less than four. An English recommendation is to keep the pH of influents to activated sludge plants not lower than six for optimum results.

Oil refinery wastes affect water supplies, recreation and aquatic life, and cause agriculture to be damaged by the brine in the oil. The brine should be evaporated or diluted before disposal onto land (4). These wastes may increase the chlorine demand, and the tastes and odors in the water supply.

The discharge of waste oil into the sewers is a serious matter, as it interferes with the proper maintenance of the system, and because the presence of gasoline coming from such discharge may cause an explosion or fire in the sewers. Such a result would affect the public health and welfare, as well as the sewerage system. As is done in Los Angeles, other cities should conduct explosive gas surveys in the sewer manholes in order that where the conditions are found to be dangerous, the gas companies can be notified and the trouble remedied. If the cause is from some source other than natural gas, efforts should be made to locate the source, and eliminate the cause.

Without the use of grease traps or intercepting basins, sewers have been clogged repeatedly by grease coming from industrial plants, or from places where food in large quantities is prepared for human consumption. Patented grease traps on the market, that guarantee high efficiencies, do not solve the problem when the grease intercepted is not removed from the trap. The remedy should be in periodic and frequent removal of the grease by those in charge of the premises, and a constant inspection by the city to see that this remedy is carried out.

Control of Waste Disposal.—Some cities in the United States have laws prohibiting the discharge of certain industrial wastes into the sewers. In Fostoria, Ohio, the discharge of iron and carbon in wastes is controlled by requiring definite amounts of flow for varying content of iron and carbon in the wastes. These requirements necessitate that the flow be gauged every two or three months.

The State Boards of Health in Pennsylvania, Connecticut, Rhode

Island, Ohio and Massachusetts have power to enforce laws restricting the disposal of industrial wastes. However it is preferable to have the state or city obtain the approval and cooperation of the industry, as has been done in Maryland, Michigan, Ohio, Pennsylvania and Wisconsin.

In Los Angeles, it is unlawful to discharge into any sewer or drain any liquid waste containing chemicals, grease, oil, tar, or other matter in solution which shall clog or fill the sewer or interfere with its effective use. It is also unlawful to discharge any liquid waste having a temperature greater than 100° F., or which shall contain more than 600 p.p.m. of oil or grease by weight, or which shall contain more than 1000 p.p.m. of suspended solids by weight.

These limits of permissible content of oil or grease, and suspended solids in liquid wastes discharged into any public sewer were proposed after a survey by the writer of existing conditions in the Los Angeles system in 1936. At about the same time (although then unknown to the writer) the State Board of Health of Massachusetts fixed their limits for these contents at 300 p.p.m. and 500 p.p.m. for grease and suspended solids, respectively, in the Essex County Sewerage District.

In Madison, Wisconsin, the Madison Sewerage District requires that packinghouse wastes reaching the District sewage treatment plant shall have no greater strength than domestic sewage. In Austin, Minnesota, the Hormel Packing Co. has a volume of waste equal to, or greater than the volume of city sewage, but the strength of this waste is much greater than the sewage. The company is now planning to reduce this waste so that the effluent from its plant shall not contain over 600 p.p.m. of B.O.D., or 200 p.p.m. of suspended solids.

In Manchester, England, the permissible limits suggested for waste disposal from industrial plants are 428 p.p.m. for both grease and oil, and suspended solids.

To control to some extent the amount of grease and solids in the liquid wastes entering the Los Angeles sewers from industrial plants, studies have been in progress by the Bureau of Engineering of the City of Los Angeles for quite a time as to the benefit that could be derived by requiring all industrial waste to pass through intercepting tanks or clarifiers before discharge of the waste into the sewer. This preliminary treatment would require that the varying amounts of grease and solids that would be collected in the clarifier should be removed therefrom at proper intervals, so that the effluent would have its content of grease and solid thus reduced to an allowable limit. The dimensions of the clarifiers would vary with the type and size of the industries.

Sand traps not over two feet in dimensions have been specified in Los Angeles ordinances for some years. Such traps however are not of sufficient capacity to give the detention period required for the collection and removal of grease and solids in the wastes discharged thereinto.

Sewage and Grease Tests in Los Angeles System.—In connection with the studies noted hereafter in this paper, the Bureau of Engineering of the City of Los Angeles has made periodical tests of the raw sewage at various manholes in the sewerage system of the city. These tests include the temperature of the sewage, its pH content, and the content of hydrogen sulfide, settleable solids, suspended solids (the latter divided into total and volatile content), and grease.

In connection with the determination of grease, a local committee of chemists has assisted this Bureau in studying the effect of various solvents of grease in tests of sewage, sewage sludge and industrial waste. This committee intends to present its findings in a report that will be published in some technical journal. It is thought that the procedure now given as a standard for its determination, can properly be revised, and such revision has been used by this Bureau.

To assist this committee, a questionnaire was sent recently to several sanitary engineers and chemists throughout our country concerning their practice and thoughts as to a revision of the present procedure for determination of grease content. Although chloroform seems to be the popular solvent in the central states, and petroleum ether in the eastern cities, the local committee favored the use of mixed hexane for the reason that this solvent would permit extraction of grease in the sample to be tested without drying the sample (as now required by the Standard procedure), and for the further reason that other solvents tend to remove hexane-insoluble substances which for the greater part should not be included with grease.

Conclusions

A start has been made in this country in solving the problem of industrial waste disposal. Our technical publications have devoted increasingly more space in their pages to this problem during each of the past four years. In its issue for November, 1939, *Industrial and Engineering Chemistry* published thirteen papers on waste disposal presented at the 1939 Boston meeting of the American Chemical Society.

The Sanitary District of Chicago has for some years been studying this problem, although it has not as yet drafted an ordinance to cover the matter. In this study, the District has investigated over 200 different establishments for at least two weeks in each case to determine what discharge is taking place. In this connection, it should be noted that the District has established legal control of its wastes by having an Act passed by the State Legislature authorizing the District to levy a charge on industries for all volumes of waste exceeding 3,650,000 gallons in any 12-month period received for disposal by the District.

This idea of limiting the amount of the volume of industrial waste that can be discharged into a sewer without any especial charge therefor, will be a matter that should interest city administrations. If carried out, this might provide funds for the treatment and disposal of the industrial waste entering the sewers. Comments on this idea in recent proceedings of the Institute of Sewage Purification of England (6) state that "great courage on the part of local authorities will be required to determine whether or not to bring into force the whole of the powers which the Act provides. If carried out too much, new industries may be kept out; and if too little, some of the income to which the Act would entitle the City may be lost.''

The Act just mentioned is the Public Health Act of 1937, and comments of English engineers as given in the *Surveyor* of Aug. 25, 1939, indicate that this Act had created certain prescriptive rights that would prevent local authorities from charging for all discharge into the sewer. ''Proper knowledge of volume of trade effluent discharge must be had before such rights are determined.'' Expressions in the Act as ''so far as is practical'' and ''without unreasonable cost'' were considered too indefinite, as they do not make the Act water-tight. Some familiarity with this English law is recommended, as it has a bearing on the Illinois revised statutes that controls the payment for disposal of industrial waste into the sewers of the Sanitary District of Chicago.

Possibly the exact limits for the content of grease and suspended solids may depend on the relative volumes of domestic sewage and industrial waste. As the relative concentration of industrial waste increases, it may become necessary to reduce the permissible limits of grease and suspended solids. Thus the volume of waste is probably a factor that should be specified in the controlling ordinance.

The subject of financial returns from the recoveries of wastes by the industry should be considered (5). In meat packing plants and fish canneries, such recoveries cannot be overlooked, as the value of by-products is as important as the treatment of the wastes.

Most industries are assets to the community as they are tax payers and give employment to many people. Accordingly the industry should be encouraged, and not driven away by unfriendly measures. However, the industry should conform to the laws in the operation of its plant, and in so doing should bear a reasonable proportion of the cost of treatment of the wastes. The basis of determining such a proportion should include the relation of quantity of flow from the industry to the amount of flow in the sewerage system of the city, and the amount of suspended solids and grease in the effluent from the industrial plant must be given attention.

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3. H. P. Eddy, Jr., *Civil Engineering*, 138–139 (March, 1935).
4. Willem Rudolfs, *Sewage Works Journal*, 1006 (Nov., 1937).
5. L. F. Warrick, *Modern Sewage Disposal*, 345 (1938).
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Discussion

By William T. Ingram

Sanitary Engineer, San Joaquin Local Health District

I hesitate to comment on this excellent paper, but, on the other hand, I feel that the presentation of some recent investigations made in connection with the handling of waste solids from Stockton canneries may be of some value and will, I hope, bring to attention further information along these lines.

The City of Stockton has an ordinance which prohibits the disposal of "any fish, fruit, or vegetable waste, or other solid matters, or materials or obstructions of any kind whatsoever of such nature or in such quantities as shall clog, obstruct, or fill such public sewer . . . or which will interfere with the efficient and successful operation of any sewage disposal works. . . ." This ordinance has been used to effect some control of grease, gasoline and oil wastes, dry cleaning wastes, and many others, but complications enter when it is applied to cannery wastes.

In industries of this nature there is a certain spirit of competition. Chambers of Commerce, without full realization of the problems involved, frequently invite industry to a city which is not in a position to handle waste products in a satisfactory manner. I say this, not in a spirit of criticism, but as a statement of fact. There is much to be done in the field of education with such bodies as may be responsible for the building of a city.

With this background in mind, it seems applicable to a discussion of Mr. Knowlton's paper to offer a few bits of information concerning the use and design of screens as a means of pre-treatment of cannery wastes.

In California, there is little information on the use of screens.

The Val-Vita Company, Fullerton, has a 5 ft. diameter by 10 ft. long screen using five 16-mesh frames, one 32-mesh frame, and eight 40-mesh frames. The speed of the screen is 24 r.p.m. The waste flows outward and solids are collected and removed by a spiral conveyor. The screen is cleaned with a continuous water jet, and by stream three or four times a day. Operating at 11.4 tons per hour, this screen removed 450 gallons of waste from 125 tons. Suspended solids removal is estimated at 16 per cent.

The U. T. C. Cannery, Buena Park, has a 3 ft. diameter by 11 ft. long rotary screen. The plate is perforated with ⅛ in. holes. Water flows outward, and the screen is cleaned by water spray. Solids are removed by spiral conveyor. This installation removes whole or broken tomatoes only, and one operates on a load of 7 tons per hour. Other data are incomplete.

Sutter Packing Company, Palo Alto, has a flexible belt screen 12 in. wide with ½ in. openings, traveling at 8 ft. per minute. Flow varies from 400 to 700 g.p.m. Trouble has been encountered with clogging and cleaning. The installation removes whole or sliced material and some skins.

Elsewhere, information is little more complete.

"Cannery Waste Treatment Studies," conducted by Ohio Canners Association, and the Association of New York State Canneries, Inc., mentions that 40 by 60 mesh rotary screens at 4 r.p.m. will handle 2 g.p.m. per square foot. The screen requires 250 gallons of water per hour to keep it clean.

Michigan Experiment Station *Bulletin,* **13**, No. 4, mentions 40 mesh screens on an average flow of 295 g.p.m. per ton of raw material. It removed an average of 174 gallons per hour on tomato waste, containing 1.19 per cent solids. The screen was 4 ft. diameter by 4 ft. long. The screw conveyor was not satisfactory and was replaced by a rotary pump. The speed of the screen was not given.

Iowa State Dept. of Public Health, in correspondence, indicates that rotary screens with 30 to 40 mesh give good service on corn, beans, carrots, and beets. Screens have been in service two and three years—no other data was given on screen sizes or speeds.

Illinois State Dept. of Health in correspondence mentions that size of screen is a matter of decision on each particular waste; principal wastes in Illinois are peas and corn. No conclusive data are available on rate of flow per unit of screen surface. Solids are removed by mechanical conveyor. High pressure water spray is desirable for cleaning, and pumping of waste prior to screening should be avoided.

A manufacturer in correspondence brings out these items:

Twenty-mesh monel metal cloth is effective. Forty-mesh clogs and necessitates oversize screens. Removals of 75 per cent of the suspended solids on tomato and pea wastes may be expected on low solids concentration (600 to 800 p.p.m.), 50 to 70 per cent removal may be expected on 2,000 p.p.m. suspended solids. Ordinarily, 25 per cent removal would be considered as probable, and a 3 ft. diameter by 3 ft. long screen, 20-mesh, will handle 338 g.p.m. or 12 g.p.m. per square foot of screen surface. Speed of screen is variable, and is not given. Solids are removed by conveyor.

Another manufacturer using the vibrating type of screens states that 2 ft. by 4 ft. 40-mesh screen at 2,100 vibrations per minute will handle 300 g.p.m., or 37.5 g.p.m. per square foot of screen surface. Solids vibrate downward, and are removed by belt or conveyor. This necessitates a gravity flow on to the screen.

In a paper entitled, "Effect of Cannery Wastes on Operation of Sewage Treatment Plants" (*This Journal,* **12**, No. 1, Jan. 1940), Ryan figured on a wet basis that 40-mesh screen will remove 30 to 35 per cent suspended solids on tomato wastes.

A shaker type, 60-mesh link belt screen has worked well at one large plant. (Type of waste not specified.)

The New York State Division of Sanitation in "The Treatment of Canning Waste," mentions that a 40-mesh screen is very satisfactory for most wastes, but 20-mesh should be used on tomato waste. Twenty-mesh is adequate when preceding chemical precipitation. Forty square feet of screen area was sufficient for 200,000 gallons per day. Screens require frequent inspection. A water spray and steam jetting are required when loaded at the rate of 3.5 g.p.m. per square foot of screen area. Speed of screen was not stated.

It may be that screening is necessary to remove solids from the waste, but it should be obvious that more effective removal is possible, if closer supervision of operation is practiced.

Reduction of waste can be accomplished if good quality materials are brought in from the field. Spilled juice, cuttings and wastes can be segregated at the plant if proper care is taken in the plant setup. The latter particularly applies to the waste products of the tomato pulper. At clean up time, garbage wastes cleaned up separately or diverted out of the sewage flow would lessen the amount of solids in the sewage.

Summarizing this information, which I grant is incomplete, it is apparent that the use and design of fine screens is rather varied. It would appear that screens should be at least 20 mesh, and not over 40. Drum screens may handle flows of 2 gallons per minute per square foot of surface to 12 g.p.m. per square foot of screen surface. Vibrating screens may handle up to 37 g.p.m. per square foot of screen surface. Band screens may handle as much as 87 gallons per minute per square foot of exposed surface, but clogging can be expected at this rate.

From 10 to 25 per cent removal of solids may be expected, although both more and less have been reported.

Water sprays and steam jets for cleaning purposes should be provided in most installations.

Conveyors, pumps, or other equipment are necessary to carry the garbage waste away from the screen. The garbage waste may be eliminated at several points in the production process by careful operation and suitable equipment.

It appears, however, that cities would be justified in requiring that garbage wastes should be removed from the sewers by some method. Close supervision and adequate equipment to divert such wastes in the plant are desirable as being a solution along more economic lines; for such waste once mixed with water is hard to remove, and not so easily handled after admixture.

If this cannot be done faithfully, then pre-treatment, consisting of fine mesh screens constructed without by-passes, should be installed. Devices for macerating garbage waste should not be installed in any cannery.

Discussion

By Albert Castro

Chemist, Sante Clara, California

As Mr. Knowlton says "Industrial plants that require some means of disposal for their wastes are willing that the city administration shall look after such disposal." While it is true that there are different degrees, there are times the industry prefers to turn a deaf ear to the pleas from city officials for co-operation in solving the problem created by the dumping of trade wastes into the city sewerage systems.

The definition of industrial wastes as defined by Metcalf and Eddy, "waste matters carrying suspended, colloidal, and dissolved matters produced by manufacturing processes and discharged therefrom as being of *no commercial value*" might in itself be thought of as a sort of yardstick, for, as Mr. Knowlton points out, the value of recovery of by-products from an industry is a score which must not be overlooked. As is generally known, it may be possible in many cases to reduce the amount of wastes dumped into the sewers by this means.

Besides the general division of industrial wastes into groups as given by Mr. Knowlton, a good classification of industrial wastes on the basis of their qualitative nature alone and general methods for their treatment can be found on page 352 of the 1938 Edition of *Modern Sewage Disposal.*

In regards to those wastes which require some adjustment of the amount of flow alone, one set of jar experiments at the Santa Clara laboratory showed that in the case of wastes from prune and apricot packing the wastes could be mixed with the raw sewage up to the point where the percentage of the total volume for prune wastes was 5 per cent, apricots 15 per cent, a mixture of 50 per cent apricots and 50 per cent prunes to the extent of 5 per cent, without the mixtures turning sour after standing 19 hours. All percentages above this were sour after this period of standing. Naturally too much emphasis must not be put on one experiment but if further studies permit us to draw the same conclusions as the first we may be able, by controlling the flow of these wastes which are normally dumped into the sewers at about 5:00 P.M. in the evening, to eliminate the "turning over" of the contents of our clarifier which occurs regularly at about 7:00 P.M. every evening the canneries are in operation.

To date, before a community decides what percentage of the additional costs necessary for the proper treatment of wastes from an industry should be borne by the industry itself, there are many factors besides strength and volume of wastes to be considered in adding up the score. At the present time it can be only after carefully weighing the assets of the industry that a conclusion of some sort may be arrived at.

While it is true that the natures of the various wastes are as variable as the industries themselves and may vary for the same industry in different locales, State, if not Federal legislation setting up maximum strengths allowable for each general type of waste and a minimum fee per ton of wastes due a city for treatment of these wastes would, besides overcoming the possibility that industries might be driven away from a community because of, as they feel, unfriendly measures, also help those communities which are at present shouldering the full expense of the treatment of these wastes.

DEVELOPMENTS IN CANNERY WASTE STUDIES AT PALO ALTO *

By Jack H. Kimball and Harold L. May

Asst. Superintendent, Water and Sewer Division, and Chief Operator, Sewage Treatment Plant, Palo Alto, Calif.

The studies on cannery wastes which have been undertaken at Palo Alto have been of a general nature only, as it has not been possible for the writers to spend their full time and energy on this work due to other departmental duties. However, the results obtained so far do reflect a picture of the problem which must be solved in the near future if satisfactory treatment is to be obtained.

The problem is created by the addition of cannery wastes at the rate of approximately one million gallons per day to domestic sewage at a point one hour's distance from the sewage treatment plant. The ratio of the volume of cannery waste to the volume of domestic sewage is 2 to 1 during low domestic flows, and 1 to 2 during peak domestic flows. By the time the mixture enters the clarifier the pH has dropped to 6.0 and gas is forming to such an extent that practically all sludge rises immediately to the top. Most of this floating sludge is carried over the effluent weir and out to San Francisco Bay.

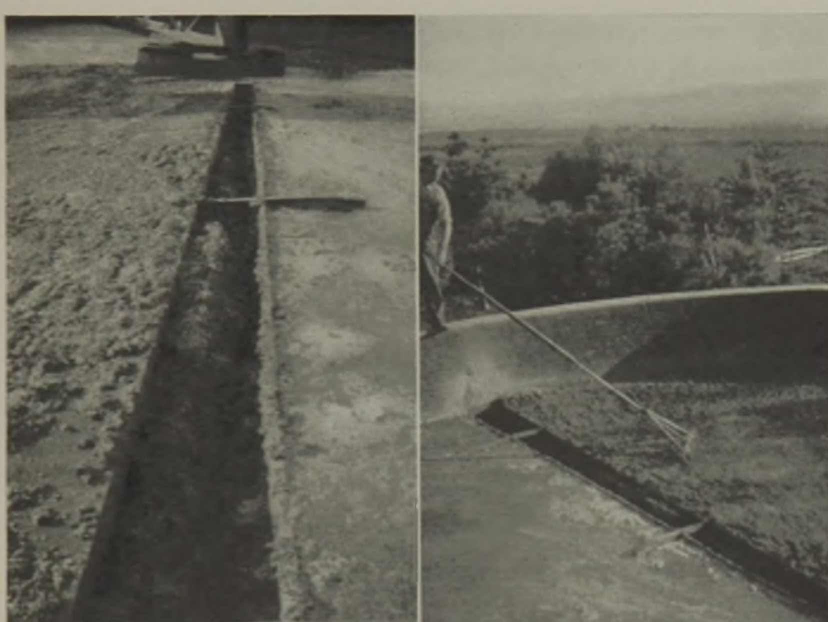

Fig. 1.—Tomato and peach cannery waste floating on surface of clarifier. Palo Alto sewage treatment plant.

* Presented at the Thirteenth Annual Fall Convention of the California Sewage Works Association, San Diego, September 17, 1940.

The problem at Palo Alto is to determine the most practical and economical method by which an effluent can be produced during the four-month canning season which is comparable to the effluent produced during the rest of the year.

Studies Undertaken

Effect of Cannery Waste on Quantity of Sewage Received at Treatment Plant.—Figure 2 shows the average daily flow for seven-day intervals for the six-year period, 1934–1940. Weekly averages were used in order to smooth out extreme variations. The volume of water contributed by the cannery during each season can be compared with the normal dry weather flow of 1.4 m.g.d. just after Stanford University has closed (latter part of June) and just prior to the apricot season.

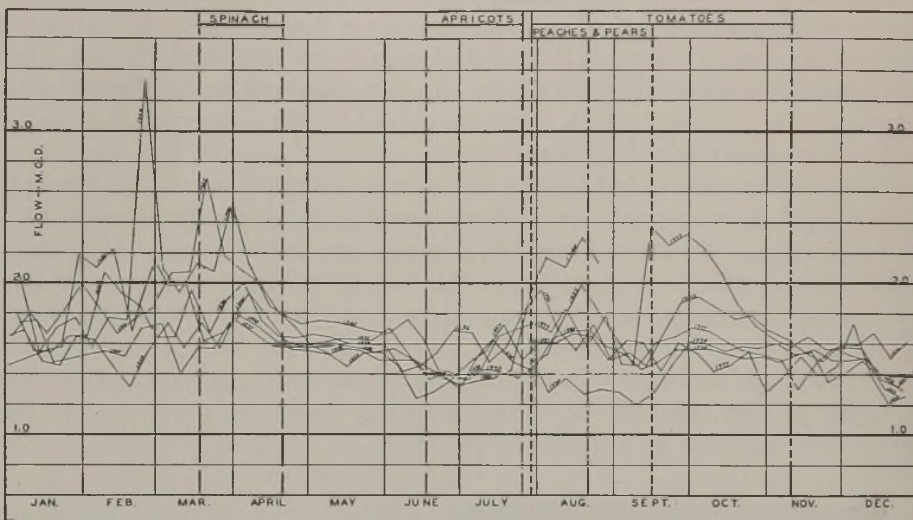

Fig. 2.—Effect of cannery waste on quantity of sewage received at treatment plant as shown by average daily flow for seven day intervals for the six year period 1934–1940, Palo Alto, California.

A considerable reduction in the amount of water used by the cannery may be noted for the years 1937, '38 and '39 as compared with the years 1935 and '36, even though the amount of material handled by the cannery has steadily increased. This reduction was accomplished by re-circulating reclaimed water through the floor drains rather than using fresh water. The volume of water used during the 1940 peach season has increased due to a proportional increase in the tons of fruit packed. The volume of water used per ton of raw fruit has been determined for the 1940 season as shown in Table I.

Effect of Cannery Waste on Strength of Sewage Received at Treatment Plant.—Figure 3 shows the B.O.D. values of 24 hr. composite samples of raw and settled sewage for the six-year period 1934–1940. An average weighted curve for this six-year period was drawn to show the relative strength of the domestic sewage with and without cannery

TABLE I.—*Strength of Cannery Wastes*
1940 Season Compared With 1936 Season

	Season	Spinach	Apricots	Peaches-Pears	Tomatoes
Maximum Pack—Raw Fruit, Tons per Day	1940 1936	85 71	180 120	357 111 208 41	675 196
Cases per Ton of Raw Fruit	1940 1936	46 —	58 —	45 38 — —	38 —
Volume of Waste Water, Gallons per Ton	1940 1936	7,400 8,100	4,700 2,500	2,900 5,180	2,000 3,600
B.O.D. in p.p.m. (Five Day)	1940 1936	615 730	1,020 380	1,340 1,350	—* 990
Population Equivalent, Persons per Ton	1940 1936	230 290	250 49	200 179	100 180
Population Equivalent for Maximum Pack, Total Persons	1940 1936	20,000 20,800	45,000 5,900	93,000 37,300	67,500 35,300

* 1936 B.O.D. used in computing population equivalent.

waste. The only value of this curve is that it emphasizes the fact that wastes from the cannery nullify the effectiveness of the treatment plant for at least four months out of every year, thus defeating the original purpose of the plant.

Chlorine Requirements of Domestic Sewage with Cannery Waste.—In 1938 a series of tests were run at the suggestion of Mr. Carl Beyer,

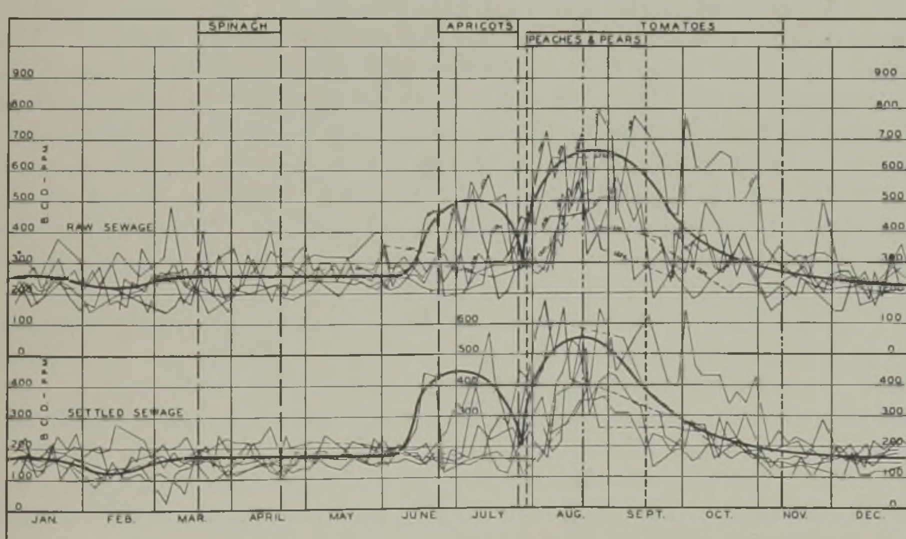

FIG. 3.—Effect of cannery waste on strength of sewage received at treatment plant as shown by B.O.D. of 24 hr. composite sample of raw and settled sewage for the six year period 1934–1940, Palo Alto, California.

District Manager, Wallace and Tiernan Sales Corporation, to obtain information on the hourly variation in strength of domestic sewage and sewage with different cannery wastes, as measured by its chlorine demand. Figure 4 shows the variation in H_2S, rate of flow, and chlorine

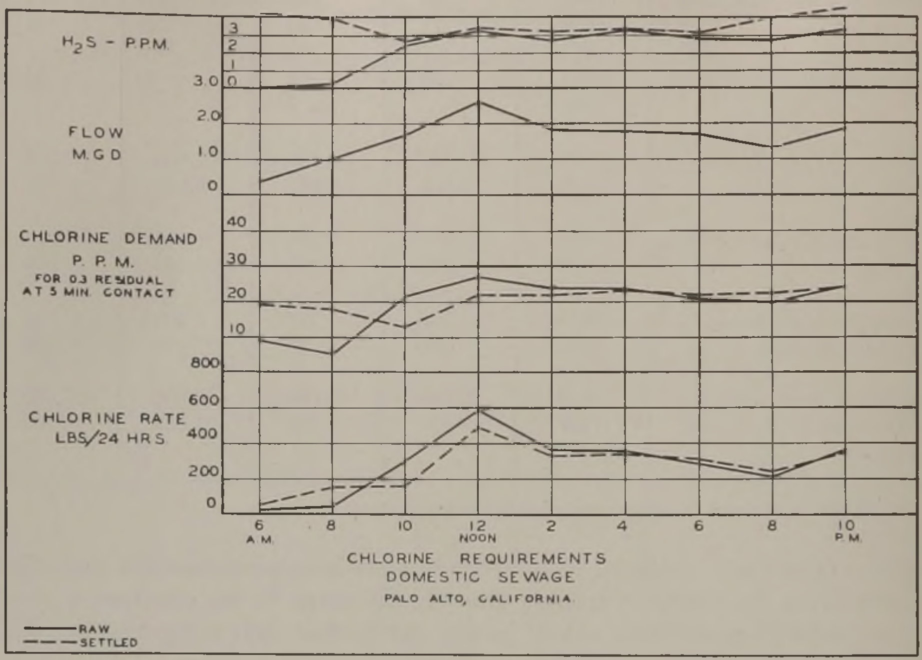

FIG. 4.

demand of domestic sewage between the hours of 6:00 A.M., and 10:00 P.M. A residual of 0.3 p.p.m. of chlorine after a five-minute contact period was arbitrarily used for comparison of chlorine demand. The curves show that when the sewage flow was at its peak, 12 o'clock noon, the strength of the sewage was also at a maximum. In order to show the total load received at the plant during each hourly period of the day, the rate of flow was combined with the corresponding chlorine demand and the results expressed in rate of chlorine application, lb. per 24 hr., that would be required to satisfy the total demand. These values are represented by the lower curve on Figure 4, and indicate that a maximum rate of 600 lb. per 24 hr. was required for domestic sewage.

Figure 5 shows a similar series of tests on domestic sewage containing peach canning wastes. A maximum rate of 900 lb. per 24 hr. was required under the existing conditions. During the 1940 season, however, the cannery packed peaches at the maximum capacity, which was three times greater than the quantity packed in 1938, when the tests were run. The chlorine demand for days of maximum pack will consequently be higher than shown by Fig. 5, and will extend over a longer period of time—about sixteen hours.

Similarly, Fig. 6 shows a series of tests on domestic sewage containing tomato wastes. The maximum rate of chlorine application required

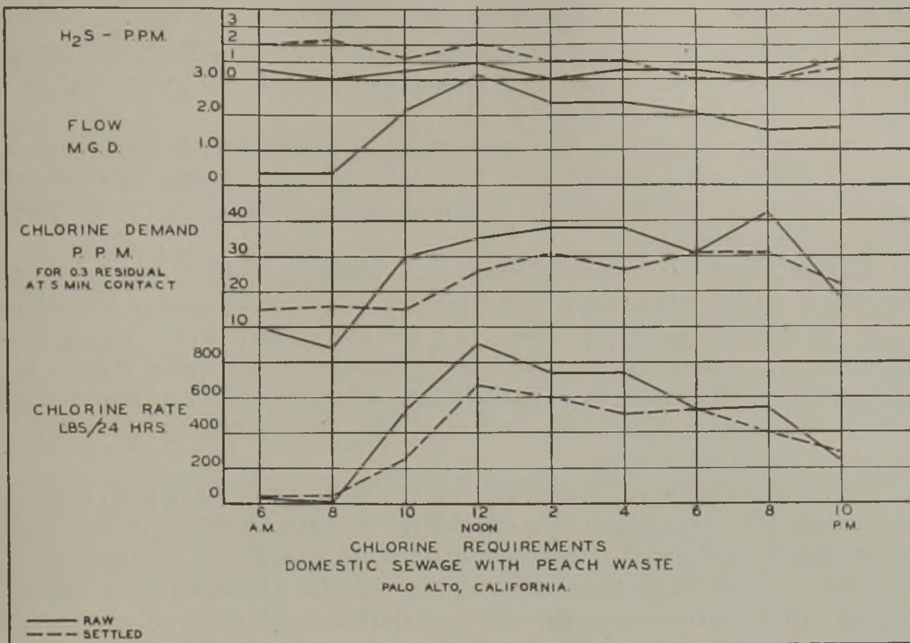
H2S – P.P.M.
3
2
1
0
3.0
2.0
1.0
0
FLOW
M.G.D.
CHLORINE DEMAND
P. P. M.
FOR 0.3 RESIDUAL
AT 5 MIN. CONTACT
40
30
20
10
800
600
400
200
0
CHLORINE RATE
LBS/24 HRS.
6
A.M.
8
10
12
NOON
2
4
6
8
10
P.M.
CHLORINE REQUIREMENTS
DOMESTIC SEWAGE WITH PEACH WASTE
PALO ALTO, CALIFORNIA.
RAW
SETTLED

Fig. 5.

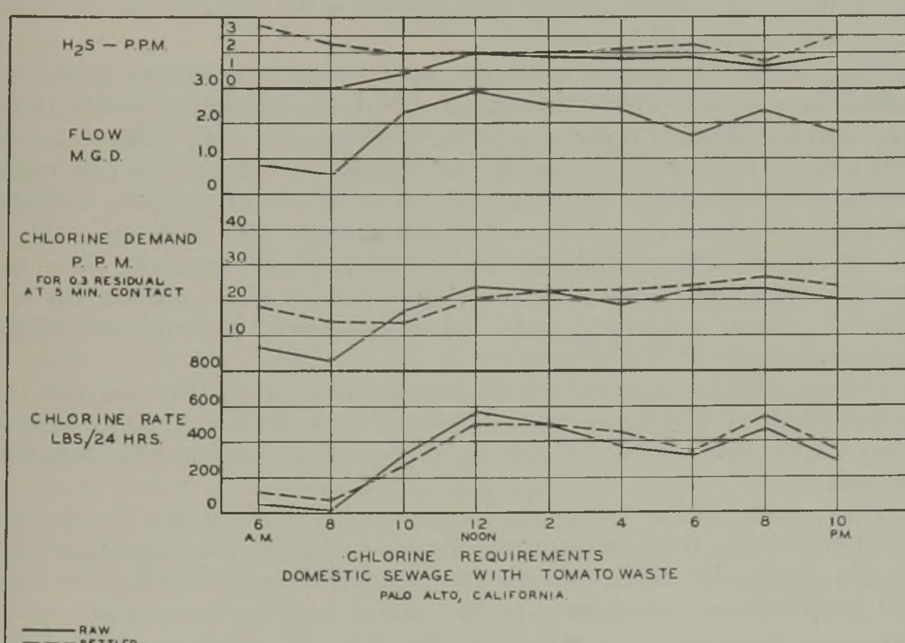
H2S – P.P.M.
3
2
1
0
3.0
2.0
1.0
0
FLOW
M.G.D.
CHLORINE DEMAND
P. P. M.
FOR 0.3 RESIDUAL
AT 5 MIN. CONTACT
40
30
20
10
800
600
400
200
0
CHLORINE RATE
LBS/24 HRS.
6
A.M.
8
10
12
NOON
2
4
6
8
10
P.M.
CHLORINE REQUIREMENTS
DOMESTIC SEWAGE WITH TOMATO WASTE
PALO ALTO, CALIFORNIA.
RAW
SETTLED

Fig. 6.

was about the same as for domestic sewage alone, 600 lb. per 24 hr., but continued over a longer period of time. These values, as for peaches, do not represent maximum conditions at the present time. During the 1940 season seven times as many tomatoes were packed in one day as on the days when these tests were run.

Pears are also packed by the cannery in considerable quantities, but only at times when peaches or tomatoes are also being worked, and consequently, isolated tests on domestic sewage containing pear wastes could not be obtained.

Figures 5 and 6 indicate that a considerable load is placed on the treatment plant when only one product is being packed. Depending upon the season, however, there is a period of two weeks or so when peaches, pears and tomatoes are being packed at the same time. It is during this period that the quantity and strength of the cannery waste is likely to be at a maximum, and plans for future treatment should be based on these conditions.

Strength and Quantity of Cannery Waste.—Tests have also been run on the straight cannery waste from time to time in order to determine its strength in terms of biochemical oxygen demand. Although the number of tests have been limited, the results obtained have made it possible to determine roughly the population equivalent of each waste. The quantity of fruit packed and the volume of water used for each day's run has been obtained from the superintendent's office for each year since 1936. With this information on hand, tests run at the treatment plant can be correlated with the quantity of cannery waste received for any particular day.

During the last several years the cannery has been improved and enlarged to a considerable extent. Table I shows the tremendous increase in the maximum daily capacity as compared with 1936, when the first studies were made on the cannery wastes. The amount of waste reaching the treatment plant on a maximum day is indicated by the total population equivalent. The waste from peaches and pears on a day of maximum pack is equivalent to the sewage of 93,000 people. The numbers of such days fortunately do not occur very often during any one season. The average day's pack is usually from 50 to 75 per cent of the maximum capacity of the cannery.

As the plant now serves a total population of 23,000 and was designed for only 27,000 people, one cannot expect a satisfactory effluent when wastes equivalent to 50,000 or so people are added to the domestic sewage.

Removal of Small Solids with a Finer Screen.—During the Sewage Plant Operators Regional Conference at Santa Clara on June 27, 1940, as arranged by Mr. G. E. Arnold, Chairman of the Committee on Schools and Certification, the subject of fine screens for cannery waste treatment was discussed along with other subjects. As a direct result of this discussion a recommendation was made to the cannery that they install a second screen which would remove as much of the solids as practicable, but small enough to catch tomato skins.

Up to this time all wastes were run through a ½ in. by 1 in. screen which removed the bulk of the material. Sliced peaches, apricot pits. pear cores, tomato skins, etc., however, would slip by and end up floating on top of the clarifier at the treatment plant. The fine screen which was installed by the cannery was quite successful in removing the small solids, except for the tomato skins. Many of the skins would not wash down into the discharge buckets, but would ride over and be washed off by the screened sewage. The fine screen does, however, remove approximately 1 cu. yd. for every 9 cu. yd. removed by the coarse screen. Although this screen has improved conditions at the plant in regard to solid material, it is only the first step toward adequate treatment.

Information on the Coarse Screen.—The coarse screen is 20 in. wide with ½ in. by 1 in. openings and has buckets spaced every 9 inches. The screen, which is of the continuous type, is driven by a 2 hp. motor at a linear speed of 0.68 ft. per second.

Information on the Fine Screen.—The fine screen is 10 in. wide, with openings approximately ⅛ in. wide, and has buckets spaced every 1 ft. 5 inches. This screen is supported by a coarse screen similar to the above, and is driven by a 1¼ hp. motor at a linear speed of 1.21 ft. per second.

Chemical Experiments on Sewage Containing Cannery Waste

In an effort to find a means of preventing sludge from rising in the clarifier, the effects of ferric chloride, lime and chlorine were investigated.

All samples treated were catch samples of raw sewage as received at the treatment plant, taken near mid-day, when the sewage was judged to be the strongest. In all the tests performed, sludge volumes were recorded when possible. These volumes ranged from 34 to 163 ml./liter for 2 hr. settling period.

The sludge in most of the samples used as controls came to the surface immediately. Forty minutes was the longest time the sludge remained down in an untreated sample. The cannery was packing chiefly tomatoes and pears during this series of tests.

Ferric Chloride.—Samples were dosed with ferric chloride from 20 to 300 p.p.m. equiv. Cl_2, mixed for 30 seconds and flocculated for 30 minutes. Control samples were set up at the same time, receiving the same mechanical treatment of mixing and flocculation.

Samples containing ferric chloride were but slightly better, in general, than the controls. Mixing and flocculation had the effect of releasing the gases in the sewage, allowing the sludge to settle. However, gases soon formed again bringing the sludge to the surface.

