SEWAGE WORKS JOURNAL

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Special Features

Reorganization of Federation

New Constitution and By-Laws

Annual Report of Research Committee

Sludge Deposits—Fair, Moore and Thomas

OFFICIAL PUBLICATION OF THE
FEDERATION OF SEWAGE WORKS ASSOCIATIONS

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

SEWAGE WORKS JOURNAL

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

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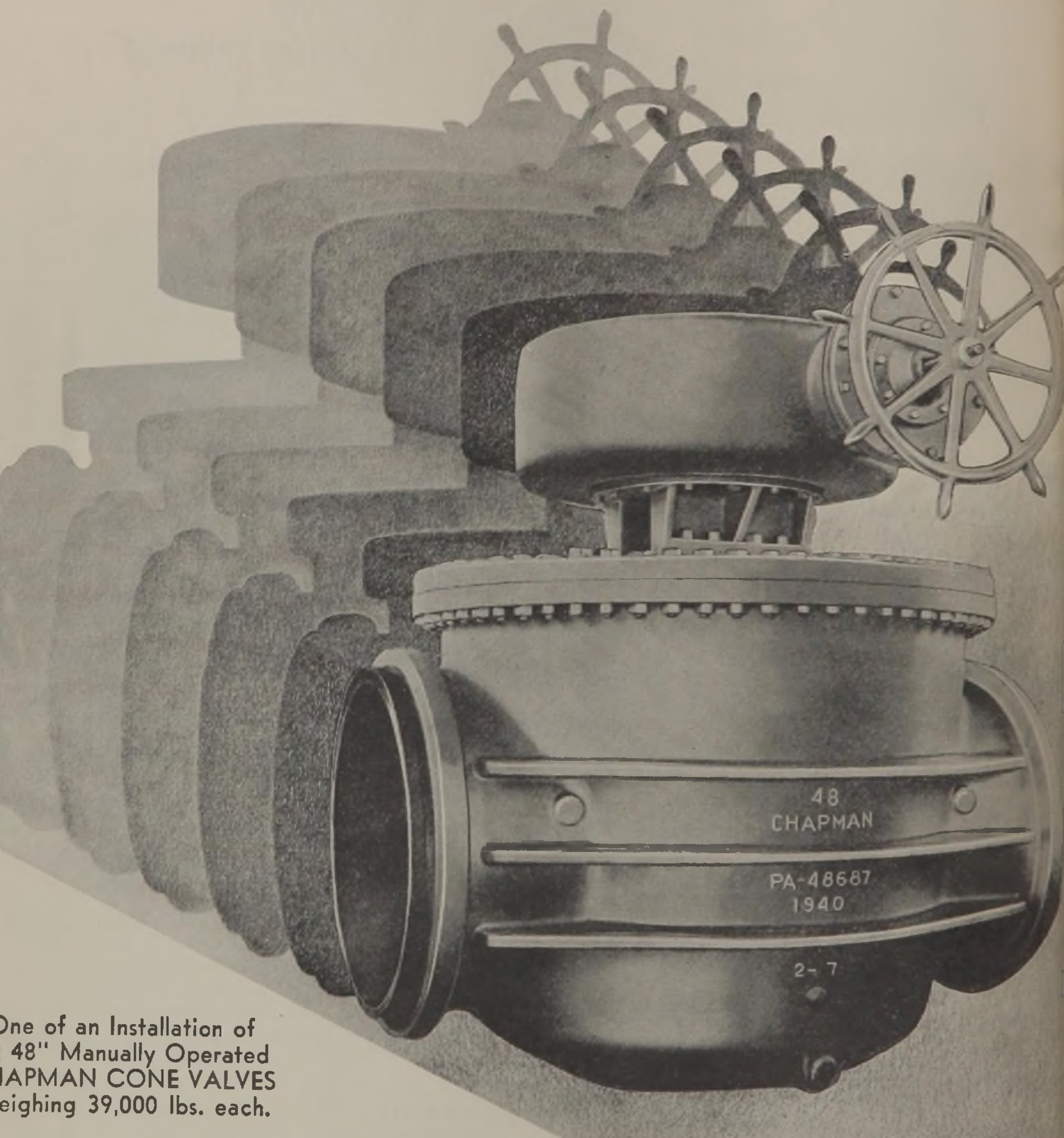

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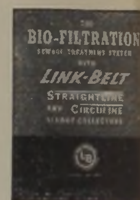

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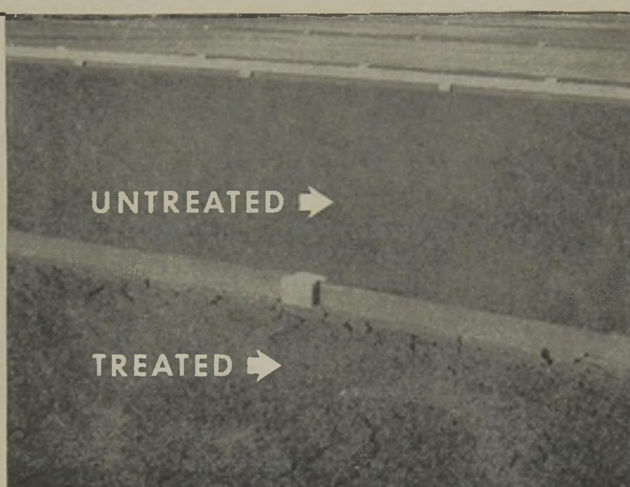

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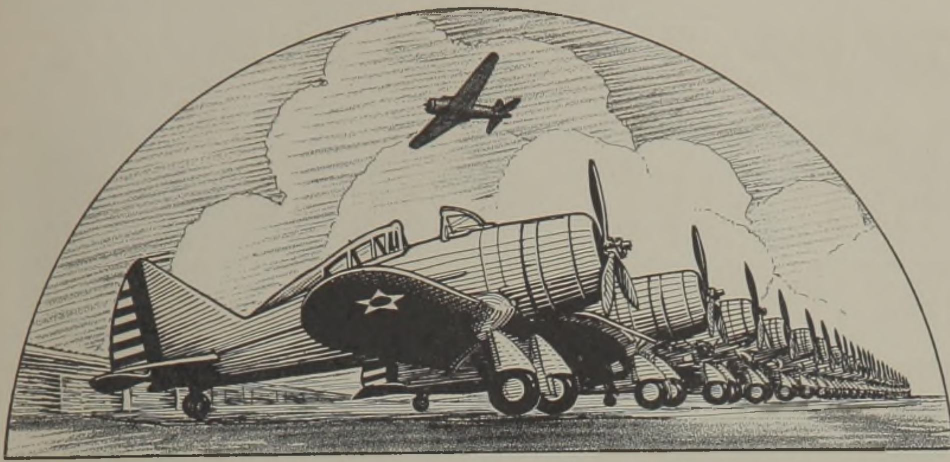

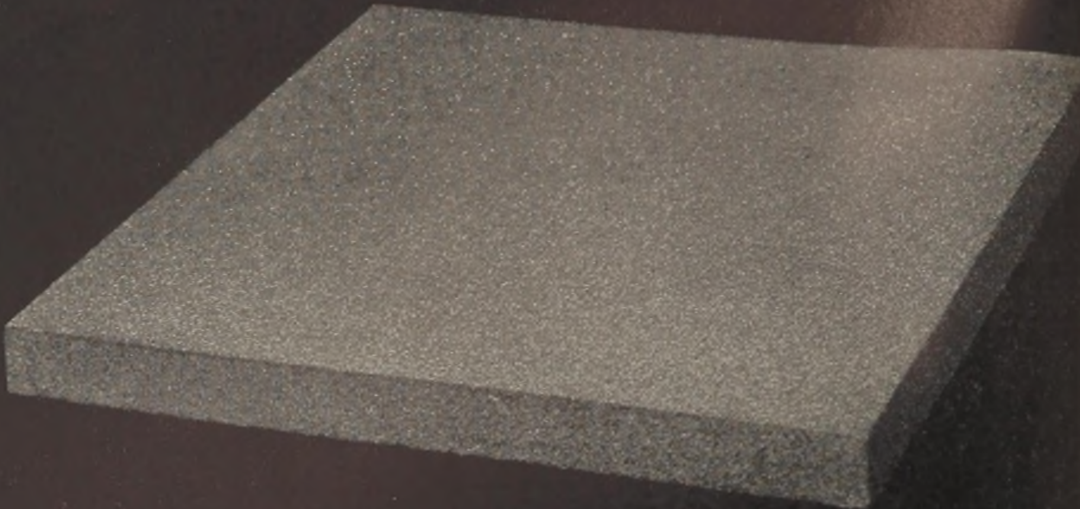

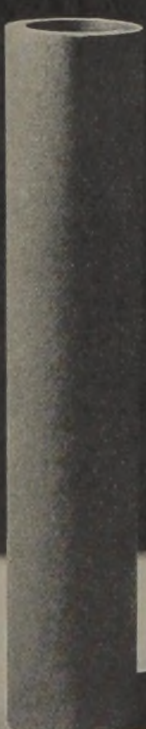

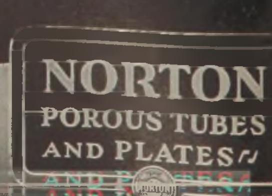

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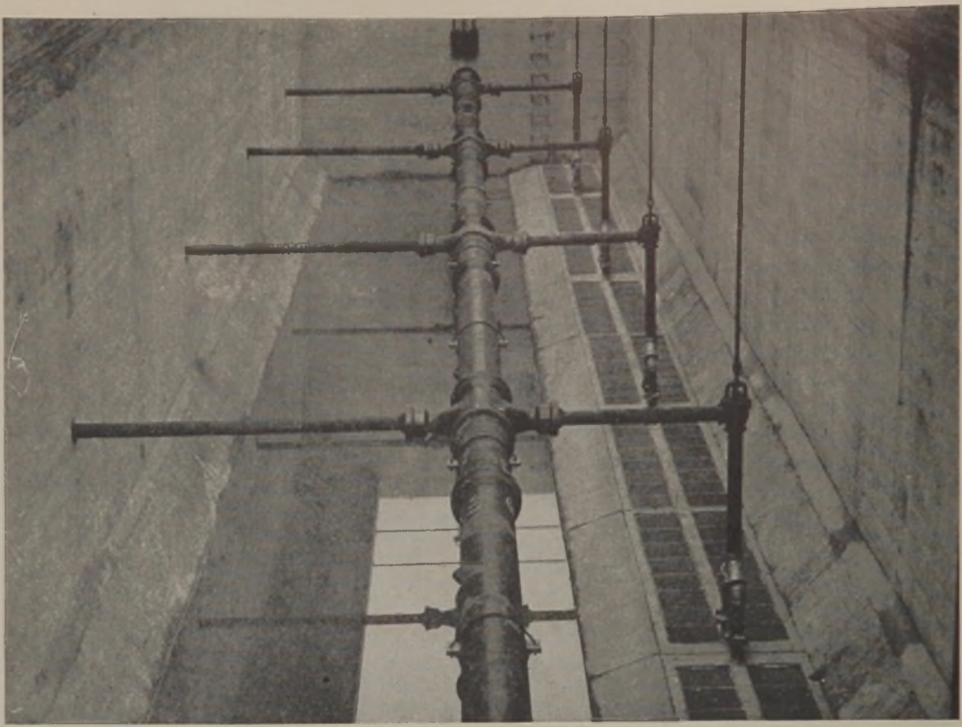

Cast iron header conducting air to activated sludge tanks at treatment plant in Springfield, Ill.

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Sewage Research:

Plant Operation:

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Operators' Reports and Suggestions:

Editorial:

Proceedings of Local Associations:

Federation Affairs:

Sewage Research

A CRITICAL REVIEW OF THE LITERATURE OF 1940 ON SEWAGE AND WASTE TREATMENT AND STREAM POLLUTION

By W. Rudolfs, *Chairman*, T. R. Camp, E. J. Cleary, G. P. Edwards, H. A. Faber, A. J. Fischer, H. W. Gehm, A. E. Griffin, H. Heukelekian, R. W. Kehr, E. M. Moore, L. R. Setter, W. E. Stanley, L. W. Van Kleeck and S. I. Zack

Committee on Research, Federation of Sewage Works Associations

The literature published during 1940 pertaining to sewage and waste treatment has been extensive in this country. Foreign contributions were considerably curtailed on account of the war. Again important contributions were made in the fields of research, operation and development. The increasing importance of industrial waste treatment is evident from the review. It appears that this branch of the work, which pertains more to cleaner streams and better living conditions than to health hazards, indicates more clearly the general tendencies and future trend of thought of the whole problem. However, the health aspect of sewage treatment has been emphasized by the possibility that the dreaded infantile paralysis virus remains viable in, and is carried, by sewage. Stream surveys and contributions to fundamental research in stream pollution have been less than in previous years, which may be a coincidence with the temporary shelving of national legislation for stream pollution abatement. Studies on fundamental principles of sewage treatment, particularly the activated sludge process, have been continued. The problem is gradually clearing up, but is not solved. The necessity for a thorough exposition of theory and practice of the activated sludge process is apparent to show where we stand in practice and research. By-product recovery from sewage and waste is becoming more and more of general interest. Proper, accurate, simple and expedient analytical methods are still demanded. This is particularly evident in methods for grease and oil determinations, chemical demands of sewage, and sludge analyses. Sludge treatment and disposal is still the heart of the problem at many plants. Of particular interest, therefore, is the increase in quantities of solids caused by so-called dual treatment of sewage and garbage.

This annual review is again presented as evidence of progress. The review has been extended somewhat and this year a brief section on new aids to practice has been included. The entire review is not complete in the sense that all papers published during the year were considered, but we believe that all important papers have been used to indicate the work accomplished, and the trends in sewage and waste treatment and stream pollution are shown.

Chemistry and Biology

Sewage and Disease. The suspicion that sewage might be a vehicle for the spread of poliomyelitis has been increasing. Successful isolation of the poliomyelitis virus from sewage of communities with poliomyelitis epidemics was reported by Paul, Trask and Cullotta.[166] Trask, Vignec and Paul[221] and Kramer, Gilliam and Milner[131] isolated the virus from human stools. Indirect evidence from statistical data obtained from different sized communities in Louisiana with and without water supply and sewage disposal systems, led Casey and Aymond[33] to conclude that the dilution of the sewage might play an important role in the incidence of poliomyelitis. In a general review of the subject Ellsworth[61] advanced evidence and arguments in favor of the water transmission of this disease. It was stated that the virus in the stools remained viable for at least 10 weeks in the refrigerator. For as long as 25 days after the onset of the disease the stools could be infective to monkeys. Virus from active cases or from carriers could be present in sewage not only during epidemics but at other times as well. Kemp and Soule[124] reported that the virus of poliomyelitis was inactivated by four hours' contact with 0.5 p.p.m. of chlorine in the form of chloramine but was not inactivated by 1.5 hours' contact.

To the information already available on the presence of typhoid bacteria in sewage and sludge and the effect of natural and artificial environmental conditions on their survival Mom and Shaeffer[156] have contributed additional information pertaining to conditions in the Netherlands East Indies. Typhoid bacteria were found regularly in municipal sewage in numbers higher than in European sewage. About 80 per cent reduction of typhoid bacteria was obtained by the passage of sewage through Imhoff tanks. The organisms were found in the sludge obtained but the recovery was lower than the removals would indicate. Digestion reduced their numbers rapidly, but did not eliminate them completely. After drying the sludge, no further typhoid bacteria could be found.

Beard[20] studied the factors influencing the longevity of typhoid bacteria in soils. He found moisture to be the most important factor. Fifty per cent of the typhoid bacteria died during the first 48 hours. The survival of the remainder extended over a period of months. In sewage-polluted soil the survival was shorter than in non-polluted soil.

There have been a number of different opinions expressed as to the effect on cattle and farm animals of sewage contaminated water. For the first time, however, the question has been subjected to controlled experimentation by Crawford and Frank.[43] The conditions of the experiment were more stringent than ordinarily would be the case, since the sewage dealt with contained not only the usual contamination from human sources but also from animals used in the U. S. Animal Disease

Station, including animals infected with tuberculosis, brucellosis, mastitis, hog cholera and other bacterial and virus diseases. It is stated that although many of the stables and barns were provided with septic tanks in which the sewage was disinfected, the causative agents of these diseases in virulent form might pass into the sewage entering the treatment plant. The sewage was treated in a trickling filter-separate sludge digestion type of a plant. The raw sewage, effluent from the plant and the sludge when fed to swine showed no harmful effect on the animals. Likewise the effluent consumed by cattle had no effect. None of the animals in the experiment manifested an unwillingness to consume the various materials. Tuberculin tests were made on all animals both during and after the test period (6 months) and showed no positive reaction. Post mortems showed no evidence of disease.

Biochemical Oxidation. Additional information relative to the effect of oxygen tension on the rate of bacterial oxidation coming from two different sources point to different conclusions. Zobell [249] reported that the rate of respiration was independent of oxygen concentration of the water within the range of 0.3–26.5 p.p.m. D.O. Zobell and Stadler [250] in a study covering the atmospheric saturation range concluded that oxygen was consumed at virtually the same rate at all oxygen tensions during 4 or 5 days unless nearly all the oxygen was depleted earlier. The rate of oxygen uptake per cell was highest during the first day irrespective of the initial dissolved oxygen and decreased gradually up to the fourth day.

The second contribution on this problem is from Viehl.[229] Average results of several series of tests showed that B.O.D. values increased with increasing D.O. values from 2 to 12.9 p.p.m. Increasing the D.O. tension from 12.9 to 40 p.p.m. had the effect of decreasing B.O.D. values. B.O.D. at 2 p.p.m. D.O. was 82 per cent of that obtained at its highest value at 12.9 p.p.m. D.O. At 40 p.p.m., B.O.D. was 73 per cent of that at 12.9 p.p.m. D.O.

Studies were also conducted by Viehl [229] on the effect of the rate of aeration, on the activated sludge process under laboratory conditions. D.O. concentrations ranging from 0.8 p.p.m. to 5.4 p.p.m. were obtained by regulating the rate of aeration. From the results obtained the author concluded that 1.5 p.p.m. D.O. was sufficient for the activated sludge process.

In an attempt to account for the rapid self-purification in streams receiving large quantities of acid mine drainage, Ruchhoft, Ettinger and Walker [185] reported that biochemical oxidation was possible in substrates containing 100 to 1000 p.p.m. free sulfuric acid with a pH of 1.9 to 3.0. The presence of large numbers of specialized organisms viable in such acid substrates was demonstrated. The purification was characterized by a lag phase which could be shortened by the addition of some old acid sewage.

A systematic study of the buffer value of sewage and the changes of the buffer value during aeration with or without activated sludge were reported by Ingols and Heukelekian.[105] It was found that the buffer value of sewage was in the Seitz filtrate fraction. Ammonium bicarbonate was one of the important ingredients in sewage contributing to the buffer value. Aeration of activated sludge-sewage mixtures under laboratory conditions showed that the buffer values decreased rapidly and that changes in pH value were due to loss of volatile acids, to the reduction of buffer values and the oxidation of ammonia to nitrate. The reduction in the buffer values in plant aeration tanks were of smaller magnitude for presumably similar periods of aeration.

Surface Phenomena and Bacterial Growth. Conn and Conn [39] reported that bacterial numbers increased in the presence of colloids irrespective of the base with which the colloids were saturated. Colloids such as bentonite, kaolinite, etc. were found to be effective.

McCalla [146] stated that bacteria adsorb the H^+ formed by the liberation of CO_2. Continuation of this adsorption might result in a complete H^+ saturated bacteria. In the presence of other ions an exchange of H^+ for basic ions would take place enabling the cell to concentrate and bind these ions as a store for future use.

Heukelekian and Heller [90] called attention to the relation between surfaces and limiting food concentration for bacterial growths. They found that *Esch. coli* did not grow in a glucose-peptone broth of 0.5 to 2.5 p.p.m. concentration. The addition of glass beads to the medium permitted the growth at such low concentrations of food material. The effect of glass beads was noticeable up to 25 p.p.m. concentration of glucose and peptone. Beyond this concentration the numbers of *Esch. coli* with and without glass beads were practically the same. The bacterial population of stream water was similarly affected by the addition of clean sand. The addition of stones covered with biologically active slime to surface waters did not prevent the increase in the numbers of bacteria but considerably reduced the magnitude of increase. Surfaces enable bacteria to develop in substrates otherwise too dilute for growth. Development takes place either as bacterial slime or colonial growth attached to the surfaces.

According to Butterfield [32] the type of bacterial growth in dilute substrates such as slightly polluted waters with 5-day B.O.D. of 6.0 p.p.m. or less, consists of single cells. In concentrated media or grossly polluted waters with 5-day B.O.D. of 100 p.p.m. or more the growth consists of colonial forms or flocs provided the liquid is aerated.

Petroleum Products and Bacteria. Micro-organisms capable of attacking petroleum and its fractions were obtained from soil by Stone, White and Fenske.[206] Temperatures of 20° to 37° C., pH values of 6.0 to 8.0, some form of nitrogen such as ammonium sulfate and a plentiful supply of air are necessary for the breakdown of petroleum. In general the lower molecular weight fractions were found to be more susceptible to attack than were the heavy oils and tar. Oils high in paraffine hydrocarbons were more readily assimilated than those high in aromatic content. Naphthalene fractions occupied an intermediate position. Strawinski and Stone [208] found cetane, naphthalene and biphenyl the most rapidly attacked by the 18 hydrocarbons studied.

Counts ranging from 1 to 1½ billions per ml. were obtained in substrate containing no other source of carbon except the hydrocarbons. Attempts to develop cultures capable of growing in benzene and toluene were unsuccessful.

Heukelekian and Schulhoff [93] determined the effect of some of these volatile solvents on the bacterial numbers of sewage. They found that benzene up to 0.5 ml. per liter concentration had little effect on the total numbers of bacteria and *Esch. coli.* At 1.0 ml. per liter concentration a definite inhibitory effect was obtained. The numbers of bacteria with low concentration of benzene were higher than in the control after 24 hours. Carbon tetrachloride brought about only a small decrease in the numbers of bacteria after 3½ hours of contact but with 24-hour contact the reductions were considerable. Gasoline and kerosene were not as toxic as benzene or carbon tetrachloride. The effectiveness of these solvents was reduced when kept in contact with the sewage in open vessels.

Miscellaneous. Using yeast as a test organism for the biological detection of growth-promoting substances in sewages and sludge, Rudolfs and Heinemann [192] found that fresh solids gave the highest assay; oxidation reduced, but chlorination did not deter the action of growth-promoting substances responsible for stimulation of yeast growth.

A search for a non-corrosive compound inhibiting the growth of sulfate-reducing bacteria by Rogers [179] showed the effectiveness of certain dyes such as acriflavine and proflavine. These dyes in concentrations of 1 to 2,000,000 inhibited hydrogen sulfide production. Hydrogen sulfide decolorized the dye without reducing its efficiency. Large concentrations of the dyes were bactericidal, while low concentrations were bacteriostatic.

Laboratory Methods and Analytical Procedures

The often repeated but under-emphasized importance of the sewage sampling problem was discussed by Pomeroy.[170] Low daily composite suspended solid values usually occur even if sewage influents are sampled hourly and significant total solids errors may occur on primary sludge composites sampled at greater than one-minute intervals. Considering these conditions a consistently reliable solids balance awaits the development of practicable automatic samplers and improvement in sewage analyses to more adequately account for the coarser solids.

Bell [21] reports the successful use of the Jackson turbidimeter readings in the control of chemical treatment. The turbidity reduction on a given sewage was found to be proportional to the B.O.D. reduction. New equipment and arrangements in photo-electric spectrophotometry [28, 159] and photocolorimetry [203] which increase sensitivity and reliability and decrease maintenance may prove a practical and simple solution to many sewage plant control tests.

The development of the dropping mercury electrode [158, 125, 230] and sensitive or direct-acting potentiometer recorders [125, 159] has promise of becoming important in the control of sewage chlorination and aeration.

The first glass electrodes (Beckman type E) for measuring the pH in the alkaline range from pH 9.5 to 13.5 and a new sleeveless calomel electrode which minimizes maintenance attention was reported.[125]

A unique photometric study of the coloration of sulfuric acid by organic constituents in natural waters was reported by Datzko.[45] Maximum coloration was obtained by heating 25 ml. of water with 3 ml. H_2SO_4, to eliminate the water, and then continuing the heating of the residue for ten minutes at 220° to 250° C. The intensity of coloration is approximately proportional to the content of organic matter. The intensity of coloration given by unit weight of substance falls in the order of humic acid, glucose, and peptone.

West and Christiansen [236] utilized a simple microtechnic in scrubbing physiological fluids for the determination of carbon dioxide which may be modified for the determination of total carbon. An evacuated 250 ml. Erlenmeyer flask containing a standard solution of $Ba(OH)_2$ serves as the absorption tower. The tower also serves for the storage of the air used to wash the sample and gas scrubbing train. The apparatus is simple in design and requires little laboratory space. Several tests can be completed in 30 minutes. A semi-microdetermination of carbon by the wet combustion (chromic acid) of pure substances gave good check results.[24]

Fair [65] presented modification of sewage tests particularly worthy of attention. The sludge respirometer appears simple in construction and manipulation and is shown to give excellent check results on activated sludge. The use of an automobile head lamp and a bulls eye lens to obtain a Tyndall beam for observing chemical floc formation appears as a definite improvement in laboratory multiple stirring devices.

Progress in laboratory methods is in no small measure dependent on manufacturers' to supply instruments and apparatus. American instrumentation is forging ahead at an amazing rate as indicated in the comprehensive compilation of recent developments by Müller [159] and the imposing directory of instrument manufacturers published in the October, 1940, analytical issue of *Industrial and Engineering Chemistry.* The application of some of these instruments in solving specific sewage plant control and research problems should follow.

Ruchhoft and Moore [184] attribute the apparent loss from calculated initial dissolved oxygen when a dilution of mud is immediately examined by the Winkler method to the interference with the analytical procedure. This interference occurs largely in the preliminary acid treatment with the Rideal-Stewart or azide procedures or during the final acidification and titration. Removal of the solids from the sample reduced the interfering materials and the initial apparent dissolved oxygen loss. Solids may be removed by centrifuging the sample in completely filled glass stoppered bottles or flocculating with alum.

In the determination of the B.O.D. of mud samples the authors have shown that if the sludge is kept in suspension by slow rotation higher values are obtained. The precaution for removing the suspended matter by centrifuging or flocculation should be practiced in the D.O. determination of the B.O.D.

Sedimentation

More data are accumulating which demonstrate the value of "self-flocculation" of sewage solids in the improvement of primary clarification. In laboratory experiments on 9 raw sewages from widely separated plants, Fischer and Hillman[69] have shown that 20 minutes pre-flocculation increases the removal of suspended solids after 60 minutes settling by 4 to 36 per cent over results obtained without flocculation, with an average improvement of 20 per cent. In plant-scale tests at Cedar Rapids by the same investigators, pre-flocculation for 30 to 40 minutes increased the removal in the clarifiers by 12 to 36 per cent with 1.9 hours settling. Similar improvements were obtained at Sioux Falls by pre-flocculation of the trickling filter effluent prior to final settling.

Snyder[216] discusses results obtained at Massillon, Ohio, where a sewage containing pickling liquor is treated. An increase of ten per cent in B.O.D. reduction was accomplished and an additional 92 p.p.m. of suspended solids were removed by pre-flocculation. Lime addition was tried but no improvement resulted possibly because only 10 p.p.m. CaO was used.

Gehm[79] presented laboratory studies on mechanical sewage flocculation. The characteristics of domestic sewage were studied in relation to their effect on the removal of solids by pre-flocculation. Results showed that pre-settling was somewhat detrimental to the process so far as degree of clarification obtained was concerned. The return of settleable solids did not improve the effluents obtained. The size of the sewage particles was measured and it was found that the size range between 15 and 40 microns was amenable to flocculation. Particles under 15 microns in size are not flocculated. The pH, alkalinity and acidity, and the ratio between them do not effect the removal obtained.

The suggestion has been advanced that the mixing velocity in trunk sewers with mean velocities normally from 2 to 5 f.p.s. should be adequate to perform the function of self-flocculation. This is doubtless true provided (1) the sewage is subjected to this velocity for a period of at least 20 minutes before it reaches the primary tanks, (2) there are no increments of sewage in this 20 minute-period of flow which contain much finely divided suspended matter or constituents which tend to peptize the mixture, and (3) the sewage is at no point prior to influx to the clarifers, subjected to turbulence sufficient to disrupt the floc. The first proviso requires a trunk sewer not less than ½ to 1½ miles in length. The third proviso prevents the use of pumps and meters of all types prior to settling. These limitations indicate that relatively few plants can take advantage of trunk sewer velocities for self-flocculation.