One sample with a dose of 50 p.p.m., stayed down 2 hr., with the control remaining down 50 minutes. Another sample with 70 p.p.m. remained down 2 hr. and 15 min. with 1 hr. and 28 min. for the control.

It seems, therefore, that to prevent the sludge from rising, the gases must be released from the sewage as it is received and the formation of

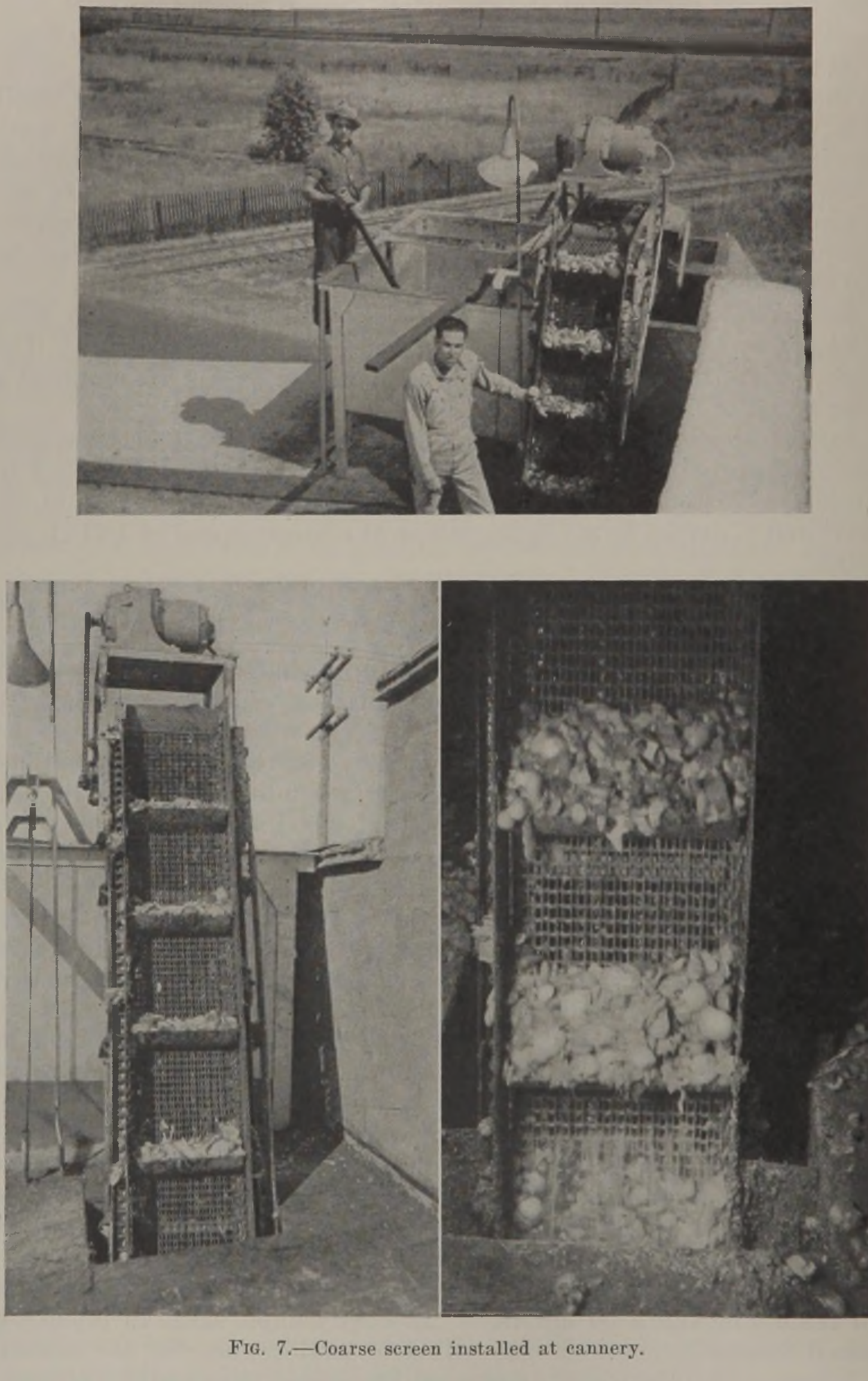

FIG. 7.—Coarse screen installed at cannery.

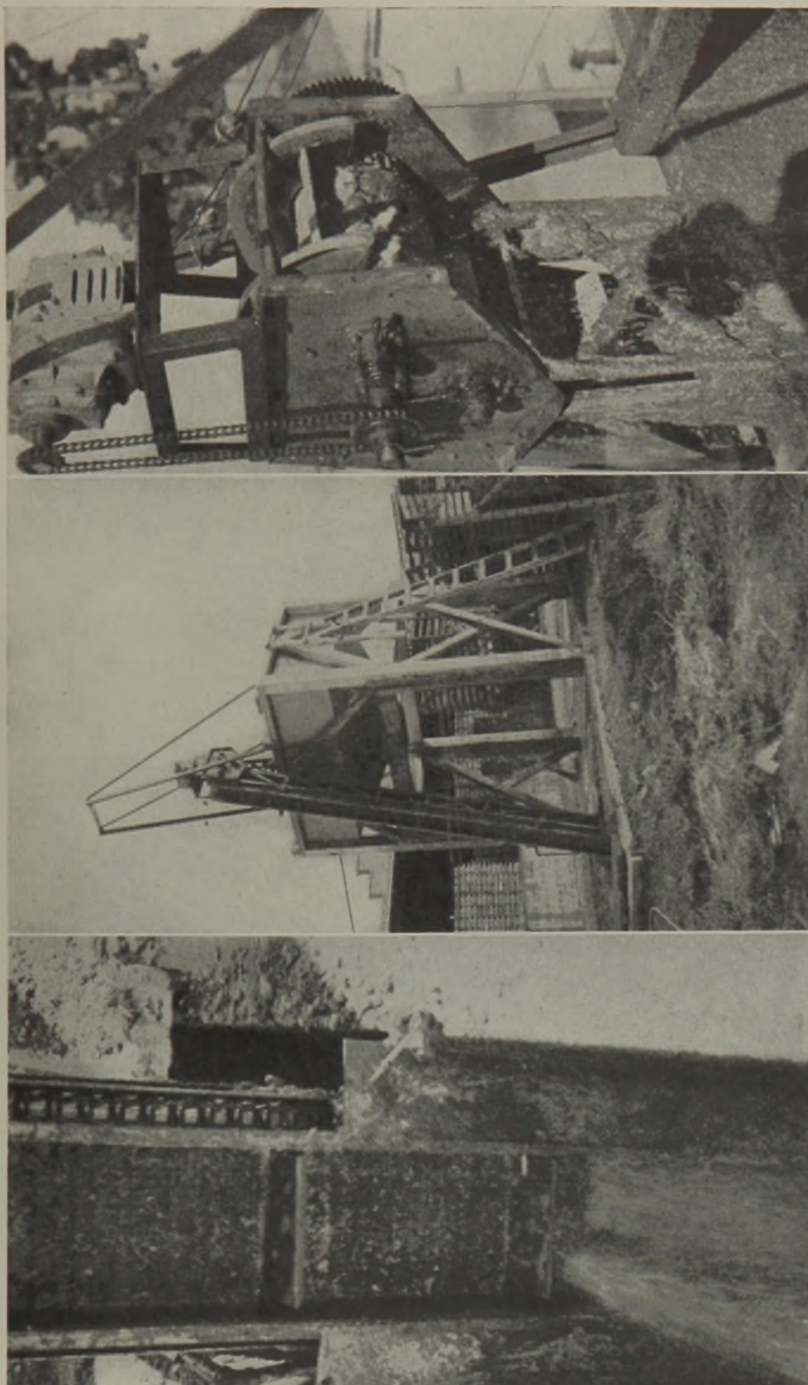

FIG. 8.—Fine screen installed at cannery.

these gases must be retarded until the sludge can be settled and removed from the clarifier.

Effect of Lime.—Samples were dosed with lime from 10 to 750 p.p.m., mixed for 30 seconds and flocculated for 30 minutes, together with controls.

FIG. 9.—Laboratory. Palo Alto sewage treatment plant.

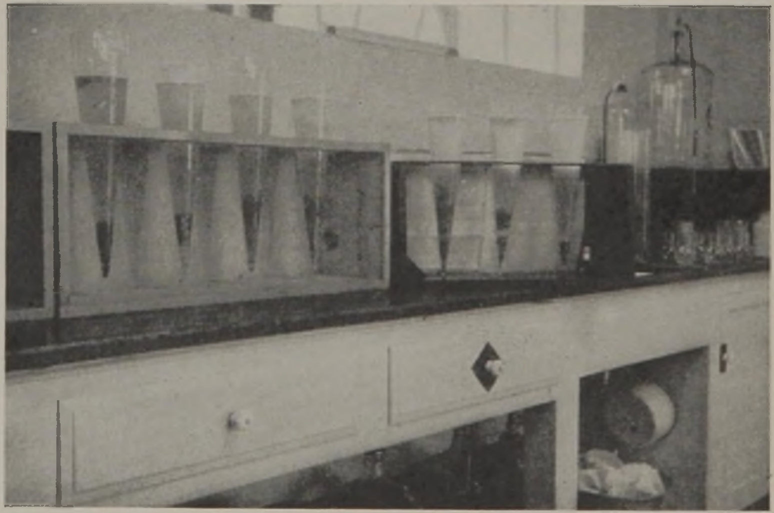

FIG. 10.—Imhoff cones. Showing volume of settleable solids in domestic sewage containing cannery wastes.

Lime was not effective until the dose was large enough to bring the pH of the sample above 7.0. The minimum dose to effect this in the samples treated was 250 p.p.m., the maximum 600 p.p.m. In all samples where the pH had been raised to 7.0, the sludge stayed down over 18 hours. The maximum time for the samples with a pH of 6.8 or below was 1 hr. and 25 minutes.

Lime plus mixing and flocculation would solve the problem, but the quantities of lime to effect this are considerable.

Effects of Chlorine.—The chlorine demand of the samples was first determined and they were then dosed with quantities above and below the demand. The demand ranged from a minimum of 20 p.p.m. to a maximum of 70 p.p.m. In each case the sample plus chlorine was mixed moderately for 5 minutes.

In the minimum and maximum cases, 15 p.p.m. and 60 p.p.m., the sludge remained down more than 4 hours. Doses below 15 p.p.m. were but little more effective than the controls.

Chlorine also would solve the problem, but again, the quantities needed are considerable.

It was thought that, perhaps, the amount of chlorine might be cut down, if either the cannery waste or the domestic sewage were chlorinated before being mixed. To this end catch samples of each were taken, combined and mixed in the laboratory as nearly as possible to simulate the conditions that exist while mixing and flowing through the sewer down to the plant. To produce the same results it took approximately one-half as much chlorine to chlorinate the domestic before mixing with the cannery waste, than chlorinating the cannery waste alone, and approximately one-fourth the amount needed if chlorination was performed at the plant. However, several other factors make the chlorination of the domestic sewage before mixing with the cannery waste impractical.

It seems, then, that chlorination of the cannery waste before entering the domestic sewers would, in our case, be the most logical point for chlorination. Chlorination at the cannery would make possible the purchase of chlorine in tank car lots, due to the spur track facilities. Accurate control of the rate of application would also be possible, since variation in strength and quantity of the cannery waste would be readily apparent.

Conclusions

Tests performed so far have not been extensive enough to arrive at any definite conclusions and more work must be done before actual recommendations can be made.

One definite part of the treatment that must be performed at the cannery, however, is the installation of a screen fine enough to prevent all tomato skins from entering the sewer.

It is felt that the studies so far have shown that some sort of treatment, such as chlorination of the cannery waste before it is discharged into the domestic sewer, is necessary before it will be possible to remove settleable solids, and that further treatment of some secondary nature is needed to produce an effluent which is comparable to that produced during the balance of the year.

TREATMENT AND CONTROL OF INDUSTRIAL WASTES *

By Milton P. Adams

Executive Secretary-Engineer, Michigan Stream Control Commission, Lansing, Michigan

The Great Lakes and their connecting waters form one of the longest and most peaceful frontiers in this troubled old world today. The International Treaty of 1907 between the United States and Canada sets forth the relations which should exist in order to maintain this longstanding friendship. The subsequent reports of the International Joint Commission disclosed the existence of certain pollution problems along this boundary which merited attention and correction. As the State of Michigan and the Province of Ontario occupy much of this common frontage, certain problems have fallen upon them to solve. These are not unlike certain interstate problems within the United States. They have brought together in conference, both officially and unofficially on past occasions, officials of this Province and the Dominion, with corresponding officials of my state and the United States Public Health Service. As Secretary-Engineer for the past ten years to Michigan's water pollution control agency, I may have some observations and experiences which will be considered pertinent.

The means of correction of pollution due to sewage are well understood and standardized today. One, or a combination, of several well-known methods will carry the treatment to various degrees of purification, depending upon local requirements. Industrial wastes, on the other hand, create a larger number of injuries to the public waters than does sewage. Less is known as to practical means of correction. Were we only concerned with the correction of the injury without the ever-present competitive and economic factors, our task would be relatively easy.

Michigan is but one of the several central states which have made marked progress during the past five years in sewage collection and treatment. During the period from 1935 to 1940, the urban population providing sewage collection and treatment facilities has increased from 19 to 83 per cent. Incidentally, the 100-odd sewage treatment plants that now operate in Michigan are solving a large number of industrial waste problems that would otherwise beset us.

The major and larger industrial problems, however, either because of their size or location, or for some other reason, are not susceptible of solution in municipal plants.

One of the important and necessary reasons for improved control of some industrial wastes is for protection of the municipal sewage plant function.

Such problems are most commonly encountered in the small, so-

* Presented before the Canadian Institute on Sewage and Sanitation, Toronto, Ontario, October 24, 1940.

called single-industry town. Local officials frequently unfamiliar with the limitations of their sewage treatment plants are inclined to offer free service along with free building sites and other inducements to attract industrial payrolls. Such liberality is occasionally attended by a serious pollution "hangover," municipal headaches aplenty, and subsequent outlays of additional public funds. Things have reached a crisis when fish die, complaints arise, and state officials find it necessary to point out that the local municipal plant, otherwise affording satisfactory control, has now been rendered inadequate by a new industrial loading. Here are a few examples:

A small town in western Michigan provided a septic tank and sand filter installation back in 1934. It had a good record of operation until this spring. The plant served not more than a total population of 1,300, plus the wastes of a small milk-receiving station. Last December the latter was taken over by a cottage cheese manufacturer. The town marshall offered the use of the city's sewage plant facilities, not only for the normal milk plant wastes but for whey, cheese washings, and other residue, as well. In June, we were visited suddenly with complaints of a serious local odor nuisance and fish distress, sickness of livestock and unsatisfactory appearance of the stream. This town is now confronted with the necessity of rebuilding completely its sand filter installations ruined in the experiment, and the whey has been diverted to a storage tank for return to farmers for stock feeding. This, of course, is how it should have been disposed of in the first place. Other residual milk wastes will be treated by the industry on a new biological filter prior to discharging the effluent to the municipal sewage treatment plant.

At another place with a similar problem, the municipal plant has been progressively less able through the years to handle its load satisfactorily. The city had made a new contract with the industry and proceeded to set up its plans and vote a local bond issue. This was in anticipation of modernizing the local waste disposal facilities. When the people had authorized the outlay, final approval of plans was sought of the Michigan Department of Health. Our sanitary engineer, sitting in on the conference, had to take issue with the adequacy of the proposed installation. As a result of subsequent tests, the original plans have been revamped. The company is to make its contribution in a somewhat larger amount than originally anticipated and, in addition, is to provide pre-treatment before passing its wastes and its responsibilities to the city.

We have also encountered situations where the wastes from certain industrial plants have exhibited definite toxic effects. In municipal sewerage systems, they have had the effect of destroying the bacterial life either in the digesters of sewage treatment plants, or ruining the activated sludge floc. This seems to be caused most frequently by discharges of copper or other metallic bearing salts. Occasionally they are present with cyanide wastes. When a digester stops working or when the purification end of the sewage treatment process ceases because of industrial contribution, we have joined with the Michigan Department of Health to require the industry to segregate and pre-treat its wastes. The discharge should not impair the municipal sewage treatment function. Local officials are reluctant generally to exercise their right of control over their sewer systems and plants. The effect of this situation is to impose a greater burden on the state administrative agency if proper pollution control is to result.

The sources of Michigan's principal industrial waste problems are found in the discharges from 13 beet sugar plants, 52 paper and 10 pulp mills, 81 canneries, 9 tanneries, 14 textile plants, 2,900 oil wells, 27 refineries, 34 breweries and distilleries, 55 gas plants, 24 gravel and crushed stone washing plants, 150 meat packing plants, 350 milk products plants, 23 salt and chemical plants, 25 metal working and plating plants, and 2 steel mills.

For the most part, the wastes discharged from these industries pass directly through company sewers or drains or ponds and occasionally waste treatment plants to the streams or waters of the state. Wastes from a few of the above industries find means of disposal in the sewage treatment plants previously mentioned.

Some of the injuries we have encountered due to industrial pollution are as follows:

Waste oil field, salt and chemical plant brines cause chemical pollution of streams, impairing their value for public or industrial or agricultural water supplies.

Oily wastes in small quantities are frequently aesthetically offensive. Where present in sufficient amount to cause "film," oil will retard reaeration of the stream, not to mention the destructive physical effect on fish and certain species of wildlife.

Phenolic and cresolic taint is frequently imparted to waters receiving the wastes from oil refineries, gas plants and certain organic chemical plants. Public water supplies and the edibility of game or commercial fish have suffered from this type of pollution.

The wastes from paper mills, tanneries, canneries, textile plants, beet sugar plants, meat packing and milk products have the common property of high oxygen demand with its resultant ill effect on fish life, water supplies and riparian land values. Settleable solids from these industries not only ruin fish feeding and spawning beds, but, seasonally, are the frequent cause of odor nuisance.

Acid, alkali and cyanide wastes from metal working and other industries cause unexpected and notorious fish killings, sometimes on a large scale. In a small south-central Michigan town, cyanide wastes caused two serious cattle killings before the problem was placed under what we hope will now prove to be adequate control.

The above generally outlines the scope of our Michigan problems. Our experience seems to indicate that satisfactory solutions come only when several contributory factors are present. Each has its important part to play.

First of all is The Law—not only that creating the administrative agency but the underlying common or court-made law of the jurisdiction.

Secondly, the Policy and Financial Support possessed by the agency or agencies charged with the administration of pollution control measures.

Third, Research and provision for the securing of additional information as required.

Fourth, stream or Water Standards and Pollution Restrictions.

Fifth, Co-operation by the offender.

When I came to Lansing some ten years ago, I recall the Commissioner of Health said to me:—"Now, Adams, you can handle the engineering side of this job OK, but the real problem is in the law. You give that special attention." With the Attorney General of the state a member of the Commission, I could see no problem on that score, but for good measure, I did join a night study class conducted by a local circuit judge and stuck to it for the better part of four years.

This and other studies bring me to the conclusion that there should be little necessity for a state agency to control pollution in Michigan—that is, if all the aggrieved individuals, township health boards, villages and cities of the several classes assumed the responsibilities under the law which are given them. It is because local government has failed or substantially failed to function in this particular that the state must assume the responsibility, for the present at least.

Now there seems to be an increasing sentiment across the border, particularly among certain sportsmen's groups, that even the states have "fallen down" on the job, and, therefore, the federal government should undertake it.

The Law

To prevent detrimental pollution occurring or continuing in the streams or waters of the state has been the work of the Michigan Stream Control Commission since 1929. This separate state agency was created by Act 245, Public Acts of 1929, of the Michigan Legislature. The Commission was established apparently for the purpose of strengthening the state's position in dealing with pollution matters. This was to be accomplished by co-ordinating and correlating the interest and activities of the health and conservation departments, together with those of any other interested state agencies. There had been times prior to 1929 when these two departments had been duplicating each other's work, or had been operating at cross purposes, although the common objective of better pollution control confronted both departments. This Stream Control Commission, then, is composed of the Commissioner of Health and Director of Conservation, and, in addition, the State Highway Commissioner, Commissioner of Agriculture, and the Attorney General. Broad powers have been conferred upon the Commission by the statute. Hand-in-hand with this power is conferred authority to exercise wide discretion both in setting up stream standards and pollution restrictions, as well as fixing the date or time in which such changes are to become effective.

Pollution injurious to public health or which tends to destroy fish life is declared unlawful, but perhaps the most unique section of the law is that paragraph which confers upon the Commission "authority to take any appropriate action to prevent any pollution deemed unreasonable by the Commission in view of the existing conditions in any lake, river, stream, or other waters of the state." The effect of this provision as interpreted by various attorneys general is to give the Commission nothing less than arbitrary authority to act to prevent even threatened pollution in otherwise clean waters of the state, and particularly those which now possess high natural quality and utility. On the other hand, in waters of the state which for many years have been heavily polluted with sewage or industrial wastes, apparently it has been the intent of the Legislature to direct the Commission to proceed with caution and care to the correction of problems of this nature.

It will be noted that the statute creating the Commission ties into a favorite common law phrase when it mentions "unreasonable pollution" and accords to the Commission certain authority toward its correction. By inference, this means there *is* such a thing as a *reasonable* pollution. And as we all know, courts of equity will not enjoin or halt *such* pollution. A reasonable pollution is always tied closely to constitutional rights of use and enjoyment of property. In my opinion, failure to understand this policy of the courts has led to much criticism of past pollution control efforts.

The rights of an industry to the use and enjoyment of its property include a qualified right to the use of the surface waters bordering or traversing the premises, let us say, for water supply and waste disposal purposes. This right must be enjoyed and exercised in common with other riparian owners similarly situated. It is when industry or a city *forgets* that as a riparian it enjoys a qualified rather than an exclusive right to the use of water that we find them vulnerable.

The Stream Control Commission statute has been in effect eleven years in Michigan without amendment. There are some changes that should be made. Few sessions of the Legislature have come and gone without efforts on the part of some to eliminate the Stream Control Commission and its jurisdiction. These efforts generally originate in sections of the state where it has been active.

The Commission is by no means the only pollution control agency. It depends upon the Michigan Department of Health for approval of plans and subsequent supervision of sewage plant operation for control of municipal pollution. The Petroleum Division of the Department of Conservation is charged with the responsibility of preventing oil field pollution. Another member, the State Highway Commissioner, attempts to prohibit the connection of sewage or septic tank effluent to state highway drains.

The state drainage code administered by some 68 different drain commissioners in as many counties of the state is as yet a sore spot in the prevention of pollution in suburban and rural areas.

Insofar as sanitarians in district and county health departments of the state can assume and discharge industrial pollution control supervision and allied obligations, their services are being increasingly utilized.

Finally, we depend upon some 110 municipal plant managements and a growing number of industrial managements throughout the state to assume the responsibility of knowing that problems within their immediate control are functioning properly.

Policy and Financial Support of Administrative Agency

Under a law as flexible as ours, policy from month to month and year to year determines to a large extent the progress that will be made. Financial support will determine the adequacy or inadequacy of staff investigative efforts and contact work.

We have found in Michigan that the large recent increase in number of municipal installations has not decreased, but, on the other hand, has increased Commission responsibilities. Where we used to say that we had a problem at Battle Creek, for instance, we now have four or five problems at Battle Creek with a fine municipal plant in operation. These "new" sources of pollution were always present, but were shielded by the presence of the major municipal problem. The minor problems must also be eliminated before pollution will really be under control at this place.

As the Commission is composed of five elective or appointive state officials, we have difficulty at times in obtaining a working quorum of voting members. Each member has his own departmental responsibilities. Gratuitous service on the Commission necessarily suffers when matters seem not to come at the right time. Even so, present conditions are a great improvement over ten or more years ago when, as Colonel Rich has said, "The only time progress was made on pollution control was during five or six months in the second year of a two-term governor."

The resistance on the part of industry to a reasonable pollution control program is much less in evidence today than at any time in the past. A stronger and stronger public sentiment has helped to break down the resistance. When the double objective of reduced pollution and salvaged materials or by-products go hand-in-hand, the least difficulty is encountered.

The staff provided for this work in Michigan is so small that we have really in effect only a trouble-shooting organization. We have been unable to devote sufficient time to the solution of any one problem. We know that provision of facilities *alone* does not assure freedom from industrial waste pollution. The matter of monthly reports such as are submitted by municipal water and sewage plants does not seem to be the answer. Frequent calls by qualified men, coming in usually without notice to check up on the current status of waste disposal, seems to be the only way by which some managements are kept on their toes. Whenever a management is sold on waste disposal or salvage reclamation as part and parcel of the industrial process, the most satisfactory record of control is maintained. Incidentally, this involves the least amount of state supervisory effort.

Research and Methods of Control

Little progress in industrial waste control would be under way today were it not for the past and present research findings of engineers, chemists and industrial associations. Much more remains to be done in this field, notwithstanding the accomplishments already made. In fact, this is the key, as we see it, to the actual accomplishment of the desired objective.

After ascertaining the amount, strength and character of a given industrial waste, the next thing we are interested in is what constituent or constituents may be salvaged or through processes of screening or settling made available for salvage. Anything that will pay its way or help to pay its way in this highly competitive era helps the cause of pollution control. We do not share the idea, however, that the limit of industrial waste control is marked by the extent to which material, salvageable by industry, can be developed. We go back to that "reasonable use" yardstick and make the best interpretation we can of its probable requirements.

The Engineering Experiment Station of Michigan State College at East Lansing has been an important research aid to the Commission and its work. The station is engaged at this time in conducting experimental work on the treatment of paper mill wastes in the Kalamazoo Valley. Following a hearing last December in Lansing, the Commission prevailed upon the paper mill managements to form a committee for the purpose of financing and conducting such a program. The problem differs from those of Wisconsin and other places—a high percentage of "de-inking" wastes are present coupled with a stream of relatively low flow and diluting value. Within a year or so, we expect both the Commission and the Kalamazoo mills will know the answer to their problem in terms of salvage, if any, as well as the degree of improvement that settling with and without coagulation will afford.

The qualified consulting engineer, chemist, technical research association and certain equipment companies have much to their credit in advancing the cause of industrial pollution control.

The development of the control of the beet sugar waste problem in Michigan may be worthy of special mention. Here is a short, seasonal, financially-distressed industry of 16 state units, nine of whose plants under four different managements were located in our Saginaw Valley in 1935 along with plenty of oil field brine, refinery, chemical plant and sewage pollution problems. Seasonal fish killings for years had been notorious, not to mention the seasonal tainting of the public water supplies at Dundee, Midland, Saginaw and Bay City. Plenty of predictions were heard that the sugar plants could do nothing, or if required to do so, would go out of business.

At the Commission's suggestion, a technical committee of the Farmers and Manufacturers' Beet Sugar Association was formed early in 1935 to find answers to their problems. The Engineering Experiment Station went to work on beet sugar wastes, while the Commission was settling orders upon oil field brine and chemical plant problems.

First through laboratory experiment, then a pilot plant at Bay City in the fall of 1935, followed by one unit of a plant-size scale operation in 1936 and 1937 were undertaken. The results of plain settling with and without coagulation were ascertained as well as the limitation of purification by aeration or by biological filtration. No salvageable by-product appeared to help meet the costs, with the possible exception of the settled waste water itself.

A meeting with the industrial managements was scheduled in September, 1937. Both the state and the industry knew what could be accomplished as the result of the work heretofore undertaken. The Commission placed a limitation on process wastes of all plants in the state amounting to 5 pounds of 5-day B.O.D. per ton of beets processed, effective as of September, 1939. This was to represent a 50 to 60 per cent improvement over waste strength as then discharged, or about 200 p.p.m. Steffens waste discharges were to be discontinued entirely beginning with 1940. The meeting ended with the distinct impression that the order would be contested in the courts. A subsequent concession was made to one plant for the use of Steffens waste as a coagulant, provided the final effluent waste should not exceed the 5 pound B.O.D. limitation.

I am glad to report, however, that following the February, 1939, meeting, the tide had definitely turned. All companies are now proceeding in various ways to meet the terms of the Commission's order. By establishing a uniform limit of B.O.D., even though in amount greater than could be satisfactorily assimilated in all streams, all plants were placed on the same basis at the beginning. All companies were given the opportunity of meeting that restriction in any way they chose. This open type of specification has developed some very unique remedies.

An outstanding accomplishment was made by one of the sugar companies located at Blissfield last fall. For the first time in 18 years, no fish were reported killed in the Raisin River below this plant. Instead of meeting a 5-pound limit of B.O.D., the company, through re-use of its settled waste water, dropped its waste load down to about two pounds.

Continuing changes are under way this year at other plants. As a result, we expect the 1940 campaign will show reduced B.O.D. loadings per mill over those reported in 1939. Another two or three years should place under control an industrial problem, which at the outset offered little or no prospect of solution.

Standards and Restrictions

One does not proceed far into the field of industrial waste control without having to answer the problem of "how much treatment" is required or "is such and such a plan going to satisfy the Commission." First of all, knowledge is required as to stream flow variation in the case of a river for the purpose of calculating the oxygen resources available as an aid to purification of a given trade waste. The sanitary survey to disclose neighboring or downstream water uses is also necessary to answer the questions of degree of improvement or treatment to be required of a given industrial problem.

We find a general reluctance throughout the states to officially adopt stream standards and pollution restrictions. The subject never fails to raise an argument. The question is always presented as to whether such restriction, if made, should be based on the necessary requirement to secure definite relief from given injuries or should it be based on what is presently known relative to accomplishing limited progress toward that objective.

Personally, I favor the former course, letting the time element in the order be subject to modification where necessary to meet current economic and technical unknowns. The stream or water standard, is, moreover, much easier to agree upon than the restriction on pollution of the individual offender. With only one source of pollution present, the restriction can automatically produce the desired standard. But with several or variable pollution sources present, the problem of apportioning equitable restrictions becomes an exceedingly complex problem, legally, mathematically, and biochemically.

About the only definite conclusion on standards coming out of the recent report of the Committee on Waterways Pollution of the Conference of State Sanitary Engineers held in Detroit some two weeks ago is that like-standards and restrictions are not applicable in all parts of the United States.

Yet, if one of the several forms of federal pollution legislation pending before the last three sessions of Congress is to become law, federal stream standards must be adopted. It is clear, therefore, that the problem of standards must be faced and solved, either by states, regions, or on a national basis.

The act creating our Michigan commission confers upon it the authority to adopt both stream standards and individual pollution restrictions. As we understand it, however, all such acts are subject to review in our state courts. If found unreasonable, or such as to deprive the polluter of his lawful and constitutional rights, it is clear that neither federal nor state standards and pollution restrictions would prove of value.

We have not had available the necessary funds nor man power in Michigan to enter upon sufficiently detailed field or laboratory work to warrant recommending adoption of state-wide or watershed stream standards and pollution restrictions.

Yet in preparation for the day that must eventually come, we have been summarizing our staff ideas and conclusions on the subject. They have been accumulating during some ten years' contact with our Michigan problems.

Certain minimum requirements should be observed for the handling of wastes from various types of industries. Additional treatment is necessary in specific instances contingent upon abnormally low stream flows, or greater than average development and subsequent use of the receiving waters. The objectives to be sought are freedom from appreciable bottom or sludge deposits, a pH value of the waste discharged ranging between 5.8 and 8.2 (acidity—alkalinity range), freedom from surface oil film, no tainting nor toxic substances, no material chemical changes, and at least four (4) p.p.m. of dissolved oxygen in the receiving waters.

In addition, waters from which public water supplies are developed should be as free as possible from sewage contamination and in no case exceed a coliform index of 4,500. The standard for recreational waters is much higher—not to exceed a coliform index of 1,000, plus satisfactory sanitary survey findings. Tentative standards of the United States Public Health Service suggest a coliform index of 50.

Quality in purely industrial waters need not be as high as average, being governed in most cases by the criteria of navigation and other industrial uses.

In making regulations and orders restricting the polluting content of industrial wastes, their volume and characteristics, the amount and conditions of stream flow available for dilution and subsequent water uses are pertinent factors to be recognized.

Tentative Waste Disposal Code

Our general summary of recommended waste disposal requirements is as follows:

1. Beet Sugar—"Straight house" waste shall not exceed five pounds of 5-day B.O.D. per ton of beets processed. No Steffens waste to be discharged. Re-use settled process water whenever possible. Continue research on by-products and further treatment to meet special cases.

2. Pulp and Paper—Limit fiber discharge to one per cent of production; waste water volume to 20,000 gallons per ton of product. Efficient settling of strawboard or other waste, high in suspended solids, is indicated as necessary. Chemical coagulation as an aid to settling may be necessary seasonally. Sulfite and sulfate liquors pose special problems.

3. Cannery—Mechanical fine screening followed by efficient settling for removal of suspended solids where necessary. Sedimentation may be aided by chemicals. Further treatment, if required, through biological processes. Seasonal impounding of high B.O.D. waste is required in extreme cases.

4. Tannery—Fine-screening for removal of fleshings and hair. Ef-

ficient settling for removal of suspended solids. Color removal involves excessive expense. Further research is required to meet special problems.

5. Milk Products—Reduce milk losses within the plant to a minimum. Biological filtration of the wastes is necessary in cases of limited stream dilution. Whey, buttermilk, skimmed milk or spoiled milk are never to be disposed of to streams or lakes. Return to farmers or dispose of it on suitably located land.

6. Oil Field and Chemical Brines—Hold discharge of waste brine to a minimum at all times in waters connecting with those from which public or industrial water supplies are developed. Water supply sources containing brine pollution in excess of an indicated 100 p.p.m. of chloride content impairs and corrodes boilers, causes "red water" in hot water plumbing and excessive softening costs. Brine polluted water containing 400 p.p.m. chloride is the limit beyond which injury is caused to brook, rainbow and brown trout and their propagation. Waters subject to brine pollution must contain at no time in excess of 4,000 p.p.m. to prevent injury to live stock, agricultural lands subject to flooding, and to bass, pike and perch water. Careful "drilling in" of wells and observance of approved regulations of the Supervisor of Wells to prevent the creation of unnecessary waste brine is of first importance. Produced brine, not constructively used for dust laying, etc., is filtered and returned to underground formations under Supervisor of Wells jurisdiction. Ponding has been generally discredited and evaporation is impracticable in our climate.

7. Phenols—The discharge of wastes bearing phenol or cresolic compounds originating either in chemical or creosoting plants or oil refineries, or other sources shall be held to an irreducible minimum at all times. The taste threshold for phenol is one part in 200 million parts of water (in public water supplies utilizing chlorination). The remedy is in segregation and impounding, recovery of necessary waste where possible, filtration of effluents under controlled temperature conditions and ponding before discharge.

8. Metal Treating and Plating—Neutralize acid and caustic wastes prior to discharge. Remove cyanide completely from plating room wastes before discharge. Bury accumulated cyanide sludges—never discharge with waste water. Careful disposal necessary to prevent subsequent human contacts or availability to livestock.

9. Textiles—Neutralization, removal of color and up to 75 per cent of the oxygen demand of such wastes by settling, aided by chemicals. Further research is in order.

10. Oil—No waste oil to be discharged or permitted to flow from oil pipeline, oil field or refinery operations. Constant patrol and maintenance of pipeline and oil fields is required to prevent waste. Refineries provide adequate and approved separators within diked sites. Routine daily attention to separator and disposal of scum and accumulated sludges. Where oil is still present in separator effluent, supplement the treatment by providing removable and renewable straw or hay filters.

Up to two or three sets of filters in a single drainage line may be necessary. Prevent the discharge of phenol-cresol wastes from the refinery by substituting solid, adsorptive filter media for "water-washing" of gasoline. Segregate and eliminate from waste lines the concentrated "doctor" and caustic solutions or process wastes. Continuing research is indicated as necessary.

Cooperation

Much may be said as to the part which cooperation plays between state and industry in the matter of accomplishing the best results. Few terms are as misused or misconstrued as this one. Many are the sins of commission and omission that have been done under the name of "cooperation." My definition, however, is compliance or good faith attempt at compliance without resort to court action.

This cooperation generally starts after the existence of a problem and the need of its correction have been officially declared. On the part of the industry not only variable cash outlays and technical studies and changes are required, but a willingness to surrender certain rights of water use previously enjoyed. When cooperation fails in part and it becomes necessary to obtain the latter by court action, decisions that have come to my attention have seemed to conditionally countenance certain industrial pollutions, whereas corresponding municipal injuries have been restrained.

The lower Raisin River as it joins Lake Erie presents such a case. Heavy paper mill discharges combined with those of the City of Monroe to produce seasonally acute oxygen depletion and solids deposits in a short navigable waterway. The development of a recently acquired state park adjacent to the river mouth in Lake Erie has been arrested until conditions are improved. The city and one of the smaller mills are now providing adequate sewage and waste disposal. Two large mills are still experimenting.

The litigation referred to occurred some 15 years ago. It is commonly spoken of as the Carp Pond Case found in Vol. 240, Michigan Reports, page 279. Suit was brought by the owner of a carp pond connecting with the lower river. His fish finally got thin and died and his business disappeared as a result of pollution of the Raisin River at this point. The state, unfortunately, did not intervene and did not become a party to the suit. Some troublesome law has been made as a result of this court decision. The effect of the decision was to place a premium upon ignorance on the part of industry in the handling of its waste disposal problem. The industries successfully defended some long and expensive litigation, although paying in the end sufficient damages to permit the carp pond owner to move his business elsewhere.

The decision both of the lower court and of the Supreme Court in this matter was predicated upon the showing made by the mill managements that there was no way in which they could operate without causing the pollution. It has taken years to convince these paper mill managements that this problem was susceptible of improvement. The problem at this place is by no means settled although some real progress has been made. The water quality requirements today are necessarily higher than they were 13 years ago. It will be some years yet before the effect of many years of discharge of paper mill pulp and refuse will disappear from the shores of Lake Erie at this place. But it has been necessary to overcome the effect of this former court decision by actual demonstration treatment before anything could be accomplished.

Cooperation is solicited wherever possible on a group basis. Some seven committees have been active at various times during the past 15 years in Michigan. They have aided and sponsored research for the development of ways and means of correcting certain waste problems and, in some cases, by aiding individual industries to police their own doorsteps. These committees are:

1. Brine Disposal Committee of the Oil and Gas Association.
2. Technical Committee of the Farmers and Manufacturers Beet Sugar Association.
3. Stream Pollution Committee of Allied Dairy Association.
4. Michigan Paper Mill Waste Committee.
5. Technical Committee of the Tanning Industry.
6. Michigan Canners' Committee on Waste Disposal.
7. Michigan Gas Association.

Some of these efforts have been very effective and others have not. I have been told that the original paper mill committee was formed to battle the state when this matter came to a crisis in 1923.

We find it necessary to understand something of the industrial processes, requirements and viewpoint toward these problems as well as our own. When we have failed to obtain cooperation by prevailing on a given industry to try remedies which have resulted in improvement elsewhere, we generally have brought these matters to the attention of the Commission. Specific notices of failure to control pollution or clean-up orders are then made. The working relationship which exists between the staff and the Commission itself is one of bringing to it only those problems which do not seem to solve themselves after a reasonable trial period. It has further been necessary to plan the Commission's work as stated previously by taking the worst problems first rather than by cleaning up entire watersheds. The law under which we operate virtually makes such action necessary. We have found in following this procedure that many of the lesser problems automatically solve themselves without much effort, perhaps from the example set by the larger installations.

It is within this field of cooperation that the state representative meets his greatest challenge. To get something done for a worthwhile cause by prevailing upon managements to do the right thing in the public interest is salesmanship at its best.

Cooperation by industry under such pressure as is necessary creates certain problems at times that require not only technical fitness but high devotion to duty on the part of the governmental employee.

One of the most satisfactory compensations that I know of, however, is when "industry finally comes through" and does a real job of cleaning up. It will take as much or more pride than you do in the accomplishment, particularly if the management feels the accomplishment was made "on their own" and without being pressed too much to do it. In this respect, industrial reaction differs from that in the municipal field. The city officials generally find it necessary to lean on state pressure to justify tapping the public treasury for such improvements as the city must make. The "skin" of industry, on the other hand, is much more sensitive to adverse public criticism than is the municipal epidermis.

Summary

Industrial waste treatment and control is susceptible of accomplishment although progress generally trails that being made in the municipal field. It is necessary for restoration and maintenance of the value of a state's water resources in order that they may best serve the public interest in the many ways which only these waters can and must serve. Treatment and control of industrial waste is also frequently necessary as an adjunct to successful municipal sewage plant operation.

Various factors, when present in their proper relation and effectiveness, contribute to the successful control of industrial wastes. There is—

First: The law of the jurisdiction, including that creating the administrative control agency.
Second: State policy and financial support of the activity.
Third: Research and methods of control.
Fourth: Stream standards and pollution restrictions, and
Last: Cooperation by industry.

None of us can accurately foresee, perhaps, the effect of the many war industries and activities on such control programs. Obviously, the national defense must come first, and time is of the essence. Most of the accomplishments now made were unknown during the last emergency.

Within the past month in Michigan, both military and industrial inquiries have been received to ascertain the extent of sewage or waste disposal requirements with respect to specific or anticipated developments. We have indicated our desire to aid in every possible way, and our suggestions have been cheerfully received. We regard this as significant. It indicates that all the bars against pollution should not have to be taken down during this period. We entertain the belief that new camp developments and industries are dependent upon the water resources protection that only the Michigan Department of Health and the Stream Control Commission can give. If such be the case, the emergency users of our water resources, should be able to comply with reasonable state requirements for the protection of others.

Stream Pollution

THE NATURAL PURIFICATION OF RIVER MUDS AND POLLUTIONAL SEDIMENTS *

BY GORDON M. FAIR, EDWARD W. MOORE, AND HAROLD A. THOMAS, JR.

Harvard Graduate School of Engineering, Cambridge, Mass.

IV. EFFECT OF SLUDGE TEMPERATURE UPON RATE OF DECOMPOSITION

Temperature changes, running their seasonal course in lakes, streams, and other bodies of water, exert profound effects upon the rate of decomposition of river muds and pollutional sediments. Chemical and biological activities, rates of diffusion, viscosity and density of interior fluids, and the solubility of gases are all functions of temperature. As the deposits warm up in the spring, chemical and biological activities are stimulated, diffusion is increased, and viscosity, density and the solubility of gases are reduced. Most of these changes combine to promote decomposition but, at the same time, to endanger its orderly progress by exhaustion of dissolved oxygen, the liberation of gas bubbles, and the gas-lifting and flotation of bottom deposits. Falling temperatures exert the opposite effects, but ice cover may bring about objectionable conditions in the water overlying sludge deposits by preventing atmospheric reaeration.

The temperature of bottom sediments is not the same as that of the supernatant water. As shown by Birge and Juday (13),† the mud temperature is less than that of the water in summer and more in winter. The deeper the mud, the greater is this difference. As a result, there is a tendency for decomposition to be decreased in summer and increased in winter relative to the water temperature.

Experimental Procedures.—A river mud rather than a sewage sludge was used in the authors' studies of the effect of temperature upon rate of decomposition. The character of the deposit employed has been described in Section I of this series of papers (Table I) and is further elaborated in Tables XI, XIII and XIV of Section V. It may be concluded from these physical properties and chemical analyses that, at the time of its collection in the late fall of the year, the sediment had probably entered the third period of benthal decomposition, *i.e.,* quiescent stabilization, and that the anaerobic component of decomposition had been nearly completed. Diminished anaerobic activity is

* This is the second group in a series of papers on this subject. The first group appeared in the March, 1941, issue of *This Journal*, pp. 270 to 307, and contained the following discussions: I. Benthal Decomposition—General Concepts; II. Rates of Benthal Decomposition; and III. Effect of Sludge Depth upon Rate of Decomposition.

† References 1 to 12 are appended to Sections I to III of this series of papers.

characteristic of deposits in this stage of decomposition, but does not imply that their oxygen demand has been fully satisfied.

The apparatus employed in the benthal studies was similar to that described in Section I, Fig. 2, except that the three samples of river mud were placed in 4-liter bottles and immersed in constant-temperature baths. Each bottle contained in excess of 2 kg. of mud which filled the bottles to a depth of 10 cm. and presented a surface of 198 sq. cm. to the flowing water. The baths were maintained at 10, 17.5 and 25° C., respectively, *i.e.,* within the upper range of river temperatures for which decomposition is measurably large. As in the "depth studies" of Section III, the progress of benthal decomposition was compared with that obtaining (1) under essentially aerobic and (2) essentially anaerobic conditions. For aerobic decomposition a single temperature of 23° C. was employed, for anaerobic decomposition the same three temperatures (10, 17.5 and 25° C.) as for benthal decomposition.

As in "the depth studies," too, the changes taking place in the muds were evaluated in the following ways:

1. Measurement of (*a*) the oxygen absorbed from the supernatant water; (*b*) the aerobic oxygen demand, or long-time B.O.D. of the sludge; and (*c*) the volume and composition of the gas liberated during anaerobic digestion of the sludge.
2. Measurement of (*a*) the loss of nitrogen from the deposit; (*b*) the changes in its iron content; and (*c*) the reduction in its fuel value.

Only the first group of observations will be discussed in the present section of this paper.

Experimental Results.—The changes observed during 145 days of benthal decomposition at 10, 17.5 and 25° C., 10 days of aerobic decomposition at 23° C., and 201 days of anaerobic decomposition at 17.5 and 25° C. are shown in Figs. 12 to 14.* At 10° C., no measurable amount of gas was evolved during anaerobic digestion.

These results confirm the conclusions drawn previously from an examination of the physical properties and chemical analyses of the river mud: that the deposit employed had been laid down over a considerable period of time and had reached a relatively advanced stage of stabilization before it was brought into the laboratory for investigation. The observed progress of benthal and anaerobic decomposition (Figs. 12 and 14) is seen to have been slow and so little affected by further changes in rate of decomposition and amount of decomposable material remaining as to yield almost straight-line variations, or substantially constant rates, even during long-time exposures in the laboratory. Nevertheless, the results obtained are believed to be amenable to partial numerical generalization by departing from the conventional formulation of the effect of temperature upon the amount of material that is decomposable. The enforced departure, incidentally, is believed to be backed by theoretical considerations. Aerobic decomposition at the single temperature of 23° C. (Fig. 13) is seen to have been of normal

* Figures 1 to 11 are found in Sections I to III of this series of papers.

rapidity ($k_u = 0.23$) after a lag period of about 2 days. This period of adjustment is somewhat obscured in its effects upon the course of the B.O.D. by the exertion of the immediate oxygen demand of the mud.

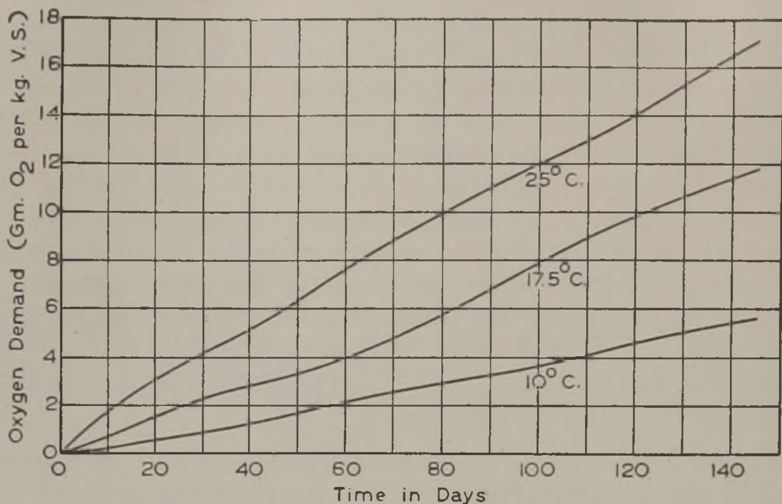

FIG. 12.—Observed course of benthal oxygen demand of river mud at 10, 17.5 and 25° C. The change in demand with time is so small that, for purposes of comparison, the rate may be assumed to be uniform over the period of observation.

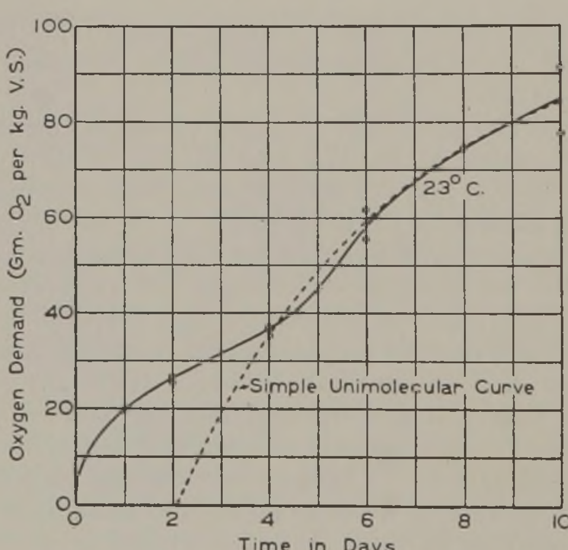

FIG. 13.—Observed biochemical oxygen demand of river mud at 23° C. High initial demand and lag combine to obscure the normal course of B.O.D. The constants of the fitted unimolecular curve are: $k_u = 0.236$ close to the normal value for polluted water (2.303×0.1) and $L_u = 99.2$. The calculated lag is 2.1 days.

The measured first-hour demand was 16.5 grams per kg. of volatile solids initially present, but this may not be a true determination of the immediate demand (5). The ultimate first-stage demand was close to 100 grams per kg. of volatile matter.

Mathematical Formulations of the Effect of Temperature on Decomposition.—In Section II of this series of papers, the progress of decomposition was formulated in terms of the following concepts:

y = the amount of material decomposed or the oxygen demand exerted in time t (y_u in the simple unimolecular formulation);
L = the ultimate amount of decomposable material or ultimate oxygen demand (L_u in the simple unimolecular formulation);
k = the reaction velocity constant, reflecting the initial availability of the substrate and depending upon the type of organic matter present and the condition of the physical environment (k_u in the simple unimolecular formulation);
and a = the coefficient of retardation, depending upon the type of organic matter present and the condition of the environment ($a = 0$ in the simple unimolecular formulation).

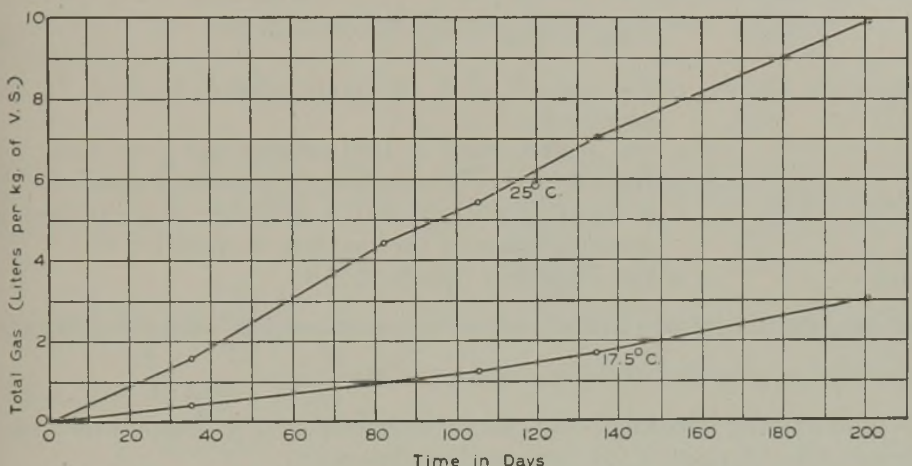

FIG. 14.—Observed course of gas production of river mud during anaerobic digestion at 17.5 and 25° C. At 10° C., release of gas was too small to be recorded. Changes in gasification are so small that, for purposes of comparison, the rate may be taken as uniform over the period of observation.

The variables y and t are here linked by the coefficients L, k, and a, which singly or in combination would normally be expected to vary in magnitude with temperature. How such variation may be formulated has been shown, by Streeter and Phelps (14), in connection with the simple unimolecular formulation of biochemical oxygen demand. For gas production by sewage sludge, it has been done, in similar fashion, by Fair and Moore (15).

Because of the character of the deposit employed in the "temperature studies," the mathematical evaluation of the parameters L, k, and a was not considered sufficiently reliable to permit the calculation of separate temperature characteristics for these parameters. It became necessary, therefore, to "cut the suit to fit the cloth" by lumping the temperature effects and developing an overall temperature characteristic in place of individualized characteristics for rate and ultimate magnitude of decomposition.

Streeter and Phelps, proceeding from the simple unimolecular equation (2a), relating y and t by means of the parameters k and L, found that the variation of k with temperature could be represented conveniently by the van't Hoff-Arrhenius equation, while that of L was satisfied approximately by the simple linear relationship:

$$L_{T_2} = L_{T_1}[1 + C_L(T_2 - T_1)] \tag{3}$$

where L_{T_2} and L_{T_1} = the values of L at temperatures T_2 and T_1, respectively;

and C_L = the temperature coefficient for L, the temperature generally being expressed in degrees centigrade.

The van't Hoff-Arrhenius equation itself reads as follows:

$$k_{T_2} = k_{T_1}e^{\frac{E}{R}\frac{T_2-T_1}{(T_1+273.1)(T_2+273.1)}} \tag{4}$$

where k_{T_2} and k_{T_1} = the values of k at temperatures T_2 and T_1, respectively;

R = the gas constant = 1.99 calories per gram mol;

E = the energy of activation, a constant equal to the amount of energy that a molecule must possess in order to undergo the reaction in question;

and e = the Naperian base = 2.718.

Within the limits of natural water temperatures, as shown by Streeter and Phelps, a portion of the exponent, namely $\frac{E}{R}\frac{1}{(T_1 + 273.1)(T_2 + 273.1)}$, is substantially constant and can be replaced by the temperature coefficient, C_k. Equation (4) then reads as follows:

$$k_{T_2} = k_{T_1}e^{C_k(T_2-T_1)} \tag{4a}$$

Expansion places this equation in the following form:

$$k_{T_2} = k_{T_1}[1 + C_k(T_2 - T_1) + \tfrac{1}{2}C_k^2(T_2 - T_1)^2 + \tfrac{1}{6}C_k^3(T_2 - T_1)^3 + \cdots] \tag{4b}$$

and establishes a close analogy to equation (3) which is seen to possess but the first two terms of a similar expansion of:

$$L_{T_2} = L_{T_1}e^{C_L(T_2-T_1)}. \tag{3a}$$

Substitution of the exponential equation (3a) for the linear equation (3) is mathematically warranted in view of the fact that C_L is small. Moreover, there appears to be some theoretical justification for the exponential formulation based upon the fact that L is proportional to the final concentration of the end products of the biochemical processes of decomposition. As shown by van't Hoff (16), the concentration of these products depends upon temperature according to an exponential relationship of a form identical with that of equation (4). While van't Hoff's equation is derived theoretically only for reversible reactions, it may be reasonably assumed that a similar formulation applies to certain irreversible reactions, such as the biochemical oxidations occurring during the stabilization of pollutional sediments. In any event, insufficient information is available at present to decide, with any degree of finality, whether equation (3) or equation (3a) is most nearly in accordance with fact. It will be shown, however, that adoption of the exponential expression facilitates the overall formulation of the influence of temperature upon the rate of decomposition.

Having decided upon the form in which temperature effects are to be evaluated, we must next find a way by which these evaluations may be adapted to the exigencies of the material used in the temperature studies and the experimental findings which, as stated before, do not permit satisfactory separation of the effects of temperature upon rate and ultimate extent of decomposition. In Section III of this series of papers, it was shown that the rate of benthal decomposition may be expressed as follows:

$$y' = \frac{dy}{dt} = \frac{kL}{(1 + at)^{k/a+1}} \qquad \text{(1d)*}$$

where $y' = dy/dt$ is the rate of decomposition or the rate of oxygen demand exerted at time t. For our purposes, equation (1d) may be transformed to read:

$$y' = k' L' \qquad (5)$$

where $L' = \frac{L}{(1 + at)^{k/a}}$ = the amount of decomposable material in the deposit at the time of sampling;

and $k' = \frac{k}{(1 + at)}$ = the reaction velocity at the time of collecting the river deposit in the field and bringing it into the laboratory for study.

Use of the product $k'L'$ makes it unnecessary to evaluate L, k and a and to know, or determine, t. If one sample of river mud is permitted to decompose at a temperature T_1 and another sample of the same mud at a temperature T_2, the observed rates of decomposition are $y_{T_1}' = k_{T_1}'L_{T_1}'$ and $y_{T_2}' = k_{T_2}'L_{T_2}'$. If we assume that k' and L' are affected by temperature in a manner similar to k and L in the simple unimolecular formulation of reaction velocities, it follows from equations (3a), (4a), and (5) that:

$$y_{T_2}' = y_{T_1}'e^{(C_{k'}+C_{L'})(T_2-T_1)}$$

and if we let $C_{k'} + C_{L'} = C$

$$y_{T_2}' = y_{T_1}'e^{C(T_2-T_1)}. \qquad \text{(5a)}$$

Here, we may call C the overall temperature characteristic and solve for

* Equations 1 a, b, c, d and 2 a, b, c, d are found in Sections II and III of this series of papers.

it by writing:

$$C = \frac{1}{T_2 - T_1} \log_e \frac{y_{T_2}'}{y_{T_1}'} \tag{5b}$$

The value of C may be determined most readily from the slope of a straightline plot based upon equation (5a) in logarithmic form:

$$\log \frac{y_{T_2}'}{y_{T_1}'} = 0.4343\, C\,(T_2 - T_1); \tag{5c}$$

but a precise evaluation of C requires a least squares analysis based upon equation (5a) itself.

Expressed in general terms, equation (5a) states that the percentage increase in the rate of decomposition per unit increase in temperature is approximately equal to $100\,C$.* A value of $C = 0.06$, for example, signifies that the rate of decomposition increases by about 6 per cent for each degree of rise in temperature. The overall temperature characteristic, therefore, is analogous to a rate of compound interest.

Calculated Temperature Characteristics.—The overall temperature characteristics calculated by means of equation (5b) from the results presented in Figs. 12 and 24 are shown in Table X * together with other values of C computed from published data for those biochemical processes that play a controlling part in the natural purification of pollutional sediments.

The values of C appear to fall naturally into two classes that correspond to the type of decomposition to which the material is subjected. For aerobic decomposition, as measured by B.O.D., C seems to lie in the neighborhood of 0.070. For total gas production in anaerobic decomposition, the average value of C is 0.095. The two results calculated for benthal oxygen demand align themselves with the average for aerobic decomposition (but see below), while anaerobic decomposition of lake and river muds seems to be affected by temperature to much the same degree as anaerobic decomposition of sewage solids. It may be noted, in passing, that the values of C for aerobic processes would about double the rate of decomposition for a rise in temperature of 10° C. For anaerobic processes, C is of such magnitude as to increase the rate about 2.5 times. The figure 0.073 obtained by Allgeier and his coworkers for the anaerobic decomposition of mud from Lake Mendota is low. It is based, however, on the production of methane rather than total gas. The reduced solubility of carbon dioxide at higher temperatures may account for this observation. It should be emphasized that values of C recorded in Table X are averages over the range of tem-

* For $(T_2 - T_1) = 1$, equation (5a) states that $y_{T_2}' - y_{T_1}' = y_{T_1}'(e^C - 1)$ and, by expansion:

$$\frac{y_{T_2}' - y_{T_1}'}{y_{T_1}'} = (1 + C + \tfrac{1}{2}C^2 + \tfrac{1}{6}C^3 \cdots) - 1,$$

or, since C is small:

$$100\,\frac{y_{T_2}' - y_{T_1}'}{y_{T_1}'} = 100\,C.$$

* Tables I to IX appear in Sections I to III of this series of papers.

TABLE X.—*Overall Temperature Characteristics of Aerobic, Anaerobic and Benthal Decomposition*

Type of Decomposition	Material	Reference	Temperatures—° Centigrade	Characteristic		Remarks
				C	e^C	
(1)	(2)	(3)	(4)	(5)	(6)‡	(7)
Aerobic	Domestic sewage and polluted river water	14	8, 10, 20, 30, 37.5	0.068	1.070	Computed from $e^{C_k} = 1.047$ and $C_L = 0.02$.
		10	9, 20, 30	0.072	1.075	Based on observed initial slopes of curves.
	Domestic sewage	*	5, 7.5, 10, 20	0.083	1.087	Based on "least square" determinations of C_k and C_L.
		*	5, 7.5, 10, 20	0.071	1.074	
		*	0.5, 1, 2.5, 5	0.139	1.149	
	River water	*	0.5, 2.5, 5, 7.5, 10, 20	0.054	1.055	
Anaerobic	Lake mud	4	23, 37, 55	0.073	1.076	Based on methane production.
	Lake mud	17	4, 21	0.092	1.097	Based on total gas production.
	River mud	—	17.5, 25	0.102	1.107	This study.
	Seeded sewage solids	†	15 to 30	0.102	1.107	Computed from $e^{C_k} = 1.073$ and $C_L = 0.027$.
	Unseeded sewage solids	18	10, 18, 24, 29.5	0.091	1.095	Computed from curves.
Benthal	Unseeded sewage solids	1	22.3, 28.7	0.075	1.078	Computed from rate of oxygen demand in 35.5 days.
	River mud	—	10, 17.5, 25	0.065	1.067	This study.

* E. W. Moore. *This Journal*, **13**, 561 (1941).

† From a statistical study of a wide range of data.

‡ This column expresses the temperature characteristic in the manner proposed by Streeter and Phelps (14).

peratures indicated. It is not to be inferred that the temperature characteristic is a constant over the entire range of natural water temperatures. As shown in Table X, appreciable changes may occur, particularly in the lower range of temperatures.

That the magnitudes of the temperature characteristics for benthal oxygen demand and anaerobic gasification are significantly different is in agreement with the authors' theory of the mechanism of benthal decomposition, according to which the two modes of stabilization are carried forward independently. Anaerobic activity, which predominates initially, runs its course towards completion in advance of aerobic decomposition because aerobic stabilization is retarded by certain physical barriers that obstruct the free movement of gases and liquids within the bottom deposits. Aerobic decomposition, which is more rapid in normal environments than anaerobic decomposition, is controlled, under benthal conditions, not so much by the rate at which the end products of the anaerobic phase of decomposition are liberated, as by the rate at which these products are transported to the oxygenated surface zone. Consequently, the two biochemical phases of benthal decomposition are not directly connected but proceed at rates independent of one another, and it is entirely reasonable that the temperature characteristic of the individual processes should also be independent.

Since it has been suggested that the rate of benthal oxygen demand is circumscribed by the rate of transport of the interior fluids of the deposit to the sludge-water interface, it is a matter of interest to ascertain whether or not the effect of temperature upon this rate is in agreement with this statement. As suggested in Sections I and III of this series of papers, the upward passage of oxidizable compounds depends upon the operation of processes of consolidation and diffusion that are governed in their rates by the coefficient of permeability of the deposit and the coefficient of diffusion of the interior fluid. Both of these coefficients are functions of the viscosity of the fluid. Consequently, differences in temperature cause changes in viscosity and therewith in the rate at which oxidizable interior compounds are transported upward into the zone of surface oxidation. If the effect of temperature upon concentrated solutions of organic compounds of the type found in pollutional sediments is formulated as in equation (5a), the calculated values of C are found to be of the same order of magnitude as those obtaining in benthal oxidation (0.06 to 0.07). This observation would appear to lend additional support to the authors' theory that consolidation and diffusion control the rate of benthal oxygen demand.

Sample Calculations.—In Section III of this series of papers it was shown that decomposable matter accumulating during the winter to a depth of about 2 in. in a pond covering an area of 10 acres would exert (*a*) an initial or maximum rate of demand of 3.18 grams per sq.m. daily and (*b*) a demand after 200 days of benthal decomposition at summer temperatures (20 to 25° C.) of 0.70 grams per sq.m. daily. If C is taken at 0.065, these rates would be reduced at winter temperatures (5 to 10° C.) to the following values in accordance with equation (5a).

(*a*) Initial or maximum rate at 7.5° C. ($T_2 - T_1 = -15$),

$$y' = 3.18\, e^{-0.065 \times 15} = 3.18 \div 2.64,$$

or

$$y' = 1.2 \text{ grams per sq.m. daily or } 1.2 \times 8.92$$
$$= 10.7 \text{ lb. per acre daily.}$$

(*b*) Rate when decomposition has been carried to the same stage at 7.5°C. as it was at 22.5°C.,

$$y' = 0.70\, e^{-0.065 \times 15} = 0.70 \div 2.64,$$

or

$$y' = 0.26 \text{ grams per sq.m. daily or } 0.26 \times 8.92$$
$$= 3.0 \text{ lb. per acre daily.}$$

Calculation of the actual benthal oxygen demand exerted in a given time at a temperature other than 20 to 25° C. must await independent evaluations of the temperature characteristics for rate and ultimate magnitude of benthal oxygen demand.

Figure 15 simplifies calculation of the expected rate of decomposition (oxygen demand or gas production) at different temperatures for known

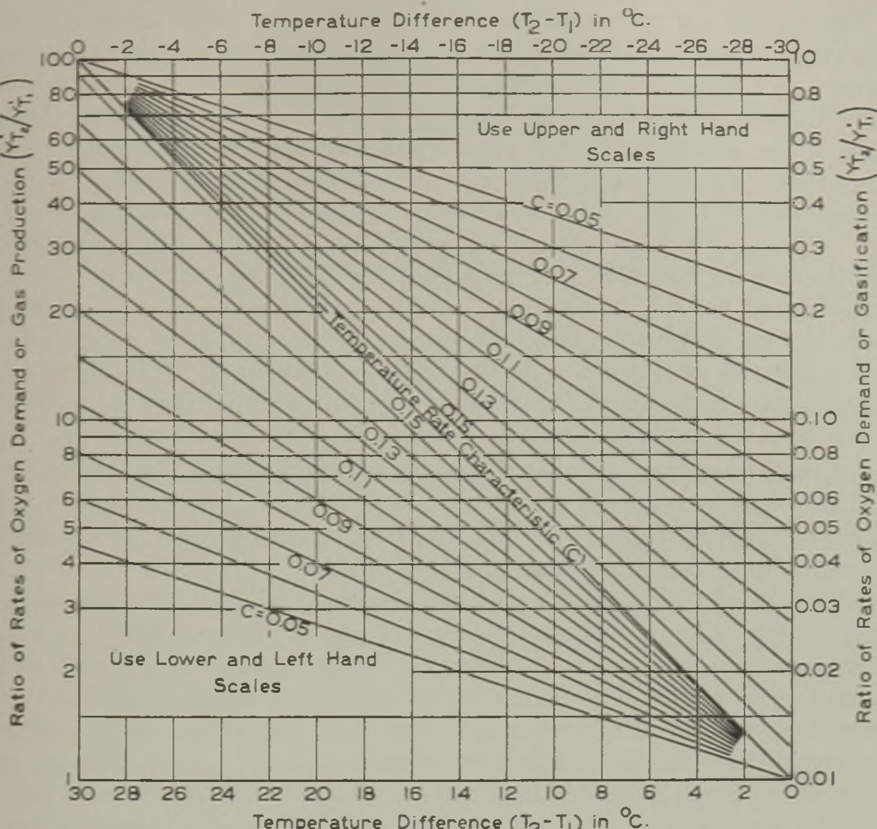

FIG. 15.—Ratios of rates of decomposition for various differences in temperature and magnitudes of the overall temperature characteristic.

y_{T_1}' and y_{T_2}' = rates of oxygen demand or gas production at temperatures T_1 and T_2 respectively.
T_1 and T_2 = temperatures in °C.
C = overall temperature characteristic.
$\frac{y_{T_2}'}{y_{T_1}'} = e^{C(T_2-T_1)}$.

values of the temperature rate characteristic. This diagram is based upon equation (5a) in the following form:

$$\frac{y_{T_2}'}{y_{T_1}'} = e^{C(T_2-T_1)} \qquad (5d)$$

and gives the ratio of the rates of decomposition at different temperatures (y_{T_2}'/y_{T_1}') for given temperature differences ($T_2 - T_1$) and temperature rate characteristics (C). In the example just given, $C = 0.065$ and $(T_2 - T_1) = -15°$ C. Read in Fig. 15 $y_{T_2}'/y_{T_1}' = 0.38$ and calculate

for $y_{T_1}' = 3.18$, $y_{T_2}' = 3.18 \times 0.38 = 1.2$

or for $y_{T_1}' = 0.70$, $y_{T_2}' = 0.70 \times 0.38 = 0.27$

both as found before.

V. Changes in Nitrogen, Iron and Fuel Value of Decomposing Bottom Deposits

Among the many constituents of decomposing river muds and pollutional sediments, the nitrogenous materials, the iron-bearing compounds, and the calorific substances were selected for study either because of their relation to the quality of the supernatant water or because of the added light that their changing concentration and constitution throw upon the nature of the processes of decomposition that are such important forces in the conservation of our natural drainage channels. Changes in biochemical oxygen demand will be discussed in a later section of this series of papers.

As stated before, the authors' studies dealt with two types of deposits in two different ways. To determine the effect of depth of deposit upon the progress of decomposition a mixture of fresh sewage sludge and inert materials was employed; this will be referred to as the sample of *sewage sludge.* To gage the effect of temperature upon the rate of decomposition, a natural river mud was brought into the laboratory; this will be referred to as the sample of *river mud.* Since it was not practicable to collect an "undisturbed" sample, interpretation of the results obtained must bear this fact in mind.

Behavior of Nitrogen.—Anaerobic decomposition of nitrogenous organic matter is known to yield ammonia and its salts. Under aerobic conditions, the ammonia is oxidized to nitrites and nitrates within the nitrogen cycle (19). The formation of elemental nitrogen and gaseous nitrogen oxides in both aerobic and anaerobic decomposition is claimed by some authorities and denied by others (20) (21). At present, the weight of evidence indicates that gaseous forms of nitrogen may be released by anaerobic decomposition only provided that nitrogen is present as nitrite or nitrate.

In benthal decomposition, the soluble nitrogen products may be leached away by the flowing water and exert in it a delayed oxygen demand. During the primary period of active anaerobic decomposition in benthal deposits, fermentation may be so vigorous as to occasion the escape of large amounts of ammonia and organic nitrogen into the supernatant water. In later stages of decomposition, however, nitrifying bacteria will have established themselves upon the mud surface and may oxidize the ammonia as fast as it is transported from the interior to the surface zone.

Results of Nitrogen Determinations.—In the authors' studies of sewage sludge, the samples passed through the first period of intensive anaerobic fermentation in the laboratory, and large proportions of the soluble nitrogen initially present in the sludge were released to the flowing water, principally in the form of ammonia. The sample of river mud, on the other hand, had completed the first stage of benthal decomposition before it was brought into the laboratory, and the soluble nitrogen transferred from it to the flowing water was smaller in quantity and contained a considerable proportion of nitrates and nitrites.

Curves showing the cumulative release of the various forms of nitrogen to the supernatant water are presented in Figs. 16 and 17. All values are expressed as percentages of the total nitrogen originally

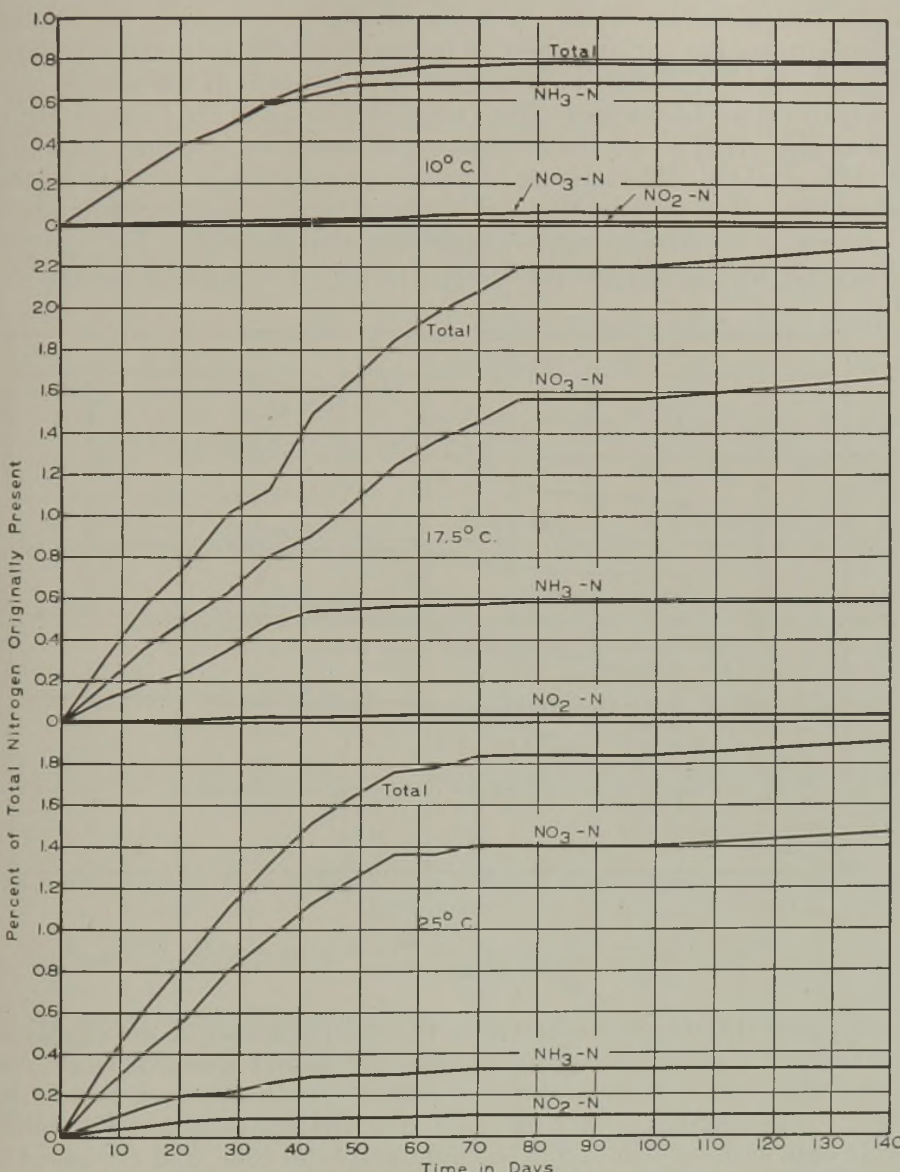

FIG. 16.—Observed recovery of nitrogen in the form of ammonia, nitrite and nitrate at 10, 17.5 and 25° C. in water overlying river mud.

present. Except for greater irregularity, the curves are reminiscent of biochemical oxygen demand curves, although measurable liberation of nitrogen ceases long before the cessation of measurable oxygen demand. In the experiments on sewage sludge, the deeper samples gave up a greater proportion of their total nitrogen to the supernatant water, probably because the release of gas per unit surface area was greater than in the shallower ones and because they were subjected to greater consolidation and resulting upward transport of internal fluids. In the curves for nitrogen diffusion from the river mud (Fig. 16), the relationships between the various possible forms of soluble nitrogen are clearly shown. At 10° C., ammonia constituted 84 per cent of the soluble nitrogen transferred to the water, the remainder being in the form of nitrate and nitrite; at 17.5° C., the percentage of ammonia was only 23, and at 25° C., only 14.5. The amount of nitrite was relatively small at all temperatures. It is evident that oxidation of soluble nitrogen prior to its liberation to the flowing water was promoted at the higher temperatures so that nitrate became the predominant form of nitrogen released.

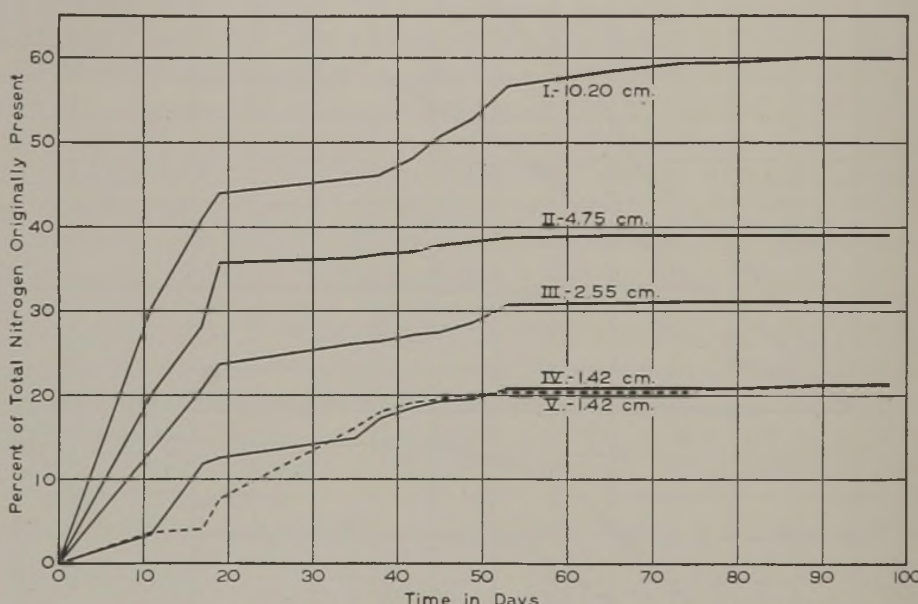

FIG. 17.—Observed recovery of ammonia nitrogen in water overlying varying depths of sewage sludge.

Because of the errors inherent in the determination of the small concentrations of nitrogen existing in the supernatant water, it is not contended that these curves represent accurately all nitrogen lost to the water. The changes occurring in the deposits are considered quantitatively only with respect to total amount and total time, and are based on determinations made directly on the sludge and mud, before and after decomposition. The changes noted are summarized in Table XI. For convenience of comparison, the results are (1) expressed on a percentage basis and (2) accompanied by the results of the anaerobic studies that were carried on in parallel with the benthal experiments.

Examination of Table XI shows marked differences in the behavior of nitrogen in the various samples tested. In the sludge studies, the or-

TABLE XI.—*Changes in the Nitrogen Content of Benthal and Anaerobic Sludge and River Deposits*

A. Decomposition of Varying Depths of Sewage Sludge at 20 to 25° C.
Organic nitrogen at start: 6.28 grams per kg. of dry solids.
Ammonia nitrogen at start: 1.07 grams per kg. of dry solids.