An important implication of the studies on pre-flocculation is that, in general, the first cost of tanks for self-flocculation and settling should be less than the cost of primary tanks alone for the same performance. Any transfer of detention time from settling to flocculation down to a minimum residual of about an hour for settling and up to a maximum flocculation time of about 40 minutes should improve clarification.

Considerable interest is manifest in studies of the transportation of sediment in flowing streams. These studies are resulting in correlations of bed load movement and suspended load with the theory of turbulent flow. Rouse [183] gives a concise analysis of present knowledge in this work. The developments promise to be of value in the settling of discrete particles such as grit and in classification such as occurs in the separation of organic matter from grit in American type grit chambers.

Chemical Treatment

By 1940 chemical treatment became established as a common American practice in sewage treatment. The basic factors governing its application, the results which can be obtained and the costs involved have been well worked out. Hence the number of papers dealing with this subject has decreased. There is a swing from a predominance of reports on new installations and operation, to papers by research workers seeking better and less costly methods and chemicals. This is a normal trend for it is to the laboratory that chemical treatment must look for further progress.

Two very interesting papers of the year were those by Christianson and Lavine [35] and Hurwitz and Williamson.[101] The former authors undertook the study of those factors affecting the preparation of "activated" silicate solutions devised by Baylis for use as a coagulant aid. They found that the aging period could be decreased by raising the temperature to 180° F. after acidification and that the pH after acidifying had a marked effect on the time required for the solution to reach its maximum activity. For sewage coagulation they found that the silicate widened the zone in which alum was effective, producing good results from pH 4.9 to 9.3. They report that very low dosages, 5 to 15 p.p.m. of silica, are required to produce the desired results. Excessive dosages retarded flocculation. B.O.D. reductions obtained by treatment with a fixed dosage of alum could be increased from 51.2 per cent to 73.5 per cent by the addition of 10 p.p.m. of silica. The results presented did not show the optimum results obtainable with alum.

A theoretical explanation attributes the "activity" of the silicate to polymerization of silica molecules and their interaction with positively charged aluminum oxide particles.

Hurwitz and Williamson [101] used "activated" silicate and copperas for sewage coagulation in a pilot plant at the West-Side Chicago Works. Their carefully conducted experiments demonstrated that the silicate-copperas treatment could produce better results, as measured by B.O.D.

and suspended solids content of the effluent than did ferric chloride alone, ferric chloride and lime or chlorinated copperas. The cost of such treatment was found to be lower than the methods with which it was compared. The chemical prices used for comparison were those obtained by the Sanitary District of Chicago which are lower than those normally quoted. Recalculation of costs using prices more commonly paid shows that even greater savings than those claimed by the authors could be obtained by this method of treatment. The only objection to this method is the number of chemicals involved and the proper preparation of the silicate solution which is not too simple. The silicate-copperas treatment is of interest in that this is the first of any of the methods employing copperas that can yield decidedly superior results at low cost. The silicate overcomes the weakness of copperas treatment which is mainly failure to obtain a settleable floc.

Rudolfs [191] after discussing progress in chemical treatment to date, presented some results obtained in the laboratory and plant with two new chemicals. Aluminum hydroxy chlorosulfate was shown to produce better results than alum in both laboratory and plant tests. This chemical can be easily manufactured and the cost of coagulant at the plant where it was tried could be lowered by its use. This chemical is of exceptional interest because of the hydroxyl ions it contains. Many preparations containing colloidal forms of aluminum hydrates have been tried from time to time but none previous to this have shown promise of improving the results obtainable with alum. This product hydrolyzes more readily than alum but not as readily as do most aluminum hydrosols. Its improved coagulating power is probably due to this characteristic.

Ferri-gel, which is a compound of ferric chloride and a protein, was the other chemical discussed. This material has the property of forming rapidly an exceedingly heavy ball-like floc which will settle despite agitation. The sludge produced compacts very rapidly and can be dewatered without the use of additional chemicals. The dosage of ferric chloride required for clarification is reduced as much as 40 per cent. The product is less corrosive than ferric chloride and can produce equal clarification at lower cost and better results at equal cost. Rudolfs concludes that chemical treatment will take a firmer and more definite place in sewage treatment practice now that its accomplishments and limitations are well understood. He looks for further improvement in chemicals and equipment in the future and that perhaps with a better understanding of the function of the chemicals now used their value will be increased.

Treating a sewage containing wool scouring waste, Lumb and Barnes [142] found that a combination of sulfuric acid and alumino-ferric was an improvement over treatment with acid alone. Fifty, 100 and 150 parts per million of alumino-ferric lowered the acid dosage 104, 183 and 263 p.p.m., respectively. The total cost of chemicals under some conditions could be reduced and the pH of the effluent raised by the combined treatment. It is a well known fact that the acid treatment to pH 4.5–6.0 will lower the alum dosage necessary for clarification and that with acid alone a pH of 3.0 will clarify sewage. This paper has shown that this relationship holds for sewage containing a large quantity of grease. The fact that alumino-ferric and acid will produce the same results at pH values as high as 4.8 as compared to pH 3.2 for the acid alone should be of importance both in preserving the equipment and producing a less objectionable effluent.

Discussing this paper before the Institute of Sewage Purification, Goldthorpe [142] calls attention to possible savings in lime, necessary for neutralizing of acid effluents prior to biological treatment, that could be effected by using alumino-ferric and acid rather than acid alone in treating grease-laden sewages. He states that such combined treatment would also permit the use of a small separate flow of domestic sewage for neutralizing the acid tank effluent. Investigations on how treatment of the sludge obtained would be effected by the use of alumino-ferric and how much of the precipitation was due to the sulfate ion, the trivalent ion and the alumina floc, respectively, were thought desirable. Goldthorpe believes the acid treatment changes the lime soaps to fatty acids, thereby releasing occluded particles in a form amenable to coagulation by the alumino-ferric.

Several new chemical treatment plants were under construction or starting operations in 1940. A plant at Albuquerque, N. M., is described by Neuffer [164] as having a design capacity of 5 m.g.d. This plant will employ chlorinated copperas and lime for clarification prior to treatment on trickling filters. A 6 m.g.d. plant at Oshkosh, Wisconsin, equipped for the application of any of the common coagulants is described by Frazier.[72] This plant will operate with chemicals up to a flow of 6 m.g.d. When storm water raises the flow above this rate sedimentation alone will be practiced. The ability of chemical treatment to handle mixed sewage and industrial waste flow was demonstrated by Heist.[89] Located at Circleville, Ohio, this installation is called upon to treat a volume of strawboard waste three times the volume of domestic sewage and other wastes combined. Satisfactory results have been obtained using 750 pounds per m.g. of alum.

Trickling Filters

During the year many smaller sized sewage treatment plants were constructed which included trickling filters. A relatively larger installation comprising 16 units, 176 ft. in diameter (48 m.g.d.) was put into operation at Dallas, Texas.[48] Principal attention along new lines has continued toward higher average rates of filtration, stage filtration and recirculation of filter effluent. A considerable number of smaller filters of shallow type, 3 to 4 ft. deep, have been reported as under construction or in operation.

Theory. Levine [136] states that sewage coming in contact with the biological films on the filter media has its colloidal and finely suspended substances agglomerated into suspended particles, soluble substances being diffused into the films while the agglomerated matter may be adsorbed to the films. He suggests that the adsorbed agglomerated matter may be degraded by enzymic action and acted upon similar to the soluble substances when the filter is operated at low rates, whereas they are removed mechanically as suspended particles when the filter is operated at higher rates. Thus, by high rate filtration it is possible to conserve the biological activities of trickling filters for action on soluble sewage matter and remove and dispose of the agglomerated matter by sedimentation and digestion. He further considers the filter as comprising strata of different biological activity and that anything which would tend to maintain these zones of biological activity would be conducive to optimum filter efficiency. He proposes to prevent the agglomerated matter reaching the lower strata by interposing a settling tank. Also he provides the primary filter with backwashing facilities. Fischer [67] discussing ''Biofiltration'' proposes that continuous passage of sewage and recirculated effluent at high rates through a filter causes a uniform action throughout the filter bed. He also considers the filter as serving to coagulate the colloidal matter and agglomerate the very fine particles in much the same way as in the chemical precipitation process or in the first stages of the activated sludge process.

Wilson and McLachlen [242] arrived at the conclusion that carbonaceous matter is oxidized to carbon dioxide to a much greater extent in filter beds than in the activated sludge process. In contrast to the production in an activated sludge process of approximately 10 per cent of total carbon input as carbon dioxide in the effluent air, this study showed a production of 8.5 to 48.2 per cent carbon input as carbon dioxide in the effluent air of a filter bed.

Insect Life in Biological Filters. On the basis of experience gained with enclosed filters at Germiston, South Africa, Murray [160] reports that enclosing a filter results in increased fly breeding due to the more uniform temperature maintained. The author questions the opinion that high rate filtration prevents excessive fly breeding by drowning them. The bodies and wings of *Psychoda* are not wetted with water and the surface tension of the water is sufficient to support them on the surface of the water. It is impossible to drown the flies with even large quantities of soap solution.

The life-history and ecology of *Lumbricullus lineatus mull.* was reported by Reynoldson [175] who previously had pointed out the role played by this organism in the unloading of the filter bed. Lloyd, Graham and Reynoldson [139] extended the systematic study of the insect life in the filter bed to include the habits, life cycle, occurrence and number of larvae and pupae of the most commonly found insects, such as *Psychoda siverini, Psychoda alternata, Spaniotoma minima, Spaniotoma perennis, Metriocnemus longitarsus* and *Metriocnemus hirticollis* as well as *Lumbriculles lineatus.*

Loading. No definite answer is yet available to the important question of the loading which should properly be applied to a trickling filter. Fischer [67] expressing the loading in lb. B.O.D. per cu. yard of filter media per day, believes that the capacity of a filter for removal of B.O.D. is not yet fully understood. He refers to data showing B.O.D. removals of 5.23 lb./cu. yd./day (8,450 lb. per acre foot) for beet sugar wastes with 1,650 p.p.m. B.O.D., and 15.4 lb./cu. yd./day (25,000 lb. per acre-foot) for distillery wastes with 20,000 p.p.m. B.O.D. These amounts appear to be extreme. Levine [136] states that B.O.D.'s up to 3,000 p.p.m. have been effectively treated and removals of 4,000 to 6,000 lb. of B.O.D. per acre-foot are feasible.

Keefer and Kratz [121] report experimental results showing B.O.D. loadings from about 1,000 to 4,500 pounds per acre foot daily with removals of 72 per cent or about 3,300 pounds per acre foot daily. These tests were made by dosing a small section of the Baltimore filter bed at rates ranging from 6.5 to 30.0 m.g.a.d. with an average 5-day B.O.D. of about 150 p.p.m. as applied to the filter. Porges, Miles and Baity [173] using recirculation on a batch basis, report 90 per cent reduction in B.O.D. by a 4-foot depth filter after five hours recirculation, equivalent to about 10,300 lb. per acre-foot.

Conventional Filters. Research along this line has been overshadowed by the attention to high rate, stage, and recirculation studies. Gilcreas and Sanderson [82] report a study of the time required for a newly constructed sewage trickling filter to reach maximum efficiency. Settled domestic sewage dosed on to a filter at about 400,000 gallons per acre daily required 40 days for complete oxidation of nitrogenous compounds, about 50 days for total development of the fauna and flora, and 60 days for maximum reduction of carbonaceous organic matter. The test was started in April which may account, in part, for the long time requirements. Dixon [48] reports that in the large Dallas trickling filter installation each filter unit has a guaranteed uniform application when operating between 700 and 2,200 gal. per min., and that by adjusting orifices the rate can be increased to 3,200 gallons per minute and allow capacity for two-stage treatment which can be arranged for by closing two motor operated sluice gates. Also by operating return pumps recirculation may be obtained. Thus this relatively large plant may be operated as a conventional filter with straight gravity flow through sixteen filter units, or as two-stage treatment or with recirculation of effluent up to 100 per cent of the sewage flow at the will of the operator. Funk [75] reports a trickling filter designed for a rating of 2 m.g.a.d. followed by a sand filter to treat cannery wastes to protect goldfish breeding ponds, this design being selected in preference to either two-stage high rate or high rate with recirculation methods. The design includes piping arrangements to permit future provision of recirculation of filter effluent. Allison [1] reports improvements in trickling filter operation by chlorination for slime control which increased B.O.D. removal from 82.5 per cent up to a peak of 97 per cent, and increased the settleable solids removal sufficiently to make the effluent satisfactory for an oil refinery water supply.

The enclosing of trickling filters by covering with concrete domes is of interest particularly for the colder areas. Foster [71] describing the dome enclosures for the two filters, 150-ft. in diameter, at Hibbing, Minn., states "Domes were provided for these filters primarily to prevent ice formation." Also he says the enclosures prevent interference by high winds and reduce the fly and odor nuisance. At the village of Excelsior [17] on Lake Minnetonka a filter 54-ft. in diameter, was put into operation provided with a blower with 3,000 c.f.m. capacity for aeration of the filter and an exhaust fan in the center of the conical dome for ventilation.

The journal *Public Works* has presented a series of articles summarizing the design of trickling filters, in which are included illustrations of design, various filter media, and other characteristics of filter design, construction and operation.

High rate, Enclosed, Aerated, Heated, Stage and Recirculated Filters. Further investigations on the advantage of enclosing a filter were reported from Johannesburg, South Africa, by Wilson and Hamlin.[241] The main advantage of enclosing a filter was the conservation of the heat and the consequent maintenance of as high a rate of efficiency in the winter time as in the summer. An open filter could treat experimentally the same quantity of sewage in the cold months as in the warm months when the applied sewage was warmed to 80° F. Experiments further showed that the efficiency of purification was increased by maintaining a bed temperature up to 95° F. but at 100° F. purification and nitrification seriously diminished. Experiments with the artificial introduction of carbon dioxide into the filter showed that although high concentrations were deleterious, concentrations such as can be ordinarily found in the beds were not harmful. Ventilation of a filter for the purpose of sweeping out carbon dioxide was not necessary.

Stage filtration has been tried out in service with and without recirculation, but usually with provision for higher rates of sewage application. Levine [136] has presented the results of operation of both experimental and full scale plants in which two stages of filtration are used. The primary filter comprises a shallow filter of fine material designed to be backwashed when needed. A settling tank follows both the primary and the secondary filters. A plant built in 1929 for the Decker Packing Company at Mason City, Iowa, and a similar plant built in 1937 at West Fargo, N. D., show overall reduction of B.O.D. or 94.3 per cent and 95 per cent, respectively. After six years of operation and laboratory studies modifications have been suggested in the Decker plant including deepening the washable filter to 6 feet, increasing the rate of application to at least 6 to 8 m.g.a.d. and decreasing the dosing cycle to two minutes or less.

Fischer [67] shows three types of two-stage treatment—(*a*) with the primary and secondary filters placed between the primary and secondary sedimentation units; (*b*) with both sedimentation units placed between the primary and secondary filters, and (*c*) with the primary sedimentation following the primary filter and the secondary sedimentation following the secondary filters. In all cases recirculation is included.

A B.O.D. removal of 90 to 95 per cent is anticipated with a well nitrified effluent, high in D.O. and low in suspended solids. Jenks [112] describes a small filter plant for Lakeport, Cal., with capacity for 250,000 gallons per day, including two-stage filtration, each filter 3 ft. deep and 36 ft. in diameter. A description of a two-stage plant built for Liberty, N. Y.,[12] and the results of a short period of operation showing B.O.D. reductions ranging from 85 per cent to 97 per cent appeared in *Public Works*.[13] This plant also includes a magnetite effluent filter and final contact tank for chlorination.

The Water Pollution Research Board [232] investigated the possibility of applying the treatment developed for milk wastes to sewage. The method consisted of applying the sewage to two filters in series and changing the order of application to the beds at intervals of one or two weeks. The experimental plant was constructed at the Minworth plant of the Birmingham area, and consisted of four beds of 115 to 118 ft. diameter and 6 to 7 ft. deep supplied with rotary distributors and different types of filtering media. Preliminary results showed that the application of settled sewage at the rate of 70 Imp. gal. per cu. yd. per day during the winter months did not give satisfactory results (B.O.D. in settled effluent greater than 20 p.p.m.). Better results were obtained during the spring. To overcome the difficulty in operating the rotary distributors, which would not revolve at a steady speed in a strong wind at lower rates of flow than the distributors were designed for, small sails were rigged at the ends of the two arms.

The reduction of the strength of sewage applied to a filter bed by recirculating the filter effluent has been used in several installations. Eldridge [58] described the conversion of a conventional filter into a high-rate filter with recirculation for the treatment of milk wastes at Perrington, Michigan. He reports a removal of 77.1 per cent of suspended solids and 90.6 per cent of B.O.D. as compared to about 60 per cent removal of B.O.D. when operating previously as a conventional filter. The B.O.D. of the influent was 537 p.p.m. and of the final effluent 46 p.p.m. The operating procedure produces a recirculation of five times during the day and once every 47 minutes during the night. Funk [75] described a plant for the treatment of cannery wastes, with piping included to provide future recirculation should operating experience warrant. Cannery waste with a 5-day B.O.D. as high as 3,000 p.p.m. (10 per cent of samples) is combined with domestic sewage with a resultant 5-day B.O.D. of 600 to 850 p.p.m. and 90 per cent of tests showing less than 1,200 p.p.m.

Promotion of the system of sewage treatment termed "biofiltration" has continued. The Dorr Company gives a list of 25 plants built or under construction during 1940 including one plant for a sewage flow of 6.75 m.g.d., one for 3.0 m.g.d. and the others for flows of 10 m.g.d. or smaller. Fischer [67] has described the general design and operation procedures and has given a limited amount of operating data.

Activated Sludge

Theory. Williams[239] in a historical review of theories of the mechanism of the activated sludge process came to the conclusion that no evidence that definitely excludes either the physical or biological factors has been fully substantiated. The evidence according to the author is in favor of a mechanism involving both factors. The relative importance of each factor is not yet apparent, but the division of the process into clear-cut stages involving physical changes in one stage and biological changes in another, is unwarranted. It is more than likely that one form of action is partly or entirely dependent on the other, though one factor may tend to dominate during one particular period.

Lumb[141] made a study of the suspended solids balance in the purification of sewage by activated sludge under laboratory conditions operated for a period of 13 months. The results showed that almost 100 per cent of the suspended and colloidal matter removed was recovered as activated sludge.

Barritt[19] studied the respiration of activated sludge under starvation conditions with constant aeration for a period of 25 days at different temperatures. Continuous aeration had little effect on the volume of sludge. The loss in weight of sludge due to respiration was greater during the first three days of aeration than subsequently. During the early period of aeration temperature did not have an effect on the relative amounts of organic matter destroyed by respiration. Subsequent loss by respiration was small, being greatest at 30° C. The sludge, after aeration for three weeks, was placed in flasks, one exposed to daylight and the other kept in the dark. The carbon dioxide given off was measured. Less carbon dioxide was given off when the sludge was exposed to daylight than when it was kept in the dark. The author believes that exposure of sludge in the aeration tanks to light would account for low loss in weight due to increased photosynthetic activity of certain flagellates.

Sawyer[196] in a study of four activated sludges possessing widely different characteristics, found that in all cases, dissimilar sludges fed on a given sewage acquired similar characteristics within three weeks. On certain diets a sludge which nitrified poorly became a good nitrifier and on other diets, good nitrifiers lost the ability and became essentially non-nitrifiers. The same author[197] observed that the loss of nitrifying power by activated sludge at low temperature depends upon the relative rates at which the organisms responsible for stabilizing both carbonaceous and nitrogenous matter grow. Rapid growth of the organisms responsible for the stabilization of carbonaceous matter is favored by lower rates of oxidation at low temperature and by the ability of sludge to hold available, at all times, a large food supply by adsorption and coagulation of sewage solids. The growth of nitrifying organisms is hindered by the slow rate of oxidation of ammonia nitrogen at low temperature and by the inability of the sludge to adsorb and hold available, appreciable quantities of ammonia nitrogen. At low temperatures, the proportion of nitrifying organisms in the sludge diminishes and the nitrifying ability of the sludge decreases accordingly.

Ingols [103] reported that the activity of sludge is dependent upon the concentration of oxidation-reduction enzymes. The rate of activity of these enzymes is affected by the temperature, the amount of oxygen supplied, the pH of the medium and the type of food. Dickinson [46] believes that the adsorption of substances by activated sludge is controlled by enzymes. He considers floc to be made up of an inorganic nucleus surrounded by a layer of enzymatically active material. Dickinson [47] also studied the changes in oxidation-reduction potential within the sludge floc. Using a special electrode made by allowing activated sludge to grow and completely cover a bright platinum electrode, he found that the addition of sewage to aerated sludge resulted in a relatively rapid fall in potential of the bio-electrode with respect to a bright platinum electrode. Then a fairly constant level maintained for a long period was followed by a slow rise to the initial potential level. It was necessary to prolong aeration for some time after complete clarification of the sewage to attain the initial potential level. This stage was probably mainly reactivation.

Barritt [18] suggested that the protozoan fauna takes an active part in the direct removal of organic matter in solution and does not live chiefly by ingestion of bacteria. He found that the production of a gelatinous matrix by *Zooglea ramigera* is independent of the composition of the nutrient solution and is not stimulated by the addition of sugar. This organism cultivated in liquid culture medium grows in a dispersed form without a gelatinous matrix.

Heukelekian and Littman [92] studied the carbon and nitrogen transformations in mixtures of sterile sewage and pure culture zoogleal sludges. They found removal of suspended organic carbon was followed by removal of organic carbon in solution. This period of biological assimilation was accompanied by an increased rate of evolution of carbon dioxide. The sludge increased in amount by the adsorption of suspended organic carbon and by the synthesis of bacterial protoplasm. Ammonia nitrogen was assimilated by the sludge but nitrification did not occur. The carbon-nitrogen ratio of the pure zoogleal sludge was about 4.7 to 1. They believe that the zoogleal bacterium, *Zooglea ramigera,* is of primary importance in natural activated sludge and that nitrifying bacteria, protozoa and higher filamentous organisms are secondary.

Mihaeloff [149] takes the view that activation is the result of microbial action which coagulates and oxidizes organic matter and cites the constant presence of filamentous organisms in activated sludges from various sources as evidence. He believes that the larger the amount of microbial filaments, the more rapid is the settling rate of sludge.

In a study of the conditions affecting the distribution of nitrogenous compounds during treatment of sewage by the activated sludge process, Corbet and Wooldridge [40] found that the amount of ammonia nitrogen adsorbed on sludge was greatest shortly after the addition of fresh sewage and decreased as the treatment proceeded. The amount adsorbed at any time was small. On non-nitrifying sludge, the decrease in ammonia was accounted for by an increase in organic nitrogen. When potassium nitrite or nitrate was added to a non-nitrifying sludge, a rapid loss of nitrogen gas occurred. No indication of any intermediate compound was found. With nitrifying sludge, a large proportion of the ammonia was converted to nitrate with intermediate formation of nitrite and hyponitrite. When potassium nitrite was added to the sludge, the concentration of nitrite remained nearly constant during aeration until all the ammonia had been converted to organic nitrogen in the sludge. Then the nitrite was oxidized to nitrate. When the carbon-nitrogen ratio of the sewage was changed by daily feeding of glucose, the ratio in the sludge itself was not affected. The addition of glucose inhibited nitrification because, in the presence of excess carbonaceous material, the ammonia was utilized to form insoluble nitrogenous compounds in the sludge. Wooldridge and Corbet [245] found that under sterile conditions, continuous aeration of activated sludge-sewage mixtures, containing added nitrite and ammonia nitrogen, did not result in loss of nitrogen. The study indicated that the loss of nitrogen was not caused by chemical reactions involving nitrite or by reactions between amino acids and nitrites but that under aerobic conditions, the loss of nitrogen was due to the action of micro-organisms or their enzymes upon nitrate.

Shibata [201] found that when a mixture of activated sludge and sewage was aerated for 189 hours, as might be expected, the pH decreased, the turbidity of the liquor increased, the volume of settled sludge decreased and the dissolved oxygen reached a saturation value of 96.3 per cent. Sludge disintegrated by prolonged aeration was reactivated by aeration with sewage in two or three days. Activated sludge mixed with garbage liquor required a longer period of aeration for purification than did sludge with sewage. Shibata believed that the additional time was needed to reduce the particles of garbage to the colloidal state.

Williams [240] observed the effect of bubbles of various gases on mixtures of activated sludge and sewage. He found that when air, oxygen, hydrogen and nitrogen were passed through sewage for six hours without sludge, about the same amount of organic carbon was removed by each gas. In the presence of activated sludge, the rate of removal of carbon by air and oxygen was greatly increased, but only a small removal was obtained with hydrogen and nitrogen.

Rokuro and Jinnosuke [180] studied the decomposition of phenol by activated sludge and found that the phenol was oxidized directly to carbon dioxide and water without the formation of any intermediate products.

The effect of sugars on the activated sludge process has been studied by several investigators. Ruchhoft, Kachmar and Moore [186] found that glucose is removed from solution much more rapidly by activated sludge than by domestic sewage, pure cultures of *Bact. coli, Bact. aerogenes, Sphaerotilus natans* or zoogleal sludge. The rate of glucose removal by activated sludge is a function of the quantity of sludge present and after the first hour, the removal rate follows the Freundlich adsorption equation. Glucose was removed more slowly than the carbonaceous organic material of synthetic sewage but more rapidly than the nitrogenous material. Heating the sludge for ten minutes at 35° C. had no effect on the rate of removal but ten minutes at 45° C. reduced the rate and ten minutes at 55° C. practically destroyed the ability of the sludge to remove glucose. Lowering the pH for 20 minutes to 5.2 before the addition of glucose retarded the removal slightly. Lowering the pH to 2.8 for 20 minutes practically destroyed the glucose removal mechanism for several hours but raising the pH to 11.0 for 30 minutes, followed by neutralization, had little effect. For optimum removal of glucose, aerobic conditions and a proper nutritive balance are necessary. Ruchhoft, Kachmar and Placak [187] found that with normal activated sludge the rate of removal of glucose from solution was 5 to 7 times the rate of its decomposition and carbon dioxide formation. Zoogleal sludge removed glucose about three times as fast as it was able to oxidize it to carbon dioxide. The addition of 1,000 p.p.m. of glucose to normal activated sludge did not increase the short-time oxygen requirements of the sludge-feed mixture to as great an extent as did 500 p.p.m. of peptone. This is probably explained by the difference in metabolism of these two substances by the activated sludge. Glucose removal was found to be the result of biological metabolism following adsorption and not simple adsorption upon the surface of the floc. Dissimilation products, besides carbon dioxide, could not be found.

Working with lactose, Jenkins and Wilkinson [111] found that sugar was removed at a high rate during the first hour of aeration. Small amounts of lactic acid were formed in the early part of aeration but disappeared in 24 hours. After a few weeks, sludge treated with lactose became extremely dense and formed short, thick, well-defined clumps which were dark brown in color. The sludge did not bulk. The dominant organism was the fungus *Pullularia pullulans.* The rate of disappearance of lactose was influenced by the carbon-nitrogen ratio. The fat content of sludge fed with a carbon-nitrogen ratio of 150:1 increased from 0.6 to 5.8 per cent and the nitrogen content decreased from 4.68 to 1.14 per cent. When the ratio of carbon to nitrogen was 1:10, the fat content remained low and the total nitrogen increased from 4.68 to 5.2 per cent.

Bulking. Considerable progress has been made in laboratory studies of bulking. Heukelekian and Ingols [91] were able to produce bulking experimentally by diluting the concentration of oxygen in the air used with nitrogen. Using quantities of oxygen comparable to those supplied in plant practice, bulking was readily produced. They found that with constant sewage load and concentration of sludge, the rate of bulking depends on the quantity of air or its concentration in the gas mixture. With constant sewage load and quantity of air, the bulking becomes worse as concentration of solids in the aeration liquor increases. A highly oxidized sludge bulks less readily than one poorly oxidized and the addition of 10–20 p.p.m. of nitrate nitrogen prevents bulking caused by oxygen deficiency. Ingols and Heukelekian [104] found that bulking occurs when sludge fed with sugar, calcium butyrate, peptone, glycerine or calcium propionate is agitated with a limited amount of oxygen. The authors believe that in an activated sludge plant, a deficiency of oxygen is more apt to cause bulking than any particular ingredient of normal domestic sewage.