	Benthal Decomposition for 450 Days					Anaerobic Decomposition for 495 Days
Mean Depth, cm.	10.2	4.75	2.55	1.42	1.42	11.3
Volatile Matter						
Initial, kg. per sq. m.	3.77	1.38	0.513	0.188	0.188	2.69
Organic Nitrogen						
Final, grams per kg. of dry solids	4.28	4.02	3.91	3.51	3.48	3.93
% of initial organic N lost *	68.4	49.7	45.7	48.6	48.7	39.5
Ammonia Nitrogen						
Final, grams per kg. of dry solids	0.0374	0.0189	0.0171	0.0167	0.0165	1.71
Change as % of initial*	−98.3	−98.6	−98.7	−98.7	−98.7	+54.3
Total Nitrogen Recovered in Supernatant Water, % of initial total N	60.0	39.1	31.1	21.4	21.1	23.0
Total Nitrogen Unaccounted for, % of initial total N	13.1	17.7	22.4	34.3	33.0	3.0
Total Nitrogen Remaining in Deposit, % of initial total N	26.9	43.2	46.5	44.3	45.9	74.0

B. Decomposition of River Mud at Different Temperatures
Organic nitrogen at start: 10.11 grams per kg. of dry solids.
Ammonia nitrogen at start: 0.089 gram per kg. of dry solids.

	Benthal Decomposition for 145 Days			Anaerobic Decomposition for 201 Days		
Temperature, ° C.	10.0	17.5	25.0	10.0	17.5	25.0
Initial Depth, cm.	10.0	10.0	10.0	12.9	13.0	11.3
Volatile Matter						
Initial, kg. per sq. m.	4.65	4.56	4.98	6.02	5.97	5.64
Organic Nitrogen						
Final, grams per kg. of dry solids	8.29	7.74	7.58	7.38	7.29	7.41
% of initial organic N lost *	16.5	23.1	25.2	26.3	27.3	26.3
Ammonia Nitrogen						
Final, grams per kg. of dry solids	0.139	0.162	0.204	0.406	0.498	0.613
Change as % of initial *	+69	+80	+125	+350	+450	+570
Total Nitrogen Recovered in Supernatant Water, % of initial total N	0.77	2.34	1.92	—	—	—
Total Nitrogen Unaccounted for, % of initial total N *	15.1	20.0	22.1	23.1	23.2	21.1
Total Nitrogen Remaining in Deposit, % of initial total N	80.8	74.3	73.6	72.9	73.2	73.8

* With due regard to reduction in dry solids during decomposition and samples removed during course of test.

ganic nitrogen lost from the deposits during 450 days of benthal decomposition ranged from 68.4 per cent in the 10.2-cm. sample to 45.7 per cent in the 2.55-cm. sample. This difference is probably associated with the more active fermentation and gas ebullition of the deeper sample.

The observed loss of organic nitrogen was relatively greater from the sludge than from the mud in which decomposition was less active. The dissolution of organic nitrogen was greater during benthal decomposition of the sewage sludge than during its anaerobic decomposition, and this excess is accounted for, in the most part, by the ammonia recovered from the effluent. Digestion and consolidation of the anerobic sludge deposit left a clear supernatant liquid that contained 23 per cent of the initial total nitrogen in the sample. The river mud had already been consolidated in nature, and no supernatant layer was observed in it.

The changes in the ammonia content of the deposits range from a loss of almost 100 per cent in the benthally decomposing sewage sludge to a gain of 570 per cent in the anaerobically decomposing river mud incubated at 25° C. This difference again appears to be attributable chiefly to differences in physical environment, relative activity of fermentation, and variation in initial concentrations of ammonia in the two deposits investigated. As previously mentioned, nitrogen was released to the supernatant water in the form of ammonia from the sewage sludge and as ammonia, nitrite, and nitrate from the river mud. The amounts recovered vary from 60 per cent in the deepest benthal samples of sludge to 0.8 per cent in the benthal sample of mud held at 10° C. This variation reflects (1) differences in the degree of disturbance of the samples due to gas ebullition, and (2) lack of sensitivity in the analytical procedures available for the detection of small amounts of all forms of nitrogen except nitrite. In the smaller, shallower samples of sewage sludge as well as the less active, colder samples of river mud, part of the nitrogen was probably not sufficiently concentrated to be detected, and a smaller percentage of recovery had to be reported for these samples. An additional reason for the disparity in the nitrogen balance is, quite possibly, the denitrification of nitrites and nitrates with the escape, in the flowing water, of elemental nitrogen, or perhaps nitrogen oxides, as gas or in solution. Even in the anaerobic samples, it is conceivable that, during the long period required for decomposition, a certain amount of oxygen reached the sample through the seal of salt solution in the gas collector and produced nitrification which was followed by denitrification with release of nitrogen from the system. The presence of nitrogen in the gas evolved from the deposits was, in fact, recorded by analyses. It seems quite probable, therefore, that the conditions in partially stabilized river muds, unlike those obtaining in ordinary sludge digestion, may permit some denitrification with the formation and escape of elemental nitrogen. This is a matter of considerable interest in connection with the natural purification and fertility of receiving waters in relation to plankton growths. Further evidence on this point is needed, however, before definite conclusions can be drawn.

The proportions of total nitrogen remaining in the samples at the conclusion of the experiments range from ¼ to ½ for the benthally decomposing sewage sludge to about ¾ for the anerobic sludge and the benthal or anaerobic river mud. The variations may be ascribed to (1) differences in physical environment, including density of deposit and admixture of inert materials; (2) differences in the disturbance caused by anaerobic activity in the deposit; and (3) differences in the length of time for which the deposits were under observation.

Behavior of Iron in River Deposits.—The iron content of stream waters is of interest because of their potential utility in municipal or industrial water supply. It is of importance, therefore, to determine whether the iron contained in river muds is bound up in the deposits for all time, or whether it can be released on occasion to augment the iron content of the flowing water. The experiments described in this series of papers furnish at least a partial answer to this question. Before citing the experimental evidence, however, let us consider the general behavior of iron in stream waters and river muds.

Combined iron may exist in the divalent, or ferrous, and the trivalent, or ferric, state. Any ferrous iron present in oxygenated water is oxidized to ferric iron at a rate depending mainly on the hydrogen-ion concentration and temperature of the water. The time necessary for complete oxidation will range from an hour or so to several days. Moreover, the solubilities of both forms of iron in natural waters are controlled by the solubility-product equilibria of their hydrates, which are, in turn, controlled by the hydrogen-ion concentrations of the waters. At a given pH value, therefore, no more than a certain definite amount of iron can be taken into, or retained in solution, and this amount is greater for ferrous than for ferric iron. Table XII gives the solubilities of ferrous and ferric iron in waters of various pH values.

TABLE XII.—*Effect of the Hydrogen-ion Concentration of Water on the Solubilities of Ferrous and Ferric Iron*

pH Value	Solubility of Iron, in p.p.m. as Fe	
	Ferrous Iron	Ferric Iron
4.0	9.18×10^{10}	6.15×10^{-2}
5.0	9.18×10^{8}	6.15×10^{-5}
6.0	9.18×10^{6}	—
7.0	9.18×10^{4}	—
8.0	9.18×10^{2}	—
9.0	9.18	—
10.0	9.18×10^{-2}	—

Brief inspection of this table will show that very little ferric iron can be dissolved in natural surface waters. Since dissolved ferrous iron is slowly oxidized, the bulk of the iron content of surface waters must be in the form of colloidal ferric hydrate. This colloid may be partially stabilized by organic substances such as the tannins. In any event, iron cannot be taken into true solution from a river deposit if it exists there in the ferric form.

There are two possible ways in which iron can be taken up by water flowing over a decomposing river mud:

1. Iron is reduced to the ferrous state in that portion of the deposit that is undergoing anaerobic decomposition. This ferrous iron will

diffuse through the mud or be displaced by consolidation of the deposit, and will eventually reach the aerobic zone. Upward transport may be further promoted by seepage of ground water into the stream through the river bed during periods of low water. The relative rates of displacement, upward diffusion, or transportation, will determine what will happen in this zone. Some of the ferrous iron will be oxidized and held as finely divided ferric oxide a short distance below the surface of the mud. This effect is readily observed in samples of sludge or mud stored under water in glass containers. Another portion of the ferrous iron may diffuse out into the river and will then be oxidized to colloidal ferric oxide as it moves downstream.

2. The gases of decomposition accumulate in sufficient amount to break through the deposit, disrupting the surface and carrying into the stream the finely divided ferric oxide previously formed in the surface layers. Passage of ferrous iron into the flowing water is also accelerated by this stirring action of the gases.

3. If appreciable quantities of hydrogen sulphide are produced in the anaerobic zone, the mechanism of iron transfer is modified by the formation of insoluble ferrous sulphide. This substance is transported into the aerobic zone by gas action and is there converted to ferric oxide. The principles involved remain essentially the same as those previously described. A factor of some importance in fixing the rate of transfer of iron from the mud is the iron content of the flowing water itself. This may change considerably from season to season. At times, the concentration of iron in the water may be sufficient to cause precipitation of iron upon the surface of the deposit. Ordinarily, however, the iron content of the mud—particularly if the sediment is composed of partially stabilized compounds or minerals containing relatively large amounts of iron—is sufficiently high to make the rate of iron transfer to the flowing water proceed uniformly regardless of the concentration of iron in it.

Results of Iron Determinations.—The changes in quantity and condition of iron in the benthal deposits studied by the authors, together with the changes occurring in the corresponding anaerobic samples, are summarized in Table XIII. For purposes of comparison, the changes are expressed as percentages.

Inspection of Table XIII leads to the following conclusions:

1. Benthal decomposition involves an appreciable loss of iron from bottom deposits. The amount of iron remaining in the sewage sludge at the conclusion of the experiment ranged from 69 per cent in the deepest, most active, sample to 79 per cent in the shallowest sample; in the river mud the range was from 82 per cent in the sample incubated at 25° C. to 89 per cent in that held at 17.5° C. On this basis, the percentages of the total iron transferred to the flowing water ranged from 21 to 31 per cent for the sewage sludge, and from 11 to 18 per cent for the river deposit. Since the initial concentration of iron per unit weight of dry solids was considerably greater in the river deposit than in the

TABLE XIII.—*Changes in the Iron Content of Benthal and Anaerobic Sludge and River Deposits*

A. Decomposition of Varying Depths of Sewage Sludge at 20 to 25° C.
Total iron (Fe) at start: 6.97 grams per kg. of dry solids.
Ferrous iron (Fe) at start: 1.22 grams per kg. of dry solids = 17.5% of total iron.

	Benthal Decomposition for 450 Days					Anaerobic Decomposition for 495 Days
Mean Depth, cm.	10.2	4.75	2.55	1.42	1.42	11.3
Volatile Matter						
Initial, kg. per sq. m.	3.77	1.38	0.513	0.188	0.188	2.69
Total Iron (Fe)						
Final, grams per kg. of dry solids	10.9	7.42	6.93	6.69	6.70	7.18
Ferrous Iron (Fe)						
Final, grams per kg. of dry solids	0.93	0.75	0.59	0.25	0.34	1.49
% of total iron	8.5	10.1	8.5	3.7	5.1	20.7
Total Iron Remaining in Deposit, % of initial *	68.5	77.7	80.0	77.8	79.0	100.0

B. Decomposition of River Mud at Different Temperatures
Total iron (Fe) at start: 48.2 grams per kg. of dry solids.
Ferrous iron (Fe) at start: 7.3 grams per kg. of dry solids = 15% of total iron.

	Benthal Decomposition for 145 Days			Anaerobic Decomposition for 201 Days		
Temperature, ° C.	10.0	17.5	25.0	10.0	17.5	25.0
Initial Depth, cm.	10.0	10.0	10.0	12.9	13.0	11.3
Volatile Matter						
Initial, kg. per sq. m.	4.67	4.56	4.98	6.02	5.97	5.64
Total Iron (Fe)						
Final, grams per kg. of dry solids	39.6	43.0	39.5	48.2	48.2	48.2
Ferrous Iron (Fe)						
Final, grams per kg. of dry solids	5.5	5.6	5.7	6.3	5.7	5.7
% of total iron	13.9	13.0	14.4	13.1	11.8	11.8
Total Iron Remaining in Deposit, % of initial *	84.2	89.4	81.7	100.0	100.0	100.0

* With due regard to reduction in dry solids during decomposition and samples removed during course of test.

sewage sludge, the actual amount of iron transferred to the flowing water per unit weight of river mud was more than twice that for the sewage sludge. The greater proportion of total iron content given up by the sewage sludge, as compared with the river mud, is explained (*a*) by greater disturbance of the sludge due to anaerobic activity, (*b*) by looser structure and lower specific gravity of the sludge, and (*c*) by the longer time allowed for the decomposition of the sludge. This is confirmed in part by comparison of the behavior of the deeper and the shallower sludge samples; the former, being stirred to a greater extent by gasification, gave up a higher proportion of their iron. The reader may find it confusing to learn from Table XIII*A* that the concentration of iron per unit weight of dry solids actually increased in some of the experiments, despite the loss of iron; but this is readily explained by the fact that solids other than iron were lost in greater amount.

As is to be expected, no changes in the total iron content of the anaerobic samples were observed.

2. The relative amount of total iron present in the ferrous state in the sewage sludge decreased markedly during the course of benthal decomposition, whereas that in the river mud decreased only slightly. Two opposing factors govern the ferrous iron content of the deposits: (1) the rate of formation of ferrous iron by reduction in the anaerobic zone, and (2) the rate at which this ferrous iron is lost by diffusion and other forms of transport. It must be inferred, therefore, that, despite the high degree of anaerobic activity in the sewage sludge, ferrous iron was lost from it more rapidly than it was replaced. On the other hand, the river mud produced ferrous iron at a rate more nearly equal to that at which it was lost from the deposit. The shallower samples of sewage sludge generally lost a higher proportion of their ferrous iron content than the deeper ones; in the shallower samples the anaerobic zone was small, and ferrous iron production was consequently limited, without a corresponding limitation in the rate at which it was lost. In the very deepest sample, however, this trend was reversed, probably because of the violence of stirring by gaseous ebullition, which occasioned a rate of ferrous iron loss more than sufficient to counterbalance the high rate of production.

In the anaerobic samples, one would expect that, so long as conditions remained truly anaerobic, the proportion of ferrous iron would tend to increase. Anaerobic decomposition of the sewage sludge does, in fact, give rise to such behavior. Anaerobic decomposition of the river deposit, however, reverses the expected trend, showing greater decreases in percentage of ferrous iron than those observed in benthal decomposition of the same material. It must be admitted that this is a strong indication that gas production from the samples of river mud was not sufficient to maintain truly anaerobic conditions at all times against the diffusion of gaseous oxygen through connections of rubber tubing and through the confining liquid in the gas collector. This conclusion is in line with that reached regarding the loss of nitrogen in gaseous form from these samples.

Whether the ferrous iron that was lost used up dissolved oxygen by being oxidized before leaving the experimental container could not be definitely determined. This would depend considerably on the detention period of the container used; it is probable that in the experiments on sewage sludge a considerable proportion of the oxidation of the ferrous iron did take place before the water left the container, and so was included in the over-all oxygen balance measured in the samples. On the other hand, there is evidence that, in the experiments on river mud, at least at the lower temperatures, a good part of the ferrous iron was not so oxidized.

It should be noted in passing that published analytical methods for the determination of small quantities of ferrous iron proved unsatisfactory for muds and sludges. It was therefore necessary to devise a suitable method, which is described in the appendix to Part V.

Changes in Fuel Values.—The purpose of determining the fuel values of the sludge and mud undergoing decomposition was to estimate

TABLE XIV.—*Changes in Fuel Value of Benthal and Anaerobic Sludge and River Deposits*

A. Decomposition of Varying Depths of Sewage Sludge at 20 to 25° C.
Fuel value at start: 1,420 B.t.u. per lb. of dry solids, or
10,200 B.t.u. per lb. of volatile solids.

	Benthal Decomposition for 450 Days					Anaerobic Decomposition for 495 Days
Mean Depth, cm.	10.2	4.75	2.55	1.42	1.42	11.3
Volatile Matter						
Initial, kg. per sq. m.	3.77	1.38	0.513	0.188	0.188	2.69
Fuel Value						
Final, B.t.u. per lb. of dry solids	1,140	935	915	925	904	930
Final, B.t.u. per lb. of volatile solids	9,850	10,400	10,300	10,500	10,100	10,800
Loss, % of initial fuel value of sample *	62.0	48.6	43.7	40.3	40.5	36.5
B.O.D. Loss, % of initial B.O.D.	80.1	82.1	83.3	93.6	92.2	43.3
Grams O_2 per kg. of volatile solids	665	682	693	778	766	360
Ratio of % Fuel Value						
Loss to % B.O.D. Loss	0.776	0.593	0.526	0.430	0.438	0.843
Ratio of Fuel Value						
Loss to B.O.D. Loss, calories per gram of oxygen demand lost	5,300	8,710	6,450	5,020	5,180	5,820

B. Decomposition of River Mud at Different Temperatures
Fuel value at start: 1,950 B.t.u. per lb. of dry solids, or
8,080 B.t.u. per lb. of volatile solids.

	Benthal Decomposition for 145 Days			Anaerobic Decomposition for 201 Days		
Temperature, ° C.	10.0	17.5	25.0	10.0	17.5	25.0
Initial Depth, cm.	10.0	10.0	10.0	12.9	13.0	11.3
Volatile Matter						
Initial, kg. per sq. m.	4.67	4.56	4.98	6.02	5.97	5.64
Fuel Value						
Final, B.t.u. per lb. of dry solids	1,950	1,935	1,920	1,920	1,920	1,920
Final, B.t.u. per lb. of volatile solids	8,200	8,230	8,540	8,040	8,310	8,310
Loss, % of initial fuel value of sample *	—	0.66	2.25	1.41	1.21	2.12
B.O.D. Loss, % of initial B.O.D.	25.6	33.2	34.0	29.4	30.2	33.5
Grams O_2 per kg. of volatile solids	19.7	29.3	33.8	22.6	26.6	33.3
Ratio of % Fuel Value						
Loss to % B.O.D. Loss	—	0.0199	0.0663	0.0480	0.0400	0.0633
Ratio of Fuel Value						
Loss to B.O.D. Loss, calories per gram of oxygen demand lost	—	1,010	2,960	2,780	2,030	2,670

* With due regard to reduction in dry solids during decomposition and samples removed during course of test.

the energy content of the substances decomposed. The precision of the fuel-value determination, unfortunately, is of a somewhat low order due to errors inherent in sampling, which are particularly large in benthal deposits that include large admixtures of non-combustible solids, and to the difficulty of controlling and correcting for the radiation of heat that takes place in the course of combustion of the sample. Only by repeated tests can the result be determined to three significant figures.

Results of Fuel Value Determinations.—The results obtained are summarized in Table XIV. A significant reduction is noted in the fuel value per unit weight of dry solids in the course of both benthal and anaerobic decomposition. This reduction is more marked for the younger, less compacted samples of sewage sludge than for the relatively stable river muds. Computed on the basis of volatile solids present at the beginning and end of the experiments, the fuel values, with few exceptions, have a tendency to increase. This indicates that the average fuel value of the volatile matter remaining in the deposits is somewhat higher than that of the volatile matter lost. It follows that decomposition may involve, at first, substances of relatively low fuel value, while substances of higher fuel value are not so readily attacked.

The relationship between the fuel value loss and the loss of first-stage biochemical oxygen demand during decomposition furnishes some information as to the type of organic material decomposed. Expressed in terms of calories lost per gram of oxygen demand lost (see Table XIV), it shows that the material attacked was of considerably higher average fuel value in the sewage sludge than in the river deposit. Furthermore, the average fuel value of the material attacked is about the same whether decomposition is benthal or anaerobic. Although speculation may not be carried too far, in view of uncertainties inherent in the experimentally determined magnitudes of B.O.D. and fuel values, it may be of interest to compare the data cited in Table XIV with values derived for certain organic compounds, assuming complete oxidation of these compounds (Table XV).

TABLE XV.—*Fuel Value and Biochemical Oxygen Demand of Certain Organic Compounds*

Compound	Formula	Calories per Gram	Biochemical Oxygen Demand, Grams per Gram	Calories per Gram of B.O.D.
Formic acid	$HCOOH$	1,360	0.348	3,900
Acetic acid	CH_3COOH	3,480	1.065	3,260
Stearic acid	$C_{18}H_{36}O_2$	9,550	2.92	3,270
Lactic acid	$C_3H_6O_3$	3,620	1.068	3,380
Sucrose	$C_{12}H_{22}O_{11}$	3,960	1.12	3,540
Benzene	C_6H_6	10,000	3.08	3,240

The values appear to cluster about 3,500 calories per gram of oxygen demand, and it may be reasoned from this that in sewage sludge the loss of fuel value exceeds that which can be accounted for by loss in oxygendemanding power, whereas in the river deposit the reverse is true. One might infer that complete oxidation was not realized for all substances in the sewage sludge, while the river deposit contained mineral substances requiring oxygen but possessing no fuel value.

The relationship of fuel value loss and loss of first-stage biochemical oxygen demand may also be expressed in terms of the ratio of the percentages of each lost. In this form, it furnishes certain information as to the relative durability of the substances constituting the fuel value, and those constituting the B.O.D. It will be seen in Table XIV that the ratio of percentage fuel value loss to percentage oxygen demand loss is much greater for the sewage sludge than for the river deposit. This may mean that there exist residual materials, not substantially decomposed by biochemical action within the time limits of these experiments, but possessing relatively high fuel values. These are probably analogous to the organic residues found in natural soils. It is evidently possible for a deposit to become completely stabilized with respect to B.O.D. and still to possess a measurable content of organic matter.

Summary of Parts IV and V

The varying temperatures of spring, summer, fall and winter determine the rate of activity of the biological agents of natural purification in river muds and pollutional sediments as well as in their overlying waters. The temperature of bottom deposits lags slightly behind that of the water and does not reach the same extremes of heat or cold. In deep lakes, thermal stratification may hold the temperature uniformly close to that of maximum water density and so suppress the effect of the seasons upon the deposits in deep bodies of water.

As shown in Part IV of this discussion, the effect of temperature upon rate of decomposition may be evaluated in terms of a characteristic based upon the van't Hoff-Arrhenius equation. For the river mud studied by the authors, this characteristic is shown to change the overall rate of benthal oxidation by about 6.7 per cent compounded for each degree centigrade of shift in temperature.

This value is of the same order of magnitude as that reported for the rate of biochemical oxygen demand of polluted water; but it is also close to the change in magnitude of the viscosity of interior fluids which determines the rate of transport of oxidizable substances to the surface zone of benthal deposits. Under anaerobic conditions, the observed temperature rate-characteristic of the mud was higher (10.2 per cent) and approximately equal to that of digesting sewage sludge. From what has been said in connection with rates of benthal and anaerobic decomposition in Part III of this series of discussions, it would appear, therefore, that although the strictly aerobic stabilization of pollutional deposits is fundamentally more rapid, the anaerobic phase of benthal decomposition may actually complete its course in advance of the aerobic phase because the opportunity for aerobic stabilization is a function of the rate of vertical transport of oxidizable substance to the zone of oxidation in close proximity to the sludge-water interface.

The quantities of soluble nitrogen products in water flowing over river muds and pollutional sediments are shown to be increased measurably and appear to be determined in magnitude and character by physical conditions of environment, relative activity of fermentation and variations in initial concentration and constitution of nitrogenous matters in the deposits. Within the limits of the authors' tests, from ¼ to ¾ of the total nitrogen was observed to remain in the deposits. Much of the nitrogen lost was recovered in the overlying water, but there is evidence of some denitrification with the formation and escape of elemental nitrogen from the system.

A significant proportion of the iron content of river muds and pollutional sediments is lost during benthal decomposition. Possible mechanisms whereby this loss might take place are discussed in the body of the paper. The iron was found to exist in both the ferrous and ferric states in the deposits, and the ratio between the two forms decreased markedly during decomposition of the sewage sludge and remained approximately constant in the river mud. In benthal decomposition, the dividing line between the aerobic and anaerobic regions in the deposits was clearly marked by the precipitation of red ferric hydrate. The zone of precipitation was ⅛ to ¼ inch below the surface of the deposit. The observed loss of iron by the deposits shows that the iron content of the overlying water must increase and that water flowing over extensive deposits may receive material additions of iron.

A significant loss of fuel value accompanied decomposition. The fuel value per unit weight of volatile solids, however, manifested a tendency to increase. Benthal decomposition, therefore, may involve in particular, or initially, substances of relatively low fuel value.

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* References 1 to 12 are appended to Sections I to III of this series of papers.

Appendix to Part V

Determination of Ferrous Iron in River Muds and Pollutional Sediments

The reagents and procedure for determining ferrous iron were as follows:

Reagents:

1. Hydrochloric acid, approximately 3N. One volume concentrated C.P. acid to 3 volumes of distilled water.
2. Potassium thiocyanate. Two g. dissolved to make 100 ml. of solution.
3. Potassium permanganate, approximately N/5. Dissolve 6.3 g. in distilled water and make up to 1 liter.

Procedure:

Weigh to the nearest 0.01 g. a suitable sample (usually 1 or 2 g.) of the wet material. Add to this a mixture of 100 ml. distilled water and 10 ml. 3N hydrochloric acid. Filter through a rapid filter paper, repeating filtration until a reasonably clear filtrate is obtained.

Take two equal aliquot portions of the filtrate, of such size as to contain 0.05 to 0.15 mg. of iron, and place them in 50-ml. Nessler tubes. Add to each a sufficient amount of 3N hydrochloric acid to bring the total acid concentration up to 1 ml. of 3N acid. (Unless very large aliquot portions are taken, it will be sufficient merely to add 1 ml. of the acid to each sample.) Add to one of the tubes, one or two drops of potassium permanganate solution, adding more if the color does not persist for five minutes.

Dilute both tubes to the mark with distilled water, and add 5 ml. of thiocyanate solution. Compare at once with temporary or permanent standards. The difference between the two readings is equal to the mg. of ferrous iron in the aliquot portion taken.

STREAM POLLUTION AND CONTROL *

By Robert Spurr Weston

Weston and Sampson, Consulting Engineers, 14 Beacon St., Boston, Mass.

With the revival of industry and with the manufacture of munitions and defense equipment, increased pollution of streams may be expected to follow. This condition concerns sanitary engineers to whom stream pollution and control are matters to which serious and increasing consideration must be given. It therefore seems fitting to review the social and legal circumstances in their connection.

In the last few weeks, thousands of Pennsylvanians and other Americans have gone to rivers, lakes and ponds to fish. Some of these have come back dissatisfied, and, especially if their creels were empty, they have tried to explain why their catches have not been what they were in former years. Some of these recreationists have observed polluting discharges from factories and sewers and placed the blame thereon. Later on in the year, because of pollution, industrial and domestic, health authorities may be led to further restrict the areas where bathing is allowed and those from which shellfish may be gathered.

It is a perfectly natural thing for those affected, especially if they be socially influential or politically powerful, to try to have restored by government action that of which they have been deprived. Laws, good and bad, are then passed. As you know, a law was passed by this Commonwealth three years ago.

The happenings in Rhode Island during the past thirty years are illustrative. Rhode Island, as you know, is our smallest and most densely populated state. Its population density in 1930 was 644 per square mile, or about three times that of Pennsylvania. Geographically, it is a ring of cities and towns about Narragansett Bay into which about a dozen industrial streams tumble from mill pond to mill pond, furnishing process water and power as they go.

The bay is a gathering ground for oysters. About twenty-five years ago this industry began to be affected, not only by pollution by factory wastes and sewage but by the discharge of fuel oil from tankers and other vessels. Then followed a law which was by no means drastic or sumptuary. It followed conferences among all parties concerned.

Enforcement of the law began, and several cities and factories built treatment works. Then came the depression, and enforcement was necessarily relaxed. Recently, following better business and increasing demand for stricter enforcement, a committee, including interested parties and advised by a professor of sanitary engineering, has made a report, and it is likely that something more will be done.

Rhode Island is a manufacturing state. The value of its manufactured products is about 500 million dollars per annum as compared with about 65 million dollars for farm products and less than 2 million dol-

* Presented at the Fourteenth Annual Conference of the Pennsylvania Sewage Works Association, State College, June 27, 1940.

lars for fisheries. This means that the mills must be tactfully persuaded to do their bit in the public interest; otherwise they will threaten to move, thus destroying the market for farm products and oysters.

Many public-spirited manufacturers have done much to reduce pollution, just as, with the cooperative leadership of Dr. Stevenson, Mr. Moses, Mr. Siebert, and the Sanitary Water Board, they have done in Pennsylvania.

Pennsylvania has a more drastic law, the one passed three years ago, which, if strictly interpreted, means that if you should destroy algae by adding copper sulfate you would do something "inimical and injurious to aquatic life," and are, therefore, creating a nuisance; or, if you should happen to kill a few perch or pickerel, you would be doing something "injurious to animal life," and both acts would be culpable whether the Sanitary Water Board "shall so declare or not."

Laws or no laws, one can't go back to the conditions which the hunter and the trapper met and enjoyed; neither should one suffer from nuisance and waterborne disease.

Because industry is reviving, the insistence upon action is becoming more urgent, not only by the recreationists and nature lovers but also by the sanitary authorities. Clean rivers are being classed more and more with beautiful public buildings and parks as goals for municipal striving. The problem is not easy since it involves the use of streams, on the one hand, and the avoidance of the abuse of them, on the other.

Some years ago, the writer expressed his idea of the problem as follows—(1)

> Rivers attract population, and population demands disposal of sewage, as well as water supply. On some industrial rivers the prohibition of pollution would so hamper industry that manufacturers would be forced to go out of business or move away; consequently, many rivers must necessarily be used for manufacturing, drainage and water supply. Others may become unfit for water supply and be relegated to drainage and manufacturing uses only. Each stream, in other words, must be used for the best interests of all riparian owners and with due regard for the right and convenience of all.

On handing down the opinion of the United States Supreme Court on the Delaware River Case (New Jersey v. New York), Mr. Justice Oliver Wendell Holmes stated that "a river is more than an amenity, it is a treasure. It offers necessities of life that must be rationed among those who have power over it."

It has been suggested that streams might be classified and relegated to specific uses, for example,—

1. Those preserved in nearly their natural condition and reserved for water supply.
2. Those used for sewage disposal after treatment of the sewage, and for water supply after purification of the water.
3. Those used for sewage disposal after such treatment of sewage and industrial waste as is necessary to prevent nuisance.

Therefore, great need exists for care and judgment, for study by state and federal departments for the control of interstate drainage areas (which is a better method than control by a federal commission), and for constructive programs not too burdensome for industry. Control could, of course, be vested in a Federal Department, but it is believed that control by agreements among the states or other interested parties is a better method.

The United States National Resources Committee has well stated the situation as follows—(2)

> The essential approach to the problem of ridding stream waters of undesirable industrial wastes lies in the active cooperation of the industries involved, always assuming, however, flexible and reasonably administered water pollution legislation. The problem cannot be settled by abstract studies on the part of government nor by inflexible and arbitrary state or federal legislation. Waste materials are so diverse and so complex that each industry, and possibly each plant, presents a special problem.

Instead of "industries involved," one might well substitute "all parties involved."

Pollution Load

While domestic sewage presents a serious disposal problem, that involved in the disposal of factory wastes is quite different because of their great demand upon the oxygen resources of the stream.

Wisely and Klassen (3) showed that in the Peoria-Pekin metropolitan area of Illinois the combined human population contributing sewage is 130,000, whereas the industries contribute a pollution load equivalent to more than 1,000,000 people, largely in the form of distillery wastes.

Calvert and Parks (4) compared the industrial wastes of Indianapolis. Table I is taken from their figures.

Table I.—*Population-Equivalents of Wastes*

Waste	Volume of Work Done	Total Population-Equivalent
Laundry	2,800 lb. dirty clothing	668
Creamery	8,000 lb. butter made	736
Dairy	155,000 lb. raw milk received	11,782
Canning	309,700 lb. pork and beans	8,429
Starch	21,574 bu. corn	90,965
Five meatpackers	20,280 equivalent hogs	267,728
Paperboard	102.1 tons produced	5,978
Garbage	72.9 tons green garbage	12,271

The ordinary oxygen demand (B.O.D.) of sewage from American residential communities with separate sewers will average less than 150 parts per million, or 57 grams per capita, whereas the oxygen demand of the industrial waste in an American manufacturing city with separate sewers will usually exceed that of the sewage. The oxygen demand as well as the suspended residue and the oxygen consumed of certain wastes are given in Table II.

Some factory wastes require special consideration. This has been given to many of these by the Pennsylvania Department of Health. Ligneous, resinous, greasy, nitrogenous, soapy, high in suspended mat-

TABLE II.—*Five-Day Oxygen Demand of Wastes*

Kind of Waste	Parts per Million		
	B.O.D. (5-day)	Suspended Residue	Oxygen Consumed
Mixed caustic and peroxide kier liquor	1,241	1,685	2,842
Wool scouring waste, Plant A	4,464	15,000	7,900
Wool scouring waste, Plant C	216	700	230
Tannery waste	5,000	5,150	2,000
Paper sizing waste	610	120	236
Sulfite pulp liquor	9,000	600	60,000
Paper machine waste	70	1,160	250
Slaughterhouse	600	3,600	356
Creamery waste	1,200	—	500

ter, acid, alkaline, or poisonous—each presents its own problem, and some present problems which are as yet unsolved.

Many objectionable conditions are due to batch discharges, as from wool-washing bowls, bleachery kiers, or from dyehouse or tannery vats. In many cases these discharges would be innocuous if they were distributed throughout the twenty-four hours.

Fish are sensitive to alkali and often succumb when exposed to the discharges of calcium hydroxide from tanneries, ammonia liquors, or laundry wastes. Species of fish vary greatly in their resistance to pollution. The introduction of silt into a non-silt-bearing stream is often disastrous to fish life. This discharge, however, is rarely prohibited by statute, for lawmakers evidently assume that what a Mississippi catfish can stand a State-of-Maine trout ought to. Suspended matter, like paper fiber (5), is not only injurious to fish but may also affect oysters (6).

Self-Purification

Natural purification in streams is effected chiefly by bacterial oxidation; that is, the bacteria feed on the organic matter and oxygen in the water and produce an innocuous oxidized product. The effectiveness of the bacteria is dependent upon the amount of oxygen present in the body of water at the point of discharge of sewage or waste, plus the amount that is added by dilution and reaeration.

The amount of oxygen required is the "biochemical oxygen demand" (B.O.D.), and this is balanced against the available asset of dissolved oxygen to give the "oxygen balance,"—positive or negative.

From the classic studies of Adeney (7) in Great Britain and Phelps (8) in this country, followed by those of Theriault (9), Frost (10), Streeter (11–12), Fair (12A) and others, the laws regarding oxygen demand, reaeration, and the oxygen balance (the main factors of self-purification in rivers and harbors) have been not only elucidated but mathematically expressed.

The progressive changes in the biochemical oxygen demand of polluted stream waters are becoming well known. They are modified, however, by additional pollution, inflow or dilution, sedimentation and absorption, channel scouring, and the presence of an "immediate" or "enzymic" oxygen demand. They are modified by the characters of polluting discharges.

Because self-purification is a combined biological, chemical, and physical process, it is evident that discharges of hot alkaline antiseptic wastes, like kier liquor, or those high in suspended matter, like wool-scouring waste, may delay self-purification, first, by inhibiting or destroying the growth of stream-purifying bacteria, and second, by forming sludge banks and introducing resistant fats. This delay may last until the dilution of the waste is large.

The significance of sludge beds was stressed by Rudolfs (13) in the case of Connecticut v. Massachusetts (Connecticut River Case); their purification requirements have been estimated by several investigators, notably by the U. S. Public Health Service group, and their requirements under aerobic conditions have been calculated by the experiments of Baity (14).

Standards for Polluted Waters

In establishing standards for waters polluted by industrial wastes, it is generally customary to use certain values, such as minimal dissolved oxygen, freedom from accumulating sludge deposits, or limiting bacterial content, all dependent upon the uses of the stream.

These standards range from those of freedom from nuisance to those of suitability for the supply of water purification plants. When industrial wastes are discharged, the physical and chemical loading is more important than the bacterial contents. In the case of domestic sewage, the opposite is usually the case.

The oxygen demand of normal sewage from separate sewers in a residential town is about 55 grams per capita, in large industrial cities as high as 150 grams per capita. This means that the discharge of sewage by 1000 people would be equivalent to from 55 to 150 kg. (120 to 330 lbs.) a day.

In 24 hours a fair sized woolen mill will discharge about 70,000 gallons of waste having a B.O.D. of about 9000 parts per million. This is an oxygen demand of 2363 kg. (5200 lbs.) daily or the equivalent of the sewage of an ordinary city having a population of 31,000 people.

In some wastes the settleable solids are excessive and may amount to 20 per cent of the volume of waste. Furthermore, the diluting power of streams receiving wastes with high amounts of inert settleable solids is less than that of streams receiving wastes with low amounts. The effect of sludge deposits on fish life is often disastrous, as Hubbs pointed out (15).

Because few industrial wastes are of human origin, although some are of animal origin, and because some of the most troublesome ones are sterile when discharged, the chemical criteria are generally more important than the bacterial. However, studies by the United States Public Health Service have indicated that the limit of tolerance for water purification plants employing chemical treatment and chlorination is about 5,000 *B. coli* per milliliter.

That analytical methods are not all-determining is well known. In studying the biology of stream pollution, Claasen (16) used schools of minnows for tests, but even these, valuable as they are, show the condition at the time of exposure only, just as chemical tests show the condition at the time of sampling only. This constitutes an argument for integrated rather than for catch chemical samples for analysis.

It naturally follows that a study of the plankton of a stream, which is a perfectly integrated index, is of great assistance in the study of pollution and self-purification. For example, the finding of the larvae of caddis flies is an index of tolerable condition, while the presence of blood worms (*Chironomidae*) or a fungus such as *Leptomitus* indicates the opposite.

The amount of self-purification performed by the plants and animals in a stream is not generally recognized, although these factors are substantial. Studies by the M. I. T. Sanitary Research Laboratory (17) of the Coweeset River receiving treated Brockton sewage showed that the river receiving the effluent lays down a ''pollution carpet'' containing an abnormal number of organisms, beginning with the lowest forms and ending with the highest; each group appears along with a definite food material.

When the Coweeset River was discharging less than 5 m.g.d. and was receiving about 2 m.g.d. of sand bed effluent, the most important changes occurred in the first mile of flow. However, the return of this stream to its normal chemical condition was not so rapid as its return to its normal biological condition. Here, as in Europe (18), where fish ponds are used for the treatment of sewage, the value of shallow storage in the course of the stream was shown.

In many polluted streams the dissolved oxygen tends to decrease until the excessive growth of animal life which is favored by pollution ceases. The rate of this decrease is usually higher than the normal rate of reaeration of the stream by absorption from the atmosphere, by plant growth, or by both.

Conclusion

It will be realized that the problem is not only one of percentage-purification of sewage or wastes, but of what the conditions require.

The most important factors are what the stream can do and what is the load upon it. For satisfactory conditions the former must be higher than the latter, the degree of excess being dependent upon the usage of the stream.

Each case is unique. Each requires a study to determine the volumes and characters of sewage or waste. This study should be thoroughly made. Frequently a study will show that part of the waste from certain industries may be discharged without treatment, with consequent reduction in cost of construction and operation. Frequently it is shown that recovery of by-products is worth while. For example, research for the paper industry has resulted in saving much fiber; wool grease is now being recovered profitably from wool-scouring waste; and even sulfite pulp liquor is yielding valuable by-products (19).