Lackey and Wattie [133] state that it is possible to produce experimental bulking of activated sludge by heavy doses of sugars or mixtures of nitrogenous and carbonaceous compounds. In such bulking, the predominant organism is the filamentous bacterium, *Sphaerotilus natans* Kutzing. They were able to isolate only one species and its cultural characteristics have been constant. However, they found morphological differences in field collections from which some of the isolations have been made. The organism grows abundantly in solutions of sugar if a suitable source of nitrogen is present. Inorganic nitrogen is readily used but only two of several amino acids, alanine and asparagin have promoted good growth. Peptone has proved a good source of nitrogen. No substance which is common or apt to occur normally in sewage has been found to stimulate *Sphaerotilus* to excessive growth. Chlorine is the cheapest and most readily available toxic substance to control its growth.

Littman [138] who studied the carbon and nitrogen transformations in the purification of sewage by the activated sludge process, found that sludge containing *Sphaerotilus* did not grow well in sterile sewage devoid of carbohydrates. The sludge containing the *Sphaerotilus* had a solids concentration of 757 p.p.m. and removed a maximum of 46 per cent turbidity and 56 per cent B.O.D. in a four-hour aeration period. A slow, limited removal of suspended organic carbon was observed but most of the carbon removed was from solution. The sludge containing *Sphaerotilus* was white and fluffy and was about three times as great in volume as an equivalent amount of zoogleal sludge.

Berg [23] believes that at certain periods bulking at San Antonio is caused, in part, by digester supernatant liquor and that 1,000 pounds of B.O.D. from digester supernatant liquor has a far greater effect on the activated sludge than 1,000 pounds of normal sewage B.O.D. The digester liquor seems to have a lasting poisonous effect on the activated sludge.

At the North Side plant in Chicago, Palmer [165] reports that bulking is caused generally by high percentage of volatile solids rather than by underaeration or the presence of filamentous growths.

Operation. Sawyer [197] pointed out that the use of low concentrations of solids in aeration tanks results in the production of sludges with high volatile solids content and high activity as measured by the base rates of oxygen utilization. Because of the high activity, the solids must be removed rapidly from final settling tanks and kept in contact with dissolved oxygen to maintain them in proper condition. High concentration of solids in aeration tanks produces sludges with lower volatile solids and lower base rates of oxygen utilization. These solids become more compact and may be kept for longer periods without aeration than sludge with high volatile solids.

Berg [23] has attempted to determine some definite mathematical relationship between the concentration of activated sludge suspended solids and the suspended solids in the primary effluent. A preliminary study indicated that the ratio of pounds of suspended solids in the return sludge per day to the pounds of suspended solids per day in the primary effluent should be between 8 and 10. Higher ratios seemed to give poorer results.

Edwards [55] reported that at Wards Island chlorination of return sludge with an average of 1.8 p.p.m. improved the settling characteristics of the aeration tank liquor about 35 per cent as measured by the sludge index. At Tallmans Island, excess activated sludge could be concentrated satisfactorily when the sludge was chlorinated sufficiently to maintain at least 1 p.p.m. residual in the overflow. Based on values from the Wards Island and Tallmans Island plants, he found that the concentration of solids in the excess activated sludge and the sludge index (Donaldson) decreased as the volatile matter increased.

Bloodgood [26] believes that the sludge index, as commonly determined, is a measure of sludge condition and not plant condition. He pointed out that the sludge index of a particular sludge varies with the solids concentration. To obtain comparable results with the sludge index, some standard solids concentration should be used.

Effluent Filtration

Additional plants using effluent filters were installed in 1940. Magnetite filters were placed in operation following high rate trickling filters at New Ulm, Minn., Sonoma, California, and Liberty, New York; following plain sedimentation at Woodbridge, New Jersey, and Rock Island, Illinois; and for polishing the activated sludge effluent at the Ley Creek Plant, Syracuse, New York. A sand effluent filter was installed for final treatment at Carlstat-Rutherford, N. J., following chemical precipitation and trickling filter treatment.

The trend in design of magnetite filters has been toward downflow circular filters with finer magnetite. Comparative parallel box filter tests with 3 in. depth of magnetite have indicated approximately 35 per cent removal of suspended solids filtering through 1.3 mm. and 70 per cent removal through 0.4 mm. size. Only 10 to 15 per cent improvement in removals was obtained by increasing the thickness of the filter bed from a depth of 3 in. to 6 in. of the various grades of magnetite tested. Tests at Woodbridge, N. J., Liberty, N. Y., and Ley Creek, N. Y., have indicated that the pollution of the effluent during cleaning was reduced to a minimum by the 3-level arrangement of a positive backhead between the effluent weir and the washwater weir. This was accomplished by sealing the wash chamber against the head over the filter bed. Filters are now either installed in separate structures or on the outside periphery of clarifiers. At Santa Fe Springs, California, two units have been installed for treating oil field wastes with the magnetite filters surrounding circular Dorr flocculators with no intermediate settling. The wastes from the gravity oil separators will be chemically treated, flocculated and applied directly to the magnetite filters.

Veatch [226] reported a year's operating results for Denver with magnetite filter removals averaging 16.5 p.p.m. suspended solids and 15.7 p.p.m. B.O.D. but noted that, due to slimy growths, the efficiency of the filters fell off considerably during the last part of the year. Solids and B.O.D. reaching the filter were 86.7 p.p.m. and 49.2 p.p.m., respectively.

Rudolfs [188] mentions the use of magnetite filters for activated sludge and trickling filter effluents when a high degree of clarity is desired. He also notes that several sand strainers are performing good work on plain settled sewage, and that screens covered with 1/4 in. to 1/2 in. coke at Niagara Falls are removing 20 to 33 per cent of the suspended solids from raw sewage instead of the usual 12 per cent by rotary plate screens.

Streander [209] outlines the importance of thoroughly washing the sand in the operation of sand effluent strainers. With improved washing, sand filters in New Jersey are operating satisfactorily at filter rates less than 1 gal. per sq. ft. per min. Modified sand filters 28 in. deep of the rapid backwash type are operating with about a 4 ft. loss of head at a full size plant in Wuppertal, Germany. These filters improve the removal of 35 per cent of the suspended solids by sedimentation, to 60 per cent by sedimentation and filters. These filters operate at 0.5 gal. per sq. ft. per min. and have 1 to 2 mm. sand. Experimental work at Wuppertal indicated that such filters ahead of activated sludge made possible a 50 per cent saving in aeration time. Six inch depth of approximately 1 mm. sand are used in the effluent filters at South River, Sayreville, Raritan and Somerville, N. J. Operation has been at normal design rates of 0.65 gal. per sq. ft. per min. to peak hourly rates of 1.7 gal. per sq. ft. per min. Removals by the filter have averaged about 50 per cent of the suspended solids reaching the filters. Suspended solids influent to the filter amounted to 100 to 150 p.p.m. after plain settling and 50 to 60 p.p.m. after chemical precipitation. Increase of suspended solids in filter effluent during washing was noted. About 50 per cent removal of suspended solids at a 2 gal. per sq. ft. per min. filter rate was accomplished with a Laughlin sand filter in tests at Atlantic City. This filter consisted of a mechanical surface cleaner which removed the dirt accumulation in the first half inch and a bottom pipe and water jet cleaner which expanded and cleaned the sand supported on the screen. This bottom cleaner has recently been replaced by a subdivided bed with means for admitting backwash water, below the supporting perforated plate screen. The backhead water is introduced at each section by means of a pump through a sliding valve connection.

Final effluents [13] of 4.4 p.p.m. suspended solids and 8.7 B.O.D. are reported for magnetite filters used as a final polish on biofiltration plant effluent at Liberty, New York. These results were obtained at average filter rates of 2.0 and maximum of 2.7 gal. per sq. ft. per min. The B.O.D. removal through the filter amounted to 49 per cent and the suspended solids removal 67 per cent.

A summary of magnetite filter operation at the Minneapolis-St. Paul Sanitary District [151] shows filter influent of 78 p.p.m. and filter effluent of 56 p.p.m. suspended solids at average filter rates of 2.5 gal. per sq. ft. per min. with daily averages as high as 5.4 gal. per sq. ft. per min.

Chlorination

Chlorination is represented in sewage literature largely by reports on operation and operating results. There is a large field and a real need for more fundamental research, particularly in some of the newer applications of chlorine. Such studies would be amply justified by improvements in operation and by economy of chlorine.

Chlorine for Disinfection. In a review of operating experiences at the new Buffalo plant, Velzy, Johnson, and Symons [227] mention variations in chlorine demand of this sewage. The average chlorine dosage is approximately 5,600 lb. per day, but may be as low as 3,500 lb. in winter and as high as 8,000 lb. in summer. The daily maxima and minima demands are higher and lower than these values. On one occasion the chlorine demand reached a rate of 63,000 lb. per day for a few hours. Sewage odors are controlled by chlorination and ventilation but, even though a low residual is maintained, there is some loss of chlorine to the air in the conduits. Vapors arising from the chlorinated sewage have resulted in condensation in the ventilating system. Analysis of the crystals precipitated from this condensed vapor indicates almost pure ammonium chloride.

Variations of chlorine demand with daily fluctuations of sewage concentration are discussed by Griffin [84] who cites a number of typical examples in detail. All of these illustrate that chlorination at a fixed rate results in long intervals of over- or underdosage. Manual variation of chlorine dose accomplishes only an approximation of ideal conditions. Automatic feed of chlorine in proportion to flow of sewage also leaves much to be desired, since a flow change of 2 to 1 may be accompanied by a change in chlorine demand of 8 or 10 to 1. Two new methods of sewage chlorination provide greater efficiency in meeting this problem. Programmed step-by-step chlorination, to maintain a different dosage rate at preselected intervals throughout each 24 hour period, is demonstrated as following the requirement curve fairly well. The new method of chlorination by potential control depends upon an electrode system which controls the dosage rate of chlorinators. A predetermined potential may be selected to maintain a residual or subresidual dosage. Charts show this to represent the ideal method of chlorine control, in that such operation meets the dosage variation corresponding to demand, daily flow, storm flow, and other unusual conditions. Klegerman [128] cites a number of other instances of the wide flow and chlorine demand variations disclosed by sewerage investigations. He notes that the potential method should provide not only ideal control of dosage but substantial chlorine economies as well.

The Covina, California, sewage treatment plant includes both biological and chemical treatment processes because odor control, a high degree of effluent quality, and flexibility are essential. According to Koebig [130] odor control and flocculation are accomplished by means of ferrous chloride and ferric chloride generated by means of a universal type chlorinator and Scott-Darcey apparatus. Disinfection of final effluent is handled by means of a separate chlorinator. These units are flexible so that any of the solutions can be applied at several vital points in the plant. The raw sewage, supernatant liquor return, secondary and final sludge returns may be treated with chlorine or ferrous chloride. This plant has operated satisfactorily and economically, the effluent being used for irrigation. At Corpus Christi, Tex., Allison [1] reports settled trickling filter effluent to be purchased by an oil refinery for condenser cooling water. This effluent is treated with chlorine for control of condenser slimes and appears to be made entirely suitable for the purpose.

Pearse [167] reviews a report on proposed sewage treatment for the city of Toronto, and Mohlman [152] notes that an election has approved plans to build the preliminary part of the plant. This will consist of sludge removal and digestion with effluent chlorination in order to protect bathing beaches and the water supply from Lake Ontario. The Ontario Minister of Health will approve this construction only as the initial stage of a complete treatment plant which must be constructed not later than four years subsequent to the first stage of the disposal works.

Prechlorination and Odor Control. The use of prechlorination at a sewage treatment plant receiving canning wastes is mentioned by Bernhardt.[25] When domestic sewage alone is treated, the effluent has a chlorine demand of 4.5 to 6.2 p.p.m., but this demand is increased by the addition of canning wastes to a figure of 15 to 32 p.p.m. Prechlorination is reported to reduce odors about the plant and to assist in sedimentation. The dose, or degree of chlorine demand satisfaction, is not given. Describing operation of the Richmond-Sunset sewage treatment plant of San Francisco, Benas [22] notes that chlorine is added in proportion to flow, both for odor control and for disinfection. Prechlorination is reported to require at least 30 lb. of chlorine per m.g. to prevent odors, while postchlorination feed is at the rate of 60 lb. per m.g. from 8 A.M. to 12 P.M. and 30 lb. per m.g. from 12 P.M. to 8 A.M.

Control of odors from the enclosed Asbury Park, N. J., plant by chlorinating the vented gases is described by Strahan.[207] According to Dixon [48] raw sewage reaching the Dallas, Texas, plant is confined in airtight enclosures. After screening and grit removal, spent gases collected from the preaeration and aerochlorination units are directed into a stack for washing and further treatment if needed. Chlorinators are provided to produce chloride of iron, chlorinated copperas, or for adding chlorine to the grit channels in order to control odors.

Chlorine for Grease Removal. The present status of aerochlorination, as a method of increasing the removal of grease from sewage, is reviewed by Faber.[64] Theory and plant scale operation of such treatment is discussed as well as studies on removal of wool grease from industrial waste. Eddy and Fales [54] describe the design of aerochlorinating tanks to be installed in the Boston sewage treatment plants. These will provide a detention of 3 to 4 minutes at average flow, the introduction of air at 0.02 cu. ft. per gallon rate, and chlorine at 2 to 3 p.p.m. At Dallas, Texas, the new sewage treatment plant, as described by Dixon,[48] is equipped with aeration and aerochlorination for removal of grease. Released scum is swept by water sprays to a scum box from which it is automatically removed at time-clock-controlled intervals.

Chlorine in Activated Sludge. At the Wards Island activated sludge plant, chlorine was applied to return sludge to prevent bulking and to maintain the desired sludge index. Edwards [55] has noted that chlorine is generally believed to be most effective in combating bulking caused by filamentous microorganisms, having been successfully used for this purpose at a number of plants. Bulking at Wards Island is caused mainly by high volatile solids but occasionally by filamentous growths. For six months, two aeration batteries, each treating an average of more than 50 m.g.d. of sewage, were operated as nearly the same as possible, except that an average of 1.8 p.p.m. of chlorine was added to the return sludge of one battery. The settling characteristics, as measured by the sludge index, were about 35 per cent better in the battery using chlorine than in the control battery. Then bulking in the control battery made necessary the chlorination of return sludge in both batteries. Over a period of eight months, with an average chlorine treatment of about 2.5 p.p.m., the sludge index in both batteries averaged about 0.75 (Donaldson index), the same as for the chlorinated battery during the previous six months period. Filamentous bacteria have not been present in objectionable quantities during chlorination. Care must be taken to add the proper amount of chlorine, as too little has no effect and too much produces a decidedly milky appearance, the result of breaking down the floc. This observation may apply to the results found by Bloodgood [26] at Indianapolis, where the application of chlorine was reported to indicate no benefit when tried on one of two plants operated as nearly as possible the same.

Chlorination of return sludge at the Mansfield, Ohio, activated sludge plant is reported by Turner.[223] *Sphaerotilus* is ever present in the raw sewage and appears to multiply rapidly in the activated sludge. Chlorination of return sludge at a 10 p.p.m. rate controlled bulking, though as high as 20 p.p.m. has been required at times. Chlorine has also been used to supplement air when a blower was down for repairs.

Chlorine in Sludge Thickening. Thickening tanks at the Tallmans Island activated sludge plant are provided with chlorinators to treat the supernatant liquor, the purpose being to prevent bulking of sludge during its detention in the tanks. Chlorine may be added near the center of the tank with the incoming sludge or near the surface in the supernatant liquor. According to Edwards,[55] for satisfactory thickening, sufficient chlorine must be added to maintain at least 1.0 p.p.m. residual in the overflow. The amount of chlorine required depends upon the condition of the sludge and the monthly average used is about 30 p.p.m. Results indicate that the concentration of solids depends more upon the volatile content of the sludge than upon the place where the chlorine is added, but addition of chlorine at the center of the tank gave better control of residual. Shapiro [198] also provides limited data on this installation which indicates that sludge of only 0.5 per cent solids has been concentrated to one-sixth of its original volume without difficulty.

Anderson [3] reports that, in warm weather, chlorine is used for thickening thin activated sludge from final settling tanks at the Rockville Center, N. Y., plant. A better concentration results by adding from 90 to 100 p.p.m. of chlorine solution to the wasted sludge and decanting the supernatant.

General Uses. Miljevic [150] and others describe the use of chlorine for controlling filter flies and filter pooling. Heavy dosage of low night flows to provide a high residual seems to be an accepted procedure. Riker [176] notes that foaming of a separate sludge digestion tank occurs when pretreatment of sewage with chlorinated iron is stopped at the end of the summer. In a round table discussion, Vermette [228] and others describe successful application of chlorine for a variety of purposes at a number of sewage treatment plants. Data given by Gibbons [81] on the effectiveness of a chlorinated organic compound (Benoclor-3) for control of vegetation in lakes and ponds is of interest.

Operation. Symons and Kin [212] provide a multiple nomograph for determining chlorine demand or dosage from given p.p.m. and sewage flow. This eliminates much calculation where the chlorine demand determination is made frequently. Weber [234] discusses improvements in the Annapolis, Maryland, plant which provide better mixing of chlorine applied to raw sewage. This has resulted in correlation between chlorine applied and chlorine residuals—a condition not formerly true. It also prevents loss of chlorine from the treated sewage and resultant corrosion of metal fixtures. Johnson and Jablon [114] describe a simple chlorine deficiency alarm which should be of value in preventing interruption of continuous chlorination at small plants.

In a paper on maintenance of the Allentown, Pa., sewage treatment plant, Krum [132] notes that the three manually operated vacuum chlorinators are given complete overhauling periodically. Equipment is dismantled, the cast iron base painted, and reassembled with such new parts as are found necessary to keep it in satisfactory condition. By this means, a spare apparatus is maintained for immediate service, and operators are familiarized with the function of all parts of the equipment in case of trouble.

Hartz[87] points out a number of safety considerations dealing with gases at sewage treatment plants. While a proper type of cannister mask is adequate for working in an atmosphere containing chlorine gas, consideration must be given to the conditions of use. If workmen must enter enclosed spaces where there may be an oxygen deficiency, then either hose masks or self-contained oxygen breathing apparatus should be available. He suggests that the location of the nearest inhalator should be known, in the event of emergency need for such equipment. It should be noted that Jones[115] recommends the use of oxygen-carbon dioxide mixture as preferable to oxygen for use in inhalators when treating cases of chlorine gassing. A report on 60 gas cases treated with the oxygen-carbon dioxide mixture (oxygen 93 per cent, carbon dioxide 7 per cent) indicates that this treatment relieves the distressing early symptoms. Frequently a community fire or police department has such equipment for its emergency work, and this may be available to the sewage plant.

Sludge Digestion

General information on sludge digestion is given in the excellent books by Keefer[120] and Imhoff and Fair,[102] while recent advances are briefly discussed by Mohlman[154] and Rudolfs.[188] British practice is outlined by Watson,[233] and Jenkins.[109]

Sibata[200] reports on the digestion of seeded garbage mixed with clay, in which liquefaction took place at a pH value below 7.0 with little or no methane or hydrogen production. Boiled soybean or starch, similarly seeded, gave considerable hydrogen. Fuel oil yields on the distillation of the residues after digestion were higher where the combustible gas yields were low.

Keefer and Kratz[122] present data on the chemical treatment of digester overflow liquor. 300 to 400 p.p.m. of ferric chloride gave best B.O.D. and suspended solids reduction. High speed mixing of the chemicals for short periods was desirable. High solids removals were obtained at pH values of 4.0 to 11.0. B.O.D. removals were best at a pH of 4.0.

Smith and Studley[202] give results of pilot plant tests where two 2-stage digestion systems were operated in parallel. In one system where the primary tank was stirred, a solids loading of 12 lb./cu. ft./mo. was attained without foaming as against 4.5 lb./cu. ft./mo. where there was no stirring in the primary unit. The temperature of the stirred primary unit was then raised from 85° to 130° F. and the loading increased to 38 lb./cu. ft./mo. without foaming.

Design. Design data on the sludge digestion tank at Dallas, Texas, are given by Dixon,[48] at Hibbing, Minnesota, by Foster,[71] at Muncie, Ind., by Burger,[31] at Gary, Indiana, by Howson,[98] at New Haven by Emerson,[62] at Albuquerque by Wheeler,[237] at Pueblo, Colo., by Veatch,[225] at Darien, Conn., by Bogert,[27] at Springfield, Mass., by Burger,[30] at Des Moines, Iowa, by American City,[4] at Seattle, Wash., by Sylliassen,[211] and at Rock Island, Illinois, by Consoer and Townsend.[41] At the Rock

Island and Gary plants the digesters are designed to handle combined garbage and sewage sludge.

A flexible arrangement of a heating system where gas engines, building heaters and digester heating coils are interconnected is shown by Frazier.[73] Eggertson [56] describes the method of pre-heating sludge and scum before pumping to the digester at the Raritan (N. J.) Township plant. Nagel [161] outlines the safety features of the Imhoff tank reconstruction at Dayton, Ohio. Langford [134] gives precautions to follow in the design of digester gas collection equipment. In *American City* [5] details are given of the gas collection and heating system at Greenwich, Conn.

Eliassen [59] presents some very useful monographs for calculating the size of digesters using the old rule of thumb cu. ft. per capita basis and the more scientific solids detention method.

Operation. Operation of the Richmond-Sunset plant at San Francisco is given in an article by Benas.[22] Velzy, Johnson and Symons [227] give operating experiences at Buffalo, where supernatant liquor is sprayed on the surface of the scum to soften the scum layer.

Experiences at Lansing, Mich., with the digestion of garbage with raw and activated sludge are described by Wyllie.[246] Particular attention is called to the necessity of providing a means of removing bones, eggshells and fruit pits from the garbage before it is added to digesters; otherwise segregation of this material in the sludge withdrawal lines occurs. The effect of the garbage in giving a poorer quality overflow liquor is also stressed. Cleary [37] discusses the digestion of garbage with sewage sludge, and states that digesters would have to be doubled in order to handle all the garbage as well as the sludge of a municipality. Operating results of the two-stage system at Grand Forks, N. D., are given by Riley,[177] and at the Barston Works of Birmingham, England, by Hewitt.[94] Anderson [2] describes his digester operation experiences at Rockville Center, N. Y. Corrosion of gas lines, gas engine operation and digester maintenance are discussed. The reasons for a slight explosion in the chamber where the gas collection equipment is housed, are also outlined.

A round table discussion of foaming in sludge digestion tanks is presented in *Municipal Sanitation*,[181] wherein a number of plant operators discuss methods of control. Lime addition was of help in some cases. In others, a temporary reduction in solids loading was beneficial. A round table discussion of sludge digestion tank operations is given in *Sewage Works Engineering*.[182] This is an excellent compilation of actual operating procedures followed at a number of representative plants. Points discussed are methods of feeding raw sludge, disposal of overflow liquor, sludge mixing, tanks, temperatures and heating, and insulation, etc. Ten good rules for digester operation are given by Reybold.[10] Important points stressed are frequent addition of small quantities of raw sludge to the digester, preparation of the digester for shock loads and winter storage, and the avoiding of depletion of seed sludge.

Patents. Streander [210] shows a digester design wherein circulation of liquid is assisted by a central draft tube. Heat is applied below the bottom opening of the draft tube. Fischer [68] covers a two-stage digestion system in which thermophilic digestion is carried out in the first stage and mesophilic digestion in the second stage. Downes [51] describes a two-stage digestion system with the primary units superposed over the secondary tank. Petersen [168] shows a tank rotating on a horizontal axis for the mixing of sludge undergoing digestion. Durdin [53] covers a digester equipped with a gas holder in which there is a screen in the lower part that normally submerges solid matter in the tank. Potts and Wigley [174] describe a process of stabilizing sludge by the action of molds and fungi. Breuchaud [29] shows a multiple hearth unit for the stabilization of organic matter, wherein anaerobic action is carried out in the first part and aerobic action in the second part. Roeder [178] covers the aerobic thermophilic digestion of dewatered raw sludge treated with stabilized material ahead of the dewatering step.

Plant Records. Seven years' operation records of Grand Rapids, Mich., are presented in *American City.*[6] Complete data from Winnipeg, Canada, for the year ending December 31, 1939, are given in This Journal.[243] A brief summary of the operation of digestion tanks at Cleveland is given by Ellms [60] in his 1939 Annual Report. In his 1939 Annual Report, Cohn [38] gives results of the Imhoff tank operation at Schenectady, N. Y.

Need for Further Study. In view of the interesting pilot plant results on thermophilic-mesophilic two-stage digestion at Los Angeles, further work along this line at other plants on a full plant scale would be well worth while.

There is still need for correlation of digestion tank operating results obtained at different plants over long periods, to better evaluate the various factors that have an influence on digestion.

Sludge Disposal

Most developments during 1940 in sludge disposal have rotated around vacuum filtration and incineration, which appear to continue their popular trend for the larger plants.

Buffalo, New York,[227] finds cotton flannel the most satisfactory filtering cloth tried for vacuum filtration of digested primary sludge. The teasel on the flannel appears to be a factor in its favor. Plain steel wire at a relative narrow spacing of 1½ inches has increased the life of the cloth, which averages 200 to 225 hours.

Calcium carbonate incrustation in the filter monel metal supporting screens has been satisfactorily removed with a 5 to 10 per cent muriatic acid solution. The filters were subjected to this bath for about 10 hours. The same solution has been used to remove incrustations in pipe lines and in the filtrate pumps. Flower [70] at Cleveland cleans filter supporting screens in 4 hours by coating an unused filter cloth with rubber latex, suspending this cloth under the filter drum and filling the bag so formed with muriatic acid so that the bottom section is submerged. He does not state the strength.

About 1.2 cu. ft. of gas has been required at Buffalo for each pound of dry solids burned, when the volatile solids in the sludge cake is around 40 per cent. When scum (top sludge) and bottom sludge are burned together the higher volatile content tends to over-heat the furnaces and water is sprayed in the drying tower. This procedure suggests a method of ridding digesters of excessive scum at other plants where the piping arrangements permit and the scum is soft enough to flow or be pumped.

Grit was burned for several hours alone and was mixed with equal parts of sludge during one whole month. Sand in the sludge (not grit as added to the sludge) has caused abrasion of fans, cage mills, ducts, etc. At elbows and bends in the fuel lines (feeding powdered dry sludge) wear has been excessive and a wear back made of a steel box, filled with concrete, and clamped to the pipe has proved effective, inexpensive, easy to construct and easy to replace.

Lynch and Milliken [143] report that winter chemically-precipitated raw sludges at Auburn, New York, have a greasy appearance and a gritty composition, these properties clogging the filter cloths and causing a build up of partially dewatered sludge in the filter vats. Grit removal is inadequate, again showing the need for sufficient grit handling facilities at all sewage plants.

Chemical doses for sludge conditioning are determined by estimating the solid content from the specific gravity of the sludge. The relation of specific gravity to solid content is based on experience. The Buchner funnel test is employed in the laboratory for filterability of the conditioned sludge.

Division bars of brass on the Conkey filters have been replaced with half round soft wood held with finishing nails at a net saving of $6.50 in material and 20 hours of labor per cloth change. Removal of the preheater at Auburn has eliminated escaping smoke and gases in the Nichols Herreshoff sludge incinerator.

Elmira [143] reports a welcomed change from anhydrous ferric chloride to liquid. A change at this plant from batch to continuous feed of ferric chloride has resulted in a considerable saving. Lime is still added to a batch of the raw sludge. The incorporation of patented valves in the oil and air lines to oil burners for the sludge incinerator so that the oil pipe is closed when the pressure drops in either line prevent the formation of oil products and subsequent charring. This has been a problem at many plants.

Denise [143] also feels that liquid rather than anhydrous ferric chloride will prove easier to handle, cheaper and be easier on the equipment at Greece, New York. A change from air diffuser tubes to a mechanical agitator in the sludge conditioning tank is giving far superior mixing.

Weber [235] at Annapolis has substituted elutriation of digested sludge with ferric chloride coagulation for filtration conditioning with marked benefits over ferric chloride and lime treatment. Benefits include savings in chemical cost, labor, power and filter cloth. Successful filter runs have been made on elutriated sludge with alum alone.