Recently, much of the work of German sewage works chemists and engineers has been in this direction, looking for products of military value or towards the *Nahrungsfreiheit* of Germany (20).

After the facts and possibilities are known, then follows in logical order the treatment necessary to preserve the stream or other body of water for its most useful purpose, whether it be for sewage or waste disposal, angling, shellfish culture, recreation, or water supply. In every case the capacity of the receiving and diluting water is the most important factor. This method has been exemplified in the work of the Pennsylvania Sanitary Water Board, of which all are aware.

In an address which was given less than two weeks ago in another beautiful college town, Mr. Justice Frankfurter emphasized two American canons or principles which might be applied to the control of streams, namely, the statement in the Bill of Rights regarding "life, liberty and the pursuit of happiness," and Lincoln's statement regarding the "government of the people, by the people and for the people."

So, those using streams should consider not only the life of the fish and the happiness of the angler but also the life of the mill owner and the happiness of those who must use the waters for domestic supply. The liberty of one must not destroy the life or happiness of another.

Likewise, following Lincoln, the control of the stream should be determinated by all those who have rights therein, and, having so determined, they should exercise it for the best good of all.

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THE OPERATOR'S CORNER

Conducted by W. H. WISELY, Executive Secretary*

Federation of Sewage Works Associations

Box 18 · · Urbana, Illinois

NO "FLASH IN THE PAN" . . .

we hope, is the influx of excellent contributions which followed the distribution of the May issue of SEWAGE WORKS JOURNAL, containing the initial appearance of "The Operator's Corner." We take this opportunity of expressing our sincere thanks for the acknowledgments which have been received, and trust that these will preface a steady flow of the practical, useful and interesting type of material that we aim to present.

An endeavor such as this is dependent upon *exchange* of experience. We must *contribute* if we hope to *receive.* Call it a game of "Put and Take," if you will, and if we all determine to be "Putters" it must follow that we shall be "Takers" as well!

As a gentle reminder, you can participate by sending us interesting operation problems and your solutions, descriptions of "gadgets" that you have devised to simplify or assist in some routine operation, copies of annual reports, photographs illustrating situations of interest to plant operators and news items which might remove a wrinkle or two from a worried brow. It is understood, of course, that prepared articles or papers are essential.

Ralph Waldo Emerson wrote that "Nothing great was ever achieved without enthusiasm," which sentiment is endorsed by the Federation's President, Charles A. Emerson and its other officers who are giving so unselfishly of their time and energy to achieve the aims and objectives of the organization. If we all add our small contributions to the activities of the various Member Associations and to the parent Federation, surprising results can be achieved.

Last, but not least, remember that

IT'S NEW YORK IN OCTOBER!

EXPERIENCES IN DIGESTION TANK SCUM CONTROL

That some form of digestion tank scum problem exists in one-fourth of all sewage treatment works employing the process is believed to be a conservative estimate. Where the problem is encountered, the resulting interference with proper digester operation, the ever-present

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

hazard to structures and equipment, and the difficulty in eliminating or controlling the cause makes it a most vexing one to operation personnel.

In reply to a number of inquiries addressed to operators of plants located throughout the continent, the Corner has received several interesting contributions to this compilation of experience in digester scum control. We are indebted to the following for their earnest cooperation:

H. W. Bauer, Superintendent, Middletown, Connecticut
Leland Bradney, Chemist, Sioux Falls, South Dakota
R. W. Frazier, Superintendent, Oshkosh, Wisconsin
J. K. Frei, Sanitary Engineer, Springfield, Missouri
E. W. Groshans, Engineer, Baraboo, Wisconsin
A. L. Hanenberg, Sanitary Engineer, Kitchener, Ontario
W. H. Hatfield, Superintendent, Decatur, Illinois
W. A. Hutchins, Superintendent, Freeport, Illinois
Jacob Klein, Superintendent, Sheboygan, Wisconsin
C. C. Larson, Chemist, Springfield (Illinois) Sanitary District
H. A. Riedesel, Engineer, Rockford (Illinois) Sanitary District
J. R. Turner, Superintendent, Mansfield, Ohio
J. B. Wirt, Superintendent, San Leandro, California

Most of the situations discussed here are extreme, and in some cases, due to unusual local conditions. Consequently, there can be no reflection upon the various types of digestion tank equipment involved.

Scum Control in Fixed-Cover Digesters

Kitchener, Ontario.—Matted hair from tanneries and meat packing plants and felt fibers from felt factories create such a dense scum blanket in the digesters of Kitchener's Main Sewage Treatment Plant that structural damage has resulted to the mechanical scum breaker arms. The two digesters at this plant were converted to two-stage operation in 1939 and scum accumulations as great as 11 ft. thick have been experienced in the first stage. The material compacts in the gas domes and occasionally in the gas piping, thus interfering with gas collection as well as overloading the mechanism.

The overload indicator on the digester mechanism is carefully watched and the scum is manually removed by dipping from the manhole when the pointer approaches critical values. An average of 440 cu. ft. per week during 1940 and almost 600 cu. ft. per week during the first three months of 1941 was removed in this manner.

The compacted scum in the gas domes is periodically broken up and softened by water under pressure introduced at the gas dome inspection ports. This has been found to reduce the scum layer to some extent by settling a portion of the material into the sludge accumulation. Occasionally it is also necessary to manually dip the scum from the gas domes and extreme caution is exercised due to the large amount of gas which is released.

The scum taken from the digesters is hauled in industrial dump cars to the low-lying river flats adjacent to the plant where dried sludge is also deposited.

City Sanitary Engineer A. L. Hanenberg is of the opinion that this difficult problem can be eliminated by the installation of fine screens between the detritus and primary sedimentation tanks, thus assuring positive removal of the hair and fibrous material which predominates in the digester scum. An alternate method of relief may be possible through the provision of adequate preliminary treatment of the troublesome wastes by the industries at which they originate.

Sioux Falls, South Dakota.—A sewage containing 54 per cent packinghouse waste is responsible for an extreme scum control problem at Sioux Falls, despite the fact that the packinghouse wastes are passed through fine screens before discharge to the city sewers. Three heated digesters, each 85 ft. in diameter and 27 ft. deep, are equipped with sludge stirring and scum breaker equipment and are operated in single stage.

During the summer of 1940, digester scum accumulated to such an extent that the breaker arms became ineffective and completely stalled. By November, the scum became so dense and heavy that the gas outlets of one tank became sealed and sufficient pressure developed to break loose and raise the roof a distance of about six inches.

A schedule of daily recirculation of the sludge in each tank at a rate of 1500 g.p.m. for two hours daily brought immediate relief and brought the situation under control. The recirculation has also been found beneficial in increasing gas production and improving digestion. No attempt was made to remove the scum from the digesters.

At this time, high-speed stirring equipment (turbo-mixers) are being installed in all of the digesters and operation is being converted to two-stage, with two primary and one secondary unit. Chemist Leland Bradney does not anticipate continuation of the scum control problem when the current improvements are completed.

Mansfield, Ohio.—Superintendent J. R. Turner has adopted a ''non-interventionist'' policy in regard to digester scum control, which is undoubtedly proper in many cases where the problem is not severe. The fixed-cover digesters at Mansfield are equipped with removable heating coils and with ''turbo-mixers'' which are operated continuously.

On only one occasion since 1937, during a case of foaming, has any scum been removed from the digester, and that was only a small portion from immediately beneath the manhole opening. At this time there appeared to be about two feet of scum, composed principally of hair, in the unit. The bulk of the accumulation was left undisturbed without detrimental effect.

Springfield, Missouri.—The presence of large numbers of snail shells in the humus sloughed from the trickling filters is responsible for the attention required to control digester scum in this plant. Digestion facilities comprise two heated units operated in single stage, one of which is equipped with a fixed cover and mechanical sludge stirring and scum breaker arms and the other equipped with a floating cover.

The snail shells collect to such an extent that removal must be effected about once every ninety days. The procedure of Superintendent John K. Frei is to plan to remove scum after sludge is withdrawn and draining off the scum through piping provided for the purpose as the digester level is raised by pumping thereto. It is usually necessary to use water under pressure to break up and dilute the material to obtain flow.

The scum piping arrangement permits withdrawal to the sludge drying beds whence disposition is by hauling away for use as fill.

Sheboygan, Wisconsin.—In December, 1940, one of the fixed-cover, primary digestion tanks "exploded" by bursting open at the edge of the double-slab concrete roof, causing about $10,000 damage. This serious occurrence has been attributed to an 8 to 10 ft. accumulation of scum, which prevented release of gas and caused a gradual increase of pressure until the unit weight of the roof was exceeded.

The Sheboygan plant receives a considerable volume of tannery wastes which contain scraps of hide, hair and lime. Much of this passes the bar screens and is removed at the primary tanks with the sludge, whence it is pumped to the digesters. Although the first-stage digesters are equipped with mechanical mixers, the scum is so fibrous and dense that the mixers were not effective and the deep layer of scum resulted.

FIG. 1.—Digestion Tank "Eruption" at Sheboygan, Wisconsin, Caused by Excessive Scum Accumulation.

No evidence of ignition of gas was noted following the "explosion," it being fairly evident that pressures inside the tank became so great that the roof (not anchored to the walls) was lifted at one side, releasing gas and sludge under such pressure as to blow down much of the brick veneer insulating wall and to spew sludge for a distance of fifty feet. Inspection of the gas piping, meters, flame traps and pressure control devices revealed all of this equipment to be in normal condition. The sludge transfer piping was known to be open thirty minutes prior to the accident and the tank is equipped with an emergency overflow for protection against damage due to stoppages in the transfer lines. The theory expressed above, concerning the effects of the scum blanket, is well substantiated by the facts at hand.

Superintendent Jacob Klein suggests the following possible methods of prevention of similar damage in the future:

1. Removal of the hair, hide scraps and other tannery waste constituents responsible for the density of the digester scum, by means of fine screens or similar equipment.
2. Installation of "extra heavy duty" scum stirring equipment, designed for the rigorous service demanded in this case.
3. Removal of the scum from the digesters before it accumulates to a dangerous extent. Two additional digestion units have just been completed, which extra capacity is expected to make possible the dewatering and cleaning of each unit at regular intervals.

Rockford, Illinois.—District Engineer H. A. Riedesel reports an unusual method of expediting withdrawal of a dense scum blanket in the fixed-cover tanks at this plant. The tanks are not equipped with mechanical sludge or scum stirring devices.

FIG. 2.—Digester Scum Flushing Arrangement Used at Rockford, Illinois. H. A. Riedesel, Superintendent.

A tripod with a block at the vertex (Figure 2) was erected over the gas dome opening ofter the dome was removed. A rope was inserted through the pulley, having attached to one end a large number of ½ to ¾-in. link chains, aggregating about 75 pounds in weight. These chains were "slushed" into the scum as it was forced to the withdrawal pipe at the center of the tank by means of a hose stream and the heavy scum accumulation was thus successfully removed by gravity flow.

Scum Control at Floating-Cover Digesters

Springfield, Missouri.—Refer to comments on this plant included under the discussion of fixed-cover units.

Oshkosh, Wisconsin.—This plant includes two heated, floating-cover digestion tanks, operated in two-stage, with 20,000 cu. ft. of gas storage afforded in the secondary unit. A heavy scum blanket is encountered in the first-stage or primary digester, creating a problem, but no difficulty of this kind has been experienced in the secondary stage.

The scum comprises the usual buoyant and digestion-resistant material removed from the sewage at the scum troughs of the primary sedimentation tanks, containing leaves, sticks, tin foil, hair, seeds, etc.

Attempts to remove the scum blanket by means of water jets and by drainage to the sludge drying beds yielded unsatisfactory results. Jetting was found to wash away the organic matter adhering to the floating material, but most of the mass still floated. Efforts to drain off the scum were deemed unsuccessful due to the difficulty in obtaining flow, even when water jets and paddles were employed.

The present method of removing scum is by manual dipping with specially designed implements (Fig. 3) which fit between the side of

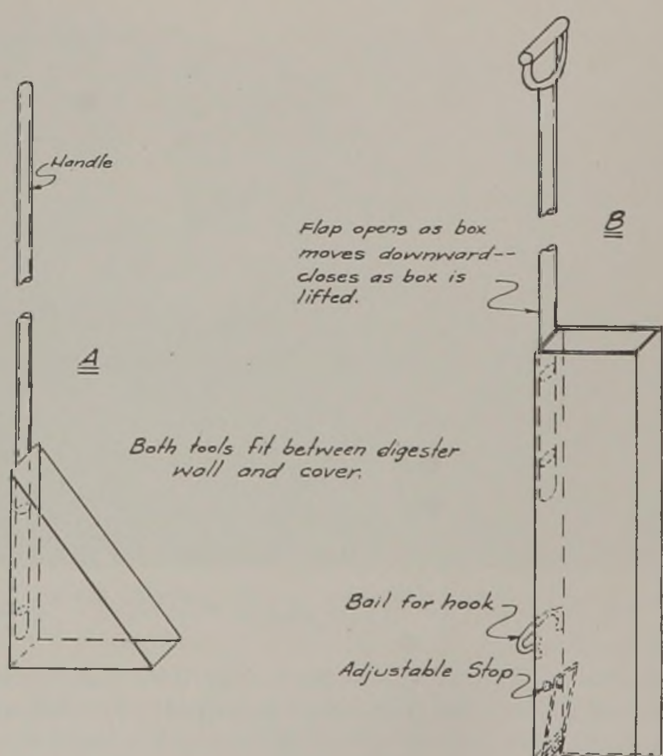

Fig. 3.—Digester Scum Removal Implements Used at Oshkosh, Wisconsin. R. W. Frazier, Superintendent.

the cover and the tank wall. The dipper marked "A" is used for dry material and that labelled "B" when the scum is mushy. The material is hauled in wheelbarrows to a marshy area in the plant grounds and covered with lime and earth. Such manual removal is necessary at variable intervals.

Superintendent R. W. Frazier indicates that an attempt will be made this summer to eliminate this problem by pumping the scum from the primary sedimentation tanks directly to compartments partitioned off in one of the sludge drying beds, thus relieving the digestion units of this load. The scum will be treated with lime or chlorine to preclude odors and will be removed to the dump after drying.

Frazier also offers the opinion that digester scum can be completely eliminated by the use of fine screens and screenings incineration facilities, although he points out that this practice may result in lower gas production due to the reduced charge of volatile solids to digesters.

Springfield, Illinois.—Following laborious endeavors to keep his digestion tanks clear of scum in the first year or two of operation, Chemist C. C. Larson came to the conclusion that his problem was not so serious and that a "leave it alone" policy could be safely followed. Periodic observations of the accumulation beneath the floating covers here have shown that it remains fairly soft and varies in thickness from a negligible amount to a depth of 18 inches.

This experience parallels that of Turner at Mansfield, Ohio, where the problem is also not a serious one.

Baraboo, Wisconsin.—Superintendent E. W. Groshans has been successful in reducing digester scum accumulation to 12 to 15 in. in thickness by occasionally raising the digester temperature to 95° to 100° F. for about 48 hours. He has found that the solids content of the supernatant liquor is increased during the treatment but that the scum blanket is effectively controlled.

Freeport, Illinois.—With raw sewage chlorination being practiced during summer months only, Superintendent Will A. Hutchins has had opportunity to observe the effects of chlorine on digester scum accumulation. His experience, similar to that at many other plants, has been that the scum blanket is negligible during chlorination but that a 2 to 3 ft. layer develops during the time that chlorine is not used.

Hutchins reports further that the blanket was successfully reduced on two occasions by increasing the digestion temperature for a day or two, as practiced at Baraboo, Wisconsin, but that this procedure was not particularly effective the last time it was attempted.

Scum Control on Imhoff Tanks

Urbana-Champaign, Illinois.—A strong domestic sewage, hard public water supply and multitudes of trickling filter snail shells are believed to be primarily responsible for gas vent scum accumulations ranging from 3 ft. in thickness in summer to 12 ft. deep during freezing weather. There is no definite proof of the influence of the hardness in the public water supply (296 p.p.m.) but it appears logical that much of the extraordinary amount of soap curd in the sewage would find its way into the scum layers. The return of ground screenings to the sewage flow may also tend to increase the scum accumulation; however, this is not borne out by plant operators who have had opportunity to observe conditions before this method of screenings disposition was practiced and who indicate that there was no visible evidence of an increase in scum after ground screenings were taken.

In the late winter and early spring months, the scum accumulation is of such depth and density that gas cannot escape from the vents. This results in ebullition of gas through the slot and belching up of large chunks of sludge into the sedimentation channels, greatly increasing the labor requirements in skimming. In non-freezing weather, past practice had been to churn the scum in the gas vents with a heavy hose stream, which was effective in releasing the gas but caused appreciable disturbance in the sedimentation channels. Hosing of the vents required about 10 to 20 man-hours per week of time by operation personnel. Removal of the scum to the sludge drying beds resulted in improvement lasting only about two weeks and the difficulty in drying the material makes this practice undesirable.

In August, 1940, observations of the effect of a fine spray of water (from the plant effluent system) showed somewhat promising possibilities. A pipe manifold fitted with spray nozzles spaced to fit the gas vents was first tried on one end of the vents of one tank and the effectiveness of these was immediately evident. The spray system was extended to all four tanks before the end of September.

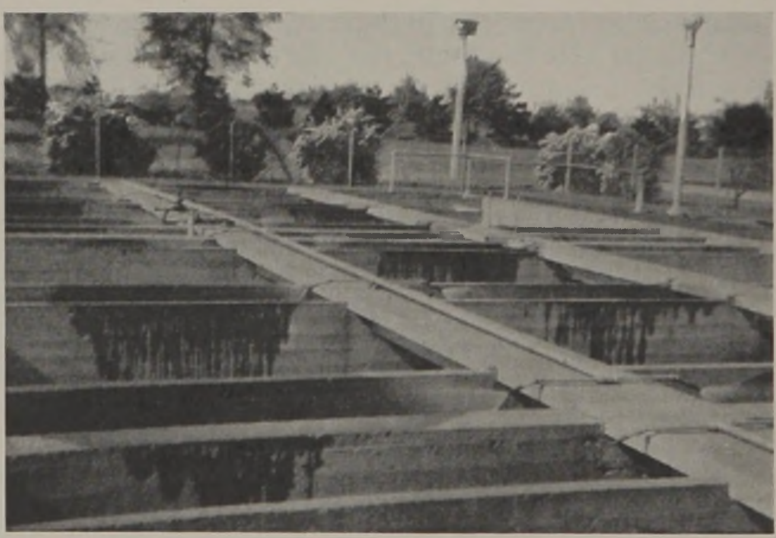

FIG. 4.—Imhoff Tank Gas Vent Sprays at Urbana-Champaign, Illinois.

The arrangement of the spray system is shown in Fig. 4. The manifold pipes are 1½ in. in diameter, which is reduced to ¾ in. at each nozzle. Ordinary garden hose nozzles were found to be most adaptable since they cost only 25 cents each, give any desired intensity of spray, can be completely shut off and are not subject to clogging even though plant effluent is used as the water source. The piping layout is economical as four tanks are completely served by 250 ft. of 1½-in. pipe and 75 ft. of ¾-in. pipe. The cost of the pipe, fittings and nozzles was $151.69 and the installation was accomplished by regular plant personnel.

FIG. 5.—Close-up View of Gas Vent Spray at Urbana-Champaign.

Operation of the sprays from 30 to 90 minutes a day has been found sufficient to bring about satisfactory results. When the scum layer is more than 4 ft. thick, operation of the sprays for about 45 minutes in the morning and again in the evening is best because overlong operation at one time under such conditions causes some fine solids to rise through the slot. No attempt has been made to use the sprays in cold weather because of the ice which would result.

Eight months experience with the sprays has led to the following conclusions:

1. Release of gas is unquestionably expedited by the softening of the scum. Active gas ebullition is noted only 2 or 3 minutes after the sprays are turned on.

2. The scum accumulation is kept under control. Each time the sprays are operated, part of the solids are deposited in the sludge compartment where much remains. Scum layers 12 ft. thick in March, 1941, when temperatures moderated sufficiently to permit use of the sprays, were reduced to 5 to 7 ft. by April.
3. It is believed that most of the organic acids in the scum are washed out, thus reducing any tendency toward serious foaming. One or two instances of mild foaming were readily controlled by use of the sprays and it is certain that there would be no difficulty in confining foam to the vents should a bad case develop.
4. The sprays do not drive down material such as sticks, hair, and other materials which are buoyant and almost non-digestible and such substances must still be directly removed from the vents by other methods.

Tracy, California.—It is reported that gas vent sprays have been installed and found beneficial in this plant; however, details are not available at this time.

Decatur, Illinois.—Numerous snail shells from the trickling filters collect beneath the gas collectors built in the Imhoff tank gas vents here,

FIG. 6.—Gas Dome Scum Spray at Decatur, Illinois, W. D. Hatfield, Superintendent.

necessitating occasional manual removal and other attention. An unusual nozzle, used successfully by Superintendent W. D. Hatfield to soften and reduce the accumulations at the gas collection domes is pictured in Figure 6.

CONCLUSIONS

The Corner takes the liberty of analyzing the material submitted and developing general conclusions therefrom. Although the control of digester scum is not difficult in many plants, it is evident that the problem may have serious aspects and that cognizance of it is well justified by sewage works designers and operators. The following conclusions are offered:

1. Consideration of the potential scum producing constituents of industrial wastes prior to design of treatment facilities is undoubtedly warranted. Where such investigation indicates that a problem is likely to result, the following suggestions are listed for the guidance of the designer:
   A. Requirement of preliminary treatment facilities by the industries producing wastes anticipated to cause trouble.
   B. Inclusion of special preliminary treatment facilities in the sewage treatment works to remove and dispose of scum-forming constituents before digestion units are affected. Fine screens with screenings incineration has been suggested as one method of accomplishing this.
   C. The provision of scum control equipment adapted to the type of problem expected, where complete preliminary removal of scum-forming constituents may not be feasible. It is evident that unusually powerful control devices would be necessary to handle some of the very heavy accumulations described above.
   D. The difficulty in forecasting digester scum accumulations in many situations where the sewage to be treated is of ordinary domestic character suggests that the development of a workable, convenient, and flexible scum withdrawal piping arrangement at digestion tanks, is justified.
2. If he wishes to avoid the damage and hazard experienced at Sheboygan and other places, the operator must exercise the utmost vigilance if digester scum formation is likely to prevent release of gas or to clog overflow, transfer or gas piping. Periodic inspection of the blanket is desirable in every plant, with the frequency of observation dependent upon local conditions. When the accumulation is reasonably soft and not excessive in thickness, it appears unnecessary to resort to unusual operation procedures to effect control. When reduction of the accumulation does appear to be necessary, the following operation measures have been found effective:
   A. Prechlorination, which may be both preventive and remedial.
   B. Recirculation of the digester contents.
   C. Temporary increase of digestion temperatures to about 95° F. for 48 hours.
   D. Use of water jets or sprays (best suited to control of Imhoff tank scum).
   E. Withdrawal or manual removal to sludge drying beds or dumps. Various methods of facilitating removal are described.

Anyone having additional comments on the above compilation of experience is cordially invited to contribute. A similar symposium on "Experiences in Odor Control" is planned for the CONVENTION NUMBER (September issue) of the Journal, and contributions on this subject are also welcome. Contributions must be received before August 1.

INTERESTING EXTRACTS FROM OPERATION REPORTS

Toledo Division of Sewage Disposal (1940)

By A. H. Niles, *Superintendent*

Sludge for Fertilizer—"Tol-e-Gro."—Although sewage sludge was first sold in 1934, it was sold in bulk with no preparation for the first two years. It was first prepared in a crude way in the fall of 1935 and sacked in used burlap sacks—calcium chloride bags obtained from the Division of Streets. In 1936, better equipment for its preparation was obtained by trading sewage sludge to the City's Welfare Farm at Whitehouse for a hammer mill they were no longer using. This was housed in a makeshift tarpaper shack. All this time attempts were made to get a W. P. A. project through for the construction of a modern sludge grinding plant and a warehouse to hold about 500 tons. This W. P. A. project was finally completed late in 1937 and the following year modern sludge grinding, conveying, elevating and storage equipment was installed for reducing the cost of preparation of sewage sludge for fertilizer. Attention was then turned more actively to marketing, and at the Municipal Exposition held in June, 1938, there was a contest for naming the new fertilizer. "Tol-e-Gro" was the name picked from some thirty names which were submitted. In the fall of 1938 an automatic bag filling and weighing machine was contracted for on a rental basis. This machine fills printed, preclosed, multi-wall paper bags through a paper valve. The spring of 1939 was the first time an attractive looking package was used—one with an identifying name to build up good will. During the summer and fall of 1938 and the spring of 1939 a salesman was sent out to acquaint the department stores, the hardware dealers and grain elevators with Tol-e-Gro. Literature and sales helps were prepared for the dealers. To give an idea of how the sale of the branded merchandise, Tol-e-Gro, has increased the following table is shown comparing some of the larger dealers in Toledo and Detroit territory.

It is to be noted that the 25 lb. package has been more popular in Detroit where the demand originated with the Lazoen Feed and Grain Co. who had used that size package exclusively in 1939.

In 1940, out of the 1,018.51 tons sold, 461.1 tons were in burlap bags which were returned for refilling. This tonnage went to fertilizer mixing plants where it is used as a base for regular standard balanced

Dealer's Name	Size Package (Pounds)	Tons Sold	
		1939	1940
Tiedke Bros.	80	56	75
Sears Roebuck & Co.	80	10	17
Lazoen Feed & Grain Co.	80	57	92
Lazoen Feed & Grain Co.	25	23	32
Michigan Hay & Feed	80	36	42
Michigan Hay & Feed	25	—	3

chemical fertilizers. The market price for this purpose is quite unstable and paper bags are of no value in building up good will in this class of business. However, it looks very much as though it will just be a matter of time when all of the available sewage sludge can be sold for retail trade in the Tol-e-Gro bags, which will be a very desirable condition. The following table shows the cost of processing per ton when packed in the type of package indicated.

	Old Equipment Cost per Ton (1936)	New Equipment [1] Cost per Ton (1940)	New Equipment [2] Cost per Ton (1940)
Labor	$2.18	$1.02	$0.58
Bags	.82 [3]	.20 [4]	1.21 [5]
Bag Ties	.04	.044	—
Electric Power	.41	.055	0.0665
Supplies and Repairs	.18	.0510	0.0510
Rental of Packer	—	—	0.1525
Total Cost	$3.63	$1.37	$2.0600

[1] Bags filled by operator.
[2] Bags filled by packer.
[3] Including bags from Street Dept.
[4] Cost of unusable burlap bags returned from fertilizer mfg.
[5] Printed multi-wall paper bag cost.

The net profit on sales of fertilizer for the years 1937–1940 is shown in the table below.

	1937	1938	1939	1940
Tons of fertilizer sold	957.66	600.22	1,265.15	1,018.51
Total selling price	$8,424.72	$6,186.25	$10,536.37	$8,656.58
Processing or mfg. cost	3,476.33	1,266.46	2,617.86	1,780.50
Processing or mfg. profit	4,948.39	4,919.79	7,918.51	6,876.08
Less advertising expense	150.83	172.21	268.65	198.35
Less sales promotion and sales expense	—	866.53	487.50	—
Net profit except general overhead and fixed charges	$4,797.56	$3,881.05	$ 7,162.36	$6,677.73

Summary of Operation Data.

Item	1940 Average	
Sewage flow treated	31.30	m.g.d.
Screenings and scum removed	164	cu. yds. per month
Grit removed	83	cu. yds. per month
Digested sludge (yearly totals):		
Removed to marsh	40,905	cu. yds.
Removed to drying beds	12,729	cu. yds.
Dried sludge from beds	2,133	cu. yds.
Dried sludge pulverized for fertilizer	949.20	tons
Pulverized sludge sold as fertilizer	1,018.51	tons
Chlorination:		
Total days applied during year	44	
Chlorine applied	3,059	lbs. per day
Suspended solids:		
Raw sewage	201	p.p.m.
Plant effluent (sedimentation only)	74	p.p.m.
Removal (sedimentation only)	62.8%	
Setteable solids removal (sedimentation only)	92.1%	
5-day B.O.D.:		
Raw sewage	211	p.p.m.
Plant effluent	119	p.p.m.
Removal (sedimentation only)	43.1%	
Gas production:	8,377,900	c.f. per month
Used for heating buildings	606,900	c.f. per month
Used for heating digesters	631,500	c.f. per month
Used for power to pump sewage	2,317,500	c.f. per month
Used for electric power generation	1,674,400	c.f. per month
Wasted	3,116,200	c.f. per month
Operation costs (per m.g. treated):		
Power	$0.01	
Supplies	$0.92	
Supervision and labor	$4.69	
Total	$5.62	

Note: Attention is directed to the figures pertaining to the disposition of digested sludge. Since the sludge drawn to the drying beds is the source of Tol-e-Gro, it is indicated that, during 1940, approximately 24 per cent of the total sludge output was marketed as fertilizer.

Butler, Pennsylvania (January 1 to November 30, 1940)

By T. R. Haseltine, *Former Superintendent*

Triturator Experience.—The operation of the triturator was a new experience for all of us. The arrangement of the screen and grinder did not lend itself to easy measurement of the amount of screenings to be ground, so we governed our rate of feed by the sound of the triturator. In other words, we fed it just as fast as we could without causing it to slow down. After several weeks of operation, we began to experience trouble drawing sludge from the primary clarifiers and occasionally a sludge pump would become clogged with long, masticated strings of rags. Our first step to correct this trouble was to place the old 1-inch bar screen under the triturator discharge, but above the sewage level. We found that almost 10 per cent of the triturator discharge could not be forced through this screen even when a hose stream was played upon it. At the manufacturer's suggestion we checked the rate of input to the shredder and found that we had been feeding it at about 60 cu. ft. per hour although the machine was only rated at 20 cu. ft. per hour. Since then we have been feeding the triturator at the rate of about 12 to 15 cu. ft. per hour and have practically eliminated all the trouble. We shall keep the 1-inch screen under the triturator discharge, however, just as a precautionary measure. It catches about 1 per cent, or less, of the material passing through it.

The triturator teeth were replaced, and the old ones resharpened, on September 15th, after about ten months of service.

Chlorine Treatment of Filter Ponding.—On February 13 we noticed some ponding on the west filter. Microscopical examinations of the growths in the filters showed them to consist mostly of filamentous organisms with some zoogloea and a very few protozoa. At first we thought that ponding was caused by excessive loading of the west filter during the times the east filter was being by-passed. But since there was no improvement by February 25 we by-passed both filters until March 12. When we started up again, we chlorinated the settled sewage using about 400 lb. per day and maintaining a residual of 2 p.p.m. or more. After four days we were getting a chlorine residual of 1 to 1.5 p.p.m. in the filter effluent, so, discontinued chlorination. However, there was still some ponding on the west filter. By April 9 there were slight indications of ponding on the east filter. Condition of both filters remained about the same until April 25. In the meantime the final clarifier had finally been put in service on March 26 but the recirculation of from 0.5 to 1.0 m.g.d. of final effluent had not reduced ponding.

On April 25 we by-passed most of the settled sewage, chlorinated the final tank very heavily (300 to 400 lb. per day), and recirculated the final effluent first onto one filter for a day, and then to the other on the following day. This was continued through May 4 without inducing unloading. The filters were rested on the fifth. From 8 A.M. to 5 P.M. on the 6th, chlorinated effluent plus some sewage was pumped to the west filter. A man stationed there held the distributor arms in one place for about ½ hour (20,000 to 25,000 gal.) then rotated them 10 ft. and repeated. This treatment produced very heavy unloading. It was applied to the east filter on the 6th, and to the west one again on the 7th and 8th. The filters were then put into normal operation on reduced flow, at noon of the 7th. Since May 11 they have treated practically all of the sewage flow and there has been no recurrence of ponding. However, there has been a noticeable increase in filamentous growths during November. *Psychodidae* flies made their first appearance in May at about the time the filters started to unload. Throughout the summer they were very plentiful. We noted a marked decrease in their numbers early in November at about the same time we noted an increase in filamentous growths. The writer does not know whether the *psychodidae* larvae actually destroys the filaments or whether the changes in numbers of both organisms are due mainly to temperature changes.

Filter Influent Screens.—The original design provided for screening the settled sewage through a ¼-in. mesh screen before pumping it to the filters. When we started operation, we found that this screen became clogged frequently in one to two hours. At the designer's suggestion, we abandoned the use of these screens for a while, but on May 11 we changed the screens to ½ in. mesh and have used them ever since. They usually have to be cleaned about three times a day. During the time that no screens were in use and sewage was being applied to both filters, an average of 67 nozzles per day required cleaning—about 33 per cent of the total nozzles. When only one filter was in use, higher velocities prevailed and only 28 nozzles per day required cleaning. Normally, from 6 to 12 per cent required daily cleaning after the ½-in. mesh screens were used, but during the period of falling leaves the percentage increased to twenty. This is due principally to the fact that the final effluent that is recirculated is not screened and leaves which fall into it are carried onto the filters. Much of the normal clogging is caused by chunks of grease. The grease passes through the screen but then congeals into a heavy coating on the walls and pipes in the wet well. At times, pieces of this coating are broken off and chunks are pumped to the filter.

Stone Dust from Filters.—After leaving the filters, the sewage flows by gravity to the final clarifier. This tank is 50 ft. in diameter and has a water depth of 10.67 feet; is arranged for center feed and circumferential overflow and is equipped with Rex-Tow-Bro sludge removal equipment as manufactured by the Chain Belt Company. At first we pumped the sludge from this tank to the sludge concentration tank, however, we found that this sludge would not concentrate in the time available. On May 23 we started pumping the sludge directly to the new digester. In our effort to draw as heavy a sludge as possible, we apparently failed to draw enough, for on June 4 the overload device threw the mechanism out of operation. We drained the tank and pumped the accumulated sludge to the digester. From that time on, we have pumped a large volume of thin sludge from this tank back to the raw sewage. On August 13 the overload device again threw the mechanism out of operation. This time when we drained the tank, we found an accumulation of fine sand or limestone dust. Two cubic yards of this material was shoveled out and since then we have had no further trouble, although inspection of the filter underdrains shows that some such material is still being washed out of the filters. It is not definitely known whether this material was simply stone dust placed in the filters with the original stone and did not wash out because of the heavy filamentous growths, or whether it indicates disintegration of the filter media since it was placed.

Note: It is not uncommon to encounter appreciable accumulations of stone dust in final sedimentation tanks immediately after a new trickling filter is placed in operation.

A Tip about Gas Engines.—We had one of the manufacturer's mechanics assist our men when the engine was torn down in December and found it to be in excellent condition. No new parts were required other than gaskets, oil rings and one new spark plug. It had run about 6,800 hours since the last overhaul. At first we had considerable trouble with spark plugs but after adopting the practice of cleaning and adjusting them at each oil change, we have had little trouble. Prior to March 20th we had to replace seven of the twelve spark plugs. On that date we put in all new ones, carefully adjusted, and since then have replaced only three.

Muskegon Heights, Michigan (1940)

By R. A. Anderson, *Superintendent*

Effects of Metal-Plating Wastes on Activated Sludge.—The trade waste received at the treatment plant during 1940 was greatly reduced in volume. The Norge Company made many plumbing changes during the early part of the year and to avoid extra expense only one main line was laid through the factory. As the chemical solutions which are harmful to biological life are scattered throughout the factory, the company decided to return all of the waste to the storm sewer system with the exception of only a few of the solutions which were connected to the sanitary system through separate lines. The wastes now being received at the treatment plant are the 42 per cent caustic solution, 7 per cent sulfuric acid and a new solution called ''oakite'' in which the main chemical used is phosphoric acid.

Investigation at the ''Sealed Power Plant'' indicated that they discharged nearly all of the machine oil and soluble oil (grinding emulsion). An oil separator was purchased by the company to remove the machine oil. The soluble oil and spent grenadine wastes have been connected to the sanitary system and the only waste now connected to the storm sewer is that from the cadmium plating department. The sulfuric-oxalic acid mixture is hauled to a dump as this waste might seriously injure the sewer. A new employee dumped this waste by mistake into the sanitary sewer on Sept. 13, 1939, resulting in a total acidity of 3,000 p.p.m. in the raw sewage composite. The analysis of the combined trade waste from the ''Sealed Power Company'' indicated that it was resin soap emulsion and that it was harmless to sewage organisms.

The caustic and acid wastes, nickel sulfate and the soda ash borax solution in the pickling line in the porcelain room at the ''Norge Company'' are all more or less harmful to biological sewage treatment processes.

The Norge has made progress in the manner of handling the wastes from the nickel sulfate tank. At present a cold process has replaced the former hot process and a large portion of the nickel sulfate solution is recovered and re-used after settling out the sludge which collects in this tank. The ceramic engineer had assumed that this sludge was almost entirely iron oxide but analysis showed that the dried sludge contained 60.25 per cent nickel sulfate. However, because of the improved method of handling, the effect of this waste upon treatment plant processes is greatly reduced.

The soda ash borax solution was replaced temporarily in December with a 0.2 per cent solution of sodium cyanide. The effect of this waste upon the activated sludge was so serious that the company returned to the soda ash borax method.

FIG. 1.—A View in the Muskegon Heights, Michigan, Plant Grounds. R. A. Anderson, Superintendent.

The caustic and acid wastes severely affect the pH and the settling characteristics of the activated sludge. Occasionally these wastes will reduce the rate of gasification in the digesters for a few days. It has been recommended that a neutralizing tank be constructed to hold all of the spent liquors from this steel pickling line.

Because of a scarcity of the mineral, the use of antimony in the porcelain frit has been discontinued and zirconium and titanium are now used as flux. This waste is being discharged to the storm sewer but should be returned to the sanitary system.

There are two chemical units which use chromic acid as a wash water. The smaller unit uses about 18 pounds potassium dichromate per day and has been continuously connected to the sanitary system. The larger unit, which is combined with the grenadine process, uses 72 pounds of potassium dichromate per day and has never been connected to the sanitary system and this waste contains 540 p.p.m. chromic acid. Recent literature points out the toxicity of chromic acid to biological sewage treatment processes. A series of laboratory tests with wastes obtained from the larger unit confirm this characteristic of chromic acid. The results are as follows:

Dilution of sewage with an equal quantity of this waste resulted in killing 16 per cent of the bacterial life after 15 minutes contact;

diluting 25 parts of sewage with one of waste resulted in 14.7 per cent kill; 50 parts sewage to one waste, 12.4 per cent; 1000 parts sewage to one waste, 3.3 per cent.

It is also reported that if this waste is discharged adjacent to a bathing beach it may cause a skin rash to appear.

The condition of the stream below the storm sewer outlet during 1940 was poor and a large increase in turbidity and floating oil wastes were noticeable.

Summary of Operation Data.

Item	1940 Average
Tributary population	15,000
Sewage flow	1.09 m.g.d.
Sewage flow	73 g.c.d.
Screenings removal	1.5 c.f. per m.g.
Grit removal	3.8 c.f. per m.g.
Volatile content	40%
5-day B.O.D.:	
Raw sewage	308 p.p.m.
Primary effluent	173 p.p.m.
Activated sludge effluent	9.7 p.p.m.
Rock filter effluent	9.8 p.p.m.
Sand filter effluent	4.3 p.p.m.
Suspended solids:	
Raw sewage	364 p.p.m.
Primary effluent	166 p.p.m.
Activated sludge effluent	16 p.p.m.
Rock filter effluent	18 p.p.m.
Sand filter effluent	5 p.p.m.
Sludge digestion:	
Raw sludge quantity per m.g. sewage	8,292 gallons
Per cent solids	3.98%
Per cent volatile	67.2%
Reduction in volatile matter	63.2%
Digester loadings (lbs. per cu. ft. per month):	
Total solids	1.69 lbs.
Volatile solids	1.13 lbs.
Digested sludge per cent solids	6.79%
Per cent volatile	43.0%
Daily gas production	21,580 cu. ft.
Per capita daily	1.44 cu. ft.
Per pound dry solids added	7.10 cu. ft.
Per pounds volatile solids added	10.56 cu. ft.
Per pounds volatile solids digested	16.72 cu. ft.
Activated sludge:	
Aeration period	7.1 hours
Applied air	0.42 c.f. per gal.
Return sludge	35.1%
Solids content	4,600 p.p.m.
Mixed liquor solids	1,300 p.p.m.
Sludge index	185
Operation costs:	
Per million gallons treated	$36.53
Per capita connected	$ 0.97

Note: Superintendent Anderson supplements the Muskegon Heights industrial waste situation by a recent letter advising of the present status:

"Because of an unwillingness of the Norge Refrigerator Company to co-operate with the City in the treatment of their wastes the entire trade waste problem has been placed in the hands of the Stream Control Commission.

"Some time ago the return activated sludge was analyzed for nickel sulfate and we learned that nickel was present in an amount equal to 6 pounds per 1,000 pounds of sludge on a dry basis. With this loading it was impossible to obtain satisfactory operation of the activated sludge unit. Nickel sulfate does not harm sludge digestion to any noticeable extent.

"The acid pickling and de-enamel tanks and the nickel sulfate sludge have been removed from the sanitary system during the past month and the results obtained at the treatment works is now much more satisfactory. It is planned to discharge these wastes to a sand pit at the rear of the factory."

BARK FROM THE DAILY LOG

July 1—Found that a section of our 18-inch, South Branch intercepting sewer, partially exposed at a creek crossing, had been broken by boys who had apparently been practicing bombing with loose rip-rap stones. Judging by the condition of the sewer, the "blitzkrieg" must have been highly successful—to the raiders!

Made temporary repairs until suitable permanent "armament" can be furnished.

July 3—Daily inspection revealed sliding current collectors attraction type final clarifier mechanism to be bent. Ordered repair parts and decided to empty the unit for inspection and painting while awaiting delivery. According to available records, the unit had not been drained for six years.

Imagine our surprise to find eighteen fat carp weighing 4 to 6 pounds in the tank after draining it! Directed that they be placed in creek.

July 5—Inspected final clarifier mechanism and found:

(a) About one third of the under-water steel surface to be still protected by the last paint application (two coats "Non-Oxide," applied six years ago), the remainder of the surface being rusty and pitted.

(b) The sheet brass plows to be curled and about 20 per cent of them to be so badly torn as to require replacement. The balance were still usable by straightening somewhat and reversing so that any remaining "curl" would be in the direction of rotation.

(c) With the exception of some of those in the center sludge sump, the steel plow arms were in good condition. Considerable corrosion of some of the center arms was noted.

(d) Steel cap-screws with bronze nuts had been used to fasten the plows to the plow arms. The cap-screws were too far gone for re-use but nearly all of the nuts were found to require only re-threading. "Nuts" to buying 275 new nuts at 6 cents each!

July 6—Began cleaning under-water steel of clarifiers in preparation for re-painting. Using scrapers and wire brushes to remove all rust and scale followed by thorough washing with gasoline to eliminate any remaining grease or oil film.

July 8—Called local National Youth Administration office to ascertain possibilities of getting an N. Y. A. project for District. Sufficient encouragement forthcoming to justify submission of an application, which was done.

July 10—Started painting clarifier mechanism. Metal above water had been painted with a very good aluminum paint. The few places at which rust showed were scraped, brushed and "spot-primed" with graphite primer. One coat of good quality aluminum paint is being applied.

July 11—Professor F. T. Mavis of Pennsylvania State College paid us a visit.

July 15—Began application of the first of two coats of Gilsonite paint to underwater portion of clarifier mechanism. If this paint job fails, it won't be due to lack of effort in preparing the surface!

July 20—Painting of clarifier mechanism complete. Began repairing, replacing and adjusting plows; cleaning and painting walkway gratings, creosoting wood baffles and similar small jobs.

July 24—Final clarifier back in service! Our plan is to drain, inspect, repair and paint this unit as needed, at least once each year in the future.

July 25—Poured new concrete floor in dry well. As originally constructed, one corner of this floor was 6 inches lower than the corner in which the drainage sump is located. The new floor has plenty of slope in the right direction and will eliminate most of the dampness which previously existed in the dry well and motor room above.

July 28—The plastic coil packing used in the past on the vertical shaft, centrifugal sewage pumps does not appear particularly good. Today we are trying top and bottom end-rings of square, plaited, asbestos packing with two rings of the plastic packing between. (Later experience indicates this packing arrangement to be much more effective and lasting than the old method.)

July 31—Removed 8.5 cubic yards of grit from our screen chamber. Although our sewers are supposedly used only for sanitary sewage, about 25 cubic yards of grit per year or 0.3 cubic foot per million gallons is removed at this chamber.

We failed to find the set of false teeth for which we were requested to look by one of our customers!

August 2—As indicated previously, we are not completely sold on this violent hosing of Imhoff tank gas vents, despite the fact that our vents accumulate scum to a depth of 5 to 12 feet, depending upon the season.

Today, as a crude experiment, we placed a garden hose so that a fine spray was projected horizontally over one of the vents. Plant effluent from the flushing water system was used. After an hour of this, the 8-foot scum layer was very soft and mushy beneath the spray and the gas was released freely, yet there was no disturbance in the settling channels. These results were considered sufficiently promising to justify design of a more elaborate spray system for further experimentation on one-eighth of the gas vents. (See "Experiences in Digester Scum Control" elsewhere in this issue, for additional details.)

August 3—One of the operators slipped and fell into an Imhoff tank gas vent this morning, while skimming the tanks. He suffered an abrasion on his leg and was sent immediately to a doctor for first aid and a tetanus "shot." Maybe it was well that the vent in question had a solid scum layer in this case—since the man hardly broke the surface in his dive!

August 5—Installed scum spray system at one end of the gas vents in Tank No. 2. The plant operators, who previously spent 10 to 20 hours weekly in hosing the vents, are already "sold" on the idea.

August 10—In this locality, an ordinary panelled door seems to present a special challenge to youth. No less than five outside doors of various buildings about the grounds show scars of numerous attacks.

Our carpenter started today at replacement of these damaged doors by new ones made of 1-inch ply-wood, faced with car siding (nailed vertically) and with hinges and lock hasps securely bolted thereto. We're almost inclined to invite the neighborhood gang to kick these in—if they can!

August 14—Enough is sufficient! The check valve on our 3.5 m.g.d. pump has been given minor repairs a number of times during the past few years but still manages to stick in an open position on occasion. Today we ordered a new disc, yoke, hinge and hinge-pin. A complete overhaul is obviously in order! (Old valve used for 17 years.)

August 18—Installed a sanitary drinking fountain in grounds for visitors and picnickers in our park. Formerly, the only hydrant available was located in the garage and shop. The saving in tools should soon pay for the new fountain!

August 22—Local N. Y. A. office advises that our project application had been rejected due to a recent change in policy in regard to training of boys in trades essential to National defense. Felt that another try at this was worthwhile, since we had good use for some of this labor, so a carefully prepared letter was sent to the District N. Y. A. office requesting reconsideration of our application. Keeping fingers crossed.

August 26—Brightening up the screen house with paint. With open screens, this spot can hardly be made attractive, but cleanliness and fresh paint do much to minimize the objectionable aspects.

August 28—One of the best plant operator's meetings we have been privileged to attend is the Annual Field Day sponsored by the Illinois Association of Sanitary Districts. Today we were the guests of the Rockford Sanitary District (H. A. Riedesel, Superintendent) and the usual high caliber of these conferences was maintained in fine fashion.

August 30—The first harbinger of winter! Were visited by representatives of a local coal company who wished to discuss our winter fuel requirements. Who wants to talk about buying coal when the mercury stands at 90 in the shade?

OFFERINGS OF GADGETEERS

An Economical Safety Belt

Many of us are prone to disregard the hazards involved when it is necessary to enter sewers or manholes where there may be a deficiency in oxygen or presence of toxic gases. No one should be permitted to enter such places unless he wears a dependable safety belt with the rope in the hands of two men on top to lift him to safety in case of accident.

R. D. Woodward, Chief Operator of Sewers at Laguna Beach, California has developed a rope hitch (Figure 1) which may be of interest

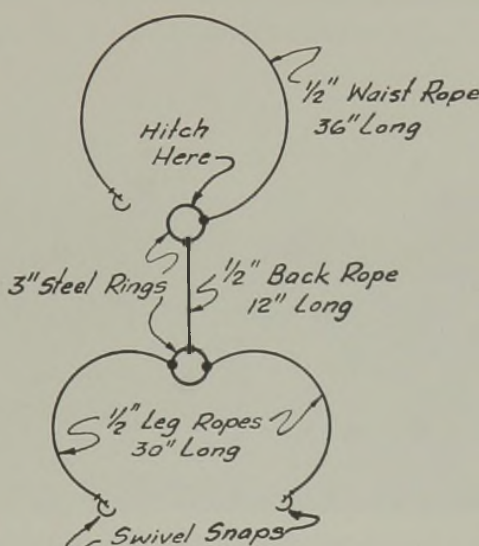

FIG. 1.—Home-made Safety Hitch, Developed by R. D. Woodward, Chief Operator of Sewers, Laguna Beach, California.

to sewage workers in municipalities which may not be able to afford the rather expensive, standard safety harness. The hitch is easy to make, inexpensive and convenient to use. The upper rope is placed around the body beneath the arms, the two lower ropes are snapped around the thighs and the pull rope is fastened on the upper ring in the back.

Moving Sludge by Tractor

To add convenience and minimize costs in removal of sludge from drying beds, Superintendent Walter A. Sperry of the Aurora (Illinois) Sanitary District uses a caterpillar tractor fitted with side bins or "saddle bags" of 3 cu. yd. capacity. The machine is pictured in Figures 2 and 3.

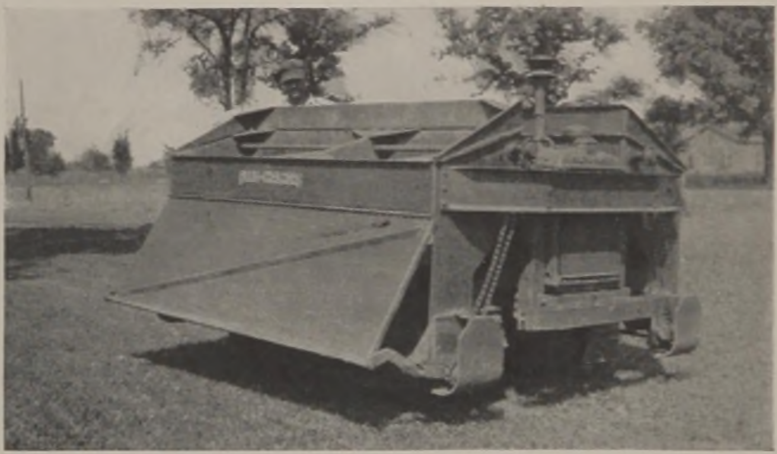

FIG. 2.—Tractor Equipped with Side Bins for Hauling Sludge at Aurora, Illinois.

FIG. 3.—Aurora's Sludge Hauling Tractor in Service.

Sperry reports that five men (including the tractor operator) can move 90 cu. yd. of sludge per day from the beds to the stock pile with the tractor. Sludge removal costs have been cut from 51.6 cents to 23.4 cents per cu. yd., a reduction of 55 per cent from the costs of removal by means of the original industrial dump car system.

The tractor is also used to haul grit and, when equipped with a bulldozer, for clearing snow, grading roadways and trimming the sludge stock pile.

A similarly equipped tractor has been successfully used for moving sludge at Springfield, Illinois for several years.

Glass-Ware Flushing Jet

Figure 4 illustrates a jet devised by Chief Operator Frank Faccini of the North Sewage Works at Stockton, California, for use in flushing

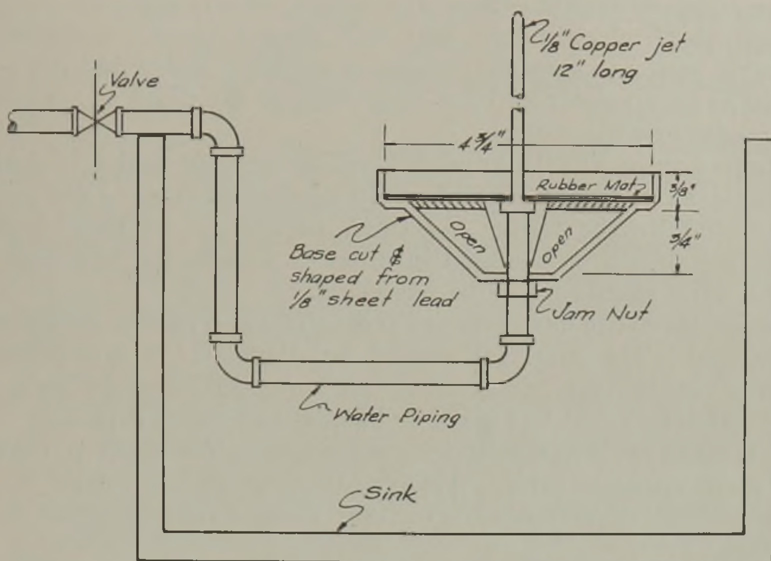

FIG. 4.—Glass-ware Flushing Jet, Developed by Frank Faccini, Chief Operator of the North Plant at Stockton, California.

out Imhoff cones, sample bottles, flasks, graduates and other laboratory glass-ware of the "tall, long and narrow" type.

The object is merely inverted over the jet, the water turned on, and a thorough rinsing results.

OPERATION OF PRIMARY TREATMENT UNITS *

By D. C. Reybold

Engineer, The Dorr Company

Operation of Bar Screens and Grit Chambers.—Bar screens and grit chambers are very essential parts of a sewage treatment plant. Although these units do not play an important part in suspended solids or B.O.D. removal, they do remove objectionable materials that otherwise hinder the efficiency of sedimentation, digestion and secondary oxidation processes.

It is advisable for the operator to remember that bar screens and grit chambers are installed as protective devices to relieve possible

* Presented at Second Sewage Operator's Short Course held at University of Illinois, March 10–14, 1941.

troubles in the balance of the plant. Consequently, they should be operated efficiently and kept in good repair.

Every sewage plant has its peculiarities and special problems. However, the following general operating rules are applicable in the majority of cases.

(1) Always keep the bar screen and grit chamber structures and surroundings neat and clean. Operation efficiency seems to vary directly with cleanliness. Not only does a good ''house-keeper'' find it easier to keep units in good working order, but his reputation as an operator and the reputation of the plant as a whole, are increased enormously.

(2) Plants equipped with hand-cleaned bar screens and grit chambers should have an established, daily routine to remove the material collected by the units. At times of storms or high flows, the routine should be changed in order to handle the increased flow. The units should never be neglected.

(3) Do not leave the hand-cleaned screenings and grit in piles for later disposal. The material should be disposed of immediately in order to reduce odors, flies, and general uncleanliness. The screenings should be buried or burned and the grit buried.

(4) If mechanical equipment is installed, keep the units painted and in good working order. Always follow the manufacturer's recommendation regarding lubrication, repairs and general maintenance.

(5) Many mechanical items are equipped with shear pins to protect the units against unusual overloads. The shear pin is a protection against more serious breakdowns. Consequently, broken shear pins should be replaced with new pins of the equipment manufacturer's specified material, and not with sections of steel rock, bolts, or rivets. Such substitute materials relieve the operator of shear pin replacements, but on the other hand, eliminate all overload protection with the possible result of serious and expensive breakdown.

(6) Nearly all mechanical screens have some method of automatically controlling the operation. The ideal in screen operation is to have the mechanism run only at the time when screenings have been collected on the bars. Automatic time clocks are furnished on some installations, and these clocks are capable of being set to operate the mechanism for any predetermined number of minutes of any hour. Screenings, particularly with varying flows of sewage, do not build up at certain periods, and consequently, time clocks do not provide control of operation at the critical time.

Some method of float control is more certain. As screenings build up on a bar screen, additional head is required to handle the volume of sewage through the screen. The additional head backs the sewage up the sewer, and may cause flooding, septicity and odors. In addition, the additional head allows some screenings, normally held back by the screen, to be forced through and carried on to the other units in the plant. Differential float controls have been developed to start the screen when this additional head is built up. These float controls minimize operation periods and have the distinct advantage of operating the unit only when necessary.

(7) In large plants, coarse bar screens or racks should be installed as a protection to the bar screen equipment. These racks have 3 in. or 4 in. openings and catch logs, tin cans, and other large objects. In small plants such racks should be installed to protect comminutors.

(8) In installations of comminutors or grinders, it is essential to keep the cutting mechanisms sharp and in good working order. The purpose of these mechanisms is to chop, grind or comminute the screenings to a small size which can be successfully handled in the balance of the plant. Dull cutting-teeth produce large size material that may cause considerable trouble in the other plant units.

(9) In hand-cleaned grit chambers, it is advisable to remember that fine grit will not stay settled at a velocity over 1.25 ft. per second. Thus, half-filled grit chambers may increase the velocity to a point where additional grit is not removed.

(10) All mechanically-cleaned grit chambers should have a bar screen preceding it for protection against rags and other screenings. These materials have a tendency to wind around grit-cleaning mechanisms, creating a great deal of trouble.

(11) Washed grit can be used for walkways, roads, sludge bed sand, etc. Equipment is available to wash the organic matter from grit, reducing the odor and fly-breeding problem.

Operation of Sedimentation Tanks.—The sedimentation tank in a sewage treatment plant plays an important role in the results obtained by any treatment process.

In primary treatment plants, the sedimentation tank efficiency determines the degree of treatment and the consequent solids load in the effluent. In complete treatment plants, the primary tank efficiency determines the load that must be handled by the more expensive, oxidation or secondary treatment processes. Final settling tanks are not only used to collect and separate the returned solids for mixed liquor treatment, but their efficiency determines the appearance and suspended solids analysis of the final effluent.

The sewage plant operator should endeavor to obtain the maximum efficiency of his settling tanks. This efficiency should not be interpreted as the per cent removal of suspended solids. Every sewage varies in the amount of suspended solids that will settle, and the most efficient tank can only remove 100 per cent of the solids that will settle. Therefore, it is the settleable solids removal that determines the efficiency of a settling tank. The following examples indicate the point in question.

Plant	Suspended Solids Per cent Removed	Settleable Solids Per cent Removed
A	45	97
B	81	96

Plant *A* has very efficient sedimentation, and the efficiency compares favorably with Plant *B*. The difference in suspended solids removed is due to characteristics of the sewage: Plant *B* contains a large amount of lime, which coagulates the suspended solids. Any settling tank that continuously removes over 95 per cent of the settleable solids is practically perfect.

Settling tanks below a 95 per cent figure on settleable solids removal can generally be improved by adjustment of baffles, weirs and elimination of short circuiting. Plants overloaded with resulting short detention periods and high overflow rates will, of course, give poor sedimentation efficiency, and there is little any operator can do to improve the results.

The greatest failure of operators in any sewage plant is in the removal of sludge. The rate of sludge pumping is too high, and the amount of sludge pumped is too great.

It must be remembered that sludge forms a light blanket in the hopper of any sedimentation basin. A high pumping rate first pulls the sludge directly over the withdrawal pipe, and then the overlying sewage, because the outer layers of the sludge blanket will not slough off into the hopper as fast as the pump requires. The net result is that a great deal of sewage is pumped to the digestion tank with very little sludge. This sewage must be heated in the digester, and as it cannot produce gas to heat itself, the digester becomes cool. In addition, the volume of supernatant liquor returned from the digester to the settling tank is increased, and since the supernatant liquor is relatively high in B.O.D. and suspended solids, the plant efficiency drops.

More important, such pumping practice leaves most of the sludge in the settling tank, where it turns septic, becoming malodorous and producing large amounts of scum.

Experience has shown that frequent pumping periods for only a few minutes at a time, and at a low pumping rate, give the best results. Supernatant liquor is reduced in strength and volume, the settling tank is kept clean and fresh, and digestion capacity is increased.

The following summary of rules to follow in clarifier operation may be helpful:

(1) Keep the mechanical equipment well painted, lubricated and in good operating condition. Follow the equipment manufacturer's recommendations regarding repairs and maintenance.

(2) Keep the weirs level in order to prevent short-circuiting and poor settling efficiency.

(3) Keep tank clear of scum by skimming frequently.
(4) Pump sludge at a low rate from the tank.
(5) Pump sludge for only a few minutes at a time but at frequent intervals.
(6) Do not allow settled sludge to become septic.
(7) If overflow rate and detention period are satisfactory and settleable solids removal is low, then adjustment of baffles, inlet and take-off arrangements should improve efficiency.
(8) Run mechanisms to produce as thick a sludge as possible. Experience will dictate this procedure.
(9) At times of low flow, recirculation of effluent back through the settling tank will reduce detention period and reduce opportunities for septicity.

EMBARRASSING SHORT STORY

O. P. Rator has
Two plants to use—
Both by-passed
With no excuse.
State Health man comes,
Inquiring frown;
Rator's caught with
His plants down!!

DERIVATION OF GAS ENGINE OPERATING COSTS *

By R. W. Frazier, *Superintendent,*

Oshkosh, Wisconsin

In deriving costs of operation of a gas engine in sewage plant operation, various methods have been used in arriving at these costs. Variables in plant installations are such that individual consideration has to be given to each case. The cost per KWH and net savings on the operation of the gas engine is the ultimate end of the accounting. The question is, how to derive the figures, and what is to be considered in the cost accounting.

A number of gas engine installations have been made with the assistance of Federal funds, together with appurtenances to the operation of the engine. Some have charged off the percentage donated by the agencies, which no doubt will show a larger saving. If the agencies did not make a donation, the original cost would still hold and if the new engines were purchased, no help would be forthcoming.

A question arises, whether or not appurtenances such as gas-holders, meters, gas compressors, electrical equipment and buildings should be

* Presented at the Wisconsin Sewage Works Operator's Conference, Sheboygan, Wisconsin, May 20, 1941.

charged against the engine. Some of the plants have a number of the appurtenances mentioned, while others do not.

In the treatment of sewage where sludge is digested and gas generated, some disposal of the gas has to be made. One instance I know of, where gas meters and holders are installed, the gas is used only for heating, and production being of such nature, all of the gas is not used for heating, so the excess is burned in the atmosphere. No doubt, a number of the appurtenances are necessary adjuncts to the collection and distribution of the gas, but may not affect the operation of the engine as far as operating costs are concerned.

A number of communities have their own electric plants and if power is used under this condition, the rate of power may be smaller. Others have to purchase power on an industrial basis, either on a flat rate per KWH or on a graduated scale. Others generate power and sell their excess power to the electric utility possibly at a rate in which they purchase their deficiency. All in all, this is variable in each community.

In suggesting a standard plan to follow, consideration should be given to the kind of a report which will appear favorable to the governing body or community. This report to show the essentials that are of importance to all.

The following is a tentative outline submitted for your consideration and discussion.

1. Make of engine and year installed.
2. Size—H.P.—No.
3. Use—Generator, pumps, blower.
4. Cost (Actual—disregarding Federal funds).
5. Maintenance.
6. Repairs (Gaskets, rings, plugs, etc.).
7. Supplies (Grease, oil, etc.).
8. Depreciation (Actual cost).
9. Interest on investment.
10. Insurance.
11. Labor (Overhaul, repairing).
12. Compensation on labor.
13. Total cost of operation.
14. Hours operated.
15. KWH (Gen., m.g.d. pumpage, cu. ft. air produced).
16. Cost of power purchased per KWH.
17. Total power purchased.
18. Total power generated.
19. Cost of power generated at utility rate.
20. Net savings shown of power generated over the amount if power had to be purchased.

Further cost can be shown on what the actual cost was for total power cost per KWH; that is, power purchased and power generated.

In all cases, the cost of gas engine operation is to bring out whether or not the engines are a paying investment.

Gas Engine Operation (Le Roi)

Sewage Treatment Plant, Oshkosh, Wis.
October 5, 1937 to February 12, 1941

	No. 1 Engine	No. 2 Engine
Labor—supervision for maintenance and repair	$1,015.70	$ 301.60
Compensation insurance on labor	17.06	4.07
Repairs—oil—grease—supplies	687.25	295.54
Depreciation	655.01	655.01
Interest on investment	357.26	357.26
Insurance	67.46	67.46
Total operating cost	$2,799.74	$1,680.94

No. 1 Engine operated 18,004 hours, generating	562,928 KWH
No. 2 Engine operated 7,694 hours, generating	226,692 KWH
Total power generated	789,620 KWH

Average KW per hr.—No. 1 Engine—31.2 @ cost of $.00497/KWH
Average KW per hr.—No. 2 Engine—29.4 @ cost of $.00741/KWH

Average total cost of power generated—$\frac{4,480.68}{789,620}$ = $.00567/KWH

Total power cost at plant:

Power purchased	$ 5,676.85
Penalty—min. charge	292.52
Operating cost	4,480.68
Total power cost	$10,450.05
KWH purchased	279,312
KWH generated	789,620
Total generated and purchased	1,068,932 KWH

Total cost of power generated and purchased per KWH = $.00977

Power generated @ P. S. Corp. rates—No. 1 Eng.—562,928 × .02	$11,258.56
Power generated @ P. S. Corp. rates—No. 2 Eng.—226,692 × .02	4,533.84
Value of power generated @ P. S. Corp. rate of .02 per KWH	$15,792.40
Operating cost	4,480.68
Net savings on power generated—3⅓ years	$11,311.72

SEWAGE WORKS AFFECTED BY NATIONAL DEFENSE INDUSTRIAL ACTIVITY

Two instances in which increased production by industries, due to national defense activity, have brought serious problems to municipal sewage treatment works, were disclosed during the April 26, 1941, meeting of the Western Section of the New York State Sewage Works Association, held at Lockport, New York.

An unusual situation at Dunkirk, New York was described by Carl J. Bernhardt. Some trouble had been experienced since 1934 with a steel pickling liquor discharge of some 500 gallons per week from the Alleghany Ludlum Corporation. The present discharge is from 1,800 to 2,000 gallons per week, and it is expected that with increased production and new plant capacity, the discharge will be approximately 5,000 gallons per week. The effects of this pickle liquor appear in several instances: metal or bar screens are corroded and dissolved until no thicker than a knife blade; holes appear in pump suction pipes and concrete has been spalled off. Digestion of the sludge has not been normal and after months of digestion, the dried sludge is still non-spadable. When acids and lime have been dumped together, the volume of suspended matter has been exceedingly high, with an Imhoff cone test showing 100 to 120 ml. per liter.

With the increased production in the steel plant, these effects are even more noticeable, and some form of pre-treatment at the plant will be afforded. Neutralizing tanks will be placed in operation and it is expected that the sludge quantity will amount to 2½ times that now produced, with approximately 2 to 3 tons per day of sludge from the steel plant.

Following the introduction of pre-treatment, it is expected that digestion tank operation will be more normal and other effects on the treatment plant structures will be absent. It will, of course, be necessary to replace a great many metal parts and fixtures in the plant and gunite the concrete wall that has been previously attacked by acid sewage.

Increased activity in the Harrison Radiator Company plant at Lockport, New York, has contributed 250 gallons of oil daily and a serious problem to Ilbert O. Lacy, superintendent of the sewage treatment works serving that city.

This material collects on the sedimentation tanks and has been skimmed off with the normal skimming process and pumped to a digester which has 4 to 5 feet of oil on it. There has been no digestion for several months, possibly partly due to the oil accumulation.

Although it is not the intention to attempt to handle this oil through the digesters, there is no other way of removing it from the settling tanks at the present time. Due to the presence of this excess amount of oil, the skimming mechanisms have worn out and are being replaced by the manufacturer. Sludge removed from the digestion tank containing oil was found, after drying, to burn for some little time. A pump capable of removing the oil from the sedimentation and the sludge digestion tanks for disposal on the sludge beds by burning has been ordered. The company now losing the oil has plans under way to install recovery separators to prevent the loss of the oil to the sewers.

TIPS AND QUIPS

. . .

Chief Operating Engineer R. R. Sotter of the Richmond-Sunset Works at San Francisco, California, suggests the use of infra-red lamps at the back of the switchboard to reduce condensation.

While draining a large sludge storage tank after three years of service, Chemist C. C. Larson of the Springfield (Illinois) Sanitary District reports that the last seven feet of the tank contents could not be drawn by gravity because of very unusual physical characteristics. Although showing a maximum solids content of 15 per cent, the sludge had solidified into a gelatinous, rubbery mass which could be pumped only after it had been thoroughly churned and comminuted with a hose stream.

Larson claims to have severely taxed his vocabulary in getting the tank drained but was still able to refer to Hatfield's studies of the thixotropic properties of aged sludge in stating that the sludge structure had apparently become so stable that it was virtually impossible to reach the yield (flow) point by agitation.

• • •

At the recent California Sewage Works Association Meeting, Chief Operator R. D. Woodward of Laguna Beach, California, displayed test samples of ordinary insulated wire and "synthole" wire which had been exposed to (*a*) submergence in sewage and (*b*) suspension in moist gases above flowing sewage. In both cases the "synthole" insulation is reported to have proven superior.

• • •

Addressing the Illinois Association of Sanitary Districts recently, Professor H. E. Babbitt of the University of Illinois offered the following masterful bit of paraphrased Shakespeare:

"The quality of sewage is most strange.
It droppeth as an awful, smelly stream
Upon the place beneath.
It is twice foul'd.
Foul'd by him that gives and bugs that work—
'Tis mightiest of the mightiest.
It becomes the limpid stream
Better than its source."

• • •

Experimental studies in the application of trickling filters to the treatment of nitroglycerine manufacturing wastes were abandoned at one of the nation's largest munitions plants for a most unusual reason. In the course of the experiments, it appears that the filter was shut down for a few days, during which time the stone became dry. When a workman accidentally struck one of the rocks with a hammer, an explosion resulted which injured the man so severely that his arm was amputated.

It seems that enough of the nitroglycerine had collected on the surface of the stones to convert the innocent trickling filter into a pile of hand grenades!

Editorial

THE SECOND ANNUAL CONVENTION

The Second Annual Convention, to be held in New York City from Oct. 9 to 11, 1941, will be noteworthy because of the attention that will be given in the technical program to the needs and interests of the average plant operator. Months ago it was decided that the problems and practices of sewage works operation would be discussed by selected persons well qualified to discuss the topics assigned to them. The program was therefore planned to include a few papers of high-class research interest, plus a preponderance of papers dealing with plant operation.

There will be a symposium on control and operation of sewage treatment units, and special topics will include the handling and disposal of screenings, biological filters, sludge digestion, and record keeping. Well-known operators, including Wellington Donaldson, M. W. Tatlock, G. E. Griffin, and Arnold H. Goodman will be asked to discuss these topics. It is hoped to have a discussion of cold weather operation by Dr. A. E. Berry, of the Canadian Institute, who will be able to give good advice to many U. S. operators of the northern states, with reference to the maintenance of treatment works in sub-zero temperature.

''Swede'' Larson, of Springfield, Illinois, will be the continuity man for this symposium, and he can add personal experiences as discussion of most of the papers mentioned.

Another session will be led by A. M. Rawn (we hope) who holds some sort of record for working, and possibly commuting, between Washington, D. C., and Los Angeles. As a result of his experiences in Washington, Mr. Rawn will be proficient in supplying the red tape to tie together various topics such as laboratory tests for plant control, handling and disposal of grit, safety, and chlorination problems. This round-table session follows the Operators' Breakfast. Mr. Rawn will probably make this as entertaining as the ''Los Angeles Breakfast Club,'' which is brought to us each morning from his native city, via radio.

Other operating problems to be discussed in requested contributions include:

Utilization of sludge gas, by George Martin of Green Bay, Wisconsin.

Operation of small pumping stations, by Grant M. Olewiler of Pennsylvania.

One of the high spots of the program will be the discussion of preparedness and maintenance of sewage treatment plants and sewerage systems during the national emergency preparations for defense. This topic will be presented by Warren J. Scott, of Connecticut, and it is hoped to have prepared discussion by well-known engineers. This keynote symposium will be announced in more detail in our September issue.

In addition to these interesting papers, there are several outstanding papers scheduled:

Milton P. Adams has agreed to discuss the effect of industrial wastes on stream pollution. This valuable contribution may be gauged by reference to Mr. Adams' paper on "Treatment and Control of Industrial Wastes" in this issue. The work done by the Michigan Stream Control Commission, under Mr. Adams' direction, has been outstanding, and its worth has not been duly appreciated throughout the country.

Gordon Fair has promised to discuss the "Effect of Load Distribution on the Activated Sludge Process." This should bring out active discussion of tapered aeration, sludge reaeration, and the New York scheme of shortening aeration periods by progressive introduction of influent sewage into the aeration tank. It is to be hoped that data will be available from one of the New York plants to show comparisons of results with and without the tapered feeding system, as introduced at Tallmans Island, where the flow has been insufficient to afford comparisons under conditions of load assumed for design purposes. Professor Fair will undoubtedly be a peerless leader for this important part of the program, and Mr. Gould has promised to discuss operating experiences in New York.

Other papers are being sought, from Dr. H. G. Baity on standards and criteria of sewage plant operation; and from W. S. Mahlie, the outstanding operator in the southwest, on relations of design to practical operation.

This summary of available information on the technical program is sufficient to indicate how interesting the sessions will be. It should be noted that an effort has been made to have speakers who did not appear on the program at the First Convention in Chicago last fall, although a few duplications may occur.

In addition to the technical program, the entertainment features of the convention will have that Broadway flavor that cannot be duplicated anywhere else.

The exhibits promise to outdo even the Chicago show in number and lavishness. We now have the manufacturers working harmoniously with the officers of the Federation to improve its status and service to members.

Finally—watch for the September issue for the more complete technical program, plus the special emphasis on operation, plus the manufacturers' section on new developments, all as a prelude to the Convention.

The New York Convention is certain to be a great success.

F. W. Mohlman

Proceedings of Local Associations

CALIFORNIA SEWAGE WORKS ASSOCIATION

Thirteenth Annual Spring Conference, Santa Cruz, California, April 20–22, 1941

On Sunday afternoon, April 20, President Harold Farnsworth Gray assembled many operators and other interested members in the Bay View Room of the Casa Del Rey Hotel at 4:30 P.M. for the purpose of conducting an operator's symposium. Highlights of the symposium were discussions on digester troubles, sewage and sludge pumps, switch boards, pump starters, float rods and floats. Ralph Sotter presided over this symposium.

At 7:00 P.M. members and guests assembled in the Trocadero Bowl for a buffet supper. Continuing along the line of operation, T. R. Haseltine presented a very interesting and informative address under the general topic, "Operating Problems in Other Parts of the United States."

Harold May, Chairman of the Local Arrangements Committee, assembled the entire group in the lobby of the hotel on Monday morning for the purpose of forming a caravan to sewage treatment plants of interest. The caravan proceeded to the Main Garrison of Fort Ord. The Association was taken on a short tour through the garrison and then to the newly completed installation of Doten septic tanks used for treatment of the garrison sewage.

The next stop was made at Carmel. Bernard Rowntree explained the operation of the various features of the plant.

A stop was made for luncheon at Biff's Place, near Monterey. Past President Pardee, city manager at Monterey, was called on during the luncheon meeting for a few remarks.

The activated sludge treatment plant at Salinas was next observed. As this plant was out of service for repair purposes, many of the group were given the opportunity of observing the construction details of this type of plant.

The caravan was concluded with a visit to the East Garrison of Fort Ord. The treatment plant here is unique in that all sewage is pumped from the camp to the top of a nearby hill, where Doten type septic tanks and drainage ponds are located.

Members and guests assembled at the Trocadero Bowl, in the evening for the Spring Conference banquet. The Association was honored by the presence of C. A. Emerson, Jr., President of the Federation of Sewage Works Associations, as the guest speaker of the evening.

Brief talks of welcome were given the group by Mayor C. D. Hinkle and by County Health Officer John D. Fuller, M.D. President Gray presented Past-Presidents Goudey, Reinke, Haseltine, and Reynolds during the evening.

President Gray gave a fine eulogy of Past-President Alexander Bell, and adjourned the meeting in memory of him.

President Gray called the business meeting of the Association to order in the Bay View Room at 9:00 A.M. on Tuesday, April 22. During the meeting, the following reports were presented:

Constitutional Revision Committee—Progress Report	L. B. Reynolds
Publicity Committee	Wayland Jones
Award Committee	Albert Castro
Legislative Committee	Carl Hoskinson
Finance Committee	J. F. Smith
Certification Committee	R. D. Woodward
Design Practice Committee	Richard Pomeroy
Industrial Wastes Committee	W. T. Knowlton
Safety Standards Committee	Joseph Corrao
Program Committee	Ray Goudey
Operators Panel	R. R. Sotter

A report on schools, submitted by Chairman R. L. Derby, was read by the Secretary and supplemented by G. E. Arnold. The business meeting was adjourned at 10:30 A.M.

During the technical session the following papers were presented:

"Hydrogen Sulfide in Sewage" by Fred D. Bowlus.
"Corrosion of Iron by Sulfides" by Richard Pomeroy.
"Cross Connections in Sewerage" by G. E. Arnold.

The following participated in a discussion of the above papers:

Roy Ramseier	R. F. Goudey
Ted Haseltine	William A. Allen
Richard Pomeroy	Harvey Ludwig

A luncheon meeting was held at the Trocadero Bowl at 12:15 P.M. During this meeting, Ted Haseltine presented a review of the Chemists' Breakfast held that morning. R. D. Woodward of Laguna Beach presented a life-saving device made of rope. He also exhibited some electric wire with a special protective coating which seemed to be quite serviceable around sewage treatment plants. Technical sessions were resumed at 2:00 P.M.

The following papers were presented:

"Mechanism of Flocculation in Water and Sewage Practice" by H. F. Ludwig and Russell G. Ludwig,
"Use of Port Orford Cedar at Sewage Treatment Plants" by Edgar A. Brown,
"Cooling of Sewage Gas Engines" by J. H. Wallace,
"Detection of Metallic and War Gas Poisons in Sewage" by R. F. Goudey,
"Sewerage Facilities of Army Cantonments" by Dwight Bissell, M.D.

Harvey Ludwig, Ted Haseltine, Harold Gray, Edgar Brown, William Allen, John Skinner, John Maga, Harold Davey, J. H. Wallace, J. C. Clark, Roy E. Ramseier, and Dr. Dwight Bissell participated in very interesting discussions concerning the above papers.