At Cleveland [70, 78] the costs of vacuum filtration for 1939 were $5.97 and $4.92 per ton of dry solids filtered at the Westerly and Southerly plants, respectively. Both handle digested sludge. Incineration costs on the same basis were $5.10 and $3.86, respectively. These are some of the first cost figures published on digested sludge filtration for a long operating period.

Faber [34] has presented some interesting data on chemicals, yields, per cent of solids, life of cloth and treatment of sludge in connection with the vacuum filtration of sludge. Of 46 vacuum filter plants, 85 per cent use ferric chloride for conditioning.

Jones [116] urges caution in the release of data on conditioning of sludge, unless there is assurance that time and mass effect of results have been sufficient to render true decision. In a summary of current opinion on present practices he also emphasizes accuracy in volume measurements and in sampling if a true evaluation of all factors involved in dewatering and conditioning is to be realized. The results of filtration at recently completed plants might well be studied, he recommends, and coordinated in a committee report by the Federation.

In a report on the cost of sludge disposal at the Michigan City activated sludge sewage treatment plant Jones [126] states that in a period somewhat over 2½ years digested sludge averaging 7 per cent solids was delivered to open beds at a total direct cost per dry ton of $1.54. The cost of delivering sludge of somewhat lower solids content to artificially constructed lagoons was $1.34 per dry ton. These costs, it should be kept in mind, do not include sludge cake removal.

Rudolfs and West [193] presented an interesting report on the properties of raw sludge affecting its discharge through pipe at the Elizabeth Valley Joint Meeting sewage treatment plant. Here sludge is pumped 4,400 feet through a 24-inch force main for barging to sea. Two years of study show an increase in loss of head with an increased dry solids content or decreasing sludge temperature. The temperature of the sludge exerted a greater influence on the head than the solids content. The studies also showed an increased rate of sludge flow with a higher ash content.

A total of 54,088 dry tons of sludge was dumped at sea during 1939 from New York City's sewage plants, principally from Ward's Island, at an operating and maintenance cost of $2.20 per million gallons of sewage or $2.55 per dry ton of solids.[49] Three sea-faring ships each holding 55,000 cu. ft. of sludge make the 68 mile round trip in about 6½ hours. The three vessels cost $1,500,000 and each carries a crew of 18 men including a cook and mess boy. Besides New York City, this method of sludge disposal is now limited to Passaic Valley, Elizabeth and Providence. New Haven at its East Street plant discontinued barging in 1940 with the installation of vacuum filters and a sludge incinerator.

Re-discovery of sludge drying with alum and results obtained at Aurora, Illinois, are of interest. Sperry [204] made an initial trial with one pound of chemical to 85–90 gallons of sludge with shortened drying time. Liquid application with a very short mix releases the carbon dioxide in the digested sludge and results in a thinner cake than untreated wet sludge applied to a similar depth. The greatest benefits occur from alum in the first 24 hours. Alum treated sludge is less affected by rain. Alum treatment is of especial benefit with poorly digested sludge or sludge containing much grease such as scum.

Agricultural Utilization. Van Kleeck [224] points out the dangers in the use of raw sludge, compares analytically sludges, manures and commercial fertilizers and advises the potential user of digested primary sludge to weigh the cost of manure in his community as a rough index of the value of local sludge. Methods of applying sludge, amounts to use for various crops, fortification of sludge and the results from its use are cited.

Rudolfs [190] stresses the "fertility" value of sewage sludges in contrast to their fertilizing values. The growth promoting substances in sludge have a definite sales appeal for sewage plant superintendents. The article contains data on the chemical constituents and growth promoting substances to be found in sludges and gives methods for applying and fortifying sludges. Sludges improve the soil and will continue to do so, he says, if acidity (caused largely by the break-down of the greases and fats present in sludge) is checked by judicious applications of lime to the soil every 3 or 4 years. The omission of this simple remedy accounts for the good results with sludge for the first few years followed by injury to plant growth by the accumulating acidity.

Experiments on the manurial value of sewage sludge from septic tanks was reported by Cranfield.[42] Application on experimental plots of sludge from septic tanks fortified with artificial fertilizers containing nitrogen, phosphorus and potassium were compared with manure on equal weight basis similarly fortified. It was concluded that under favorable conditions sewage sludge may be as effective as manure but if conditions were adverse militating against rapid decomposition, then manure may have an advantage over sludge. To get good results adequate dressing with artificial manure is recommended. The residual effect of the sludge may carry over for a second year's crop.

The preparation of manure from town refuse by composting was reported by Tripp [222] from England. The refuse after sorting and pulverizing is inoculated. It is subjected to aerobic and anaerobic fermentation for 16 days in cells where the temperature rises to 170 to 175° F. The dry matter in the manure varied from 63.9 to 74.4 per cent and nitrogen in dry matter from .97 to 1.42 per cent. This manure when applied to kale and sugar beets gave higher yields than farmyard manure on the basis of equivalent nitrogen applications.

Mechanical Developments

Although it does not appear that outstanding mechanical developments in the sewage field took place during 1940, even a casual reading of the literature cannot fail to impress one with the steady growth of mechanization of sewage treatment and improvements in the mechanisms. Several interesting articles were published on the research which led to the development of some equipment.

The new sewage treatment at Gary, Indiana,[98] has many interesting mechanical features. One of these is the ventilation of the rack room through a filter protected connection to the suction side of the blowers for the aeration tanks. Three out of five large sewage pumps are direct connected to gas engines which are automatically throttled by the sewage level in the suction channel. These installations are designed to work efficiently over a range from 15 to 25 m.g.d. discharge. Since the engines are located on the first floor of the administration building great care was taken to minimize vibration and noise. The concrete engine pads are mounted on vibration dampeners. Piping has flexible connections and double flexible couplings are installed between the engines and the pumps. Acoustical tile has been used on the ceilings of the pump and blower rooms. Double doors and a double framed and double glazed observation window are provided between the office hallway and the blower room.

Since Gary is a steel center it is not surprising, but interesting to know, that approximately seven miles of steel pipe in sizes up to 60 in. diameter were used in the plant. Sizes smaller than 6 in. are galvanized. Sizes larger than 6 in. are of black steel ½ in. thick. All buried piping is bituminous coated and wrapped. The interior of air piping was given a rust protecting high temperature resisting paint.

Garbage to be ground at this plant will be dumped into a hopper from which it will be carried to the grinders by belt conveyor from which bones, silver ware, cans and some of the other materials which have been bothersome elsewhere may be picked out.

Emerson [62] reports that recent developments in materials and methods for under water work made feasible a 4850 ft., 36 in. diameter underwater connecting sewer at New Haven, Conn. This eliminated the necessity of one sewage treatment plant which had been contemplated in a comprehensive plan of several years ago for three plants. The leakage in this line was reported to be less than five gallons per day per inch diameter per mile.

An existing plant was enlarged and one new plant built at New Haven.

The sludge filters are completely enclosed in a sheet aluminum ventilating hood piped to the air intake of the incinerator to control odors from the filtration of raw sludge. An annular space in the incinerator chimney takes the discharge from the vacuum pumps.

Specifications for the sludge incinerator limited the combined cost of fuel oil and power to $1.50 per ton of dry solids, with oil at 5¢ per gallon and power at 1.5¢ per kw. hr. Fly-ash content of gases to base of chimney is not to exceed 0.75 grains per cu. ft. of gas at discharge temperature.

The new Bond Island sewage treatment plant at Springfield, Mass.,[30] incorporates the latest improvements in mechanization. These include detritors for grit removal and washing, comminutors, aerated influent channel to sedimentation tanks, automatically controlled sludge pumps, spherical, pressure gas holder, gas pressure boosters and compressors in a separate gas control building, vacuum filtration of elutriated digested sludge, and flash drying and incineration of sludge cake. Incinerator ash is pumped to a low area for disposal as fill.

Fuhrman [74] reviewed the uses of sludge gas with particular attention to power production. A comprehensive list of engine installations indicates that they have been installed rapidly in small as well as large plants. The table lists a total of 22,170 horsepower, 20 per cent connected to pumps, 35 per cent to blowers and 45 per cent to generators. Fuel requirements vary from 8400 B.t.u. per brake horsepower hour for the 1200 H.P. engine at Washington, D. C., to 14,500 for a 45 H.P. engine at Ontario, Cal. A common guarantee figure is 10,000 B.t.u. with gas at 600 B.t.u. per cubic foot. In some installations the investment has been saved in two or three years. In one or two rare cases the use of an engine has been discontinued because of noise or cost. The use of an early installation at Rockville Center, L. I., was discontinued because of noise and the low cost of municipally produced current.

The estimated savings at Washington, D. C., is $13,000 annually which could be increased to $23,000 by installing another 1500 H.P. gas engine, a 750 H.P. Diesel and severance of the utility lines. These estimates include both fixed and operating charges. In 1939 the 1200 H.P. engine operated 95 per cent of the time and produced over 95 per cent of the total power. Recoveries from the engine were estimated as electrical energy 23 per cent, jacket water 30 per cent, exhaust 12 per cent and losses as electrical and heat 35 per cent. This would indicate an overall efficiency of 65 per cent.

Hecking [88] estimates a 20 per cent loss from the potential power in gas to the driven unit when electric current is generated and used instead of direct drive. He estimates that 100,000 population should produce sufficient gas for the continuous operation of a 150 H.P. engine.

One advantage of engine-generator drive is indicated in installations at Albuquerque,[164] Fort Dodge [140] and Oshkosh [72] each of which has arrangements with the local utility to draw from, or furnish power to their lines. At Oshkosh utility power is utilized through the generator acting as an induction motor to start the engine. Fort Dodge has a 25 year contract with the utility company to buy or sell power at 0.85¢ kw. hr.

Dowling [50] has given an interesting explanation of the development of rotary positive blowers from a machine originally designed for water power. This type of blower might well be called a positive volume blower since the volume remains practically the same for constant speed regardless of the outlet pressure. This feature is utilized for metering the output. A recent development is a dual compartment blower giving three different capacities at one speed or six with dual speed drive. Fisher and Hillman [69] describe the development of a combined flocculation and sedimentation tank called a "clariflocculator." The flocculator occupies a central well in a circular clarifier. Inlet is at the center, agitation is produced by moving V-shaped vertical paddles. The flocculated sewage passes directly through the bottom into the clarifier with little agitation. Kivel,[127] Tark and Gilbert [217] and Nichols [163] have written of the development of the modern mechanical devices for the automatic removal and washing of grit.

Some progress has been made in the problems of corrosion, erosion and abrasion of metals used in sewage treatment. A symposium on this important matter was conducted [215] at which the resistance properties of nickel, aluminum and copper alloys and rubber linings was discussed. Cox [215] reported that studies were underway at Newark, N. J., where gas contains 100–300 grains of hydrogen sulfide per 100 cu. ft. These tests are on the nickel-copper alloys, "monel" and "ni-resist." Burr [215] stated that for sludge gas, copper tubing has shown scaling and pitting, red brass was little attacked while "admiralty" metal was scarcely attacked beyond a little blackening over a period of several years in one test. He suggested "admiralty" metal for heat exchanger tubes. Considerable erosion or abrasion of metal parts in the sludge handling equipment at Buffalo [227] has been bothersome. This has taken place in bars of the flash dryer, fan blades and casing. This effect is apparently due to very fine sand in the sludge. Experiments are being carried out to find an economical and satisfactory solution of the problem. In one case a steel box filled with concrete has been clamped to the outside of a bend in a fuel line. This has proved effective, inexpensive, easy to construct, and to replace.

Material used for ladies' stockings would hardly seem suitable for any use in a sewage treatment plant yet brushes made of "nylon" bristles are reported at Milwaukee [11] to outwear those made of hog bristle for cleaning the fine screens. Although higher in first cost they appear to be more economical because of at least 50 per cent longer life.

New Aids to Practice

Each year sewage works operators, engineers and equipment manufacturers contribute new aids to better performance and economy of plant operation and sewerage service. The following developments, representing refinements and in some cases innovations in practice, command a special place in this review. Set apart in this fashion these practical developments acquire individuality which otherwise might be overlooked in a panoramic picture of progress.

Departing from conventional practice in building filter bed inclosures of reinforced concrete, Jenks [113] is using corrugated iron sheets in two California plants with a resulting saving in cost of 20 per cent. The corrugated iron plates are of the type normally used for culvert construction. In addition to economy of construction the use of this material has the merit of quick and easy assembly, thus recommending its employment in disposal works urgently needed in army camps and centers of industrial expansion. According to Jenks the use of these thin iron sheets has probable limitations—in beds of diameters greater than 50 ft. the curvature of the inclosure would be so flat as to necessitate some means of stiffening the sheets against bulging. It has been found very satisfactory, however, for beds of 36 and 45 ft. diameter and 3 ft. in depth.

One way to cut the cost of treatment plant construction was demonstrated at Liberty, N. Y., where a magnetite filter and chlorine contact tank were combined in a single structure.[7] This eliminated the need for extra tanks and resulted in a more compact design.

Substantial economy in cost as well as improvement in hydraulic characteristics resulted from a model study of a backwater gate structure built in Detroit.[99] The test, using a scale model 1/24 of full size, showed that a six channel structure, originally proposed, was inferior to a smaller, simpler and less costly four channel arrangement. Here again was demonstrated the desirability of wider use of model studies as an adjunct of design procedure.

New information on the flow of sludge in pipes resulted from studies made at the University of Illinois.[16] In the pumping of sludge it has been assumed that the common hydraulic formulas for flow of water may be used provided that the velocity is sufficient to insure turbulent flow. But the Illinois investigation indicates that this method is only an approximation of the true condition. Viscosity and plasticity are important factors, and it is considered evident that sewage sludge and clay slurries are true plastics. Conclusions presented are, in brief, as follows: (*A*) Sludges such as mixes of clay and water used in deep well boring, sewage sludges, sludges from water softening plants and other similar aqueous suspensions of fine particles, obey the fundamental formula for the flow of a true plastic; (*B*) for sludge flowing in a pipe a critical velocity is encountered as the velocity of flow is increased—below the critical point the flow is laminar, while above it the flow is turbulent; (*C*) further research as to the factors affecting turbulent flow in pipe is desirable, as the common hydraulic formulas for flow of water are not applicable to the flow of sludge.

A sludge-carrying tractor with specially fitted ''saddle bag'' bins is the answer to economical cleaning of drying beds, according to reports from Sperry.[8] A removal cost of 14.5 cents per cu. yd. is cited as against 48.6 cents using the narrow gage track and car system originally installed at the plant. Equipment consists simply of a standard tractor fitted on each side with No. 8 gage sheet metal dumping bins of 3 cu. yd. capacity, and it is similar in construction to a machine previously built by the Springfield (Ill.) Sanitary District. When not transporting sludge, the tractor has a score of other uses around the plant, such as clearing snow, trimming sludge piles, moving grit, etc.

A "vacuum cleaner" for septic tanks, which is useful also for removal of sludge from tanks, can easily be made in the plant workshop, according to the department of water supply and waterworks at Salt Lake City, Utah.[135] This ingenious homemade device employs a 550 gal. airtight tank mounted on an old auto truck, a 10 gal. auxiliary tank, a few check valves and some hose. Air in the 550 gal. tank is sucked out by means of a tube that goes in the tank to the inlet manifold of a truck motor. When the truck is operated, a vacuum is thereby created in the tank; then a 3 in. hose connected with the tank is dropped into the sludge, a quick acting valve is opened, and the sludge immediately flows upward into the tank. The operation continues until the tank is almost full, after which it is emptied and is then ready for use again.

The idea of putting a laboratory on wheels is not new, but the design and equipment of mobile units employed by the U. S. Public Health Service on the Ohio River survey, introduces some novel features.[9] The mobile unit consists of two elements—a trailer containing complete laboratory facilities, and a tow car. The latter is a dual purpose accessory; it not only provides motive power for the trailer but also serves as a means for rapid collection of samples. Thus the laboratory can be located in the center of an area under study for a period of one or more weeks, during which the towing car collects samples within a 40 mile radius. The total cost of this mobile field laboratory including the tow car, equipment and six months' supplies is given as $3,671. The experience gained by the Public Health Service in designing and operating these units should be of considerable value to state health organizations and sanitary districts who have frequent need of mobile laboratory equipment.

A simple but effective scheme for removing floating grease and scum from settling tanks which lack mechanical equipment for doing this job is to use a water spray.[137] At Cleveland's Westerly plant some 1,360 Link-Belt spray nozzles have been installed on Imhoff tanks for this purpose. The water spray is made to strike the surface of the tank at an angle thus imparting motion to the floating material. The nozzles are located at intervals so that the material is kept moving until it reaches a scum trough at the end of the tank.

Rubber balls covered with a chain netting were made available this year for use in sewer pipe cleaning.[189] The chain-inclosed ball, which comes in various sizes, is first inflated with air so that it will float through the pipe and thus scrape the upper surfaces and also remove major obstructions. Then it is filled with water and permitted to roll along the pipe invert as a final cleaning measure.

Some new facts on ventilation of sewers, pointing to the usefulness of simple ducts in manholes for aeration, were made available by studies of the U. S. Bureau of Mines.[118] Among other things, these investigations showed that natural ventilation by means of openings in manhole covers increases as the area of the openings are increased, and that wind velocity across the openings has a marked effect on ventilation; a 50 per cent increase in ventilation was noted when the velocity of the wind increased from zero to 10 m.p.h.

A method whereby sludge drying on sand beds can be speeded up by the simple expedient of applying heat to the bed was described by Phillips.[169] A grid system of 3/4 in. pipe was installed just below the sand surface of the bed, and excess hot water from the digester heating system was circulated through the pipe. It was reported that 43 per cent more dry solids could be handled than was heretofore possible on the same beds without heat.

Industrial Wastes

European work on industrial waste treatment has been diminished by the war, and the literature is meagre and difficult to obtain. In this country, however, interest still remains at a high level, and more attention has been devoted to the treatment of wastes in conjunction with domestic sewage.

General. The developments of 1939 were reviewed by Mohlman[155] in a paper published early in 1940, which contains a number of things not widely reported in the literature. Among these are the German work on wastes from coal hydrogenation and fatty acid synthesis. The wastes from the latter process contain 5,000 to 10,000 p.p.m. of fatty acids. The low B.O.D. reduction obtained in the treatment of sulfite wastes by the Howard process is also mentioned. The same author[153] has described the work of the Sanitary District of Chicago in classifying and studying the individual wastes making up the 89 m.g.d. of industrial waste received at the District's sewage plants.

The Annual Report of the Division of Sanitary Engineering of the Maryland State Health Department for 1940 contains a resumé of the industrial waste problems handled by the Department in the past few years. It is of general interest as an indication of the wide variety of problems encountered in an industrial state. The general aspects of the industrial waste problem have also been discussed by Knowlton.[129]

A symposium of the Institute of Sewage Purification (Eng.) on pretreatment of trade effluents[15] discussed the principles of pre-treatment, specifically chromate wastes, acid wastes, cyanide wastes, metallic wastes, and oil and grease wastes. Quantitative determination of the objectionable constituents of these wastes, and limitation of the amounts allowed to be discharged, also came under discussion.

Beet Sugar Waste. Construction of a plant for treating beet sugar wastes has been described by Eldridge.[57] The plant consists of a revolving screen, grit chamber, coagulation tanks with 20-minute detention, and settling tanks with 90-minute detention. Sludge is sent to a drying pond. The plant was intended to receive flume, beet washer, battery wash and pulp press waters, and to coagulate them with Steffens waste. During the first operation period no Steffens waste was available; plain sedimentation yielded an effluent with 201 p.p.m.

B.O.D. (30.3 per cent reduction). After normal operation was established, using Steffens waste as a coagulant, an effluent of 264 p.p.m. B.O.D. was obtained, corresponding to a 71.3 per cent reduction for the mixture including the Steffens waste.

Cannery Waste. Treatment of cannery waste in the sewage plants of New York State is discussed by Ryan.[194] A table of analyses of cannery wastes is included. Ryan states that the most difficult wastes are corn, pea, tomato and beet, in the order named. He concludes that canning wastes can and should be treated with domestic sewage, if proper screening is provided and an adequate ratio of sewage to waste is maintained. However, the activated sludge process is not suited for treating mixtures of sewage and cannery waste. Ryan advocates the use of activated carbon for reducing the odors of waste solids and ensilage juice, and the treatment of screenings dumps with bleaching powder.

Reports on the treatment of wastes from citrus juice canning plants have been issued by the Texas State Department of Health.[218] The waste from the peel bins contains the bulk of the B.O.D. and should be separated and carried to waste land. Grinding the peel in hammer mills will reduce the amount of this liquid drainage from the peel bins. The floor-washing wastes may be treated by chemical precipitation with alum and lime to reduce their B.O.D. from 1,700 to 1,200 p.p.m.; this effluent, mixed with the cooling waters and other weak wastes, gives a final waste containing about 115 p.p.m. B.O.D. The chemical cost of such treatment for the average plant was about $1.00 per day. It was also found possible to treat the wastes by activated sludge or trickling filters, either alone or mixed with domestic sewage.

Coal Washery Water. Results of investigations dealing with the flocculation of coal washery water are reported by Yancey et al.[247] Starchy materials such as potato starch, wheat flour and cornstarch were found to be effective as flocculants for coal. The maximum effectiveness of these materials was over a short range of concentration. Electrolytes were effective flocculants over a wider range, but the concentration necessary to produce good flocculation was much higher than with the starchy materials. Flocculated coal slurries filtered much faster than unflocculated ones.

Gas Plant Waste. In experiments on treatment of phenol wastes on trickling filters, Eldridge [57] found complete removal of 20 to 30 p.p.m. of phenol in single-stage filtration, and of 180 p.p.m. in two-stage filtration. When the work was repeated using gas plant scrubber liquor containing 1,932 p.p.m. of phenol, it was found that other toxic materials accumulated in the filter, necessitating dilution of the waste in the ratio of 1 to 64. For such wastes, trickling filter treatment would be prohibitive but it might be suitable for wastes containing low phenol concentrations.

Milk Plant Waste. Following practice abroad the use of the activated sludge process for treating milk waste at dairies in Somerset, Pa., and New Bremen, O., is discussed by Montagna.[157] The plants differ from the usual activated sludge plant in that the waste is treated with lime to pH 8 to 9, mixed, and given primary sedimentation with recirculated primary sludge. The casein sludge from the tank, amounting to about one per cent of the total waste volume, is disposed of by transporting to waste land by tank truck. The effluent from the primary tank is aerated with activated sludge for about 24 hours, the lactic acid produced lowering the pH to 7.6–7.8. The air used amounts to 2.8 cu. ft. per gallon of waste. Secondary sedimentation follows, and all sludge from the secondary tank is returned to the aeration tank. The average B.O.D. of the influent waste is 545 p.p.m., that of the effluent 7.4 p.p.m., a reduction of 98.4 per cent. The maximum B.O.D. of the influent is 1,800 p.p.m., that of the effluent 16.5 p.p.m. Each plant treats about 50,000 gallons of waste per day. The construction cost for each plant was $12,000 and the operating cost is reported to be $3.00 per day.

Mallory [144] has described a "package delivery" plant for treating milk wastes, consisting of two factory fabricated steel tanks designed to treat the wastes by the "oxidized sludge" process. This process consists of fine screening, aeration with activated sludge, clarification, coagulation with unspecified chemicals, and secondary clarification. Reductions in B.O.D. of 94.5 to 99.2 per cent are claimed. The prefabricated units make for economy in construction and rapid installation for small plants.

Eldridge [57] converted a low rate trickling filter at a milk plant into a high-rate recirculating filter, operating at a gross rate of 16 m.g.a.d., and a net influent rate of 3.4 m.g.a.d. The low rate plant had given a B.O.D. reduction of 60 per cent; the reconstructed plant gave an average reduction of 90.6 per cent, on the basis of an average influent B.O.D. of 537 p.p.m., and an effluent B.O.D. of 46 p.p.m.

The report of the British Water Pollution Research Board [232] for 1939 contains an account of experiments on the treatment of whey washings from a cheese factory by two-stage trickling filters and by activated sludge. The two-stage filters, operating at 160 gal. (Imp.) per cu. yd. of filter medium, produced from whey washings of 270 p.p.m. B.O.D., an effluent of 70 p.p.m. B.O.D. The activated sludge process, using a 36-hour aeration period, handled washings of 660 p.p.m. B.O.D., and produced an effluent containing 60 p.p.m.

Disposal of milk waste on land by irrigation or by spraying (artificial rain) is described by Christophersen.[36] The "tank process," in which the water is subjected to successive fermentations in a series of tanks, is recommended as a preliminary to agricultural utilization of the waste.

Nichols [162] describes the treatment of dairy waste by chemical precipitation with alum and sterilization by hypochlorite. The usual alum dose is 25 to 35 grains per gallon; sufficient hypochlorite is added to produce a chlorine residual of 2 to 3 p.p.m., and the waste is settled in fill-and-draw tanks holding one day's discharge. Sludge is dried on cinder filters. A weak milk waste had its B.O.D. reduced from 846 p.p.m. to 119 p.p.m. by this process, and a strong waste from 1980 to 534 p.p.m.

Oil Well Brines and Oil Refinery Waste. In California, according to Humphreys and Rawn,[100] brines from producers in adjacent fields are collected, given the necessary treatment to remove oil and suspended solids, and carried to the ocean in pipe lines of considerable length. At one of these central treatment plants a special two-compartment sedimentation and skimming tank is used. The effluent from the tank passes downward through an excelsior filter. The treatment removes 95 per cent of the 1,000 p.p.m. of oil contained in the waste, and practically all of the suspended solids. The entire plant, including the outfall, cost \$750,000, and has a capacity of 4 m.g.d. Operation and maintenance costs are \$25 per m.g. and fixed charges \$50 per m.g.; from this may be deducted the \$20 per m.g. realized from the sale of the recovered crude oil for road or fuel oil.

Gibbons[80] shows what small quantities of petroleum products will produce taste and odor difficulties in water supplies. For example, No. 2 heating oil can be detected by the hot odor test in dilutions of 1 to 12,000,000. Gibbons discusses the removal of these tastes and odors.

Packinghouse Waste. The treatment plant of Armour and Co. at West Fargo, described by Howson,[97] treats 700,000 g.p.d. of packinghouse waste with an average B.O.D. of 1000 p.p.m. Treatment takes place in the following steps: screening, grit removal, grease flotation, flocculation, primary settling, primary filtration on trickling filters equipped for both air and water washing, secondary settling, secondary filtration on conventional trickling filters, final settling, and cascade aeration prior to discharge to the stream. The sludge is lagooned without digestion. Most interesting is the performance of the primary filters: dosed at 6 m.g.a.d., or 5,000 to 6,000 lb. of B.O.D. per acre-foot, they remove 3,000 to 4,000 lb., reducing the B.O.D. of the effluent waste to 250 to 350 p.p.m. The secondary filters may be operated in parallel or in series. The plant has consistently bettered the 95 per cent B.O.D. removal upon which the design was based.

Paper Mill Waste. The Howard process for treating sulfite pulp mill wastes, as installed at the Marathon Paper Co., Rothschild, Wisconsin, is the subject of a number of papers. The details of the process are given by Howard,[96] who claims a B.O.D. reduction of approximately 80 per cent, and describes the utilization of the precipitated lignin. A study of the Howard process effluent by Warrick[231] showed a 43.5 per cent decrease in the potential hydrogen sulfide generating power of the waste. Warrick also found that the results obtained depended to some extent on the types of wood and cooking procedures used in the paper mill. The greatest percentage of the total oxygen demand of the waste was exerted by its carbohydrate content. Warrick found B.O.D. reductions of 31 to 45 per cent to be the best obtainable from the process. River water was used as dilution water, since the standard dilution waters proved unsatisfactory for the waste. Keeth[123] discussed the use of the precipitated lignin as fuel. Pressing of the material reduced the moisture content to 50 per cent. The press-cake, when mixed with 15 per cent of coal, was burned in boilers equipped with stokers. A recovery of 64 per cent of the available heat was indicated.

The chemistry of lignin and its utilization is discussed by Harris [86] in a paper which summarizes recent research, and shows the relationship of the structure of the lignin molecule to the commercially useful materials produced from it. The production of tanning materials, iron-removing compounds for water, vanillin, and other materials is taken up.