The 83 members and 32 guests who attended the Conference adjourned to their various ways at 5:00 P.M.

William T. Ingram, *Secretary*

SOUTH DAKOTA SEWAGE WORKS SHORT COURSE

First Annual Meeting, South Dakota State College, May 19–21, 1941

The Division of Engineering, South Dakota State College, co-operating with the South Dakota State Board of Health, held the first Annual South Dakota Sewage Works Operators' Short Course, May 19, 20 and 21, 1941. The classes were conducted in the Engineering Building of State College in Brookings, South Dakota, and the laboratory analyses were run in the Sanitary Engineering Laboratory, there being sufficient room and equipment for the registrants to work individually.

Announcements were sent to every operator in the state a month prior to the start of the school, and in these announcements it was emphasized that this was to be a school and not a convention. Every registrant was expected to attend all classes, participate in discussions and to perform his own laboratory work. As an incentive to the fulfillment of these obligations the College presented Certificates of Attendance to those men who registered, attended all classes, and did satisfactory work.

At the time of registration all of the registrants received a bound notebook containing information relating to the course, certain material prepared by the State Board of Health (safety precautions, conversion factors, tabulation of chemicals used in sewage treatment, etc.), procedures for the various analytical determinations, data sheets, calculation and note sheets, and publications from a few commercial houses. It is planned to have the lecturers' notes mimeographed and sent to the registrants so that these notes may be incorporated into the notebooks. The men seemed to appreciate these books, were glad to get the information contained therein, and by keeping notes on the notesheets bound in the books they had a complete record of the course as well as a supply of essential information between two covers.

Arrangements were made to house all of the men under one roof in one of our boys' dormitories. This proved to be quite satisfactory as there were 20 men registering representing some 16 South Dakota communities. By housing the men under one roof they became better acquainted, could discuss among themselves questions that arose in connection with the school and problems peculiar to each operator, their expenses for the school were materially decreased, and they seemed to feel that they were a fraternal unit.

During the formation of plans for the short course a definite attempt was made to assign a certain general subject to each instructor for the duration of the course. Other men were asked to give talks on more specialized topics such as sewage bacteriology, utilization of sludge gas, concrete in sewage treatment plants, etc. The instructional work was handled in this manner because it was felt that if one man handled, for instance, sewage treatment, he should develop the work from primary screening through the complete process up to and including the disposal of the effluent. In this way duplication of effort was limited, conflicting opinions of the various speakers were kept to a minimum, and it was felt that the men would be better able to follow a single individual's trend of thought on one particular subject rather than varying the general trend by having more than one speaker handle one general subject.

The general plan of the school was to have classwork in the mornings, the lecture periods to correspond to the regular College recitation periods, there being a ten-minute rest period between classes. The asking of questions during lectures was discouraged; instead, the men were asked to make a note of any comments they cared to make and to save them all until the rest period. This plan worked very well in that all speakers completed their remarks in the allotted time and many times there were lively discussions during the ten-minute free period. The afternoon periods were given over to laboratory demonstrations and procedures. The first day the men made an inspection trip of the Brookings disposal plant, filling out the regular inspection forms of the South Dakota State Board of Health. They also collected samples from three points throughout the plant and brought these samples into the laboratory to be used in their analytical work. The second afternoon samples were brought in for the men and they proceeded with the analytical determinations after laboratory demonstrations. Each man performed each determination and kept individual results and data sheets, all of this material being kept in the notebooks that were handed to the men at the start of the course.

The annual banquet was held Wednesday noon, May 21, 1941. Mr. W. W. Towne, Director, Division of Sanitary Engineering, South Dakota State Board of Health, presided and introduced the main speaker, Professor R. L. Patty, Head, Department of Agricultural Engineering, South Dakota State College. Professor Patty discussed his work with "Rammed Earth," elaborating on its qualities as a structural material. At this dinner meeting the Certificates of Attendance were presented to the registrants by H. B. Blodgett, Head, Department of Civil Engineering and Acting Dean, Division of Engineering, South Dakota State College.

The Short Course was very fortunate in being able to obtain the services of John A. Logan, Assistant Professor of Civil Engineering, University of Missouri. Professor Logan, in line with the plan outlined above, gave a series of three lectures. The first talk, primary treatment of sewage, dealt with the various forms of primary treatment including racks, screens, grit chambers, sedimentation units, Imhoff and septic tanks. Proceeding in a chronological order, his second talk covered the secondary treatment of sewage, dealing with contact beds, trickling filters, sand filters, activated sludge, and disposal by dilution. In his third talk Professor Logan covered elementary hydraulics of sewage flow, friction losses, transporting capacity of sewage and necessary velocities in sewers, leading up to a discussion on sewage pumps and sewage pumping stations.

A second man who carried a very large share of the teaching load was Kenneth Spies, Associate Sanitary Engineer, South Dakota State Board of Health. Mr. Spies gave papers on sewerage characteristics, sewage plant operation and sludge digestion. Each of his papers was very completely outlined, the outline being put on the blackboard as he talked. The men were very careful about copying these outlines and many favorable comments were heard on this method of presentation. Mr. Spies had compiled much interesting and valuable information and the operators will profit from being able to get down all of the material that was presented.

W. W. Towne, Director, Division of Sanitary Engineering, South Dakota State Board of Health, gave papers on public health aspects of sewage treatment, sewage arithmetic, chemicals in sewage treatment in the absence of H. E. Holst, President of the South Dakota Water and Sewage Works Conference, and led a general discussion on the last afternoon of the school. Mr. Towne has served in his present capacity for approximately 12 years, consequently he is familiar with the problems the operators have to face in this state. In his first paper he elaborated on the growth in percentage of persons served by sewage treatment plans in South Dakota and the nation, stressed the need for more complete sewage disposal units by citing instances of water-borne epidemics, and presented to the operators the role that they had to play as public health agents. His paper on sewage arithmetic dealt with conversion factors of parts per million to grains per gallon, grams to pounds, liters to quarts, cubic feet per second to gallons per day, etc. (all of these factors and many more were composited on one sheet and placed in the notebooks distributed to the registrants). Mr. Towne's paper on chemicals in sewage treatment dealt with the growth and present status of chemical treatment as well as describing the mechanics of the process. The discussion led by him on the last day of the school was given over to the problems faced by the different operators, the conditions under which the various plants have to operate, and the attitude of the State Board of Health in regard to the keeping of records, sewage analyses, etc. One of the major issues taken up was the type of paint to be used in tanks subject to alternate wetting and drying. It was suggested that all operators communicate immediately with the State Board of Health regarding paint problems and satisfactory solutions. It was also suggested that the State office be contacted on any other major problems and their possible solutions.

In addition to the above named speakers, Professor Calvin C. Oleson, Department of Civil Engineering, South Dakota State College, gave a very interesting talk on "Concrete in Sewage Treatment Plants." His paper dealt with the fundamentals of sound concrete leading to a discussion of the proper method of mixing and placing concrete subject to alternate wetting and drying in localities with a large temperature differential. In answer to certain questions he elaborated on the proper method of repairing unsound concrete walls. A very lively discussion centered around his paper.

W. I. Metzger, Instructor in Bacteriology at South Dakota State College, presented a paper, "Bacteriology in Sewage Treatment." He discussed the various types and classifications of bacteria and elaborated on the different kinds of bacterial action in each type of treatment. His discussion on bacterial action in trickling filters was well taken and afforded a subject for discussion as the majority of treatment plants in this state have trickling filters and at the present time many operators are experiencing difficulties with their filters due to sloughing.

Mr. Leland Bradney, Chief Chemist of the Sioux Falls plant, gave an interesting talk on the "Utilization of Sludge Gas." Mr. Bradney spoke as a practical man, the Sioux Falls plant utilizing the sludge digestion gas in gas engines. Mr. Bradney gave costs, operating data, difficulties encountered, and plans for future installations.

Mr. R. E. Bragstad, City Engineer of Sioux Falls, presented a paper on "Choice and Maintenance of Pre-treatment Works"; Mr. C. A. McTaggart, Dakota Pipe and Culvert Company, presented interesting information on the "Manufacture and Use of Armco Pipe"; and Charles E. Carl presented a short movie on sewage treatment and conducted the demonstrational classes for the various analytical determinations that the registrants were to make. These tests consisted of (1) methods and procedures to be followed in sampling, (2) temperature, (3) settleable solids, (4) relative stability (methylene blue), (5) dissolved oxygen, and (6) five-day B.O.D. Mr. Towne, Mr. Spies, Professor Logan and Mr. Carl worked together in the laboratory helping the men perform these tests and assisting them in making the necessary calculations.

CHARLES E. CARL,
South Dakota State College

Reviews and Abstracts

EIGHTH BIENNIAL REPORT OF THE STATE WATER COMMISSION FOR YEARS 1938–1940

State of Connecticut, Public Doc. No. 78 (1940)

Following a general description of current changes in municipal sewage works, are some brief notes on special industrial waste problems. In the manufacture of ball bearings, large volumes of an emulsion of oil in water are used. This can be cracked with acid and ferric sulfate, so that the oil rises to the surface. The settled sludge can be removed and after drying used for fill.

Paper mill waste liquors, particularly from mills making low grade stock, may contain over five pounds of suspended solids per 1,000 gallons. By installing settling tanks, savealls, and filters, the solids can be cut below ¼ lb. per 1,000 gallons. Part of the recovered waste can be reused, and the clarified water recirculated.

In metal working mills, the waste liquors contain acid, salts of cadmium, chromium, copper, iron, lead, zinc, etc., as well as cyanides. If collected and diluted, the impurities can be reduced or removed by treatment. Barium sulfide, lime and copper as added to plating room waste liquors containing acid, chromium, copper, etc., will reduce the chromium from the hexavalent to trivalent form and precipitate the various metallic salts.

Pickling wastes result from cleaning metals for further processing. Research has developed electrolytic pickling for steel, but this is not applicable to all metallurgical industries. When used, the volume of waste is smaller, the acid content lower and the iron content higher than in straight acid pickling.

Textile wastes may be treated by copperas and hydrated lime, removing over 75 per cent of the color, organic matter, and suspended solids. The sludge, when dried, burns readily.

B. F. Dodge contributes a special report on the electrolytic regeneration of spent brass pickling liquor; the chemical methods for treatment of spent brass pickle liquors; and a survey of pickling wastes from brass mills. Treatment is complicated if all the wastes are mixed. In the electrolytic process, the products are regenerated pickle liquor, metallic copper and zinc, which can all be re-used in the brass plant. However, there is the cost of electric energy and equipment. Some modification of pickling technique may be required. Chemical treatment uses simpler and less expensive equipment, but may utilize a zinc oxide sludge, as treatment agent. There is the drawback of making a zinc salt for optimum profit.

He considers electrolytic regeneration essentially a reversal of the chemical reactions occurring in the pickling operations with the aid of electric energy. The chief factors involved are the concentrations of ions involved; acidity or pH; current density; temperature; degree of agitation; nature of diaphragm; nature of electrodes; addition agents.

Among the important findings are:

1. Good copper deposition cannot be obtained until all the chromate in the spent liquor has been reduced.
2. Copper deposition and chromate reduction are best done by chemical means, leaving zinc deposition and chromium oxidation for electrolytic handling.
3. Zinc concentration should exceed 30 to 40 grams per liter.
4. Presence of chromium complicates deposit of zinc.
5. Metals such as nickel, cadmium, copper, arsenic, and antimony, must be removed from solution before zinc can be satisfactorily deposited. This can be done by treatment with brass, followed by dosage with zinc dust. Iron can be tolerated up to 300 p.p.m.

6. Deposit of copper and oxidation of chromium should be stopped well short of completion.

7. The acid content of the usual spent chromate liquor is insufficient to allow the complete reduction of the chromate either by electrolysis or brass. In a regeneration process, the acid can be built up. If sulfur dioxide is used for reduction, the acid content is sufficient.

8. Temperature of cells should be kept low.

9. The porosity of the diaphragm must be carefully chosen.

10. Inclusion of chromium in the zinc deposit may occur if the Cr^{+++} concentration runs high.

11. Small amounts of colloidal organic material, such as glue, improve the zinc deposit.

12. Buffering agents, such as borax, improve the zinc deposit.

13. Acid concentration is critical. If too low, low anode current efficiency results, with spongy zinc deposit. If too high, zinc trees may form, which may injure diaphragm and cause low cathode current efficiency.

These conclusions are based on small batch cells, holding one liter, with active electrode 6 sq. in. Some results are confirmed in continuous cells with electrode areas 100 times as great.

Various diaphragm materials were tried. The most promising is a stagnant layer of electrolyte, restrained by parallel fabrics stretched across the cell.

Among the quantitative results are:

Function of Cell	Voltage	Current Density	Current Efficiency	
		Amp. per sq. cm.	Anode	Cathode
Arsenic and antimony removal	2.5	0.5	—	—
Chromate reduction	3.8	2.0	60	100
Copper deposition	3.2	1.0	85	90
Zinc deposition	7.0	3.0	70	50

Subject to the operation of a pilot plant, the indications are the processes may be profitable.

Among the chemical methods for treating spent pickle liquors is dilution and dosage with lime. If chromate is present, it must be first reduced to trivalent chromium. This method is simple, but has the objections of the cost of lime and volume of sludge to be disposed of. Waste zinc oxide sludge is being tried as a treating agent, on a laboratory scale. In chromium-containing liquors, the chromate is first reduced by SO_2 or other suitable means. In liquors containing not more than 4 grams of chromium per liter, copper can be removed by addition of waste zinc oxide to less than 100 p.p.m. with at least 75 per cent recovery of the zinc. This requires about 8 hours at 100 deg. C. In a two-stage process, the acid in the spent pickle is neutralized by sludge from the second step. Next, the clear liquor from the first step is treated with zinc oxide sludge produced from the skimmings of the brass melting operation, to precipitate copper and chromium. This operates well on liquors with low chromium content, producing a clear zinc sulfate solution, containing no chromium, little iron, and under 100 p.p.m. copper, in two hours' time, with about 95 per cent recovery of zinc. Difficulties occurred with higher chromium contents.

In the brass industry, the pickling wastes vary greatly in concentration. The pollution load is split between spent pickle liquor and wash water. The survey of a brass plant showed that 85 to 90 per cent of the total acid and metals were discharged in the form of dilute wastes. Such wastes contained sulfuric acid, copper, zinc, chromium, and iron. The study is now focussed on methods for concentration of the dilute wastes, to combine with the spent liquor, for treatment.

C. R. Hoover adds a special report on laboratory studies of industrial wastes. For chromium plating wastes, reduction and precipitation is suggested, effective reagents being sulfides of sodium and barium, scrap iron and lime, and sulfur dioxide and lime.

Color printing wastes may be chlorinated before discharge into sewage for biological treatment. Textile wastes have also been studied.

In Meriden, during a 45-hour week, approximately 3.5 m.g. from 30 processes in seven plants were discharged, containing, in particular, zinc, copper, nickel, cyanide, chromium, iron, aluminum, and oil. Such wastes would affect a sewage plant. The use of equalizing aeration and dilution tanks is recommended.

In Danbury, from the hat industry, two tons of strong acid are discharged weekly into the city sewers.

Wastes containing cutting and soluble oil, with a B.O.D. of 6,500 p.p.m., can be treated with 5 lb. sulfuric acid and 15 lb. ferric sulfate per 1,000 gal. at pH 4.8 and produce a clear effluent, with a B.O.D. of 230 p.p.m.

In Middletown, textile finishing wastes in the amount of 10 per cent by volume, is the maximum that can be added to sanitary sewage, without decreasing the rate of sludge digestion. The waste discharge must be equalized so as not momentarily to exceed a proportion of 15 per cent as against 85 per cent sewage by volume.

Copper concentrates rapidly in settled sludge from relatively low traces in sewage; *e.g.*, sewage containing 0.5 p.p.m. copper produced sludge with 100 p.p.m. Copper in sewage exceeding 1 p.p.m. decreases the efficiency of sludge digestion. Suggested treatment is scrap iron filters for acid wastes, and sodium or calcium sulfides, followed by copperas with alkaline wastes. Chromium wastes do not accumulate in sewage sludge to the same degree as copper, but if precipitated, show comparable harmful effects. If over 200 p.p.m. of precipitated chromium is present in sludge, the rate of digestion is markedly reduced. When more than 1 p.p.m. of chromium is present in sewage, arriving at a plant using sludge digestion, the chromium should be removed at the source.

The manufacturer should study plant processes to eliminate or decrease objectionable wastes.

LANGDON PEARSE

SEVENTH JOINT ANNUAL REPORT ON SEWAGE DISPOSAL, JOHANNESBURG

BY H. WILSON AND H. T. CLAUSEN (1940)

Johannesburg is served by five disposal works. The flow of sewage is 10,864,000 Imp. gal. (13,000,0000 U. S. gal.) per day. The European population in 1939 was 285,400; the non-European, 243,250. The flow increased 653,100 Imp. gal. per day from the previous year. The revenue was 9,913. The Klipspruit works is the largest, accounting for 6,921,296 Imp. gal. per day. This is being remodeled.

The report contains a paper by E. J. Hamlin and H. Wilson on "Investigations on Percolating Filters. Part II." Trials at the Klipspruit pilot plant indicate an enclosed artificially ventilated trickling filter can treat 3½ times the settled sewage that an open filter can. Artificial ventilation of the enclosed filter is required for an effluent of 100 per cent stability at rates above 120 Imp. (144 U. S.) gal. per day per cu. yd. Heat conservation by the cover is of value.

The 1893 work of Lowcock in introducing air about 3 feet deep in a trickling filter was repeated. The air was blown in through perforated pipes 2 ft. below the surface. The air was of little value.

More than twice as much sewage can be treated on an open filter in the summer as in the winter, sometimes as high as four times.

Running up the flow to 715 Imp. (858 U. S.) gal. per cu. yd. per day produced an inferior effluent. In another case, increased load from industrial waste produced an inferior effluent, but the total work done by the filter was greater.

The presence of CO_2 in a filter is not injurious.

The maintenance of a relatively high temperature in winter in a trickling filter may be helpful.

Another paper by H. Wilson and J. A. McLachlan on the "Carbon Dioxide Production in the Activated Sludge Process" briefly reviews the literature, but questions whether the conclusions of Adeney and others on the phenomena in the purification by dilution can be applied to trickling filters and activated sludge. The examination of the works results does not indicate that CO_2 is the main end product in the activated sludge process. Laboratory tests show that when a carbon balance has been established, about 10 per cent of the transformation products of the carbon originally in the sewage appear as CO_2 in the effluent air. The CO_2 in the effluent liquor is approximately the same as in the original sewage. Carbon dioxide is not the major product of aerobic oxidation. The removal of hydrogen is of equal significance to the attachment of oxygen. Carbon, however, is transferred from sewage to sludge.

LANGDON PEARSE

MELBOURNE AND METROPOLITAN BOARD OF WORKS (AUSTRALIA)

Report for the Year Ending June 30, 1940

The total number of houses sewered on June 30, 1940, was 274,974, serving 1,091,646 population, or 3.97 persons per house. The total cost of construction in the year ending June 30, 1940, on the sewerage system was £352,342, of which farm purchase and preparation was £39,192, and treatment works £46,642. For sewers of all sizes £266,863 was spent.

To restrain corrosion in the outfall sewer, mechanical ventilation is being installed.

The net capital cost of the farm is £1,298,930. After charging £34,703 as the operating cost of sewage disposal and £56,357 as interest, and crediting £9,574 as trading profit, the net cost of sewage purification was £81,486, or 1 s. 6 d. per capita for the current year, compared with 1 s. 4.7 d. last year.

The operation of the farm includes subsoiling, grading and seeding. An area of 1,100 acres is being prepared for grass filtration in its natural state. In the farm nursery, 41,800 trees were planted out. 900 tons of hay were harvested for the farm horses. 440 acres were seeded and 1,163 acres top dressed with superphosphate.

The average yearly rainfall was 16.12 inches, as compared with a 46-year average of 18.28 inches.

49,600 sheep were purchased. The wool clip returned £10,608. The turnover of live stock (sheep, cattle, horses, skins, wool and hides) produced £80,535.

The farm staff totals 358.

LANGDON PEARSE

RECENT CONTRIBUTIONS TO THE STUDY OF INDUSTRIAL WASTE TREATMENT

The Surveyor, 99, 205–207 (Mar. 21, 1941)

Inauguration of the Public Health (Drainage of Trade Premises) Act, 1937, and war conditions have increased the interest of British sewage works managers in the treatment of industrial wastes. Among the problems which have arisen are the need for treatment of industrial wastes in separate plants at isolated sites; evacuation of civilians from industrial towns with consequent change in the characteristics of sewage to be treated in the town sewage treatment plant; and large increases in the amounts of industrial wastes to be treated in existing sewage treatment plants.

Sewage works managers are anticipating treatment of canning wastes since the canning industry is almost certain to be developed by the Government.

The quantities of pickling liquors and iron wastes from metal industries has increased tremenduously and these wastes are hazardous to the operation of biological processes, particularly trickling filters. The quantity of laundry wastes has greatly increased.

At one plant which has received wastes from a large wall paper factory, operation of the works had been upset due to a falling off in the amount of effluent from the factory. The effluent contained China clay which assisted in the flocculation and coagulation of the sewage.

Large quantities of coal-washery wastes are being treated in England. The treatment comprises sedimentation of the drainings containing the fines and the slurry from the wash boxes. The overflow from the tank is used over again. Lime is added to the washery water, followed by frozen farina or potato starch and caustic soda which causes the slurry water to flocculate. The slurry is then thickened and filtered on vacuum filters. The cake is used for boiler fuel.

K. V. Hill

THE POSSIBILITIES AND ECONOMICS RELATING TO ORGANIC MANURE AS APPLIED TO AIR-DRIED SLUDGE

The Surveyor, 99, 225–227 (Mar. 28, 1941)

Active salvage operations and the need for greater agricultural production appear to have stimulated the use of sewage sludge in Great Britain. At a meeting of the Institute of Sewage Purification held at Leeds, February 15, 1941, the entire meeting was given over to discussion of the use of sewage sludge as a fertilizer and soil conditioner.

The discussion brought out the following points: sludge had about the same fertilizer value as manure; it should not contain too much grease; it should be ground to a reasonable size to be readily spreadable; sludge gives up its nitrogen very slowly; it is a fine soil conditioner and is especially good for keeping soil moist; it is good fertilizer for crops such as cabbage, kohlrabi and other members of the brassica family.

K. V. Hill

DISCUSSION ON THE UTILITY AND LIMITATIONS OF THE METHYLENE BLUE STABILITY TEST FOR SEWAGE EFFLUENTS

By H. M. de Vaal and G. J. Stander

Inst. Sewage Purif., Part II, 355–360 (1939)

This is a discussion of the history of the test and its shortcomings. The authors were disturbed by the discrepancies between the B.O.D. test and the methylene blue stability test and experimented on filter bed effluents and settled sewages to which nitrites and nitrates had been added. From the results cited, the conclusion is reached that the methylene blue test holds for filter bed effluents as a stability test, but not for all other sewages, as the disappearance of the blue color does not always coincide with the elimination of the nitrate and nitrite oxygen. The methylene blue test does not always differentiate between an effluent with a B.O.D. of 20 and one of 50 p.p.m. Hence the methylene blue test is of little value in determining the approximate standard of effluent purity.

In the discussion, Wilson held that neither the B.O.D. test or the relative stability test was entirely satisfactory. Dr. Hamlin noted that the two tests do not agree. Meyling pointed out that sometimes in samples of bad effluent the methylene blue decolorizes rapidly and later the color returns. The presence of nitrite and nitrate delays decolorization. Wooldridge and Standfast are quoted as of the opinion that the relative stability test is an index of enzyme activity.

Langdon Pearse

PROGRESS IN THE METHODS OF TREATMENT AND DISPOSAL OF SEWAGE SLUDGE

By S. H. Jenkins

Inst. Sewage Purif., Part II, 278–316 (1939)

This is a general review of progress in sludge disposal since 1876, with data from the U. S. and Great Britain. The most important methods are sea disposal, land disposal by irrigation, and ploughing in, or trenching; digestion in separate tanks, followed by sea disposal or drying on beds and dumping, or using dried sludge as fertilizer; filtration of sludge for disposal in the wet state or dried to recover grease or for fertilizer, or for destruction of organic matter by incineration. The pounds of dry solids per person per annum vary from 45.5 at Elizabeth, N. J., to 230 at Bradford, England. Birmingham Main Works is 90.7 pounds.

At Wolverhampton, England, liquid sludge from 120,000 people is disposed of on land, by dosing once in three years, at the rate of about 27 square yards per person. Trenching requires from 1.25 to 1.75 square yards per person. In 1910–1912, Whitehead and O'Shaughnessy pointed out the value of mixing crude sludge with a larger volume of sludge undergoing alkaline fermentation.

In open tanks, from 2 to 8 cu. ft. per capita are required for digestion. Stage digestion is often used. Much of the data on heated digestion comes from the U. S. Less volume is required in heated than in unheated tanks. The practice in heating, charging, shape of tanks and concentration is noted. Activated sludge is reported to digest easily when mixed with crude sludge, with a minimum of 15 per cent of raw sludge by volume. The digester liquor is usually added to the raw sewage, in not less than 20 volumes of sewage. Some chemicals, such as chromium, retard decomposition. With wastes from food industries, the sludge should be kept alkaline. The effect of gas liquor needs further research. Mineral oils may be more resistant than animal grease.

The practice of gas collection and utilization is growing. The complexities of chemical and physical changes during sludge digestion under anaerobic decomposition are discussed. The composition of sludge gas is largely methane (59 to 77 per cent) and carbon dioxide (14.7 to 32.4 per cent), with a B.T.U. from 570 to 742 per cu. ft. Sludge pressing in plate presses is still practiced in England. Grease is sometimes recovered. Vacuum filters are in the trial stage in England. Palmer's discovery of the beneficial effect of ferric salts in aiding filtration makes vacuum filters of value.

Air drying on open air beds is hard to compare for various plants. Well-drained beds aid, but evaporation finishes the drying. Covered beds are not used in England. Mechanical methods of sludge drying have been neglected in Great Britain. Reference is made to the Chicago tests on dewatering and incineration. In Great Britain opinion varies as to the fertilizer value of sludge. A few works dispose of air-dried sludge, crude or digested, in some cases with a small return. Only at Barnsley is activated sludge separately treated for fertilizer. Apparently proof of the fertilizer value by a recognized authority is required in Great Britain. A bibliography of 70 items is appended.

The discussion brought out the great variation in sludge offered to farmers; the injury to fertilizer value by lime added to facilitate pressing; the lack of uniformity of method for applying sludge and incorporation in the soil; the decreased use of sludge because of increased cost of transportation (20 years ago Glasgow loaded 50 wagons with a total of 400 tons of cake a day), which makes the use of sludge uneconomical to the farmer. At Glasgow sea disposal at 5 d. (10 cents) per ton takes care of 750,000 tons per year. Halifax sells 3,000 tons a year at 10 s. 6 d. per ton at the works ($2.12 per ton at 20 cents per shilling).

Lockett states that generally the belief was that volatile sulfides were not produced when the water content of the sludge was 95 per cent or lower. However, in heated tanks he noted no odor with 2 or 3 per cent of solids.

In closing, Jenkins believes that it is sound practice to mix chemical fertilizers with organic fertilizer. Settled or digested sludge is slow acting, in the soil, and has sometimes proved disappointing, whereas activated sludge has its nitrogen in a very easily nitrifiable form, with its organic nitrogen almost as quick acting as sulfate of ammonia, and has been found to be a good fertilizer. Sludge may be composted, with soil and some nitrogenous material. Odor control is best attained by the larger amount of seeding sludge used.

At Birmingham, the cost of handling sludge has been reduced from 12.74 d. (25.5 cents) in 1923 to 9.8 d. (19.6 cents) in 1938 per ton of crude sludge containing 90 per cent water. This is the result of digesting over twice as much sludge in 1938, in the same plant, with heated digestion and reduced charges for power because of use of sludge gas, as well as other systematic economies.

LANGDON PEARSE

RIVERS POLLUTION PREVENTION AS A PUBLIC HEALTH SERVICE

By FRANK WRIGLEY

Inst. Sewage Purif., Part II, 259–277 (1939)

This is a general discussion of the control of river pollution in Nottinghamshire, England, under a policy of obtaining results by persuasion, assistance, and encouragement. In the County are 84 sewage works, including one bio-aeration plant unit on a portion of tank effluent, of which 56 are in rural districts. There are 147 parishes discharging some raw sewage and 18 giving partial tank treatment. The predominating industry is coal mining. There are 39 mines, of which 26 have coal washing plants, varying from 40 to 300 tons per hour. The slurry is of a shaley or clayey nature, and may be removed by lagoons, settling tanks, or flocculation and filter plants. In some cases settled effluent is treated by small final tanks and filters or filtered through cinder barriers or passed into shallow lagoons. Nine collieries have modern clarification plants. Water circulation is an essential feature, with removal of slurry, to avoid building up high concentration of suspended matter in the circulating system. In one case chemical flocculation results in a sludge which is dewatered on a rotary filter for incineration. If the ash is high, the filter is sometimes omitted. In one plant a rotary filter is used, without settling. Boiler water wastes, water softening wastes, and oil, though intermittent, should be kept out of streams. Generally this is done by settling, followed by some form of straining filter.

In the County are two beet sugar works. In one, the extraction waters from the diffusion batteries and pulp presses are treated in mechanically cleaned tanks and filters, with reuse of most of the filtrate. The excess waste goes to the general settling ponds. The carrying and washing waters pass through dredgers and screens, and then to settling ponds. In the other works, complete separation of the waste waters is provided. The extraction wastes are fermented in separate ponds, and settled. The carrying and washing waters are settled in another set of ponds. The ponds are created within earth dikes, and gradually fill up. The efficiency of the ponds decreases as the campaign progresses.

There are 9 gas works, of which 6 are connected to the sewers and 2 dispose of waste liquors on land. One was replaced by bought gas.

In the discussion, spillage of oil from oil vessels on the river was noted. In some cases the recovery of slack or powdered coal may pay for the cost of recovery.

Dr. Parker pointed out that the reuse of water in the beet sugar industry did not decrease the refined sugar and did increase the molasses. He recommended rapid, rough sedimentation, so the waste water does not stand and become acid. Otherwise it may prove corrosive.

LANGDON PEARSE

UTILIZATION OF LIGNIN

By Edwin C. Jahn

Ind. and Eng. Chemistry, News Edition, **18,** 993 (Nov., 1940)

Disposal of lignin is the world's greatest industrial waste and stream pollution problem. In the United States alone 12,000,000 gallons of lignin solution must be disposed of daily. Logging, sawmilling and wood working industries add another 15,000,000 tons of lignin annually in the form of sawdust, shavings and wood wastes. Straw, corn cobs, grain hulls and other wastes of the agricultural industry contain 15 to 20 per cent of lignin and must be added to the total lignin waste whose disposal taxes the ingenuity of technical researchers.

Lignin wastes are derived from the soda and sulfate process or from the sulfite process of paper pulping. In the former process a large portion of the lignin is burned in the recovery of soda at the mills. The sulfite process is the most important chemical pulping process. Nearly all the lignin in the form of lignin sulfonic acids is contained in the liquid waste liquors. Practically all of this is sewered and accounts for 1,000,000 tons of lignin lost to the streams annually in the United States.

Attempts at salvaging this waste for useful purposes have not been too encouraging. Some progress has been made in the use of lignin waste as a road binder, manufacture of vanillin and in plastics. Most progress has been made in developments to overcome pollution of streams. The Howard process is particularly noteworthy. In this process calcium sulfite and basic calcium lignosulfonic acid are recovered and the primary organic residue is burned for power production.

To date, use has been found for only a very small proportion of the waste produced.

Another interesting article on "Utilization of Lignin Wastes" is reported in *Ind. and Eng. Chemistry,* 32, 1049 (Aug., 1940).

E. Hurwitz

DISPOSAL OF WASTE LIQUORS FROM CHROMIUM PLATING

By C. R. Hoover and J. W. Masselli

Ind. and Eng. Chemistry, 33, 131 (Jan., 1941)

The discharge of wastes from chromium plating operations into sewers and streams has created a pollution problem in the stream and operation problems in biological sewage treatment works.

Analyses of the effluents from three metal finishing plants show:

	Plant 1	Plant 2	Plant 3
	Parts Per Million		
pH	2.7	6.2	3.0
Total Cr	4.1	18.1	87
Cr^{VI}	3.5	16.6	76
Cu	7.1	2.0	32
Ni	0.1	0.14	2
Zn	6.8	2.1	0
Fe	2.3	3.1	2.3
SO_4	215.	65.	271.
CN	1.1	0.8	12.

Studies of methods to prevent the harmful effect of these wastes on streams and treatment plants and incidentally to recover valuable metal led to (1) a study in the plant of means to reduce the quantity of these wastes and (2) chemical means of removing the metal from solutions.

It was found feasible in some plants to segregate the chromium plating solutions thus providing a more concentrated solution with which to work. The range in composition of the segregated waste showed:

Total Cr	87–643 p.p.m.
Cr^{VI}	75–636
Cu	0.2–34
Ni	Trace—6.4
Fe	0–80
SO_4	84.769
CN	0–22.4
Mineral acid	55–634

After extended tests in the laboratory four methods were selected for more detailed study on a semi-plant scale:

1. *Reduction of Chromic Solutions with Sodium Sulfide and Addition of Copperas to Remove Excess Sulfide Ion and to Clear the Solution.*—Hydrous chromium oxide is formed. In concentrations greater than 150 p.p.m. hexavalent Cr the addition of a small amount of a strong oxidizing agent is necessary to clear the solution. The precipitate settles slowly, is difficult to filter on vacuum filters and dries slowly on sand beds.

2. *Reducation of Chromic Solutions with Barium Chloride Followed by Addition of Lime and Ferrous Sulfate.*—The barium sulfate is added hot (60–65° C) in 30 per cent solution. The precipitate obtained settles rapidly and dewaters readily.

3. *Reduction with Scrap Iron.*—Complete reduction of chromic solutions were obtained in 4 hours when acidified with 3–4 pounds sulfuric acid per 1000 gallons of waste. This process can be made continuous if 6 hours detention period are allowed in the reaction tower. After treatment with iron the effluent is treated with lime and the precipitated trivalent chromium is collected along with ferrous and ferric iron. The mixed precipitate settles well and can be dried best on sand beds. Copper is deposited on the scrap iron and can be recovered.

4. *Reduction with Sulfur Dioxide.*—The waste is treated with sulfur dioxide. After reduction is complete, excess SO_2 and CN are removed with air and the trivalent chromium precipitated with lime. This process can be manipulated so that a saleable chromium trioxide can be recovered.

The costs of treatment by the four methods are given in the following table:

Reagent	Lb. per 1000 Gal. Treated	Secondary Reagents			Sludge, Per Cent of Total Volume	Cost per 1000 Gal. Treated, Cents
		H_2SO_4	Copperas	CaO		
Na_2S	4	3	1–3	3	10	50
BaS	7	—	1–3	4	6	54
Scrap iron	5	3–4	—	6	9	40
SO_2	5	—	—	7	11	42

E. Hurwitz

PREPARATION OF NESSLER'S REAGENT

By A. P. Vanselow

Ind. and Eng. Chemistry, Anal. Edition, 12, 516 (Sept., 1940)

Phase rule consideration of the three component system potassium iodide-mercuric iodide-water and studies to determine the influence of the concentration of potassium iodide and potassium hydroxide in preventing the formation of the red precipitate that develops when some Nessler's solutions are diluted led to the following recommendation for the preparation of an entirely satisfactory Nessler solution.

1. Dissolve 45.5 gms. of mercuric iodide and 34.9 grams of potassium iodide in as little water as needed.
2. Add 112 gms. of potassium hydroxide (140 c.c. of a solution sp. g. 15°/40° = 1.538).
3. Dilute to one liter.

Use 5 ml. of this solution with each 100 ml. final volume and compare with standards 30 minutes after mixing.

E. Hurwitz

DETERMINATION OF BIOCHEMICAL OXYGEN DEMAND COMPARATIVE STUDY OF AZIDE AND RIDEAL–STEWART MODIFICATIONS OF WINKLER METHOD

By O. R. Placak and C. C. Ruchhoft

Ind. and Eng. Chemistry, Anal. Edition, 13, 12 (Jan., 1941)

Comparison of the azide and Rideal-Stewart modification of the Winkler method for dissolved oxygen determination are equally satisfactory for the determination of B.O.D.

An average of the B.O.D. of 1936 samples taken at various sampling stations on the Ohio River showed an average deviation of 0.06 p.p.m. in the 5-day B.O.D. The minimum deviation was 0.01 and the maximum 0.45 p.p.m.

Samples from the Scioto River, a small stream which carries a greater pollutional load than the Ohio gave an average deviation of 0.10. Nitrites are always found in the Scioto River varying from a few hundredths to several p.p.m.

Comparison of the Alsterberg procedure with preliminary acid azide treatment indicated that from the standpoint of reliability there is no choice between the procedures. For routine work where no unusual conditions might arise, the Alsterberg procedure is recommended since it has the advantage of shortened time and ease of manipulation. The preliminary acid azide treatment has greater flexibility and is recommended for use in any case when the period of alkalinization must be shortened.

Preliminary treatment with acid and azide is advantageous in preventing oxidation when the determination of D.O. must be delayed as in shipping. In this use it is superior to complete Winkler treatment through the final acidification.

E. Hurwitz

B.O.D. REMOVAL FROM WASTE SULFITE LIQUOR–SEWAGE MIXTURES BY ACTIVATED SLUDGE

By G. N. Sawyer

Ind. and Eng. Chemistry, 33, 411 (March, 1941)

Studies on the rate of B.O.D. removal from mixtures of sewage containing 2 to 20 per cent sulfite liquor showed evidence of some limiting factor in concentrations from 8 per cent up. Since sewage was added primarily to furnish the phosphorus, nitrogen, etc., necessary for normal biological metabolism, it was considered possible that the capacity of sewage to furnish these substance had been overstepped and that an insufficient supply of these minerals affected the rate of stabilization.

Experiments were designed to prove this assumption by feeding nitrogen and phosphorus to sulfite waste-sewage mixtures. These tests showed that in a mixture containing 10 per cent sulfite waste the B.O.D. removed after 6 hours' aeration with added nitrogen corresponded to an amount removed by 15 hours' aeration from the unsupplemented mixtures. Phosphorus alone as a supplement appeared to have a little effect. The combination of nitrogen and phosphorus gave somewhat more rapid B.O.D. removal than nitrogen alone.

In mixtures supplemented with nitrogen only the ratio of the B.O.D. removed to nitrogen utilized was approximately 11 to 1. In mixtures supplemented with both nitrogen and phosphorus the B.O.D. removed per unit of nitrogen was 14 units.

Treatment by supplementing sewage-sulfite waste mixtures with nitrogen and phosphorus would add a cost of approximately $2.65 per ton of pulp. In a so highly competitive industry such an outlay would be untenable. However, the suggestion is advanced that part of this outlay can be recovered through lower capital costs since the installations can be smaller; through sale of sludge as a fertilizer (24 tons of fertilizer would be produced per 100 tons of pulp); and through recovery of gas for heat and power production.

E. Hurwitz

FLOW OF MUDS, SLUDGES AND SUSPENSIONS IN CIRCULAR PIPE

By D. H. Caldwell and H. E. Babbitt

Ind. and Eng. Chemistry, 33, 249 (Feb., 1941)

A theoretical analysis of the flow of sludge through circular pipes led to the conclusion that two distinct types of flow occur depending on the velocity of flow. These types have been termed "plastic flow" and "turbulent flow." The velocity at which plastic flow changes to turbulent flow is called the "critical velocity."

Equations have been developed and verified experimentally for determining friction loss for plastic flow and for turbulent flow in circular pipes.

For plastic flow the equation is given as:

$$\frac{H}{L} = 32\left[\frac{\tau_y}{6\rho D} + \frac{\eta V}{g\rho D^2}\right],$$

where H = difference in static head between two points in a pipe.
L = length of pipe in feet.
V = mean velocity of flow in pipe, ft./sec.
D = diameter of pipe, ft.
τ_y = shearing stress at yield point of plastic material, called "yield value," lb./sq.ft.
η = coefficient of rigidity, lb./sq.ft.
ρ = density of flowing substance, lb./cu.ft.
g = acceleration due to gravity, ft./sec./sec.

Results of tests show that the friction factor—Reynolds number chart may be used for determining friction losses for turbulent flow if the viscosity of the dispersion medium is used in determining the Reynolds number in place of the viscosity of a true liquid.

The equation for the critical velocity is given for the lower critical velocity as:

$$V_{lc} = \frac{1000\eta + 1000\sqrt{\eta^2 + \frac{D^2\tau_y\rho g}{3000}}}{D\rho}$$

and for the upper critical velocity as:

$$V_{uc} = \frac{1500 + 1500\sqrt{\eta^2 + \frac{D^2\tau_y\rho g}{4500}}}{D\rho}$$

where

V_{lc} = lower critical velocity, ft./sec. (Re = 2000),
V_{uc} = upper critical velocity, ft./sec. (Re = 3000).

Other symbols as given above.

E. Hurwitz

COLORIMETRIC METHOD FOR DETERMINATION OF NITRITE

By Martha B. Shinn

Ind. and Eng. Chemistry, Anal. Edition, 13, 33 (Jan., 1941)

The method employs sulfanilamide in place of sulfanilic acid and N-(1-naphthyl)-ethylene diamine dihydrochloride in place of alpha naphthylamine. Finally inasmuch as sulfanilamide and nitrite react stoichiometrically in the presence of a suitable excess of either, sulfanilamide is recommended for the primary nitrite standards.

The method as proposed follows:

Reagents—

1. Sulfanilamide; 0.2 per cent solution in water. (Keep in refrigerator.)
2. Hydrochloric acid; 1 to 1 dilution of conc. HCl.
3. Sodium nitrite; 0.1 per cent solution. (Keep in refrigerator.)
4. Ammonium sulfamate; 0.5 per cent solution in water.
5. N-(1-naphthyl)-ethylenediamine dihydrochloride; 0.1 per cent solution in water.

Standardization of Sulfanilamide Solution—

(1) Dry sodium nitrite (analytical reagent) for 24 hours in a desiccator. Make up a solution of one gram in 100 c.c. of water in a volumetric flask and assay by titration with potassium permanganate.

(2) From this solution of sodium nitrite prepare accurately a solution containing 0.005 mg. nitrite per c.c. Transfer to each of two 50 c.c. volumetric flasks, 5 c.c. of this solution, add one c.c. of 1:1 HCl and 5 c.c. of 0.2 per cent sulfanilamide solution. After three minutes add 1 c.c. of ammonium sulfamate solution and then two minutes later 1 c.c. of the ethylene diamine dihydrochloride solution and dilute to volume.

(3) Into two other 50 c.c. volumetric flasks measure 5 c.c. of a 1:100 dilution of the 0.2 per cent sulfanilamide solution. Add one c.c. of 1:1 HCl, one c.c. of 0.1 per cent sodium nitrite and 5 c.c. of water. Allow to stand 3 minutes, add one c.c. of ammonium sulfate solution and allow to stand 3 minutes longer. Add one c.c. of the ethylenediamine dihydrochloride and dilute to volume.

Solution 2 and 3 are read against each other in a colorimeter. With a Duboscq colorimeter the nitrite equivalent of the sulfanilamide solution is:

$$\frac{\text{Reading of (2)}}{\text{Reading of (3)}} \times \text{mg. } NO_2 \text{ in (2)} \times 20 = \text{mg. } NO_2 \text{ in one c.c. of 0.2 per cent sulfanilamide solution.}$$

Procedure for determining nitrites:

(1) Samples should be either acid or neutral.

(2) To a sample containing between 0.0025 mg. and 0.05 mg. nitrite add one c.c. of 1:1 HCl. and 5 c.c. of 0.2 per cent sulfanilamide solution and let stand 3 minutes.

(3) Add one c.c. of ammonium sulfamate and allow to stand 2 minutes.

(4) Add one c.c. of ethylenediamine dihydrochloride and dilute to volume.

(5) Prepare a nitrite standard as outlined in (2) under standardization of sulfanilamide solution.

(6) Read the unknown against the standard and compute the nitrite present by the

equation

$$\frac{\text{Reading of Standard}}{\text{Reading of Unknown}} \times \frac{\text{mg. } NO_2 \text{ in 1 c.c. of 0.2\% Sulfanilamide}}{20} = \text{Mg} \cdot NO_2 \text{ in sample.}$$

The nitrite value of the sulfanilamide has been found to remain constant for at least a month. About 20 mg. per mg. of nitrite are required for complete recovery of nitrite. Excess up to 2000 mg. per mg. of nitrite gives no interference.

Ammonium sulfamate is used to remove the residual nitrite before addition of the N-(1-Naphthyl) ethylenediamine dihydrochloride.

The method, similar to the sulfanilic acid-alpha naphthylamine method, depends on the diazotization of the sulfanilamide followed by coupling of the diazotized sulfanilamide with H-(1-Naphthyl) ethylenediamine dihydrochloride.

The method has an advantage in that the reagents are water soluble; the time for color development is reduced to two minutes; the final color remains constant for several hours. The sulfanilamide is less sensitive to changes in pH acting equally well in concentrations of acid from 0.1 to 1.0 normal.

E. Hurwitz

ACETONE–BUTYL ALCOHOL FERMENTATION OF WASTE SULFITE LIQUOR

By Averill J. Wiley, Marvin J. Johnson, Elizabeth McCoy and W. H. Peterson

Ind. and Eng. Chemistry, **33**, 606 (May, 1941)

Utilization of the sugars present in waste sulfite liquors for the production of acetone and butyl alcohol shows promise of value in reducing the B.O.D. load on streams into which the sulfite waste liquor is discharged.

A strain of *clostridium butylicum* was found to give the highest yields after treatment of the waste to remove sulfur-dioxide, lignin and calcium. Approximately 75 per cent of the sugar was recovered as a mixture containing 75 parts butyl alcohol, 20 parts acetone and 5 parts ethyl alcohol. The B.O.D. of the waste sulfite liquor was reduced from 28,150 p.p.m. to 5,425 p.p.m. Treatment of the waste to remove the sulfite and lignin complexes brought the B.O.D. down to 46.4 per cent of the original. Fermentation of the sugars removed an additional 34.3 per cent of the original B.O.D. The overall reduction by this process was 81.7 per cent.

E. Hurwitz

NEW SEWAGE TREATMENT PLANT AT ANDERSON, INDIANA

By B. A. Poole

Civil Engineering, **11**, 275 (May, 1941)

The city of Anderson, Indiana, is located on one of the state's most important streams. Although used extensively for recreational and agricultural purposes, its chief use is as a source of water supply for the cities of Muncie, Anderson, and Indianapolis, with their estimated 1940 combined population of 484,505. In addition to carrying the domestic sewage of its tributary population, it has been used extensively as a means of disposal of industrial wastes, chiefly of an organic nature. Recently, the completion of a number of sewage treatment plants has almost completed the cleaning up of the West Fork of the White River above Indianapolis. Progress has also been made in the treatment of industrial wastes, although minor problems of this nature still exist.

The sewage treatment plant employs the bio-chemical or Guggenheim process. The flow sheet includes comminutors and a detritor preceding the main sewage pump. These are followed by primary clarifiers, aeration tanks, and final clarifiers. Sludge is thickened, then given partial digestion before vacuum filtration and incineration. The plant has been designed for an average flow of 8 m.g.d. and a maximum flow of 12 m.g.d. Chlorinated copperas is added to the sewage after primary sedimentation to the extent of approximately 4.5 p.p.m. as iron. An aeration period of 1.95 hours is provided with 15 per cent returned sludge, and approximately 0.63 cu. ft. of air per gallon of sewage.

Consideration had been given in former years to the use of the activated sludge or trickling filter processes. However, industrial wastes from a vegetable packing plant, a meat packing plant, a clay tile works, a small steel mill, and a lamp manufacturing plant made the situation somewhat difficult to be treated by ordinary biological processes. Iron content in the raw sewage averaged 12 p.p.m. and chromates also presented a problem as they varied from 0 to 50 p.p.m. on 24-hour composites. This bio-chemical process has given reductions in B.O.D. averaging approximately 85 per cent on a raw sewage with a B.O.D. of 150 p.p.m., and a reduction of suspended solids of approximately 85 per cent on the basis of a raw sewage with a suspended solids content of approximately 300 p.p.m. Detailed data are presented by the author to show operating characteristics of the plant. Detailed analyses of the cost of treatment per million gallons of sewage are also presented. Over a period of nine months, these average $10 for salaries and labor, $8 for power, including cost of pumping sewage, $1.75 for chemicals for the treatment of the sewage and $3.80 for chemicals for sludge conditioning, $3.00 for fuel oil in sludge incineration, or a total of approximately $26 per million gallons.

ROLF ELIASSEN

SEWAGE TREATMENT FOR ARMY CAMPS

Engineering News-Record, 126, 479 (March 27, 1941)

In order to provide for adequate sewage treatment at the multitude of army camps being constructed throughout the country, the consulting firms of Metcalf and Eddy and Greeley and Hansen were retained by the War Department. They were authorized to "advise and report as to the simplest sewage treatment plant at each project suitable and adequate to meet the minimum requirements under local conditions." Very little information regarding the characteristics of sewage and sewage flow from army camps was available. Most of the sewage would be discharged during 16 hours of the day and required the establishment of liberal detention periods based on the 24-hour average flow. The per capita quantity of suspended solids is a good deal higher than is normally found in domestic sewage. This may be accounted for by the adult and male character of the personnel and by the relatively large amount of grease. The per capita quantity of B.O.D. is about the same as that in average domestic sewage but is somewhat higher than often found in residential sewage. The per capita quantity of grease is two to three times that normally found in domestic sewage. In general, the sewage will be very fresh and should have good settling characteristics and be readily amenable to treatment by biological processes.

The following bases of design for sewage treatment plants were adopted by the consulting engineers:

1. Quantities: Average 70 gal. per capita per day; maximum (for several hours) 140 g.c.d.; peak 210 g.c.d.

2. Sewage Characteristics: Suspended solids, 460 p.p.m.; B.O.D. 290 p.p.m.; other soluble material, 150 p.p.m. There will be 0.37 lb. suspended solids and 0.17 lb. B.O.D. per capita per 24 hours.

3. Measuring Devices: Parshall flume, rectangular flume, Palmer-Bowlus or Venturi meter.

4. Grit Chambers: Omit, except in special circumstances. If used, they should be hand cleaned, with disposal by burying.

5. Bar Screens: Hand cleaned or mechanically cleaned as local conditions indicate. Screenings to be disposed of by burial or by burning in a suitable incinerator. Comminutors or screenings grinders to be employed under some circumstances such as proximity of plant to occupied buildings. Clear space of bar screens, 1 to 1½ in.

6. Primary Sedimentation Tanks: Displacement period based on average flow. Sedimentation only or ahead of trickling filters 3.0 hr.; in case of high dilution of settled sewage 2.5 hr. may be used. Ahead of activated sludge use 1.5 hr. based on average flow. Ahead of biofilters, based on average flow, use 7.5 hr. for a dilution ratio of 1:1.5 (single stage filtration) and use 6 hr. for a dilution ratio of 1:1 (two-stage filters).

7. Trickling Filters: (*a*) Standard, or low-rate, trickling filters in southern locations with no severe winter—not to exceed 5,000 population per acre-foot. With filters 6 ft. deep, this is 2.1 m.g.a.d. average at 70 g.c.d. In northern climates loadings should not exceed 4,000 population per acre-foot. (*b*) High-rate trickling filters to have loads not in excess of some 3,000 pounds of B.O.D. applied per acre-foot, for camps in the south. This is equivalent to a population of 35,000 per acre-foot. In northern camps the loading should not exceed 30,000 per acre-foot.

8. Final Sedimentation Tanks: Flow not to exceed 800 gal. per sq. ft. per 24 hr. and not less than 2.25 hr. displacement, both based on the average flow, except when following two-stage biofilters with recirculation ratio of 1:1 from the secondary tank effluent to the influent of the second-stage filter, in which case the capacity of the secondary tanks should be doubled. Depth 10 to 12 ft. with some reduction, or increase, in the depth in special cases.

9. Sludge Digestion Tanks: For plants of the trickling filter type for primary and secondary sedimentation and with heated sludge tanks use 2.0 to 3.0 cu. ft. per capita. For unheated sludge tanks in warm climates, add 25 to 50 per cent to the foregoing, using the larger capacities in locations close to occupied buildings. For plants of the activated sludge type, increase the foregoing allowances by 50 per cent.

10. Sludge Drying Beds: In warm climates and where the location permits, drying sludge in lagoons without underdrains or filter material is acceptable with 2.0 to 3.0 sq. ft. per capita. Sludge drying beds with underdrains and filter material are also acceptable. For plants of the trickling filter type the area provided should be 0.5 to 1.0 sq. ft. per capita, and for plants of the activated sludge type this allowance should be increased to 1.0 to 1.5 sq. ft. per capita. The lower unit in each case applies to the most favorable conditions with opportunity for lagooning any excess sludge.

11. Imhoff Tanks: Sedimentation compartment same as primary sedimentation tanks and digestion compartment same as for unheated separate sludge digestion tanks. In northern climates use for the sludge compartment of Imhoff tanks: With plain sedimentation, 2.0–2.5 cu. ft. per capita, and with plain sedimentation and trickling filters, 3.0–3.5 cu. ft. per capita.

The article includes a table showing the design flow and type of treatment used for 38 installations on some of the larger defense projects. This table shows that of the 38 plants, 20 use some form of trickling filters, either high- or low-rate; 11 use primary treatment; 4 use activated sludge; 2 have connections to city sewer systems; and 1 uses slow sand filters.

Rolf Eliassen

INTERSTATE SANITATION COMMISSION ANNUAL REPORT—1940

Report to the Governors of the States of New York and New Jersey by the Commissioners of the Interstate Sanitation Commission—January 15, 1941.

(103 pp.)

The policy of the Interstate Sanitation Commission has been to persuade municipalities to take more positive action and to assist and prepare financial plans for the accomplishment of work for the abatement of pollution in New York Harbor and the adjacent waters. The report outlines the activities of the Commission and shows pictures of sources of pollution. The major portion of the report presents data on sewerage and sewage treatment systems in the Interstate Sanitation district, including populations served, dates of construction, types of treatment, and other pertinent information. Operating data on a number of plants are also included. Progress from new construction is carefully analyzed.

Of particular interest to engineers engaged in sewage treatment is the summary of the results of the research work carried on by Mr. Manning as a cooperative venture between the Interstate Sanitation Commission and the Sanitary Engineering Research Laboratory of New York University. This research covered four investigations: *1,* the suitability of a simpler method of making analyses for dissolved oxygen in salt water; *2,* the suitability of a more convenient means of collecting samples for dissolved oxygen analysis; *3,* the suitability of a more convenient incubation schedule for the bio-chemical oxygen demand analysis of sewage; and *4,* investigations concerning coliform determinations in an attempt to develop more economical methods of analysis and of preserving and transporting samples.

For the determination of dissolved oxygen in sea water, the Commission used the Rideal-Stewart modification of the Winkler method. This method has two major objections, namely, that six reagents are required prior to titration, and two of these reagents require periods of contact that are time consuming. The sodium azide modification of the Winkler method, as employed by the Sanitary District of Chicago, is applicable for the determination of dissolved oxygen in fresh water. Experiments were carried out to determine the applicability of this method to salt water in the concentrations found in and around New York Harbor. Results indicated that this latter method was suitable and has now been adopted as it saves considerable time, requiring less skillful analytical technique and the use of only three reagents prior to titration.

The customary means of collecting D.O. samples is to fill a bottle with water collected from the depth desired, admitting no water into the bottle until this depth has been reached. The apparatus required for this method of sampling is quite cumbersome, and when samples are taken from a boat, it requires that the boat be stopped. An investigation was made to determine if samples should be taken by means of a hand-operated rotary pump. The bottom of the suction hose was weighted and sufficient hose provided to carry it to the depth where the sample was desired. Parallel runs were made using both methods and indicated that comparable results could be obtained. The sampling method by means of rotary pump was adopted because the suction hose could remain overboard at the desired depth while the boat was under way and the stopping of the boat was not necessary.

The ordinary B.O.D. test requires 5 days incubation at a temperature of 20° C. This procedure made it necessary for samples taken on Tuesday and Wednesday to be analyzed on Saturday and Sunday. On account of limited personnel, it was difficult to arrange schedules accordingly and an attempt was made to use the 7-day B.O.D. test as the standard of operation. The experimental work proved that this would be satisfactory and that correlation could be made between 5- and 7-day B.O.D. tests. The 7-day value could be interpreted to the 5-day B.O.D. in order that results might be in accord with standard procedure. This enabled the laboratory to be conducted more efficiently and economically.

The Interstate Sanitation Commission makes many analyses for coliform organisms in the waters around New York each year. A large number of presumptive, positive tubes of inoculations in lactose broth failed to be confirmed in brilliant green bile. The Commission was particularly interested in the results of the confirmed tests and not gas formers as a whole. Investigations were made on the direct inoculation of samples in brilliant green bile, using a 48-hour incubation. This eliminated the use of lactose broth. 4,800 inoculations were made in lactose and an equal number were made in brilliant green bile as a primary medium. 1,167 tubes planted in lactose as primary mediums for positive confirmed in brilliant green bile, while 1,137 planted in brilliant green bile as primary medium were positive. The final results varied by only 30 positive, or less than 1 per cent difference in results. The investigations carried on justified the use of brilliant green bile as a primary medium for sewage analysis. This method reduces the number of tubes handled by about 25 per cent and results in a considerable saving in time and material.

Experiments were conducted on the means of transportation of samples for coliform analysis. There are four general methods of making the analysis on samples taken at a point distant from the laboratory. These are: *1,* culture tubes inoculated at the sewage treatment plant; *2,* bottled samples returned to the laboratory for inoculation by transporting without preservatives or refrigeration; *3,* bottled samples dechlorinated and transported to the laboratory; *4,* bottled samples dechlorinated and transported to the laboratory in a refrigerator. The first method requires that the man planting the samples has the ability to inoculate the culture tube properly while the fourth method requires considerable equipment and is quite cumbersome to carry out. The experiment showed that the results using the first and fourth methods were practically the same and either one would be satisfactory for the Commission. The second method gave a lower count as the residual chlorine present in the bottled sample disinfected the sewage and gave a lower count. The third method gave a somewhat higher count, because the samples taken in the morning were kept warm and by the time they reached the laboratory in the evening, the number of coliform organisms had increased considerably. Since the Commission had an experienced man taking samples, they continued to use the method of inoculating the culture tubes at the sewage treatment plant.

To facilitate calculations made in connection with taking samples in waters under their jurisdiction, the Interstate Sanitation Commission prepared two charts which would be of general use and interest to engineers engaged in pollution studies in the vicinity of salt water. The first chart enables the observer to record the specific gravity by means of a hydrometer and the temperature in degrees Centigrade and from the table to obtain the per cent sea water in the sample being analyzed. This is particularly valuable where fresh water rivers empty into harbors or estuaries. The other chart was drawn for the purpose of obtaining the maximum solubility of oxygen at various temperatures and in various specific gravities of sea water. This was necessary to obtain the per cent saturation of oxygen in the waters of the District.

Rolf Eliassen

GREASE FROM SEWAGE HELPS GREAT BRITAIN

By H. Wontner-Smith

Engineering News-Record, **126,** 411 (March 13, 1941)

The City of Bradford, England, is the center of the wool washing industry of the world. One-fifth of the wool of the whole world, and four-fifths of the wool grown and imported into England is washed and dealt with by this municipality. The wool-grease is present in globules in the water, some in emulsified form with large quantities of soap and alkali used in the scouring of the wool. Some years ago, the Esholt sewage treatment works was built at a cost of $13,800,000 to care for the sewage of this community. The flow sheet of the plant involves grit chambers, primary sedimentation tanks, secondary sedimentation tanks, followed by trickling filters 6 ft. deep filled with coal ranging in size from ¾ to 1¼ in.

Into the sewage entering the primary sedimentation tank is added sulfuric acid to produce an acidity of 100 p.p.m. The object is to crack the soap in the sewage and precipitate dissolved organic matter, together with the wool waxes and suspended matter. The resulting sludge has a moisture content of from 80 to 83 per cent. It is mixed with gritty sludge from the grit chambers. Then it is passed to 7-ton vats where it is heated by means of steam coils to about 170° F., at which point it tends to froth. The sludge is then filtered in a battery of filter presses, with super-heated steam added to keep up the temperature. Liquid grease and water are discharged in the process. The usual practice is to press the sludge for 64 hours. In that time the grease content of the filter cake is reduced to about 15 per cent of the dry solids, as compared with 40 per cent in the original sludge. The moisture content of the resulting cake is about 26 per cent. After the grease is treated for the removal of impurities, it is barreled. Supernatant liquors resulting from purifying the grease and also the liquors passing from the presses, after separation of the grease, are returned to the sedimentation tanks. The press cake is dumped on a drying area in the open where it remains for about 12 months to mature. Then the material is passed through a disintegrator which grinds the dried cake into a fine powder and the product finds a ready market for fertilizing purposes.

Considerable research has been undertaken to develop by-products and methods for the production of clarified greases of a better quality than those ordinarily obtained from the sewage. For some time it was not possible to sell the greases at a good price and the city had been storing them. With the advent of war, the city found itself in possession of probably the largest stocks of native grease in England. The demand for this grease is such that, while sending out an average of 500 tons per week, the works are more than one month behind delivery. The biggest demand is for the new and clarified greases. In the last financial years (ending March 31, 1940), grease sales exceeded $400,000. For the present year, an amount several times this figure will probably be realized.

Another product of the treatment process is organic manure which contains the valuable organic nitrogen content of the fine wool fiber. Approximately 30,000 tons are available every year and are distributed largely for the dressing of grasslands, for which purpose it gives excellent results. It is sold to golf clubs throughout England at a delivery price of $7.50 per ton. Public schools, athletic fields, and farmers use considerable quantities, and compounders of manures exert a steady demand for this product. Digestion of the sludge is not practiced because it would injure the grease and manure values of the dried sludge.

It is generally considered that the City of Bradford is the largest user of sulfuric acid in one individual plant in England. Approximately 20,000 tons per year are necessary. At the sewage plant there is a sulfuric acid manufacturing plant capable of providing for 9,000 tons annually. The government has requested the city to double this capacity in order that they can manufacture the acid they need without making demands on the heavy chemical industries.

The author ends with a note of optimism as he states "and it can be said with confidence, now that all surrounding townships, with similar trades, have agreed to join the central works, this part of the world, at any rate, will be a better place in which to live."

Rolf Eliassen

PROCEEDINGS OF THE TWENTY-SECOND TEXAS WATER WORKS AND SEWAGE SHORT SCHOOL

February 19–23, 1940

Arriving at Actual and Expected Sanitary Sewage Flows. By R. U. Andrews, pp. 98–99. At Fort Worth, Texas, the average hourly flow is taken as 85 gallons per capita per day. The maximum peak flow is then computed by

$$M = \left[1 + \left(\frac{14}{4+p}\right)\right]\frac{85}{24}$$

where M is the maximum peak flow in gallons per hour and p is the population in thousands. An example of an actual design is given.

The answer to infiltration is the control of a number of factors such as old house connections and unused wyes in the sewer lines. Others include house connections poorly located and poorly laid and gravel sub-drainage under and around basements.

The Design of Storm Sewers. By William E. White, pp. 99–101. The design of a storm sewer system involves application of the principles of hydrology, hydraulics and structural design. The rational method of estimating runoff is used at Houston, Texas. The intensity of rainfall is determined from a statistical study of rainfall records. The intensity-duration curve is usually based on the 20 per cent or 10 per cent storm. The value of C is determined from the empirical equation $C = 0.175t^{1/3}$. The computed value of C is then adjusted according to the estimated imperviousness.

Nearly all of the Houston sewers are of concrete. An "n" value of 0.013 is used to compute capacities. Grades are established to provide a minimum velocity of 3 feet/sec. for a filled section. Velocities greater than 12 to 15 feet per second have caused no damage.

Soil conditions found by borings, conditions at the time of construction, and depth of cover over the sewer determine whether plain or reinforced concrete is used in sewer construction. Loads are determined from data given by Marston and Anderson, Bulletin 96, Iowa Engineering Experiment Station, Ames, Iowa.

Discussion on Design of Storm Sewers. By W. O. Jones, pp. 101–103. Methods of design used at Ft. Worth, Texas, are discussed. Common errors in hydraulic design are listed as (1) To underestimate the amount of rainfall reaching the sewers, (2) To overestimate the sewer capacity, (3) Failure to plan for extensions, (4) Omitting a part of the drainage area.

Street inlets should be located to intercept the water before it reaches pedestrian cross walks. The grate type inlet has been found unsatisfactory.

Aims in Sewage Treatment. By E. J. M. Berg. The author discusses the various methods available for the disposal of screenings, sludge and liquid wastes. The paper is concluded by a discussion of the natural purification power of streams and its relation to sewage treatment.

Characteristics of Sewage. By W. S. Mahlie, pp. 107–109. A general discussion.

Operation Methods of Sewage Treatment Trickling Filters. By H. D. McAfee, pp. 110–111. Trickling filters are described and biological oxidation is discussed.

Manholes, Cleanouts and Flushtanks. By R. R. Cooke, pp. 111–113. Manhole openings should be about 22 in. in diameter increasing to about 4 ft. at the sewer. In Dallas, Texas, manholes are built only at intersecting sewers and at changes in grade. Cleanouts are spaced at 200 ft. intervals on all 6 in. and 8 in. sewers. Manhole covers and seats are machined to true bearing. The necessity of machining forces the foundry to produce a good quality casting. Brick used in manholes should have a low absorption per cent in order to resist disintegration. Manhole steps are constructed of cast iron The invert of the manhole should be built up as high or possibly a little higher than the sewer pipe to avoid flow disturbance. The table should slope toward the invert to a degree sufficient to be self cleansing but should not be too steep for safety. It is usually good practice to extend the edge of the bottom some 6 in. beyond the outer edge of the wall.

Cleanout manholes are built like standard manholes except that a cleanout wye is inserted in the sewer on the down grade side so that the cleanout stack enters the manhole about 2 ft. below street level. Sewer rods can then be inserted from the street The wye and stack must be well supported.

Flush tanks are considered a nuisance and their use has been discontinued in Dallas

Inlets and Appurtenances. By C. G. Levander, pp. 113–115. A description of storm water street inlet construction at Dallas, Texas, is given.

Economics of Sewage Treatment. By W. A. Hardenburgh, pp. 115–119. Three important angles of approach to sewage treatment economics are: (1) the money value to a community of adequate sewage treatment (2) the method financing sewage treatment (3) the comparative costs of various methods of treatment.

Biofiltration. By O. V. Lindell, pp. 119–120. "Biofiltration involves the application of presettled sewage to a trickling filter and the recirculation of all or part of the filter discharge back to the pre-sedimentation tank."

Control of Activated Sludge Plants. By Milton Spiegel, pp. 121–132. The paper is opened by a general consideration of the essential features of the activated sludge process. The work of Nordell and Kessler in connection with the rate of oxygen demand of activated sludge-sewage mixtures is briefly reviewed.

Control of Activated Sludge Plants. By William Pralle, pp. 132–133. General.

Correlation of Sampling, Sample Preservation, Sample Composition, Flow Measurement and Analysis. By W. S. Mahlie, pp. 134–138. Topics considered are (1) importance of correct sampling (2) changes in the composition of sewage (3) changes in rate of flow (4) changes in flow composition for days of the week (5) composite samples (6) method of compositing samples at Fort Worth (7) sampling intervals (8) automatic samplers (9) care to be taken in sampling (10) preservation of samples (11) measurement of sewage flow. Illustrative examples of sampling and compositing methods are given.

Stream Pollution from a National Standpoint. By E. C. Sullivan, pp. 138–139. "Reasonably clean streams and other natural bodies of water are essential (1) for the prevention of water borne diseases (2) for the conservation of the agricultural, industrial, recreational, and aquatic life resources of waterways; and (3) for the prevention of nuisance conditions."

The status of domestic and industrial waste disposal is summarized as follows:

1. The population served by sewers in the U. S. is about 73,174,000, or slightly less than the total urban population of 73,200,000.

2. The sewage of about 33,400,000 people, is discharged to natural bodies of water without treatment.

3. The sewage of approximately 39,800,000 people is discharged to receiving bodies of water through treatment plants, representing an increase from 31 to 54 per cent in the urban population thus served in the period 1933–39 inclusive.

4. Of 39,800,000 persons served by treatment plants 19,000,000 are tributary to plants providing primary treatment only. The remainder are served by more complete works. In the period 1933–39 the proportion of these municipal wastes receiving only primary treatment has decreased whereas plants which provide more complete treatment have relatively increased.

5. Industrial wastes impose on the self-purification capacity of the streams of the U. S. an additional burden equal to at least ⅔ of the load of bacterial and organic polution contributed by the domestic population.

Legal Aspects of Stream Pollution. By George E. Murphy, pp. 140–142. A review of the legal rights of the State of Texas in connection with stream pollution prevention is given. In addition to sovereign and statutory powers, the State has inherent powers to abate a public nuisance by injunction. Under the Constitution of the State all rivers and streams are designated as natural resources and their preservation and conservation are declared by the Constitution to be public rights and duties. The legislature is invested with authority to pass such laws as may be appropriate thereto.

What Stream Pollution Means to the Water Works Man. By D. B. Dickson, pp. 142–143. The difficulty of continuously furnishing the public clear, odorless and tasteless water from a polluted source of supply is discussed.

Disposal and Treatment of Citrus Fruit Canning Wastes. By C. H. Billings, pp. 143–146. Experiments have shown that cannery waste can be treated by chemical precipitation, employing lime and alum. A typical treatment unit consists of a self-cleaning screen followed by batch dosing and settling tanks. Minimum lime dosage was found to be 4.3 grains per gallon for each 100 p.p.m. of citrous acidity present. The acidity of the average waste was about 600 p.p.m. The alum dose was usually of the order of 3.5 grains per gallon. This treatment reduced acidity and high solids content but B.O.D. reduction was only 30 per cent or less. More efficient treatment methods were, therefore, sought. Slow sand and sand and gravel combination filters were not satisfactory due to clogging. Aeration methods along the lines of activated sludge gave better results. Pilot plant studies on contact aeration methods with a two hour retention in the aeration tanks gave a B.O.D. reduction of 54 per cent. Initial B.O.D. was 2,800 p.p.m.

Trickling filter treatment was also studied on a pilot plant scale. A filter having a surface area of 2.64 ft. and a depth of 5 ft. was employed. Continuous dosing even at rates of less than 1 m.g.a.d. was unsuccessful. Intermittent application gave good results. Various rates ranging from 0.5 to 3.0 M.G.A.D. were tried. Average B.O.D. reduction at a rate of 1 M.G.A.D. was 71.9 per cent from an average initial value of 947 p.p.m. Mean temperature during the test run was 64° F.

A careful study of canning operations was made. The findings on the basis of 1,000 gallons of juice canned are as follows: fruit wash water, 700 gal., 100 p.p.m. B.O.D.; peel bin drippage, 31 gal., 50,000 p.p.m. B.O.D.; waste juice diluted in washing down, 100 gal., 4,000 p.p.m. B.O.D.; cooling water, 1,350 gal., 20 ppm. B.O.D. Combined wastes, 2,181 gal., 940 p.p.m. B.O.D. Average small juice plant will can about 1,000 gallons per hour.

Grinding the peel before placing in bins eliminates bin drippage. Reuse of cooling water reduces the volume of waste.

The City's Sewage Problem and Its Relation to Industry. By Walter Dillard, pp. 146–147. A discussion of industry's responsibility in stream pollution control. An example of cooperation between city, county, state, and industrial officials in studying an industrial waste problem is cited.

Discussion of the City's Sewage Problem and Its Relation to Industries. By E. J. M. Berg, pp. 147–148. A review of the problem of industrial waste disposal in relation to sewage treatment.

Treatment Methods for Creamery and Dairy Wastes. By Vernon P. Crockett, pp. 148–151. The author summarizes this paper as follows: to reduce fluid milk losses in the milk plant; to separate the unpolluted or slightly polluted cooling and condenser waters and the direct discharge of them to the sewer or stream will reduce the size of the required plant; and to recover or remove valuable by-products from the waste discharge, such as whey, buttermilk, skim milk and drip milk.

Broad irrigation is recognized as a satisfactory method of disposal under favorable conditions. Chemical precipitation is a means of securing clarification but requires additional treatment. The biochemical or Guggenheim process offers a treatment that is worthy of further consideration, but biological or trickling filters provide the most effective unit for the treatment of creamery and dairy wastes in common use today.

Paper Mill Wastes and Their Treatment. By L. F. Warrick, pp. 151–156. Paper pulp is manufactured by four important commercial processes, (1) the groundwood process, (2) the sulfite process, (3) the sulfate or kraft process and (4) the soda process. The first is a mechanical process, the latter three, chemical. The object of the chemical processes is to separate the fibrous material (cellulose) from the non-fibrous material (lignin). In any process the wood is prepared by cutting logs into definite lengths and removing bark. Sawdust and bark refuse from these operations formerly were discharged into streams but are now burned in the power plants or otherwise reclaimed.

Waste water from the groundwood pulping process in some cases contains fibrous and extracted material equivalent to 10 per cent of the dry weight of the wood. Good mechanical equipment, careful operation and installation of pulp saving equipment, however, will reduce such losses to a negligible amount. Pulp fiber does not ordinarily accumulate in and clog the gills of fish. However, fibers and other solids may settle to the bed of a stream and decompose there, using up oxygen.

Lime sludge produced in the caustisizing of the cooking liquor in soda and sulfate mills was formerly discharged into water courses. The sludge is now either calcined for reuse, sold to farmers or made into whiting.

For many years there has been no practical method for utilization or disposal of the sulfite waste liquor. By-products such as sulfite alcohol, glue, core binder, road binder, briquetting material, tanning extracts, etc., have been prepared from sulfite liquor. However, a few sulfite mills can supply the entire demand for these materials. The deleterious effects of waste sulfite liquor on fish life are largely due to the depletion of oxygen. However, there is evidence that in the case of sulfate pulp wastes a resinous component exerts a toxic effect.

The oxygen demand of the waste sulfite liquor produced per ton of pulp is equivalent to the sanitary sewage from a population of around 1,500 and may be as high as 5,000 persons per ton of pulp. Groundwood pulp wastes have an average population equivalent of 10 persons per ton of pulp.

The Treatment and Disposal of Oil Field Brine. By Joe J. Rody, pp. 156–159. Recent court action by the State of Texas against 55 oil companies charging water pollution from waste salt water has focussed attention upon the problem of oil field brine disposal.

Proper drilling methods, careful bottom hole plugging and cementing of the annular space between the outside casing and the drill hole will reduce the intrusion of brine into fresh water strata and into the well. However, brine cannot be excluded under all conditions in spite of all precautions. The quantity of brine produced increases with the life of the field. The high mineral content and wide concentration variation is illustrated by the following table showing composition limits of representative brines from Kansas, Oklahoma and Texas oil fields.

Ion	P.P.M.
Calcium	600 to 13,000
Magnesium	230 to 4,000
Sodium and potassium	5,000 to 76,000
Bicarbonate	20 to 650
Sulfate	trace to 2,500
Chloride	10,000 to 150,000
Total solids	15,000 to 250,000

Three methods of disposal are being tried. The first consists of impoundment in evaporation ponds. However, the net evaporation is too slow to be effective and seepage from the ponds is a continuous source of trouble. The second method is that of diversion into surface streams. This procedure requires a large initial investment and its operation depends upon regulated release of brine when dilution ratios are favorable. Where adequate storage has not been provided or where the brine discharge has not been carefully controlled this method has not proven satisfactory. The third method involves the return of the oil field brine to subsurface formations. In applying this method proper location of the disposal well and conditioning of the brine are essential.

Two systems are used for conditioning brine for subsurface injection, the open type system and the closed type. The closed type involves complete removal of suspended matter and maintenance of the brine under pressure from the time it reaches the surface until its return underground. The open type which is more widely used involves brine separation, aeration, carbonate stabilization, dissolved oxygen reduction and filtration. Special attention should be given to the use of corrosion resistant materials in pipes, pumps and meters.

It is impossible to formulate fixed rules for brine disposal. The most feasible plan for attacking the problem appears to be to separate the State into drainage basins or specific oil fields and study each area as a unit. These studies should include reports on topography, surface drainage conditions, oil well locations, surface and subsurface geology, oil and brine production, and analytical data on brines. Careful studies should also be made of private and public water supplies and stream flows in each area.

Paul D. Haney

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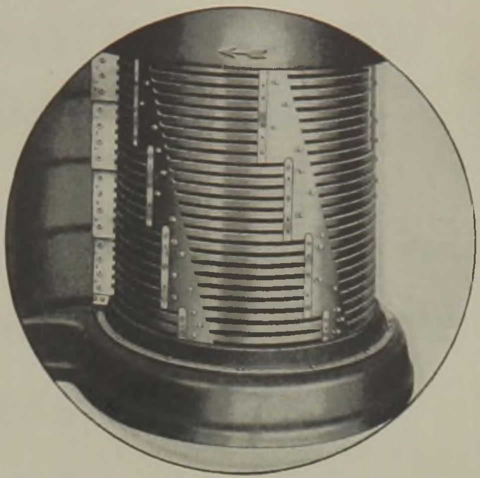

Close-up of Comminutor drum, showing distribution of cutters for minimizing shearing stresses and power requirements.

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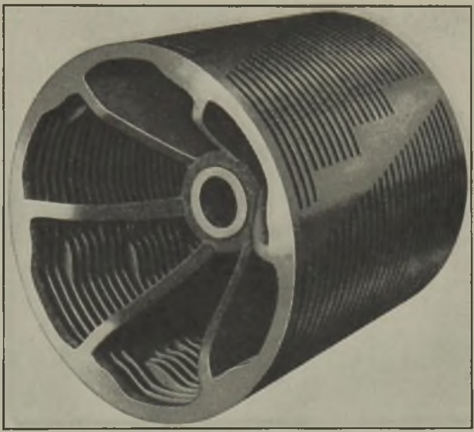

Bottom view of slotted Comminutor drum, showing ribbing and heavy bearing housing necessary for maximum rigidity and strength.

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