In experiments on the purification by activated sludge of mixtures of sewage and sulfite waste liquors, Sawyer [195] found that satisfactory results were obtained with sewage containing 6 per cent or less of Howard process effluent, and 10 per cent or less of raw calcium-base sulfite liquor. Higher percentages produced sludges too heavy to be kept in suspension by normal aeration, due to precipitation of calcium carbonate. Magnesium-base sulfite liquor produced bulking sludges. The importance of adding nitrogen and phosphorus in assimilable form to dilution waters used for determining the B.O.D. of mixtures containing high proportions of sulfite waste was demonstrated. Failure to add these necessary nutrients, according to Sawyer, accounts for the claims of high B.O.D. removals by the Howard process.

German investigators, according to Fink and Lechner,[66] are using sulfite wastes for growing yeast which is dried and used at cattle fodder.

The use of magnesium instead of calcium as the base of sulfite cooking liquor facilitates recovery and re-use of chemicals; operation of the process on a pilot plant scale is described by Tomlinson and Wilcoxson.[220] Descriptions of a number of recent patents on the disposal of paper mill wastes, particularly sulfite wastes, will be found in TAPPI, sections 276 to 278 of the *Paper Trade Journal* for 1939.

Experiments on the flocculation of white waters, described by Poor,[171] showed that the best results were obtained with fatty acid soaps in conjunction with alum. The amount and character of the filler contained in the white waters had a considerable effect on their flocculation.

Spulnik *et al* [205] studied the specific effects of raw waste sulfite liquor on plant growth and soil properties. It was found that waste sulfite liquor in concentration below 80 tons per acre was not toxic to sunflowers. It increased carbon dioxide production in the soil, organic decomposition and the microbiological population of the soil.

Textile Wastes. Experiments by Porges, Miles and Baity [172] have shown that direct addition of sulfur dye wastes to activated sludge in amounts as low as 0.5 per cent by volume will retard digestion. Digestion of sludge produced from sewage-dye waste mixtures is also inhibited, but the effect per unit of dye waste is not as great as that obtained by direct addition. The inhibiting effect of the dye waste may be minimized by using sludges acclimated to the waste as seeding material, and by increasing the quantity of seeding sludge used per unit of fresh sludge. Production of hydrogen sulfide and colloidal sulfur was noted during digestion of the dye-waste treated sludges.

An anonymous article in the *Surveyor* [14] describes the history of grease recovery from wool-scouring waste at Bradford, the English wool center. Wide fluctuations in the price obtained for the recovered grease are noted, with especially favorable prices in war time. Progress in the production of higher quality greases has widened the market.

A British patent granted to Jones, *et al* [117] recovers grease and soap from wool scouring wastes by using soluble salts of metals such as calcium to form insoluble soaps. Gaseous carbon dioxide and coagulants such as bentonite or alum are added, and the mixture is filtered. The filtrate may be re-used in scouring. The precipitate is extracted with benzene to recover grease, which is further purified by extraction to separate the true grease and the soaps.

Recovery of tin compounds from silk weighting liquors by filtration through activated alumina, solution of the adsorbed tin by sodium sulfide, and ultimate conversion of the tin to tin-chloride is described by Downie.[52]

Phillips [169] has found that kier liquors may be digested in the same manner as sludge, and will produce 4 to 5 volumes of a gas similar to sludge gas per volume of liquor. The B.O.D. of the liquor is reduced by 80 to 90 per cent in the process. It is planned to dispose of kier liquors at Durham, N. C., by piping them directly to the digesters of the sewage plant.

Tannery Waste. A detailed study of chrome tanning waste at a tannery in Waukegan, Ill., has been made by Harnly, Wagner and Swope.[85] The wastes are treated by sedimentation only, and the sludge is used to fill an adjacent marsh. A small portion of the waste, consisting of highly colored spent vegetable tanning extract, is lagooned on an old sludge bed, which removes the color by chemical action and filtration; the decolorized effluent is added to the general plant waste.

The strongly alkaline beam house waste, constituting about 75 per cent of the total flow, precipitates practically all of the chromium in the spent tanning liquor; the final waste is not toxic. The treatment process as described reduces the average suspended solids from 1,050 p.p.m. to 162 p.p.m., and the B.O.D. from 335 to 202 p.p.m. The lower B.O.D. of chrome tanning waste, as compared with that of vegetable tanning waste, does not appear to be due to the presence of toxic substances. Experiments on coagulation of the waste with ferrisul showed that 20 to 25 p.p.m. would yield an effluent 50 per cent lower in suspended solids than that obtained by sedimentation alone. Equations are developed for computing total and suspended solids, nitrogen, and B.O.D. in the wastes, in terms of the quantity of hides in process.

Treatment of waste from a sheepskin tannery on a pilot plant scale is reported by Eldridge.[57] The methods tried included plain sedimentation and lime precipitation; both fill-and-draw and continuous-flow methods were used. Eldridge recommended the fill-and-draw lime precipitation, using 14 lb. of lime per 1,000 gallons of waste. The suspended solids were reduced from 1,980 p.p.m. to 497 p.p.m., and the B.O.D. from 1,630 to 823 p.p.m. The sludge volume was 5.3 per cent of the total waste volume, and the sludge contained 3.9 per cent of solids by weight. It was found that the breaks and fleshing machine wastes could be treated separately with 1.25 gallons of sulfuric acid per 1,000 gallons of waste, aerated, and skimmed to recover about 31 lb. of grease per 1,000 gallons. The commercial value of the process was not determined.

Winery Wastes. Hodgson and Johnston [95] have made a study of winery wastes, which included operation of a pilot plant, and final design of a pre-treatment plant to remedy the difficulties caused by these wastes at the Glenelg activated sludge plant of Adelaide, Australia. The wastes, consisting mainly of spent liquors and residues from final alcohol recovery by distillation, were found to amount to 200 to 250 (Imperial) gallons of waste containing 4,200 p.p.m. B.O.D. per ton of grapes processed. On the basis of the pilot plant experiments, the final treatment comprised the following steps: precipitation with about 1,200 p.p.m. of lime, flocculation, sedimentation, dilution of settled waste with plant effluent, adjustment of pH to 7.0–8.0 with acid, and treatment of the liquid on trickling filters in two stages, with a humus tank after the first stage. The effluent of the second stage is sent to the aeration tanks of the activated sludge plant, to be treated with the domestic sewage of the city. Because of the possibility of odor nuisances, covered sedimentation and flocculation tanks, and enclosed, forced-ventilation trickling filters were specified. The pilot plant experiments indicated that an effluent not exceeding 60 to 80 p.p.m. of B.O.D. could be produced, which would not be harmful to the activated sludge plant. Construction of a separate sewer from the winery to the pretreatment unit, located at the sewage plant, was avoided by providing storage at the winery, and discharging the winery wastes into the main sewer during the early morning period of low sewage flow. The resulting mixture of waste and sewage goes directly to the pretreatment plant.

Effect of Industrial Wastes on Sewage Treatment

General. Admission of industrial waste to sewers has received considerable attention in England. Garner [77] and Dart [44] have discussed the principles governing such admission as derived from the Public Health Acts of 1936 and 1937. Local authorities are directed to admit trade waste to the sewers at the request of the manufacturer, but are empowered to make rules covering period, rate, and quantity of discharge, temperature and pH value, exclusion of injurious wastes, and payment for admission. The legislation confers on manufacturers a prescriptive right to discharge, without payment, wastes equal in quantity and composition to those discharged into the sewers at any time during the year ending March 3, 1937. This provision has been a source of dissension and discussion. The City of Manchester [145] has had prepared a review of methods proposed and in use for assessing charges for the handling of industrial wastes. Manchester is considering dividing wastes into three classes, A, B, and C, according to the difficulty of handling and treatment, and making a flat charge per 1,000 (Imperial) gallons of 2, 3 and 4 pence, respectively.

McKee [147] has described the ordinance put into effect by the Borough of Middlesex, N. J., governing the acceptance of industrial wastes in its sewers and sewage plant. A plant manufacturing glazed fruit was required to pre-treat its wastes by sedimentation, addition of lime to pH 7.0, and chlorination to 1 p.p.m. residual. A motion picture developing concern, with a waste having a chlorine demand of 5,000 p.p.m., was required to maintain a pH of 7.0, and a chlorine residual of 1.0 p.p.m. The plant subsequently reduced its high consumption of chlorine by recovering the sodium thiosulfate in the waste. A plant manufacturing Paris green and calcium arsenate was required to reduce the arsenic content of the waste to an amount which would not interfere with digestion. It was shown by experiment that digestion was stimulated by 0.05 g. of calcium arsenite in 400 ml. of mixed fresh and digested sludge, while 0.25 g. had no effect, and 1.25 g. retarded digestion. Paris green markedly retarded digestion in amounts as low as 0.05 g. in 400 ml. mixed sludge. This requirement was met by installing a filter press, and the recovery of the arsenic sludge was subsequently found to be profitable. The plants pay the borough at the rate of $33 per m.g. for disposing of their waste, in addition to fulfilling the pretreatment requirements.

The sewage plant at Greensboro, N. C., was designed to handle domestic sewage and textile wastes. After operating for six months on domestic sewage alone, textile wastes were admitted. This, according to Mengel,[148] necessitated a number of changes in the operation of the plant. The practice of adding excess activated sludge to the primary tank had be to abandoned, and the excess sludge pumped to the digesters separately from the primary sludge. Re-aeration of the return sludge was found necessary, and air consumption increased in the aeration tanks. The amount of ferric chloride required for sludge conditioning prior to filtration increased by 8 to 20 per cent, and the equipment for handling the filter cake was redesigned. At one time, excessive dumping of kier liquor raised the pH in the secondary tanks to 11.5, resulting in a cloudy effluent. The condition was remedied by treatment with acid. Close co-operation between the municipality and the textile plants is indicated as a necessity to prevent recurrence of such conditions. Other desirable changes indicated were a 50 per cent increase in primary tank and digester capacities, and provision for pH control of the influent, and for the thickening of excess activated sludge.

Activated Sludge. At the Glenelg activated sludge plant, according to Hodgson and Johnston,[95] the high carbohydrate content of untreated winery wastes, present to the extent of one per cent by volume in the sewage flow, resulted in the conversion of the activated sludge to something closely approaching a pure culture of filamentous organisms within one or two weeks. Sludge indices went as high as 500 to 600, with complete breakdown of the plant. All conventional methods of controlling the growth of the filamentous organisms failed, and the only remedy was the construction of a pre-treatment plant to remove 75 to 80 per cent of the carbohydrates from the winery wastes. This plant is described in the section on industrial wastes.

Sedimentation. In discussing the paper of Ryan,[194] Bernhardt[25] described difficulties encountered at Fredonia, N. Y., where the flow of cannery wastes was at times double the sewage flow. Poor maintenance of screens in some of the canning plants resulted in accumulation of cannery solids on the bar screens of the sewage plant, and in an unsatisfactory effluent. Lime is applied to the Imhoff tanks two or three times per week during the canning season, at the rate of 100 lb. per dose. Prechlorination is also employed at this time. The maintenance of cannery screens is discussed.

Trickling Filters. Jenkins and Hewitt,[110] in an experimental study of the effect of chromium compounds in sewage on the operation of trickling filters, found that 1 p.p.m. of chromium in the form of potassium chromate had a slight effect, 10 p.p.m. appreciably reduced the quality of the effluent, and 100 p.p.m. reduced nitrification by 66 to 78 per cent, and produced an effluent containing twice as much organic matter as the effluent from the control filter. Heavy deposits of solid matter were noted in the upper part of the filter receiving 100 p.p.m. of chromium.

Stream Pollution

Foreign research in stream pollution has suffered considerably because of the war; a condition which is probably due to continue for some time. Less material is available because peace time work is out of joint and through failure to receive published material from blockaded countries. This effect is not yet apparent on American studies but will doubtless become so as more personnel and funds are diverted into national defense work. In contrast with a probable decrease in funds spent for pollution abatement, there is to be expected a sharp rise in the amount of industrial pollution due to increased production and the construction of new industrial plants.

National legislation for stream pollution abatement seems temporarily shelved with the failure of the Senate and House conferees to reach an agreement on their respective bills. The Congress did, however, authorize the Ohio and Potomac River compacts on July 1st. When finally ratified by all of the states concerned, these compacts should greatly facilitate and stimulate pollution abatement in their respective basins.

Shaw[199] has reported in some detail the work of the California Fish and Game Division in the control of pollution in that state. California laws pertaining to this division restrict pollution control to those substances deleterious to fish, plant or bird life and require proof of damage except for pollution by petroleums, acid, sawdust and certain specific types of factory wastes. The pollution control unit, charged with enforcement of these laws, varies from eight to ten men. A large number of pollution cases have been settled by cooperative correction of conditions, but 210 cases have been prosecuted during the past five years with fines totalling $35,625.

In a progress report on chemical treatment of lakes and streams, the Wisconsin Committee on Water Pollution[244] discussed the origin and control of swimmers itch which was in all observed instances found to be due to penetration into man's skin of the larvae of schistosome flukes (flatworms). Control measures considered most feasible were: Control of the intermediate host, the snail, by chemical treatment with copper carbonate in some instances or by physical removal of snails in others; restriction of bathing in infested waters; destruction of the schistosome cercariae by vigorous rubbing with a towel immediately after bathing. They found that hard waters could be safely dosed with 80 p.p.m. of copper sulfate without serious danger to fish life. Inasmuch as the eggs of these flukes are excreted by mammal and avian hosts, the possible dispersion of infestation through sewage pollution becomes an interesting problem.

Improvement in the bacteriological quality of water in the Niagara River following the installation of intercepting sewers and sewage treatment at Buffalo, was studied by Symons and Simpson.[213] Treatment and disinfection of Buffalo sewage reduced the inflowing coliforms by 98.5 per cent and total bacteria by 97.5 per cent. Reductions in bacteria in the Niagara River below Buffalo averaged 97 per cent for coliform bacteria and 84 per cent for total bacterial counts. Bacterial after-growth following chlorination was not strongly evident and heavy peak loads at downstream filtration plants were eliminated. Symons and Torrey[214] have also published an analysis of the Buffalo River covering these same periods. Coliform organisms in this river were reduced 75 per cent and the B.O.D. 57 per cent. However, D.O. depletions in the Buffalo River during warm weather were not eliminated.

Thomas[219] has presented an extension of his "slope method" of analysis of B.O.D. results which is applicable to curves containing a positive lag and to the nitrification stage of B.O.D. curves. Application of this formulation to B.O.D. curves of sewage gave second stage reaction velocity constants 20–30 per cent of those for the first stage. Probable errors in computing second stage demands were thought to range from 15 to 65 per cent as against 5 to 25 per cent in calculating first stage demands.

Gallaher[76] reported oxygen depletion with resultant destruction of fish in the lower Fox River caused by the concentration by wind and subsequent decomposition of floating algae near the outlet of Lake Winnebago, the head of this river. Goudey[83] found measurements of solar ultra violet radiation to be more effective in forecasting algae growths than either water temperature or hours of sunshine.

Jones[119] has noted the absence of normal biological life in a Wales stream polluted by discharge from old zinc mines. He attributed this to the zinc content of the stream water which averaged 0.7 to 1.2 p.p.m. The water also contained from a trace to 0.05 p.p.m. of lead.

Williams [238] has summarized the problems presented by salt water waste from oil fields in Texas. Disposal by dilution and by evaporation seriously threaten ground water supplies as these methods allow percolation into the absorption areas of ground water strata. Furnace evaporation pits leave unsolved the disposal of the crystal salt as refining of this salt to a saleable product has not been attempted. Pretreatment of the wastes by aeration, chemical treatment and filtration has made possible the continuous disposal of large quantities of salt water into a single injection well which may serve a hundred or more producing oil wells.

Young [248] has reported the effects of sewage treatment, industrial waste control, mine sealing and low flow augmentation upon the polluted surface water supplies of Western Pennsylvania. He found the downward trend of indices of pollution had recently been reversed but concluded that a uniform program for the completion of these pollution control measures was necessary to assure further improvements in river conditions.

The Interstate Sanitation Commission [106, 107, 108] has published an interesting series of reports on pollution in the New York City area. The first of these is a broad review tracing the history of the shellfish and fishing industries of that area and the effect of various factors, including pollution, upon these industries. While unrestrained exploitation caused the original decline of most species, recent conservation measures have not proven effective because most waters of this area are now unfit for fish life. Pollution abatement has already improved conditions to some extent and should, with proper conservation, restore fishing in the area. The second report of this Committee [107] deals with tides and currents and the basic causes of the hydraulic phenomenon observed in the tidal waters of this area. Chemical and bacteriological data and field and laboratory methods are included in the third section.[108]

Improvement in the sanitary condition of the Mississippi River following treatment of sewage from the Minneapolis-St. Paul Sanitary District is discussed in a report [151] from that District. In the section of river above the new treatment plant outfall, pollution has been largely eliminated, but below this point D.O. levels have averaged under 2 p.p.m. during the three months, July, August and September. Treatment of additional sewage and industrial wastes in plants now under construction is expected to improve this condition.

Eriksen and Townsend [63] have reported an extensive study of the pollution of Gray's Harbor, Washington, by sewage and sulfite pulp wastes. They found these wastes were shuttled back and forth on the average by 80 tidal cycles—42 days—before passing out to sea. Considerable stratification of fresh water was observed during high river stages of streams tributary to this harbor with the position of a given chloride gradient differing by as much as ten miles between winter high and summer low flows. Fish deaths could be explained by D.O. depletions but existing concentrations of sulfite pulp waste were found experimentally to be a contributing factor in the susceptibility of fish to low concentrations of D.O. Sharp peaks in dissolved oxygen occurred when the local pulp mill, producing 260 tons of pulp per day, was closed down for short intervals and it was concluded from this and other evidence that fish deaths were due largely to the oxygen demand of the wastes from this plant.

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CHEMICAL COAGULATION OF SEWAGE *

XII. IRON SALTS AND LIME

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To date numerous plant and laboratory scale trials with various coagulants have been made. Such trials have been stimulated by competing chemical manufacturers and by engineers desirous of determining what chemical or combination thereof will produce satisfactory and economical results at particular plants. On examination of the results of such studies it is evident that some chemicals work better on a particular sewage than do others. This is due to variations in character of sewage such as age, strength, septicity, kind and amount of dissolved matter, and in some cases the presence of industrial wastes. No general laws can be set down as to comparative coagulating power of different chemical reagents. Nevertheless, if a number of sewages react in a similar manner general facts, subject to variation under peculiar conditions, can be determined.

Methods

It is the purpose of this paper to demonstrate the relative effectiveness of the processes of chemical treatment of sewage employing iron salts. Since industrial wastes cause the greatest variations in effectiveness of different chemicals their presence was avoided by selecting sewages of mainly domestic origin and containing little if any of other types of waste. The methods employed were similar to those discussed in former papers of this series (1, 2), except where otherwise stated. The chemicals used were of technical grade and special compounds such as chlorinated copperas were prepared.

Procedure

The iron compounds commonly used for coagulating sewage are ferric chloride, ferric sulfate, and chlorinated copperas (3). Untreated copperas has been used in conjunction with lime and aeration (4), but this process did not gain headway due to the poor settling characteristics of the floc formed. Laboratory trials have been made with iron sols of various types (5). These compounds proved to be of more theoretical than practical interest. Much attention has been given to the preparation of ferric coagulants from the action of chlorine on iron, particularly in the southwest where the ferric salts demand a high price (6, 7, 8). The solution of iron by electrolyzing the metal itself was the basis of several patents but this procedure has proven too

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costly. Ferrites have also been tried on a laboratory scale, but their high alkalinity and sodium content limit their practicability.

In comparing the relative coagulating ability of iron salts only the three most used compounds were employed. The relative clarifying power of ferric chloride, ferric sulfate and chlorinated copperas were determined over a pH range from 2.5 to 10.0. The pH adjustments were made with sulfuric acid and lime. When acid was used it was added after the coagulant, and lime, before coagulant addition. These procedures have been shown to produce the best results with iron salts (9). Six different domestic sewages were treated over the pH range with a dosage of iron which would give practically complete clarification at the optimum pH values. The dosage employed in all cases was 10 p.p.m. on the iron basis. Another series of tests was made to determine the relative degree of clarification obtainable by graduated dosages of the three coagulants without pH adjustment.

Iron Salts

Comparisons with pH adjustment are shown in Fig. 1, where the curves obtained for six sewages are presented as averages. The trends

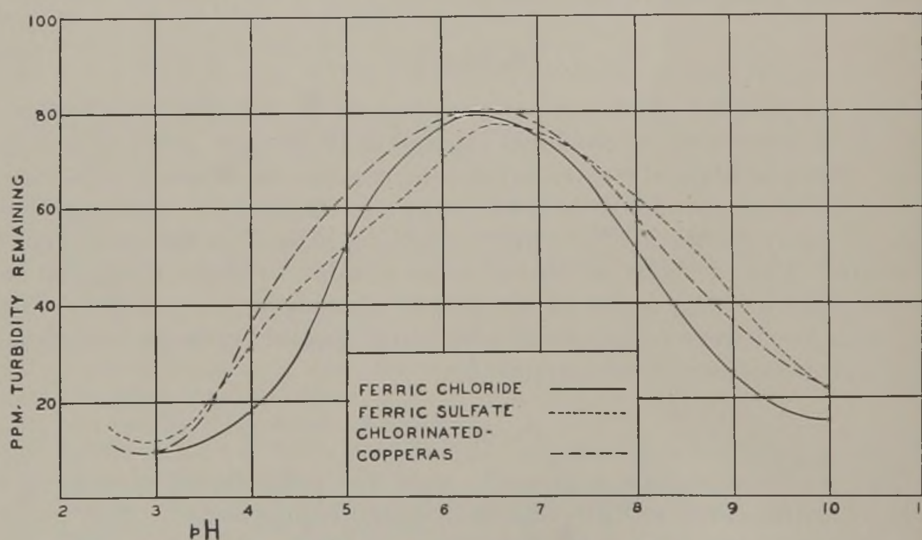

Fig. 1.—The relative clarifying power of three iron compounds.

of the data obtained were sufficiently similar to allow averaging. Ferric chloride yielded somewhat better clarification than the other two compounds, with the exception of the results in pH ranges 5.0 to 7.0 and 2.5 to 3.0. In the former range ferric sulfate was slightly better while in the latter little difference between the three chemicals was noticeable. However, clarification by the small coagulant dosage was not great in the 5.0 to 7.0 pH range and the comparison of graduated coagulant dosages without adjustment (Table I) is probably better. Here the pH was between 6.5 and 7.0 and inspection of the data shows that ferric chloride gave the best clarification. In general the order of effectiveness of the three chemicals was ferric chloride, chlorinated copperas and ferric sulfate.

TABLE I.—*Clarification Obtained by Equal Dosages of Three Ferric Salts*

Sewage	P.p.m. Iron	Ferric Chloride	Chlorinated Copperas	Ferric Sulfate	P.p.m. Turbidity Remaining Greater Than with $FeCl_3$	
P.p.m. Turbidity Remaining					Chlorinated Copperas	Ferric Sulfate
Highland Park	5	58	67	73	9	15
	10	29	25	34	4	9
	15	5	9	20	4	11
Madison-Chatham	10	93	105	111	11	18
	15	44	49	53	4	9
	20	15	23	27	8	12
Morristown	15	51	63	64	12	13
	20	23	35	39	12	16
	25	5	18	19	13	14
South River	25	121	146	158	25	37
	30	36	42	49	4	13
	35	14	19	24	4	10
Princeton	5	142	161	160	19	18
	10	110	143	136	33	26
	15	39	55	48	16	9
Plainfield	10	71	72	84	1	13
	15	50	58	69	8	19
	20	33	36	47	3	14
				Average	10	16

Mixtures of the salts were also compared as to clarifying value. Ferric sulfate, ferric chloride and chlorinated copperas were first applied alone in concentrations of 20, 25, and 30 p.p.m. of iron and the degree of clarification measured. Solutions of equivalent strength (on the iron basis) of ferric chloride and ferric sulfate in equal proportions, ferric chloride and chlorinated copperas, and ferric sulfate and chlorinated copperas, were prepared. Portions of these solutions were applied to the sewage in the same dosages (on the iron basis) as used with the single salts alone.

The clarification was measured in each case. The data obtained are presented in Table II. It does not appear from these figures that combinations of these salts exceed to any measurable extent the clarifying power of a single salt when the iron content is used as the basis for their addition.

Table II.—*Clarifying Activity of Mixed Ferric Salts*

P.p.m. Iron	20	25	30
	Turbidity Remaining		
Ferric Chloride	60	36	10
Ferric Sulfate	63	48	23
Chlorinated Copperas	62	36	15
Ferric Chloride and Ferric Sulfate	54	38	15
Ferric Chloride and Chlorinated Copperas	68	32	10
Ferric Sulfate and Chlorinated Copperas	61	34	15

In order to determine if the anions of the salts were responsible for the differences in the clarifying power of the iron salts, titration curves on sewage were made employing 0.1 N solutions of sulfuric and hydrochloric acids. It was thought that possibly the chloride ion was more effective in reacting with the sewage materials, thus effecting coagulation. If this assumption is correct differences in the titration curves with the two acids might be shown.

Five samples of sewage were titrated electrometrically with both acids. As the results were similar in every case one typical result is shown in Fig. 2. Practically no difference in the titration curves obtained with the two acids are observed as far as pH changes are concerned.

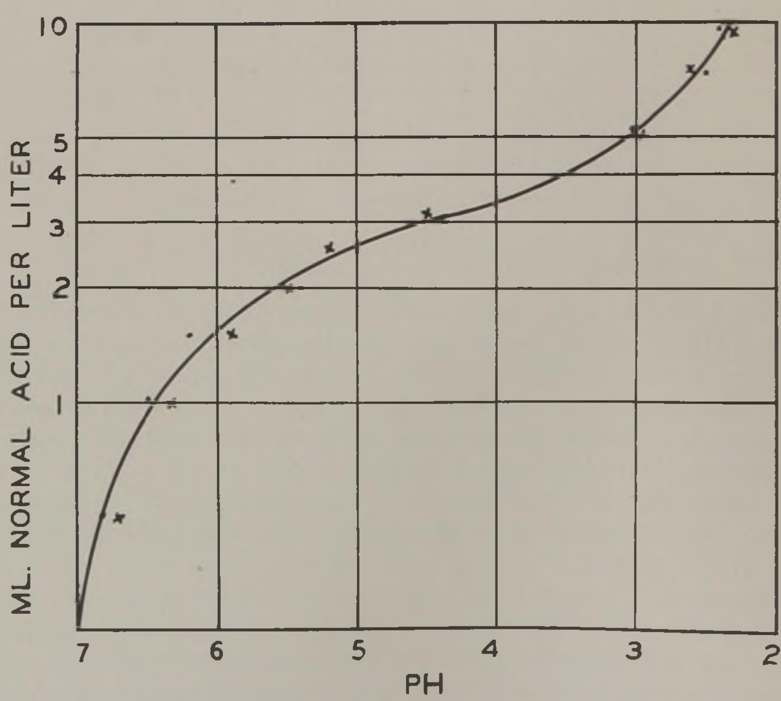

Fig. 2.—Titration curves of sewage with hydrochloric and sulfuric acids.

Since the acids themselves have definite clarifying power the question of the relative effect of sulfuric and hydrochloric acids in equivalent quantities arises. To determine the relative effects dosages of both acids were added to separate samples of the same sewage, so that pH values of 6.8, 6.0, 5.0, 4.0, 3.0 and 2.0 were obtained. The samples were flocculated, settled and the turbidity remaining measured.

The results were plotted as shown in Fig. 3. Examination of this graph reveals the fact that hydrochloric acid is more effective in clarifying sewage than sulfuric acid.

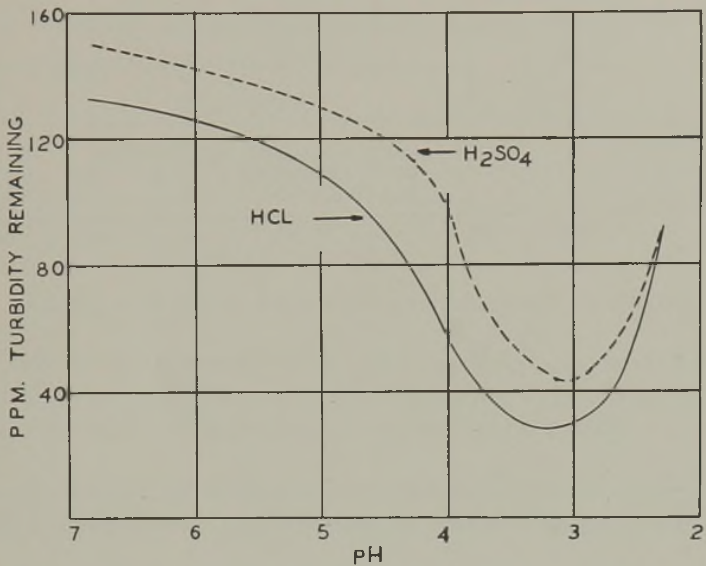

FIG. 3.—Relative clarifying power of hydrochloric and sulfuric acids.

IRON SALTS AND LIME

It is well known that the amount of ferric coagulants is reduced when lime is also used. Fig. 4 shows the possible reduction of iron salts by application of lime. This curve represents the average results obtained for fourteen different sewages. Relatively small quantities of lime (20 to 40 p.p.m.) did not effect appreciable reduction (4 p.p.m.) of $FeCl_3$. After a pH of 8.0 was reached, small additional quantities of lime effected a considerable reduction. Forty p.p.m. more of lime accounted for 10 p.p.m. lower iron dosage. Increases of lime over a total of 80 p.p.m. allowed a further reduction of but 2 p.p.m. of iron.

Whether the effectiveness of lime in clarifying sewage is due to the calcium or the hydroxyl ion has not been demonstrated. The experiments described below were conducted to study this question.

Liter portions of sewage were treated with increasing dosages of calcium hydroxide so that a series of pH values ranging from 7.0 to 10.5 was obtained. A similar set of liter samples were treated with sodium hydroxide to give the same range of pH values as obtained with

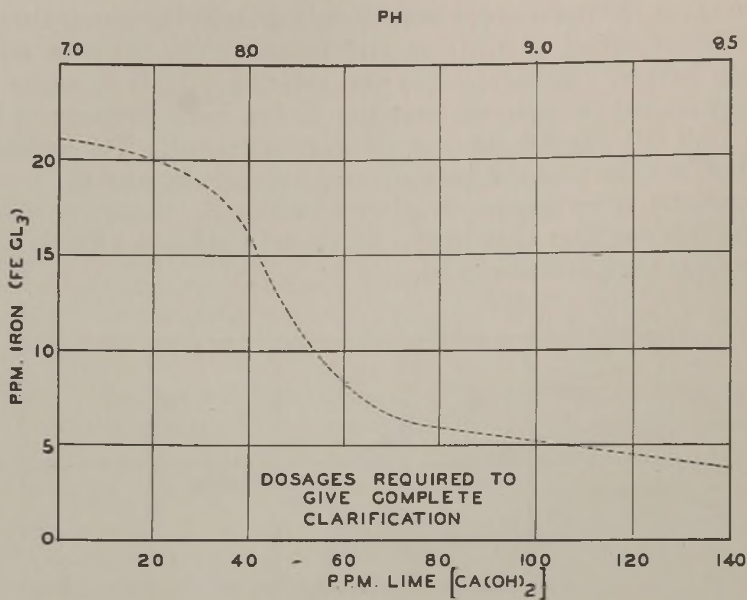

FIG. 4.—The clarification of sewage with lime and ferric chloride.

the calcium hydrate. All samples were flocculated, settled, and the degree of clarification measured by the turbidity remaining in the supernatant. This procedure was repeated with three different sewages.

The average of the four series of results are graphically shown in Fig. 5. No appreciable degree of clarification was obtained with sodium

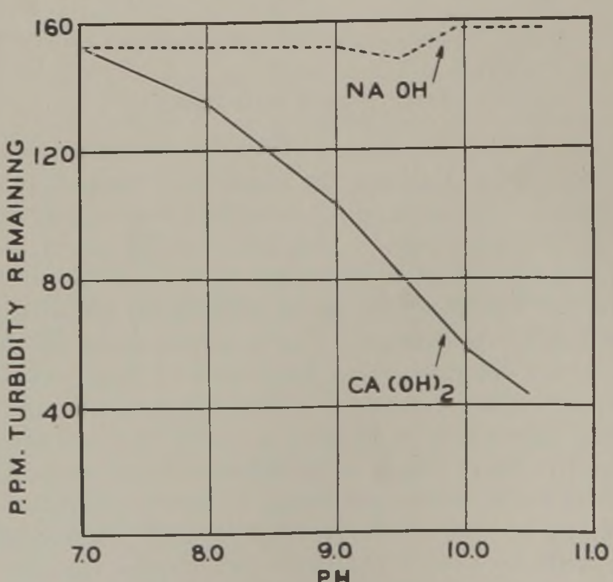

FIG. 5.—The clarification of sewage with sodium hydroxide as compared to calcium hydroxide.

hydroxide. At high pH values (10.0 and above) a small degree of dispersion took place. With the calcium hydroxide the sewage clarified to a considerable degree. The clarification increased in general as the lime dosage increased. The hydroxyl ion alone, therefore, is not the factor involved in clarification of sewage.

The same procedure was repeated using combinations of caustic soda and ferric chloride covering a pH range of 7.0 to 10.0. Two dosages of ferric chloride were used, namely 5 and 15 p.p.m. of iron. As shown in Table III no additional clarification resulted from the use

TABLE III.—*Effect of NaOH on Clarification with Ferric Chloride*

Adjusted with NaOH to pH	P.p.m. Iron ($FeCl_3$)	
	5	15
	P.p.m. Turbidity	Remaining
7.0	80	59
7.6	83	55
8.1	86	54
8.5	80	59
9.0	86	60
9.6	84	56
10.0	83	65

of caustic soda with either dosage of ferric chloride. Neither did any noticeable degree of dispersion result from the application of the caustic.

The effect of the calcium ion was then investigated. A sample of sewage was divided into four series of six one-liter aliquots. In each series the liter samples were treated in order with 0, 20, 40, 60, 80 and 100 p.p.m. of Ca as calcium chloride. To one series 5 p.p.m. of Fe as ferric chloride was added, to the second 10 p.p.m., to the third 15 p.p.m., and to the fourth, 20 p.p.m. The samples were flocculated, settled, and turbidity determined on the supernatants.

The clarification curves resulting from the addition of calcium chloride (illustrated in Fig. 6) show definitely that calcium chloride aids in the clarification of sewage when added in conjunction with an iron salt.

Sodium chloride does not act in the same manner as calcium chloride. This is demonstrated by the data presented in Table IV. It is noted that as much as 500 p.p.m. of sodium chloride did not effect clarification to any appreciable extent.

It has been stated that the clarifying effect of lime used in conjunction with iron salts was due to the precipitation of calcium carbonate (4). The activity of the calcium chloride which could not precipitate as calcium carbonate led us to make the following experiment.

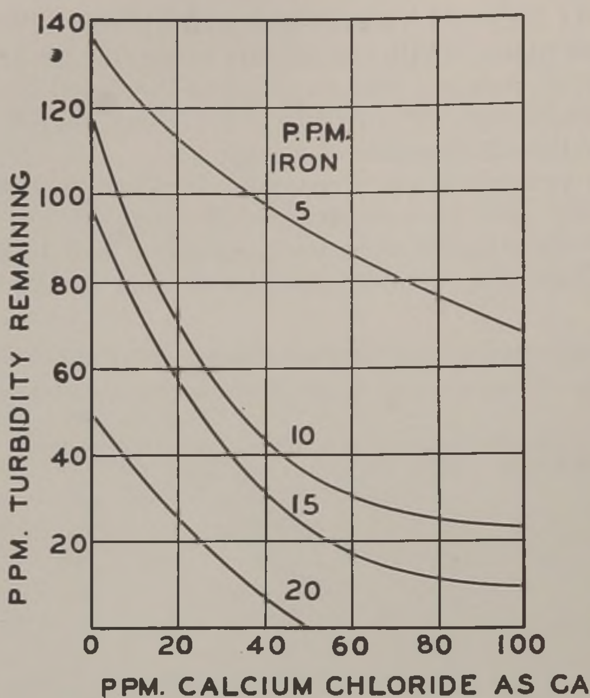

FIG. 6.—The clarification of sewage with calcium chloride and ferric chloride.

A sample of sewage was divided into five aliquots of one liter each. Lime as calcium was added in the form of lime water at dosages of 0, 10, 20, 30 and 40 p.p.m. The sewages were flocculated and settled, and samples of the supernatant withdrawn. The pH and calcium content were determined on these samples.

TABLE IV.—*Effect of Sodium Chloride on Clarification with Ferric Chloride*

		P.p.m. Iron ($FeCl_3$)			
		0	5	10	15
	0	138	75	42	10
P.p.m.	50	142	72	38	15
Sodium	100	132	68	37	10
Chloride	200	128	78	45	10
	300	142	70	43	10
	500	140	74	39	15

The results of the analyses showed that increases in the p.p.m. calcium remaining in the supernatants were in direct proportion to the amount added. Table V serves to illustrate this point. It will be noted that in every case practically all the calcium remained in the supernatant rather than precipitated in the sludge.

Table V.—*Calcium Content of Sewage After Treatment with Lime and Settling of the Sludge*

pH	Calcium Added	Calcium in Supernatant (Found)	Maximum Possible Calcium
	P.p.m.	P.p.m.	P.p.m.
7.2	0	43	43
7.7	10	51	53
8.3	20	66	63
8.8	30	71	73
9.1	40	79	81

Discussion

A comparison of the clarifying power of the three common ferric salts employed in sewage treatment over a pH range of from 2.0 to 10.0, using lime and sulfuric acid for pH adjustment, showed that in general the effectiveness of the three compounds on the iron basis was similar. Ferric chloride appeared to be somewhat better than ferric sulfate in clarifying power and the activity of chlorinated copperas was intermediate, except in the pH range of 5.0 to 7.0 where it gave the best results. Theoretically, its clarifying power should lie between the two other compounds as it is either a mixture of ferric sulfate and chloride or a compound containing both anions $\left(Fe\genfrac{}{}{0pt}{}{/\!\!/ SO_4}{\diagdown Cl}\right)$.

At some plants chlorinated copperas has not produced as good results as the other two salts. The reason is probably that the copperas was not chlorinated in the proper manner and oxidation was not complete. The reaction between copperas and chlorine is not completed as rapidly as was formerly believed.

The difference between the clarifying power of the iron salts has been shown to be due to varying clarifying power of the anions employed. Hydrochloric acid gave a greater degree of clarification than sulfuric acid, although no differences in the pH values were produced with equivalent amounts of the acid. This is contrary to findings with pure colloidal suspensions dispersed in definite agents. Under such conditions greater coagulating power is ascribed to the sulfate ions.

The difference is not difficult to understand when the material dealt with is considered. It has been shown (10) that in sewage coagulation the dispersion medium plays a more important role than the dispersed material. The observations made with sewage are not contradictory to the theory, as the anions evidently act on the dissolved material, which determines the coagulability of the dispersed particles.

The addition of lime with an iron salt was studied in an effort to determine the mechanism of action of the lime. Measurements of clarification of sewage at pH values from 7.0 to 10.5, obtained by the addition of calcium as compared to sodium hydroxide, showed that sodium hydroxide failed to clarify while calcium hydroxide showed strong clarifying properties. It is clear, therefore, that merely changing the pH value or making the material alkaline does not cause clarification. It appears then that the hydroxyl ion alone does not promote clarification.

It was believed that the sodium present might have acted as a dispersing agent, neutralizing the coagulating power of the hydroxyl ion. This does not appear to be true because it was shown that neutral sodium salts have neither dispersing nor coagulating properties for sewage when added in concentrations up to 500 p.p.m. with and without addition of ferric chloride.

That calcium chloride itself has little clarifying power was also demonstrated. This salt was effective in aiding clarification when used in conjunction with ferric chloride. These results seem to indicate that the calcium in the form of a neutral salt can act to change the character of the dispersion medium. The action of lime is probably twofold: Some of the calcium reacts with the dispersion medium allowing a reduction in the amount of iron salt necessary for clarification; some of the calcium becomes itself a clarifying agent at high pH values. It is clear that in the case of lime the hydroxyl ion may play a role.

Conclusions

1. The iron salts commonly used in sewage clarification are effective over the pH range 2.0 to 10.0.

2. Ferric chloride, chlorinated copperas and ferric sulfate is the general order of effectiveness in clarifying sewage although differences are not great.

3. The chloride ion is more effective for clarifying sewage in the acid pH range, which may account for the differences in effectiveness of ferric chloride and ferric sulfate.

4. The action of lime in lowering the coagulant demand appears to be due to the action of the calcium ion on the dispersion medium and its own clarifying power in the presence of hydroxyl ions.

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Plant Operation

VARIATIONS IN THE CHLORINE DEMAND OF BUFFALO SEWAGE

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More than two years have passed since the beginning of sewage chlorination at the Buffalo Treatment Works. During this time, studies begun in the construction period (1, 2, 3) were continued. Throughout this period of operation, the effectiveness of chlorination of Buffalo sewage has been studied and reported in papers on the reduction of bacterial pollution of the Niagara River (4, 5). It appears warranted at this time to make a study of the data that have been collected on the chlorine demand of sewage itself. This paper which covers the data collected in 27 months of chlorination is the first in a new series of sewage chlorination studies which were inaugurated with the beginning of sewage treatment at Buffalo. Additional papers will cover the subject of chlorine dosage control, the effectiveness of chlorination in the reduction of bacteria in sewage, the determination of chlorine demand and the estimation of coliform bacteria in chlorinated effluents.

In considering the results of any study of this kind, the effects of the physical plant and its operating schedules and conditions must be taken into account. For example, at Buffalo the sewage is pumped by one or more of six vertical centrifugal pumps of 550 h.p., each having a capacity of 120 to 140 m.g.d. Two of the pumps have two speeds and at low speed can pump from 80 to 100 m.g.d. The actual pumping rate depends on the total dynamic head.

The effect of this physical factor is shown in the record charts of the metered flow through the plant for, with an interceptor which allows some reservoir capacity, it is possible to use one pump for a long period of time independently of the variation in the flow into the interceptors. This reservoir capacity has a damping effect on the flow peaks and makes normal variations gradual. For this reason any study of chlorine demand must take into account the fact that although the flow does follow the normal curve for a sewage treatment plant, it is relatively constant throughout the day and any significant changes in pumping rates are step-wise by the capacity of either a low or high speed pump.

Another factor to be considered in interpreting the chlorine demand of Buffalo sewage is the relatively short run from the outskirts of the city to the treatment works. The total time of flow through the interceptors is not over five to six hours, with the major portion of the sewage flow reaching the treatment works in three to four hours. Although the interceptor has a capacity equivalent to approximately five hours, the rate of pumping under normal operating conditions is such that actual storage is relatively small. Thus the sewage arrives at the plant relatively fresh. With the absence of sulfates in the city water supply there is little or no hydrogen sulfide present in the sewage and, as has been reported heretofore (2), the chlorine demand is therefore relatively low in comparison with that of many other cities.

Still another reason for the low chlorine demand is the high dilution of the sewage. This derives from a high per capita pumpage and flow equivalent to approximately 200 g.c.d. Although this results in low chlorine demand in p.p.m., the total demand is not necessarily low when the total flow is considered. A third reason for somewhat lower demands than observed elsewhere may be due to the technique used in the Bird Island Laboratory for determining chlorine demand. The spot plate technique, which has been reported heretofore (1, 2), apparently gives results slightly lower than the technique of the present standard method (6). Inasmuch as the Bird Island Laboratory method of determining chlorine demand maintains a chlorine dosage control that effects practically complete reduction of coliform bacteria in the sewage, it is our opinion that the use of this method was warranted in making these studies.

It is doubtful that the results of these studies are strictly applicable to the sewage existing in any other city or treatment works. On the other hand, the statistical study of over 20,000 chlorine demand tests made at hourly intervals for twenty-seven months has produced some very interesting data. From these studies, it appears in a general way that the chlorine demand of Buffalo sewage varies with a number of factors; the time of day, the temperature of the sewage or season of the year, storm and runoff effects, industrial effects, and the day of the week. The following discussion presents our findings on the effects of these various factors.

Technique of Studies

The technique of the investigation was to tabulate, for statistical study, the hourly determinations of chlorine demand made by the routine laboratory sampler analyst. Samples were tested for chlorine demand within fifteen minutes after their collection. No changes were made in the Bird Island Laboratory spot plate test (1) for the determination of chlorine demand. It should be noted here that it has been found quite satisfactory to use tap water instead of distilled water for making the chlorine reagent solution. This appears to be feasible so long as the mineral salts, particularly the alkalinity of the water, are not great.

The reading accuracy of the chlorine demand test appears to be 0.1 ml. of reagent, equivalent to 0.3 to 0.5 p.p.m. Therefore, it has not been deemed feasible to report the chlorine demand in p.p.m. to more than one decimal place.

In tabulating and plotting the data to ascertain the various effects, it became evident that in order to develop the normal trend of the chlorine demand of Buffalo sewage, it was necessary to eliminate all effects of storms and industrial peak loads from the basic tabulations. Quite obviously it was neither possible nor desirable to eliminate the effects of normal industrial loads because they constitute a normal portion of the demand. There were, on the other hand, a great many times when the demand suddenly increased out of all proportions to normal expectancy and these effects were attributed to waste load discharges from industries and were termed industrial peak loads.

Variations in Chlorine Demand

Effect of Compositing and Standing.—It has been previously reported (2) that the proper chlorine demand of sewage could not be determined from a composite sample and that the true chlorine demand of the sewage must be determined from a series of hourly tests, weighted properly for the effect of flow. As a further test of the effect of compositing and standing of samples on chlorine demand, comparative studies were continued for several months on both raw and chlorinated effluent samples. The results of this study are shown in Table I. Except in one month, in the case of raw sewage, the chlorine demand of the composite sample was always less than the average chlorine demand of the fresh sewage. The extent of this difference was from + 6 to —25

TABLE I.—*Comparison of Chlorine Demand of Daily Composite Samples with the Weighted Average of 24 Hourly Tests.* Results in p.p.m.*

Month	Raw Sewage			Chlorinated Effluents		
	Weighted Avg. C.D. of Hourly Samples	C.D. of Daily Comps.	% Diff.	Weighted Avg. C.D. of Hourly Samples	C.D. of Daily Comps.	% Diff.
1938						
Sept.	5.8	4.8	−17.3			
Oct.	7.8	7.3	− 6.4			
Nov.	7.0	5.6	−20.0			
Dec.	6.6	5.8	−12.1			
1939						
Jan.	4.8	5.1	+ 6.2			
Feb.	4.7	4.0	−14.9			
Mar.	4.7	3.5	−25.5			
April	4.3	3.6	−16.3	1.0	1.9	110
May	5.6	4.5	−19.6	.5	2.1	320
June	6.2	5.3	−14.5	1.1	2.7	145
July	6.1	4.9	−19.7	1.0	2.6	160
Aug.	5.9	4.5	−23.7	.6	2.1	250
Sept.	6.6	5.4	−18.2	1.0	2.8	180
Avg.	5.85	4.9	−16.2	0.87	2.37	172

* Results include storm and industrial loads.

per cent, with an average of —16 per cent. In short, compositing and refrigeration of sewage samples apparently decreases the chlorine demand by about one-sixth.

In the case of chlorinated effluents where the demand of the effluent is 1 p.p.m., or less, it appears that the chlorine demand of the composite sample increases from two to four fold, with an average somewhere between. These data serve to confirm the contention that all tests should be made on fresh sewage samples.

Effect of Temperature.—In Table II the monthly average data on chlorine demand in p.p.m. are tabulated with the monthly average sewage temperatures for the period of study. These data are plotted in

TABLE II.—*Variation in Chlorine Demand (p.p.m.) with Sewage Temperature (excluding effects of storms and industrial peak loads)*

Month	1938		1939		1940		Average	
	Temp. °F.	Avg. C.D. Hourly Samples p.p.m.	Temp. °F.	Avg. C.D. Hourly Samples p.p.m.	Temp. °F.	Avg. C.D. Hourly Samples p.p.m.	Temp.	C.D. p.p.m.
Jan.			47.3	4.6	48.7	5.1	48.0	4.9
Feb.			46.7	4.4	46.6	4.8	46.7	4.6
Mar.			45.8	4.4	45.5	4.3	45.7	4.4
April			47.9	4.0	48.5	4.0	48.2	4.0
May			56.3	5.2	54.8	4.9	55.6	5.1
June			66.1	5.8	64.2	5.8	65.2	5.8
July			72.0	5.7	69.5	5.8	70.8	5.8
Aug.	75.2	5.8	74.7	5.7	72.5	5.9	74.1	5.8
Sept.	71.0	5.8	70.8	5.9	68.4	6.3	70.1	6.0
Oct.	65.0	7.2	65.4	5.8	64.2	7.0	64.7	6.7
Nov.	57.5	6.8	58.8	6.5			58.2	6.7
Dec.	50.2	6.9	52.8	5.8			51.5	6.4
Avg. for 27 Mo.							59.5	5.6

Fig. 1. One of the most interesting observations about these results is that the chlorine demand in p.p.m. lags behind the sewage temperature. In other words, the demand rises after the temperature begins to fall and falls after the temperature begins to rise. This might be considered an anomoly and some considerations should be given as to the reasons for it. In the first considerations the factor of flow will be omitted.

It is to be noted that the chlorine demand in p.p.m. is apparently representative of the general strength of the sewage as it varies with the temperature because the p.p.m. of 5-day B.O.D. and suspended solids of the sewage follows very similar curves to that of the chlorine demand.

There are certain effects to be observed, namely that during the summer months there is apparently a flattening off of chlorine demand, followed by peaks in the late fall. An inspection of the tabulated data indicates that there is a similar recurring trend of the chlorine demand at certain seasons, e.g., January, February, and March group together; April, in both years, was the minimum; May shows an increase; June, July, August, and September appear to be on a plateau; October, November, and December represent the high of the year although, actually, during December the daily data show a decrease.

It was not possible to tabulate and plot the total chlorine demand in pounds per day (excluding rain and industrial peak effects), but a calculation was made based on median flow data (approximating the dry weather average) and the demand in p.p.m. These total demand results confirmed the lag effect, but the minimum occurred in May instead of April and there was a tendency toward a gradual increase from May to December with a decrease toward a minimum in January, followed by increases in February and March (the latter due to high flows from melting snows).

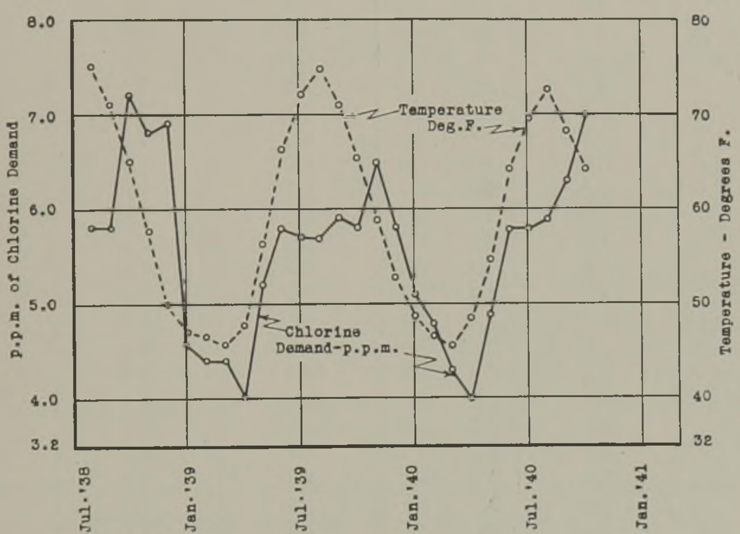

FIG. 1.—Variations in temperature and chlorine demand of sewage by months.

There are two possible explanations for this apparent lag in chlorine demand behind temperature. First, during the early spring months, February and March particularly, normal flows are quite high and the sewers and interceptors may be washed relatively clean of sewage solid depositions. The flow decreases following that period and the chlorine demand of the sewage decreases due to a deposition of some of the sewage solids. Secondly, the bacterial activity in the sewage is at its lowest during the winter months and begins to increase with the rise in temperature. This activity may also take place in the solids which are deposited during the lower flows of late spring and early summer, with the result that decomposition products are introduced into the sewage, thereby increasing the chlorine demand in the late summer and fall. Sewer slime growths may also be important in this seasonal effect.

Hourly Variations.—After giving full consideration to temperature and seasonal effects, it appeared that any tabulation to determine the hourly variations of chlorine demand must be made in accordance with the seasons as given above. An average hourly demand would not be indicative of actual operating conditions and would be of little or no value in the determination of the dosage control under the various seasonal temperature conditions. The data in Table III show the average

TABLE III.—*Hourly Variations in Chlorine Demand by Seasons*—Results in parts per million*

Hour	Average Jan.–Feb.–March	April	May	Average June–July–Aug.–Sept.	Average Oct.–Nov.–Dec.	Average Jan.–Dec. inclusive
8:00 a.m.	3.6	3.1	3.9	4.4	5.0	4.2
9:00	3.7	3.0	4.1	4.5	4.9	4.3
10:00	4.1	3.5	4.4	5.1	5.5	4.8
11:00	4.6	4.0	4.9	5.5	6.1	5.3
12:00 m.	5.2	4.6	6.0	6.4	7.2	6.2
1:00 p.m.	5.3	5.1	6.6	6.6	7.5	6.4
2:00	5.3	4.9	5.8	6.9	7.5	6.4
3:00	5.2	4.8	5.6	6.8	7.5	6.4
4:00	5.3	4.8	5.5	6.9	7.7	6.5
5:00	5.6	4.7	6.0	6.9	7.7	6.5
6:00	5.6	5.0	5.8	6.9	7.9	6.6
7:00	5.4	4.6	5.7	6.7	7.8	6.6
8:00	5.2	4.6	5.7	6.7	7.5	6.4
9:00	4.8	4.5	5.6	6.5	7.1	6.1
10:00	4.8	4.0	5.3	6.2	6.9	5.8
11:00	4.5	3.8	5.2	5.8	6.5	5.5
12:00 p.m.	4.7	3.6	5.2	5.8	6.6	5.6
1:00 a.m.	4.4	3.5	5.0	5.5	6.4	5.4
2:00	4.3	3.4	4.8	5.6	6.3	5.3
3:00	4.1	3.4	4.7	5.5	6.1	5.1
4:00	3.9	3.4	4.5	5.3	5.9	5.0
5:00	3.6	3.3	4.2	4.9	5.5	4.6
6:00	3.5	3.1	3.9	4.6	5.5	4.4
7:00	3.4	2.8	3.8	4.3	5.2	4.2
Average	4.6	4.0	5.1	5.8	6.6	5.6

* Excluding storm flows and industrial peak loads.

hourly chlorine demand in p.p.m. for the five seasons mentioned, considering that April is a season of minimum demand and May is unlike any other time of the year because it immediately follows the minimum demand and does not reach the average demand of the summer months. These data are plotted in Fig. 2 and, as indicated above, exclude the effect of storm and industrial peak loads. It should be borne in mind that these data are in p.p.m. and therefore do not take into account the effect of flow on total chlorine demand. They are, however, useful in formulating a set of curves for the control of chlorine dosage. These will be discussed in a subsequent paper.

Certain definite trends are to be observed from the curves in Fig. 2. There is a general increase in chlorine demand between the hours of

8:00 A.M. and 12:00 M. to 1:00 P.M. from January until June. During the months when the sewage is cold or just beginning to warm up, there is a drop in chlorine demand after the 1:00 P.M. peak, followed by an increase at 5:00 to 6:00 P.M. Thereafter the chlorine demand decreases at a relatively constant rate until the end of the fiscal day at 7:00 A.M. In the summer and late fall months, when the chlorine demand is higher, there is no definite decrease after the first peak, but the demand tends to remain relatively constant throughout the afternoon, or rise to a peak about 6:00 P.M.

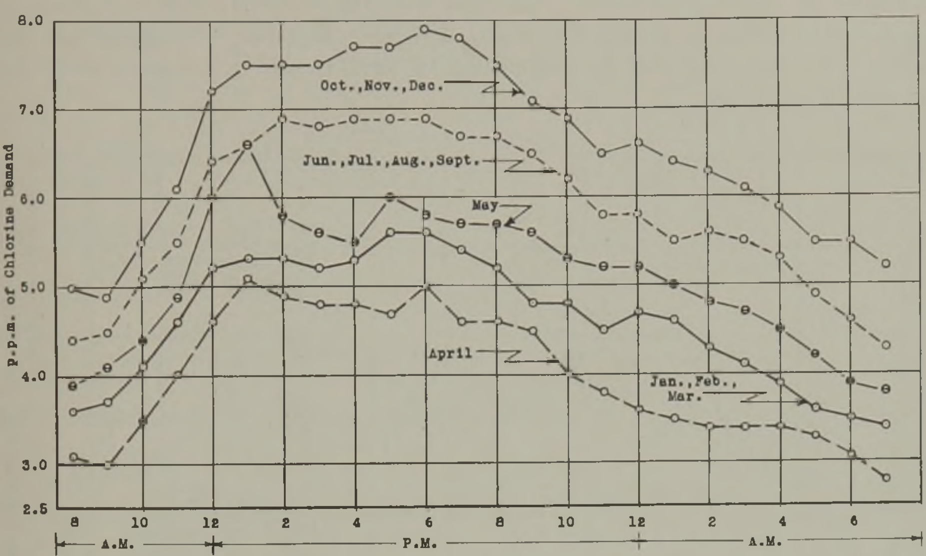

FIG. 2.—Hourly variations in chlorine demand by seasons—(excluding storms and industrial peak loads).

It may be argued that since only a two-year period is covered, the choice of April and May as separate seasons is unwarranted because there are too few data. On the other hand, it appears from Fig. 1 that April is definitely the month of minimum chlorine demand (in p.p.m.) and that May is definitely between the minimum demand and the summer demand. The probability is that the data for these two months indicate a general tendency.

For that matter, it is quite probable that at the end of five years of study when these summaries are to be revised and the data re-averaged, the general trend of these curves will remain relatively the same, but the individual tendencies may vary somewhat.

The effect of the volume of sewage flowing at any particular time on the total chlorine demand of sewage in pounds per day is indicated in Fig. 3, for a typical month of August, 1939. It is apparent from these dry weather data that the pumping schedule for sewage at the Buffalo plant does have a damping effect on the flow curves. Because of this, the hourly variation in the total demand is not as great as might be expected in some plants (7). Averages of the hourly rates of flow of sewage are not available and it is therefore not possible to show the effect of the hourly flow variation on the hourly total demand rate in the various seasons listed in Table III.

Using the data in p.p.m., shown in Table III, however, and the median flows for the various months, it was possible to estimate the average total demand in pounds per day for these seasons. (Note: The median flow has been found to approximate the dry weather average.) From these calculations, it appears that the difference between total demand in the months of January, February, and March, and the total demand of April was much less than the difference in p.p.m. Also, in May as mentioned above the total demand was the minimum for the year, although the chlorine demand in p.p.m. had increased over the previous months.

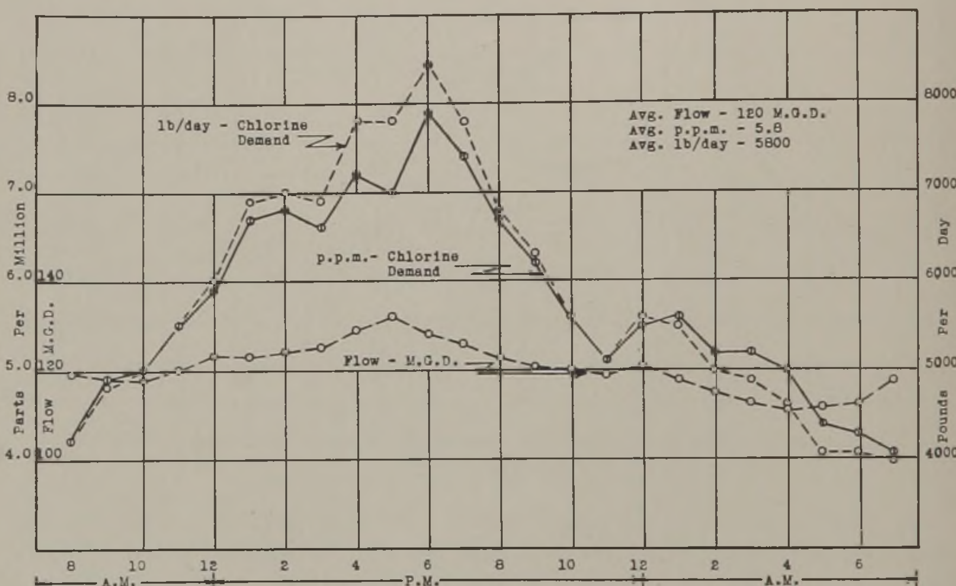

FIG. 3.—Hourly variations in D.W. flow and chlorine demand in p.p.m. and lb./day for typical month—Aug. 1939.

These calculations likewise indicate that the total demand in pounds per day in the summer months was but little more than that of January, February and March, although the demand in p.p.m. was 1.2 p.p.m. higher. These differences between total demand and demand in p.p.m. are best shown, perhaps, by comparing the percentage relationships of the various seasons with the average demand in p.p.m. and in pounds, as shown in Table IV.

Daily Variations.—In Table V are listed the average data for each day of the week. These data present observations both including and excluding storm flows and industrial peak loads. These data are plotted in Fig. 4. The effect of storm and industrial peak loads was equivalent to approximately 0.3 p.p.m. on the daily average.

TABLE IV.—*Comparison of Chlorine Demand by Seasons on the Basis of p.p.m. and Pounds Per Day. Data in Per Cent.*

On Basis of p.p.m.

	Jan.–Feb.–Mar.	April	May	June–July–Aug.–Sept.	Oct.–Nov.–Dec.
% of Yearly Avg.	82	71	91	103	118
% of June, July, Aug., Sept.	79	69	88	100	114
% of Oct., Nov., Dec.	70	61	82	77	100

On Basis of Lb. Per Day

	Jan.–Feb.–Mar.	April	May	June–July–Aug.–Sept.	Oct.–Nov.–Dec.
% of Yearly Avg.	99	96	86	102	117
% of June, July, Aug., Sept.	97	95	85	100	114
% of Oct., Nov., Dec.	85	82	74	87	100

TABLE V.—*Variation in Chlorine Demand by Days Results in parts per million. Average of 27 months*

Day of Week	Avg. of All Data	Avg. Excl. Storm Flow and Industrial Peak Loads
Sunday	4.8	4.7
Monday	5.9	5.6
Tuesday	6.2	5.9
Wednesday	5.9	5.6
Thursday	5.9	5.6
Friday	6.2	5.9
Saturday	6.2	6.0
Average 7 days	5.87	5.61
Average Excl. Sunday	6.84	6.55

It appeared that the Sunday chlorine demand (p.p.m.) was approximately 70 per cent of the average demand for the remainder of the week, and, as was observed in experimental studies (2), Tuesday appeared to be a high day. There was an apparent decrease on Wednesday and Thursday, followed by an increase on Friday and Saturday. These data would then appear to give the effects of normal industrial operation during the week. On the basis of total pounds of demand, the Sunday chlorine demand was equivalent to approximately 59 per cent of the average for the other six days since the flow on Sunday is approximately 85 per cent of the flow for the remainder of the week.

Effects of Storm Flow.—Although it was easy to remove the storm effect data from the general averages, it was not so easy to estimate the exact effect of storms themselves. This was true because a rain storm might occur during the time of day when there was a normal

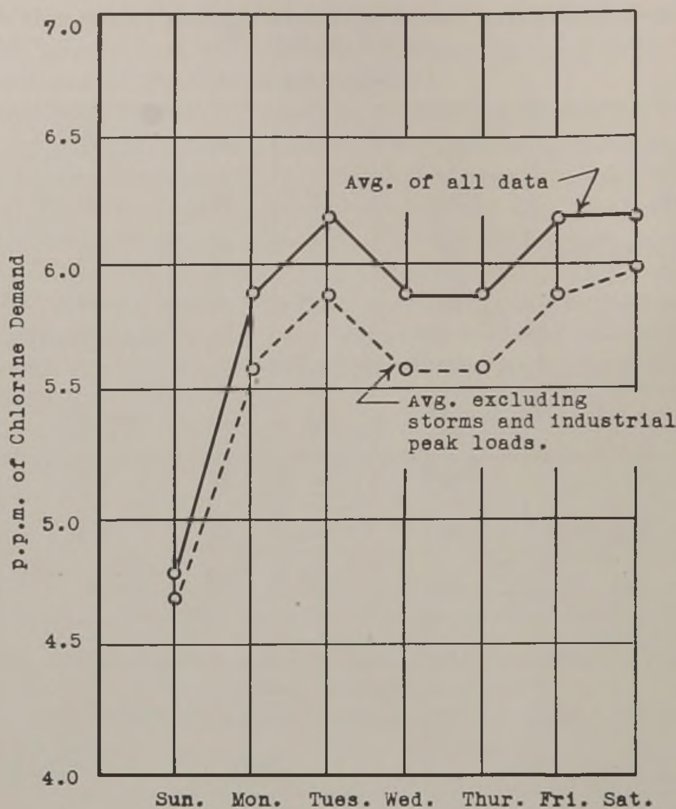

FIG. 4.—Daily variation in chlorine demand.

expected rise of chlorine demand and this normal rise might augment the peak due to the sudden flushing of the sewers. On the other hand, the normal demand might offset the falling off of the chlorine demand with the higher dilution due to rain flows after the sewers had been flushed. A study of the one hundred twenty-six days on which rain occurred at various hours of the day produced the average data shown in Table VI. On the basis of these data, it appears that for the first two hours after a rain has started (usually when the pumping rate is increased by a second pump), the chlorine demand rises. This is followed by a drop to what may be considered a normal demand.

TABLE VI.—*Effect of Storm Flows on Chlorine Demand of Raw Sewage*

	Parts per million
Before storm	5.3
First hour	6.0
Second hour	6.8
Third hour	5.7
Fourth hour	6.0
Fifth hour	6.0
Sixth hour	5.8

In cases where rains continue over a long period of time, from eight to twenty-four hours, the demand is usually considerably less after the first few hours. In cases of sudden sharp showers, the demand may increase greatly during the first hour and return to normal within an hour or two. On the average, the effect of storm flows was to raise the daily average chlorine demand by 0.2 p.p.m. Considering that due to rainstorm runoff the average flow is 22 m.g.d. higher than the dry weather flow, this would indicate that the effect of storms was to increase the daily average total demand by approximately 360 lb. per day.

The greatest effect of any storms observed was to increase the daily average chlorine demand for any single month by 0.4 p.p.m. This occurred during the normal dry weather months. The greatest effect toward decreasing the demand was observed in the cold months when there was a normal high flow. In this case, in one month, the daily average demand for the month was decreased by 0.5 p.p.m. due to storm water.

Industrial Effects.—As indicated above, there appears to be a normal industrial load which varies as the days of the week. But there were at least three hundred thirty-eight times during the twenty-seven months when the chlorine demand at a single hour suddenly increased above the normal demand for that time of day and season of the year. The effects of these industrial peak loads are shown in Table VII, Parts A and B. In Part A is shown the frequency and time of the peaks. On Saturdays the number of peaks was greatest for any single hour and the majority of these peaks occurred at noon with a smaller number at 11:00 A.M. and 1:00 P.M. Totaling the number of times that these peaks occur at various hours indicates that there is a definite rise to a maximum between 10:00 A.M. and 2:00 P.M. followed by a recurring tendency to a maximum between 5:00 P.M. and 9:00 P.M., and a rapid decrease thereafter. There were very few peak industrial effects observed after midnight.

It is not so easy to explain the source of these peaks, but from previous studies it would appear that they may be due to sudden discharges of strong waste loads from the city's industrial section which is about three and one-half hours flow time from the treatment works.

It is possible that these tendencies toward maxima may indicate approximately definite dumping times of waste loads. The spread of these tendencies over several hours is probably due to the natural streaming effects in the sewers and the damping effect of the interceptor reservoir capacity.

The effects of these loads on the normal demand are shown in Part B of Table VII. The average demand before the peak hour, the demand during the peak, and the demand for the two succeeding hours thereafter, together with the average for the days of the peak are listed for each day of the week.

On the average, the demand was practically doubled although there were several days when the demand increased four and five fold. The highest demand ever observed was 63 p.p.m. The general effect of

TABLE VII.—*Effects of Industrial Peak Loads on Chlorine Demand of Raw Sewage*

Part A—Frequency and Time of Peaks

Hour	Sundays	Mondays	Tuesdays	Wednesdays	Thursdays	Fridays	Saturdays	Total
8:00 A.M.								0
9:00				1			1	2
10:00		4	1		2	4	1	12
11:00		4	7	2	6	2	5	26
12:00		8	5	3	9	8	15	48
1:00 P.M.		9	7	1	10	3	6	36
2:00		8	5	9	8	4	1	35
3:00		7	6	4	4	2	2	25
4:00		4	5	3	2	4	1	19
5:00		4	4	3	1	6	1	19
6:00		9	5	7	3	2	1	27
7:00		6	9	4	7	8	1	35
8:00		2	7	4	1	4	1	19
9:00		1	1	3	1	4	1	11
10:00		1	2			1		4
11:00		1	2		1			4
12:00		2	1	2		1		6
1:00 A.M.		1	3					4
2:00			1					1
3:00		1						1
4:00								0
5:00			1	1				2
6:00				1				1
7:00			1					1
Total	0	72	73	48	55	53	37	338

Part B—Effect of Peak Load on Demand

Before peak p.p.m.		6.6	6.9	6.7	6.5	6.8	6.4	6.7
Peak hour p.p.m.		13.2	14.8	14.6	12.9	14.2	13.4	13.8
First hour after peak p.p.m.		8.4	7.6	7.5	7.4	7.4	7.3	7.6
Second hour after peak p.p.m.		7.5	7.6	6.9	6.8	7.3	7.0	7.3
Avg. for day of peak p.p.m.		5.7	6.0	5.7	5.8	6.1	6.1	5.6

these peaks was to raise the daily average demand by approximately 0.1 p.p.m. This was equivalent to 110 lb. per day on the total average flow. On the individual days in question when peaks occurred, the effect was to raise the demand from 0.3 to 5 p.p.m. or more. Not only are these facts interesting from a strictly observational standpoint, but they also indicate the need for special chlorine dosage control at such times.

DISCUSSION

The presentation of these data and results is not complete without some discussion of the comparison of the analytical results and their indications with the experimental work which was carried on during the construction of the treatment works project and which lead to the continuation of these studies.

On the basis of these published preliminary and field studies on the chlorine demand of sewage (2), the senior author prepared a report (8) estimating the probable total chlorine demand and variations therein of Buffalo sewage as it might be expected to be received in the treatment works. It is interesting to note that in this unpublished report it was "concluded that the average chlorine demand will be between 57 and 60 lb. per million gallon or approximately 6,000 lb. per day on a dry weather flow of 105 m.g.d. excluding rain effects." The present studies indicate a dry weather flow of approximately 113 m.g.d. and a total demand of 5,970 lb. or approximately 53 lb. per m.g.

The preliminary studies upon which these predictions were based involved studies made in July, August, November, and February, and from those studies it was impossible to determine the trend during the week but it was observed (8) that the total Sunday demand was approximately 58 per cent of the average for the other days in the week and that the maximum demand occurred on Tuesdays. In the present studies it appeared that the highest demand occurs on Tuesdays, Fridays, and Saturdays, and that on the basis of total pounds per day the Sunday chlorine demand appears to have been 59 per cent of the average demand for the remainder of the week.

It was predicted (8) that the minimum would occur about 6:00 A.M. and the maximum between 12:00 M. and 1:00 P.M. Actually the minimum occurred at 8:00 A.M. and the maximum at 1:00 P.M. or later, depending upon the season of the year. It was also expected that occasional maxima of 25 p.p.m. would occur. This has been borne out in the studies of the industrial peak loads which are generally less than that figure although one maximum demand was recorded at two and one-half times that value.

On the basis of a lower estimated flow than actually occurred it was estimated that the average demand would be approximately 7 p.p.m., whereas on a 10 per cent higher flow, it was found to average 5.6 excluding storm flows and varied between 4.0 and 6.6 on monthly averages. It was estimated that the variation in chlorine demand during a dry weather day would be from 30 to 225 per cent of the average. This was found to be approximately correct although on the average the normal variation was from 70 to 130 per cent during the day. Single peak loads of 800 to 1000 per cent of the average for a single day occurred infrequently.

The preliminary studies indicated (2) that the cold weather chlorine demand would be approximately 65 per cent of the warm weather demand. It was assumed at that time that the cold weather demand would prevail from January through April and the warm weather results the remainder of the year. On the basis of the studies reported herein it appears that the cold weather demand is from 70 to 80 per cent of the warm weather demand as regards concentration in p.p.m., but as regards total demand in pounds the cold weather demand is from 85 to 95 per cent of the warm season demand with the transition month between cold and warm seasons having the lowest total demand.

Previous studies (2) included an attempt to determine the chlorine demand per capita and the results of the study of the sewage of a district not containing industrial plants indicated that the average per capita demand was approximately .0047 lb. per capita per day. On the basis of the present studies it was indicated that the per capita of demand for Buffalo was 0.01 lb. per capita per day excluding storm and industrial peak load effects, or 0.011 lb. per capita per day including all sewage flows. Whether this high per capita demand can be entirely attributed to industrial wastes cannot be ascertained from a study of the data collected.

The study of 126 storms indicated that the data available from the early preliminary studies, though lacking in completeness, were correct in indicating that the "chlorine demand in p.p.m. of combined sewage and storm water is not materially less than that of dry weather sewage and during the early runoff is usually higher" (2). The data of these present studies show increases in p.p.m. of chlorine demand during the first and second hour of the storm flow. Therefore it is readily to be seen that since this demand occurs with flow increases of 200 to 300 per cent, the total chlorine demand rate in pounds per day rises precipitously.

In the published summary of the laboratory and field studies (2), it was pointed out that "two criticisms of the analytical results might be raised. First, that the data presented covered only four short periods at different seasons and might not be representative. Secondly, that the results as determined in the laboratory probably are not strictly transferable to plant operation."

The fact that the results of 27 months' study in the sewage treatment works are not greatly different from the predicted results based on those four short periods indicates that it is possible, by proportional sampling and judicious choice and weighting of the sewers to be sampled and analyzed, to utilize preliminary studies as a basis of plant capacity design.

In accordance with the findings of preliminary studies that up-sewer chlorination was not necessary at Buffalo due to lack of sulfates in the sewage and consequent lack of hydrogen sulphide, no further studies were made on the subject.

Summary and Conclusions

In reviewing the analytical work of these studies and interpretations thereof certain factors become evident.

1. The chlorine demand of sewage is dependent on local conditions of sewage strength, chemical composition and sewage flow. For water low in sulphates, where the rate of flow is maintained relatively constant by pumping, following a relatively short sewer run, the chlorine demand

of the sewage in p.p.m. is not high. In the case of Buffalo the dry weather demand is approximately 5.6 p.p.m. equivalent to 53 lb. per m.g.

2. The determination of chlorine demand on composite samples of raw sewage or chlorinated effluents does not give a true demand of the sewage when compared to the average of 24 hourly tests. It is generally from 12 to 25 per cent low in raw sewage and is high in the case of chlorinated effluents by 100 to 300 per cent.

3. The chlorine demand of Buffalo sewage in p.p.m. rises and falls with the temperature but lags behind it, for the demand continues to rise after the temperature begins to fall and vice versa. The total chlorine demand, in pounds per day, also lags behind the temperature but the effect of volume changes the characteristics of the curve somewhat.

4. The chlorine demand in p.p.m. during an average day varies from 70 to 130 per cent of the average, but a single day's variation may be much greater. Minimum demands occur at 7:00 A.M. to 9:00 A.M. and maximum demands at noon and after, reflecting the normal industrial and domestic life of the city.

If the pumpage in the Buffalo Treatment Works were at a less constant rate and more nearly reflected the actual hourly variation in sewage flow, it is quite probable that the chlorine demand rate in pounds per day, if plotted by hours, would show a much wider variation than do the data in p.p.m.

5. Generally speaking there is little difference in the average demand during the week although Monday, Wednesday, and Thursday appear to be somewhat lower than the other days and the demand on Sunday, both in pounds per day (59 per cent) and p.p.m. (70 per cent) is considerably less than the average for the remainder of the week.

6. Storm flow and runoff effects do not greatly increase the concentration of chlorine demand although there is a tendency to increase during the first two hours of a storm runoff. On the other hand, the total chlorine demand rate per day increases by several fold during these hours due to the increased flow occurring.

7. Normal industrial loads on the sewers may not be strictly recognized as such, but at times peak loads occur. On the average, the peak is approximately double the normal demand for that or the previous hour and these effects have usually disappeared within two hours. There appear to be two periods in the day when peak loads occur, between 10:00 A.M. and 2:00 P.M., and between 5:00 P.M. and 9:00 P.M.

8. The per capita demand of Buffalo sewage is 0.01 lb. per day, excluding storm effects. This is slightly more than twice the value reported for strictly domestic sewage (2). For purposes of designing capacity for chlorinating machines, it is apparent that this per capita demand or the total demand in pounds per day is more important than the p.p.m. of chlorine demand.

9. The compilation of these data has shown the variability of the chlorine demand of Buffalo sewage and the need for control of chlorine

dosage to meet these variable factors. The data have also furnished the basis whereby a system of chlorine dosage control could be developed.

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PUBLIC HEALTH ASPECTS OF SEWAGE TREATMENT IN DETROIT *

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The discharge of untreated sewage into watercourses is objectionable for many reasons. A certain reason may be of the utmost importance in one situation and insignificant in another. Thus the objects of sewage treatment may and should vary with the situation. Oxygen depletion in streams, decomposing sludge banks, floating oil and grease, damage to fish and game, bacterial pollution of water supplies and bathing beaches, tastes and odors in water supplies, odor nuisance, and injury to shellfish industries are some of the results of sewage discharge that have made sewage treatment necessary.

In America, and even more so in England and Germany, treatment plants have generally been built to remedy gross pollution, as such situations naturally demanded first attention. The public health was usually endangered, but in most cases it is safe to say that sewage treatment would not have come, at least for many years, if there had not also been conditions offensive to sight and smell or damage of some other kind. So public health has until now usually been secondary, and sometimes decidedly unimportant, as the real reason for adopting treatment.

The sewage disposal problem at Detroit is most unusual. Among all the large cities in the United States, and most of the small ones, there is probably no case, with the single exception of Buffalo, where such an enormous quantity of pure flowing water is available for disposal by dilution. The flow in the Detroit River is very uniform and is never less than 300 times the average sewage flow from the city. This situation is to be contrasted with those at Chicago and Indianapolis, for example, where the flow of diluting water is often less than the flow of sewage.

The result of this has been to make the nuisance aspects of sewage discharge less important at Detroit, increasing the relative importance of the public health aspects. Reduction of biochemical oxygen demand of the sewage, which has sometimes been taken as a general measure of the success of sewage treatment, is of no practical importance at Detroit. The objectives of the Detroit plant are to eliminate visible nuisance, sludge banks, floating oil and grease due to the discharge of sewage from the city and to reduce as much as possible the discharge of sewage bacteria.

The principal treatment of the sewage proper is in sedimentation tanks which are designed to give 1½ hours detention at average flow

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and remove 55 per cent of the suspended solids, which is believed to be quite sufficient for the conditions. Results for the first six months of operation indicate that the actual removal will be somewhat greater than was contemplated.

The tank effluent is treated with chlorine before discharge into the river through a tunnel more than a mile long. The chlorine demand has averaged between six and seven parts per million and the plan has been to dose at a rate somewhat in excess of the demand found, so as to be reasonably sure of a residual in the final effluent, in spite of sudden variations in the chlorine demand. Because of lack of sampling facilities, which will soon be provided, it has not been possible to determine directly the actual residuals and bacterial kills obtained. Laboratory samples, treated with the same chlorine dose as the plant effluent and given the same contact time as it receives in passing through the effluent conduit, have shown an average reduction of coliform bacteria of over 99 per cent. This is probably a better result than that obtained by the plant, because of difficulty in following there the rapid fluctuations in chlorine demand.

The estimated cost of chlorine, for the first year of operation, is about 20 per cent of the total operation and maintenance budget, showing the unusual importance of disinfection in the plant scheme. The actual chlorine demand is proving to be less than was expected, and as other costs have been closer to estimates, the actual cost of chlorine for the year will probably amount to nearer 10 per cent of the total budget.

One of the most obvious public health effects of sewage treatment at Detroit will be a decrease in the bacterial load on water purification plants taking their raw water from the Detroit River below the city. There are two of these on the American side of the river, one supplying about 30,000 people and the other about 4,000. It does not appear that Detroit pollution has had any effect in increasing the load on water plants on the Canadian side of the river.

The bacterial load on the two American plants has been serious. The larger plant, for which better data are available, has its intake located about one-third of the way across the river and so has missed most of the pollution from Detroit sewers. Because of the positive velocity of flow in the river at all times, the pollution passes down the river much faster than it works out from the shore. In spite of the fact that its intake is located in a relatively clean part of the river, the average coliform index for the five years, 1934 to 1938, inclusive, was 19,900 per 100 ml. The corresponding average index for the month of August was 63,000.

Considering Streeter's suggested standard of 5,000 per 100 ml. as an upper limit of pollution for water to be safely handled by a modern, well-operated purification plant, it is apparent that the figure represents a heavy overload on the plant in question.

Direct observations have been made of the bacterial condition of the river but interpretation of the results is complicated by the fact that other sewage effluents and some untreated sewage are being discharged at and below Detroit. It is not yet possible to say to what extent the remaining bacterial pollution is due to the Detroit effluent and to what extent to other sources.

The best available information is in regard to the Trenton Channel of the river, that is the part of the flow between Grosse Ile and the American shore. It is an interesting fact that this channel, carrying only 23 per cent of the river flow, carries probably more than 95 per cent of all coliform bacteria in the river, certainly more than 95 per cent of all those of American origin. Good longtime-average bacterial results on the improvement of conditions are not yet available and long-time results are necessary because of the seasonal variation in bacterial numbers. The average coliform count at the Wyandotte water intake, for example, was formerly six times as great in August as in February. Preliminary figures indicate that the bacterial pollution of the American half of the river has been decreased at least 75 per cent and that this percentage will increase as the remaining untreated sewage from Detroit and other communities is diverted from the river, as a better method of sampling makes closer control at the Detroit plant possible, and as the smaller plants adopt chlorination.

The Detroit River, from Lake St. Clair to Lake Erie, is about 27 miles in length. Because of sewage discharge, largely from the city itself, bathing has for many years not been considered safe at any point on the American shore for the entire length of the river. Much of this shore is a potential playground for a population of two million but the bathing possibilities have been nearly destroyed by sewage discharge. How soon and to what extent sewage treatment will make bathing in the river safe is a question for sanitarians. There can be no doubt however that the intercepting, settling and disinfecting of Detroit sewage is a long step in the right direction.

Nearly all of the sewage discharged into the Detroit River and its tributaries on the American side is now treated. Treatment of most of it has started within the past year so its effects are only now becoming apparent. It is certain however that the river will be much more attractive for recreational use and such use is certain to increase. It has been limited in the past by offensive conditions rather than by actual public health hazards, although a certain amount of health danger was involved. For such recreational uses as picnicking on the banks or on islands in the river, and for boating, the degree of sewage treatment now provided will practically eliminate public health risk and will doubtless mean an actual public health gain through recreation.

There is one respect in which sewage treatment is unsatisfactory at Detroit and in most other cities where bacterial pollution is a factor. This is brought about by the discharge of diluted sewage from the stormwater overflows of combined sewer systems during heavy rains. Where the purpose of sewage treatment is to avoid nuisance, such discharge has not been particularly serious. The most objectionable conditions are due to extremely low flows in the receiving streams, and such low flows almost never exist at the time of stormwater overflow. The dry weather sewage is much diluted if there is any considerable amount of rain, so that in biochemical oxygen demand, for example, the untreated sewage at a time of heavy storm may be better than the settled effluent during dry weather.

With regard to bacterial pollution, however, the conditions are quite different. The drainage area of the Detroit River is so great that its discharge is only very slightly affected by any local storm and not much affected by any cause whatever. In cases of extreme downpour the combined sewers may discharge at full capacity for hours, with the total rate being perhaps 25 or 50 times the volume of dry weather sewage flow. Since the sewage treatment plant is able to handle only about two times the dry weather flow, it means that perhaps 95 per cent of all sewage bacteria must be discharged without disinfection into the river. Whereas the concentration of bacteria, per unit volume, is apt to be much less in the case of a heavy rain, the total bacterial discharge is certainly greater.

Thus any bacterial protection that is secured by sewage treatment to the present extent is almost entirely lost during an extremely heavy rain. As this condition affects the safety of downstream water supplies, it must now be met by extreme vigilance at water treatment plants during such periods. The first Detroit water filtration plant was formerly exposed to such a situation. Special care and increased chlorine dosages were necessary during heavy storms to guard against increased chlorine demand or heavier bacterial pollution because of stormwater discharge.

The effect on recreational use of the stream is less serious. Stormwater pollution will disappear from the upper reaches of the river within a few hours after discharge from the overflows ceases. In twenty-four hours the effect will probably have disappeared from the entire length of the river. Since recreational use will naturally be much limited during actual storm conditions, there will be relatively small hazard from this cause. If it is found that bathing is safe in the lower river at most times but unsafe for a day or so after heavy storms, it may be necessary to post bathing beaches to warn of unsafe conditions. Notices are now issued through newspapers to show whether skating is available in public parks and there seems to be no practical reason why a similar system could not be used for bathing beaches. Doubtless for weeks on end, in hot summer weather, it will not be necessary to limit bathing, so that most of the advantages of unlimited bathing conditions could be obtained with very little risk.

A complete remedy for this situation of storm weather discharge is not easy to foresee. It may seem fanciful to suggest that it will eventually be found practicable to chlorinate stormwater discharges. The cost of chlorine will be relatively unimportant, for the total amount of rain water involved is usually less than the total amount of dry weather sewage discharged. The difficulty is due to the fact that the discharge is at scattered points, at very high rates, and for relatively short times. The difficulty then lies in securing adequate equipment at moderate cost and getting either automatic operation or immediate attendance when a stormwater discharge starts. Available equipment for applying chlorine is certainly much too expensive to be considered for this field. The carefully made equipment available is too good for the job, that is, it involves expensive construction and careful control which is very desirable in water treatment but could well be dispensed with for occasional treatment of stormwater sewage.

In some cases, as where the discharge of sewage is through stormwater pumping stations, the question of attendance for stormwater chlorination would not be difficult. In other cases it is difficult to see how any practical arrangement could be developed. Possibly investigation would show that automatic equipment might be perfected. At least it is clear that this is a field of sewage treatment which present methods do not cover and the results are, to that extent, unsatisfactory. It is to be hoped that more attention will be given to this question in the future.

In conclusion, it may be said that sewage treatment is fully as much a matter of decent, municipal housekeeping as it is a matter of public health. Advocates have been inclined to exaggerate the health aspect, knowing well that it is generally easier to secure funds for a project if the question of health appears important. It is a doubtful proceeding to urge a false reason, even for a good project, and in the long run it appears that the cause of public health will be retarded by such action.

Communities adopting sewage treatment should understand the real reasons for their action and that when this action is to eliminate nuisance, rather than to safeguard health, no improper emphasis should be placed on the health aspect.

In the case of Detroit, the sanitary value of the improvement is obvious. The Detroit River, even before any sewage treatment was undertaken, was still in sufficiently good condition so that it was used as a source of water supply, with or without treatment. It is too much to expect that the river can ever be restored to its original condition of purity. As a result of sewage treatment, however, the load of sewage contamination has been vastly reduced, to such an extent that treatment for water supply purposes is reasonably easy and safe. For other purposes than water supply the treatment adopted has practically eliminated the objectionable conditions due to sewage contamination.

Stream Pollution

THE NATURAL PURIFICATION OF RIVER MUDS AND POLLUTIONAL SEDIMENTS *

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I. Benthal Decomposition—General Concepts

Much of the suspended matter poured into streams and other regional drainage channels by natural runoff, the runoff from sewered areas, and the discharge of water-carried wastes from household and industry settles to the bottom of sluggish river reaches, backwaters, lakes, reservoirs and mill ponds to form river muds and pollutional sediments. The bottom deposits that are built up in a given receiving water fluctuate in depth, composition and location: (1) with the character and amount of waste matter entering the body of water; (2) with changing hydrographic conditions; and (3) with the rate and nature of decomposition prevailing during different seasons of the year. It is the purpose of this series of papers to discuss (1) the processes of natural purification by which river muds and pollutional sediments are stabilized and (2) the effects of this natural purification upon the supernatant waters.

Significance of Benthal Decomposition in the Sanitary Economy of Receiving Waters.—The organic débris included in river deposits is subject to decomposition, the processes of decomposition being transferred by sedimentation from the flowing waters to the pollutional carpet spread, sometimes to considerable thickness, upon the bottom of the stream. In this *benthal* or bottom environment, decomposition proceeds in a manner that is at variance with that obtaining in the flowing water. To distinguish it from the *aerobic* stabilization of organic matter that is dissolved or suspended in well-aerated water and from the *anaerobic* decomposition prevailing in sludge digestion tanks, this process of decomposition is called *benthal* decomposition.

River muds and pollutional sediments are decomposed by the life activities of numerous different organisms. Worms, mollusks and insect larvae burrow and delve in the bottom deposits, and large numbers of bacteria and protozoa find their sustenance in the organic débris. If the water overlying the sediments contains dissolved oxygen, aerobic conditions will prevail at the surface of the deposits, but oxygen will penetrate into the mud only as deeply as the balance between oxygen diffusion and oxygen consumption will permit. Ordinarily, the downward diffusion of oxygen is not sufficiently vigorous to maintain aerobic conditions below

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the superficial layers. There is, however, (1) an upward diffusion of products and residues of anaerobic decomposition and (2), accompanying the consolidation of deposits with time, an upward displacement of the liquid contained in the interstices of the sediments. Such vertical transport is a very important element in benthal decomposition since many of the substances reaching the sludge-water interface are capable of consuming oxygen or otherwise affecting the quality of the supernatant water. Within all but the uppermost mud strata, the available supply of dissolved oxygen is quickly exhausted, and anaerobic decomposition must of necessity become established. In deposits of measurable thickness, therefore, decomposition is forced to proceed in part aerobically and in part anaerobically, *i.e.* benthally. The picture is further complicated by the activities of living organisms like the sludge worms that ingest subsurface mud and deposit their fecal pellets upon the surface or that otherwise, by burrowing operations, bring subsurface mud to the sludge-water interface. Wherever decomposition is active, furthermore, the gases liberated by decomposition accumulate as bubbles that overcome the frictional and surface-tension forces in the sludge voids, break through the surface and rise through the supernatant water. In escaping through the deposits, these gas bubbles may stir up the sediment, expose new surfaces of mud to the water, and create a path for the liquid products of decomposition to pass out of the sludge into the receiving water. When decomposition becomes very active, sludge particles are gas-lifted into the water and may rise to its surface to form unsightly islands of floating sludge.

All of these phenomena of anaerobic activity may be observed while the supernatant water contains dissolved oxygen. In heavily polluted streams, however, sludge activity may be raised to the point where the dissolved-oxygen content of the flowing water becomes depleted by the high and rapid oxygen demand of putrescent sludge banks. Anaerobic conditions will then penetrate into the flowing water in the same manner as if the stream was transporting too heavy a flowing pollutional load. During periods of bottom scour, when much of the sediment is carried away by the flowing waters, aerobic conditions are generally maintained, because scour is normally associated both with high river stages, *i.e.* high oxygen supply, and with the colder months of the year, *i.e.* high oxygen solubility and low oxygen demand. In standing bodies of water that are sufficiently deep to establish a zone of stagnation by thermal stratification, anaerobic conditions will generally prevail in the bottom waters and bottom sediments.

The interest of sanitary engineers in the decomposition of river deposits centers on the effects of decomposition upon the quality of the supernatant water. These are broad and varied. In a heavily polluted water that serves primarily as a sewage receiver or carrier, the most important consideration is probably the effect of decomposing sludge banks upon the oxygen balance with which the nuisance question is so intimately associated. In a more normal water that receives only small amounts of municipal or industrial waste waters and serves as a source of process water for industries or of drinking water for industrial or communal supply, the effect of decomposing deposits is broader in scope. Increases in suspended solids or turbidity, in color, iron and organic matter, and in odors and tastes become of importance. Changes in hydrogen-ion concentration and other attributes that affect the purification of water must be taken into account, also changes in the fertility of the water in relation to undesirable plankton growths.

Not all of the manifold aspects of the problem are discussed in this series of papers, which is confined more particularly to the analysis of certain experimental investigations conducted in the authors' laboratory.

Composition of River Muds and Pollutional Sediments.—The sediments of rivers are composites of particulate organic and inorganic impurities that have been thrown down and impounded, generally over relatively long periods of time associated with stream flows too low to prevent sedimentation of suspended solids or to move deposited solids downstream by bottom scour. The sediments of lakes and other standing bodies of water are similarly constituted but only in so far as differences in hydrographic conditions permit. The composition of river muds and pollutional sediments, as actually laid down, depends upon many factors: (1) the primary source of the pollutional (decomposable) solids; (2) the amount of natural silt that is carried down with the pollutional solids; (3) the flocculating properties of the receiving water (notable, in particular, in sea or brackish water); (4) the removal of certain constituents by washing, or natural elutriation; (5) the hydraulic selection of deposited particles as a result of differential sedimentation; and (6) the compacting of the sediment under its own weight.

The composition of a number of different types of muds and pollutional sediments is shown in Table I in order to exemplify their general properties and variability. It is seen that the percentage of dry solids in the wet sediments varies in a general way from 10 to 40% and that from 10 to 30% of the total solids are volatile. The high value of 83% of volatile matter belongs to a sewage sludge studied by Baity (1) as collected from plain sedimentation tanks, *i.e.* without the addition of inert or weighting solids. Usually, the discharge of sewage into a stream will lay down sludge deposits that have from two to eight times the solid content and from one-half to one-sixth the proportion of volatile matter of sludge that is collected by primary tanks in sewage-treatment works. Factors responsible for these differences have been enumerated before and are reflected within the series of benthal deposits shown in Table I by the low solids content and high volatile content of the lake deposit in particular.

The proportion of organic nitrogen in the volatile solids of river muds is not unlike that of sewage solids. Dissolution of organic nitrogen, therefore, appears to be of the same order of magnitude as that of the remaining organic substances. The proportion of iron, on the other hand, seems to be larger in benthal deposits than in sewage sludges. Actual values must be expected to vary with the amount of iron in the receiving water itself and with the selective presence of iron in the material deposited. The B.O.D. of deposited solids depends largely upon the character of the

TABLE I.—*Composition of Benthal Deposits*

	Sewage Sludge	Sludge Deposit	River Muds	River Mud	River Muds	Lake Mud
	(1)	(2)	(3)	(4)	(5)	(6)
Analyst	Baity	Authors	McGowan et al.	Authors	Rudolfs	Allgeier et al.
Reference	(1)	—	(2)	—	(3)	(4)
Origin of deposit	Sewage treatment works		English Rivers	New England Stream	Connecticut River	Lake Mendota
Dry Solids—% of sediment	8.5	11.25	16.6 to 39.7	17.4	—	9.6
Volatile Solids—% of dry solids	83.0	13.85	11.0 to 17.1	24.2	—	27.4
kg. per sq. m.	0.07 to 2.8	0.19 to 3.8	0.15 to 2.2	4.5	10 to 20	—
Organic Nitrogen (N)—% of volatile solids	4.5	4.5	1.3 to 5.1 *	4.2	2.1 to 4.9	—
Iron (Fe)—% of volatile solids	—	5.0	7.9 to 15.8	4.8	—	—
B.O.D. (5-day, 20° C.)—grams per kg. of volatile solids	173	331	16 to 111	47.7	40.9 to 110	—

* Total nitrogen—probably mostly organic.

organic matter and the age of the sediment. Freshly settled solids are found to exert a 5-day, B.O.D. comparable to that of fresh sewage sludge (from 300 to 500 grams of oxygen per kg. of volatile matter). In older deposits, all gradations of B.O.D. below this value may be encountered. B.O.D. values below 40 grams per kg. of volatile matter, however, appear to be unusual. This may mean either that there is a residual B.O.D. that cannot be released in the benthal environment or that the rate of decomposition is extremely slow in its later stages, and so escapes our analytical techniques.

Of the tests that are well established in sanitary analysis, the B.O.D. test might seem to reflect most directly the decomposability of benthal deposits. Interpretation of 5-day results is complicated, however, by two factors that are related to the shift in conditions of decomposition from benthal (partly anaerobic) to strictly aerobic ones when samples of sludge solids are suspended in dilution water. These factors are: (1) the rapid, chemical or immediate oxygen demand exerted upon substances present in the sludge as a result of the preceding anaerobic decomposition and (2) the time lag before aerobic decomposition has become well established. To a certain extent, these are compensating effects, but their existence casts additional shadows upon the otherwise already questionable habit of generalizing widely from the 5-day, 20° C., B.O.D. test. Moreover, the significance of short-time oxygen demand results is sometimes further obscured by difficulties inherent in the analytical determination of dissolved oxygen in suspensions of muds, which, as shown by Ruchhoft and his coworkers (5), may lead to anomalies in the evaluation of immediate oxygen demand.

The two samples of material studied by the authors are identified as a sludge deposit and a river mud in columns 2 and 4 of Table I. The sludge deposit was employed in a series of experiments, begun in 1938, dealing with the effect of depth upon benthal decomposition and referred to, in this paper, as "depth" studies. The river mud was used in a series of experiments, begun in 1935, dealing with the effect of temperature upon benthal decomposition and referred to in this paper as "temperature" studies. The sludge deposit consisted of fresh sewage solids mixed with inorganic matter in such proportions as to approximate in its gross chemical constitution natural sediments that had been laid down in a heavily polluted stream. The sewage solids were collected during the late summer from the upper story of an Imhoff tank at Natick, Mass. The sewage from this community contains only a small amount of industrial waste. Preliminary experiments had demonstrated that it was not possible to keep fresh sewage solids, representing in excess of 2.5 to 3.0 kg. of volatile matter per sq. m. of benthal surface, at the bottom of carboys unless inert materials were added to weight the sludge. This observation may explain in part the relatively low percentages of volatile matter found in natural sludge banks. A mixture of fine sand, passing a sieve with 40 meshes to the inch, and diatomaceous earth, in a ratio to the sand of 1 to 5 by weight, was added to the sewage solids together with an amount of lime sufficient to adjust the reaction of the sludge to a pH of 7.0. By these means, the total-solids content of the sludge was raised from 2.65 to 11.25%, and the proportion of volatile-solids was decreased from 64.4 to 13.85% of the total dry weight. A small amount of iron, present in the admixed materials, increased the percentage of iron slightly above that occurring naturally in the fresh sludge.

The river mud was collected in the fall of the year from a New England stream draining an upland valley and receiving in addition to natural run-off with its included surface wash—largely mineral matter and vegetable débris—some industrial wastes as well as a small amount of sewage. Gas bubbles rose from the natural deposit when it was disturbed.

Course of Benthal Decomposition.—The benthal environment, as has been explained, gives free play to both aerobic and anaerobic activities; mutually stimulating and mutually retardant. Much remains to be learned about the interlocking mechanisms by which benthal decomposition proceeds. Three salient stages are readily distinguished, however, when benthal decomposition is observed in the laboratory: (1) intensive fermentation; (2) gradual consolidation; and (3) quiescent stabilization. The various manifestations of sludge activity associated with these three stages may be outlined schematically as follows:

Benthal Decomposition

I. Period of intensive fermentation. Fermentation may be so vigorous as to occasion the escape of large portions of the sediment into the supernatant water.
   A. Physical manifestations.
      1. Effervescent fermentation and rapid evolution of gases (CO_2 and CH_4)
      2. Unstable equilibrium, internal agitation, and flotation of solids.
      3. Release of hydrogen sulphide and similar putrefactive odors.

B. Biochemical manifestations.
1. Lowered pH values, production of organic acids, and reduction of nitrates, sulphates, and the like.
2. Presence of a large, active bacterial population. Uniformly high gelatin (20° C.) counts and rapid decrease in coliform organisms.
3. Rapid reduction in B.O.D. of organic solids.
4. Uniformly high benthal oxygen demand with frequent surcharges due to the release of readily oxidized interior fluids and the ebullition of gases.

II. Period of gradual consolidation. Consolidation may control the rate of transport of oxidizable materials to the sludge-water interface.

A. Physical manifestations.
1. Marked retardation of gas production.
2. Slow but persistent subsidence of the sediment with accompanying increase in sludge density.
3. Creation of a definite surface zone, gray in color, into which materials originating in the anaerobic interior of the deposit escape and in which they are subjected to aerobic stabilization.

B. Biochemical manifestations.
1. Recovery of pH values to magnitudes obtaining in the supernatant water. Release of ammonia and soluble nitrogenous compounds to this water.
2. Development of an active, varied protozoan population and gradual evolution of a specialized bacterial population that is capable of oxidizing a widely diversified number of compounds, including ammonia and nitrites.
3. Slow but measurable decrease in B.O.D. of organic solids.
4. Continuance of a relatively high rate of benthal oxygen demand.

III. Period of quiescent stabilization.

A. Physical manifestations.
1. Cessation of consolidation.
2. Gradual expansion of the light-colored surface zone. Deposition of ferric iron as a brownish red surface film that is sometimes slick and glistening. This film may be relatively impervious and retard or prolong subsequent benthal oxidation.
3. Blackening of lower layers and acquisition of a distinctive tarry odor.

B. Biochemical manifestations.
1. Gradual decrease in bacterial population and activity. Establishment of higher forms of life, including worms and insect larvae, upon and within the deposit. The burrowing operations of these larger organisms may honeycomb the sediment and increase diffusion processes from and to the interior.
2. Nearly sustained values for the B.O.D. of the organic solids indicative of the exhaustion of anaerobic decomposition.
3. Reduced but still measurable benthal oxygen demand.

Experimental Procedures.—It is evident that the progress of benthal decomposition can be traced in many different ways. Interpretation of benthal decomposition in engineering terms requires, however, that the yardsticks employed shall either measure the effect of river muds and pollutional sediments upon the supernatant water in terms of changes in water quality or that they shall evaluate in over-all terms the amount of stabilization of the sludge itself that is accomplished. Experimental procedures must be adapted to these requirements. Among the methods reported in the literature, there are three that have yielded quantitative results. For purposes of identification, they will be referred to in this paper as the methods of Adeney (6), Rudolfs (7) and Baity (1).

As employed by McGowan, Frye and Kershaw (2), the apparatus devised by Adeney (Fig. 1) is a simple form of respirometer in which the loss of oxygen from an atmosphere overlying a sample of mud is measured as a difference in pressure and change in volume, the release of carbon dioxide being prevented by adding magnesium hydroxide to the mud. That there is no opportunity for products of decomposition to be washed away by supernatant water is the most obvious defect in this arrangement. The oxygen demands measured are, however, closely akin to what seem to be more naturally benthal demands.

To investigate the progressive stabilization of sludge banks, Rudolfs (7) placed sludge in carboys that were left open to the air, the supernatant liquid being withdrawn from time to time and replaced by tap water. The B.O.D. (5-day), pH, and volatile-matter content of the sludge were determined. The conditions of test, here created, appear to be quite unlike those encountered in many receiving waters, particularly streams, in which a residual concentration of dissolved oxygen is continually present in the supernatant water and a delicate and precise balance between the,

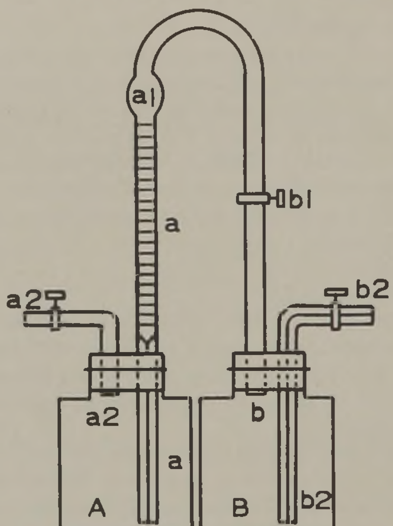

FIG. 1.—Adeney's apparatus for measuring the rate of absorption of oxygen by river mud (6). This is a manometric respirometer. Bottles *A* and *B* are similar. To work the apparatus, *B* is partially filled with a known volume of mud to which a little magnesium hydroxide has been added and a similar volume of distilled water is poured into *A* which acts as a standard pressure bottle. Oxygen absorption reduces the pressure in *B*, and the volume of water that rises into the graduated portion of the tube *ab* at any given time, and the height of it above the zero mark give the means of calculating the volume of oxygen absorbed during the period of observation.

more or less supplementary, processes of anaerobic and aerobic fermentation within the sediment is continually maintained. The partial or temporary absence of the aerobic factor may reduce the amount of overall stabilization that is effected and confine the conditions of decomposition to those obtaining in deep sludge deposits or sediments that lie within the zone of stagnation of deep lakes and reservoirs. As shown later, this does not mean that the rate of anaerobic decomposition is necessarily slower than that of benthal decomposition, only that the amount of material that can be decomposed anaerobically may be smaller than the amount that can be decomposed benthally. Benthal oxygen demand is not measured directly, by Rudolfs' method, and the mistake must not be made of interpreting the progressive reduction in the 5-day B.O.D. of the sludge as being equal to the demand that the sludge would have exerted upon the oxygen supply of the supernatant water.

In Baity's method (1), samples of sludge or sediment are placed at the bottom of stoppered glass carboys through which a continuous, controlled flow of water is maintained. Progress of decomposition is evaluated by determining measurable and significant changes in the composition of the water passing over the deposit. Benthal oxygen demand, for example, is calculated from the depletion in dissolved oxygen suffered by the flowing water. Under favorable conditions, changes in the sediment itself can be observed by withdrawing samples of the deposit for analysis; otherwise sampling must be confined to the beginning and end of the test. The principal objections to this apparatus are (1) the difficulty of balancing flow against oxygen depletion or other changes in water quality so as to make possible the measurement of all of these factors with adequate precision and (2) the great demands made upon the observer's time in operating the equipment and performing the necessary tests. The conditions encountered in a flowing stream, however, appear to be happily simulated without the interference of changing hydrographic elements, wide fluctuations in temperature, and the fortuitous addition of fresh sediment.

The methods employed by the authors in the studies reported in this paper followed essentially along the lines established by Baity. A sketch of the apparatus is shown in Fig. 2. Departures from Baity's design

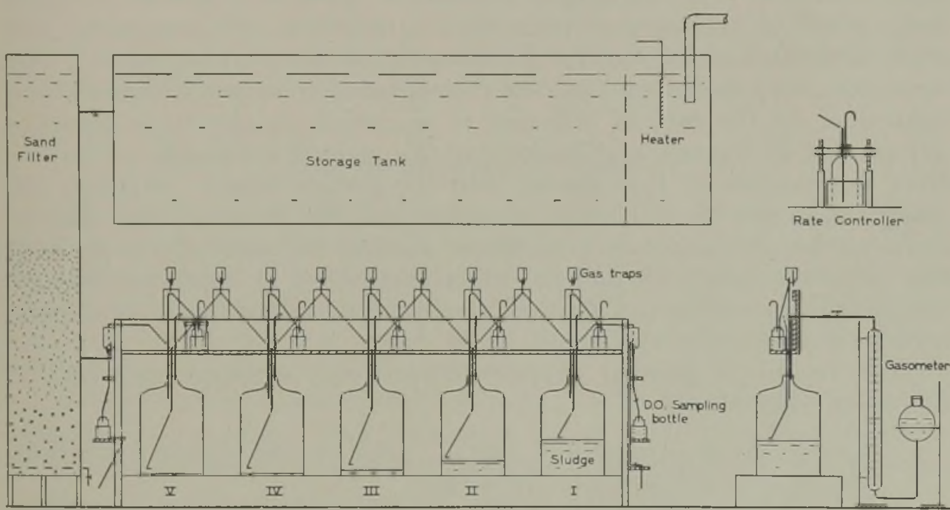

Fig. 2.—Apparatus for measuring the rate of benthal oxidation and the rate of gas evolution. This is a continuous-flow respirometer.

included: (1) improvements in regulating flow and temperature; (2) modifications of the piping system to eliminate, so far as possible, the interruption of flow by entrapping gases in the tubes; and (3) provision for collecting and measuring gases that are released by the sediments during decomposition. The water supplied to the carboys (warmed, if necessary, with an electric knife-edge heater to eliminate supersaturation with oxygen) was first held for about a day in a large storage tank that served to equalize the temperature of the water and render its oxygen content uniform; the water passed next through a sand filter, to remove iron that might be present in granular or flocculent form, and finally through a sand trap. The water was delivered to the surface of the sediment through a glass tube so shaped as to force the flow to take a spiral course towards the outlet at the top of the bottle.

Rate of flow and drop in the dissolved-oxygen content of the water in its passage over the sediments were measured daily, the flow being adjusted to establish measurable differences in the oxygen content of the incoming and outgoing water. In the "depth" studies, to be reported in Section III of this paper, the dissolved-oxygen gradient ranged between 0.5 and 3.5 p.p.m., the lowest recorded dissolved-oxygen content of the outgoing water being 3.6 p.p.m. in a single day's run. The average detention period of the water in the carboys lay between one and two days. In the "temperature" studies, to be reported in a later section of this series of papers, the dissolved oxygen gradient was generally lower than that observed in the "depth" studies, ranging from 0.5 to 2.0 p.p.m., and the dissolved oxygen content of the outgoing water was usually 6 to 8 p.p.m., only once falling as low as 4.0 p.p.m. The detention period in these experiments was 4 to 16 hours. No attempt was made to vary the concentration of oxygen in the water overlying the sediment. Baity's observation (1) that the oxygen demand of deposits of sewage sludge is independent of the oxygen concentration of the supernatant water was confirmed during the routine performance of the authors' tests. The conclusion may be drawn that the rate of benthal oxygen demand is not controlled by the rate of diffusion of oxygen from the water into the deposit but by the rate of diffusion and transport of oxidizable substances from the interior of the deposit into the surface zone. Although the maximum depth for which this was observed was 10 cm., there appears to be no reason to suspect that deeper deposits will not behave in much the same way, since all but the superficial layers of sediments become completely anaerobic and upward transport of oxidizable substances is increasingly retarded with depth.

The record of benthal oxygen demand was supplemented by the following observations:

1. Quantities of nitrogen and iron in various forms, disappearing from the mud or appearing in the water.
2. Long-time or short-time B.O.D., volatile-matter content and fuel value of the deposit at the beginning and end of the experiment and at such intermediate times as practicable.
3. Volume and composition of gases liberated in the course of decomposition of various depths of sediment (in the "depth" studies only).

Where sludge activity is high—in warm weather and during the deposition of fresh solids, for example—the supernatant water must be expected to take up some of the oxygen-demanding substances that leach, or otherwise escape, from the deposit. In streams, the flowing pollutional load may be increased in this way and the oxygen reserve of the flowing water drawn upon for some time and distance below the area of sludge deposition. The substances that pass through the surface zone may also be expected to exert an immediate, or chemical, oxygen demand in addition to their B.O.D. Accordingly, the effluent of the carboys was tested for ammonia and B.O.D. In the "depth" studies in which fresh sewage solids were employed, the recorded increase in ammonia and B.O.D. was significantly large for about the first month. After that, differences became too small to be measurable. In the "temperature" studies, in which a natural river mud was used, no consistent measurable increase in B.O.D. of the effluent water was found at any time after the first day or two of the experiment. Measurable increases in ammonia, nitrite and nitrate, however, were observed for about two months.

Since benthal decomposition is a vertically integrated aerobic-anaerobic process, the two phases of the process were isolated, for purposes of comparison, by subjecting separate samples of sediment to stabilization by essentially aerobic and essentially anaerobic processes. The progress of aerobic decomposition was followed by B.O.D. dilution methods, that of anaerobic digestion by capturing and analyzing the gases of decomposition and determining the salient changes occurring in the composition of the digesting solids. Benthal decomposition may be expected to merge (1) with aerobic decomposition when sediments are laid down in layers so thin that oxygen can penetrate into them sufficiently fast to satisfy the oxygen requirements of the bacteria and other living organisms of decay, and (2) with anaerobic decomposition when sediments are laid down in stagnant pools in which the waters in contact with the sludge are devoid of oxygen.

II. Rates of Benthal Decomposition

The rate of decomposition of organic matter by microörganisms depends generally upon two factors: (1) the amount of decomposable matter in the substrate; and (2) the availability of this decomposable matter for the life and reproduction of bacteria and other microbes. During the course of stabilization of an organic deposit, both amount and availability of the food supply diminish progressively. The quantity of organic matter decreases as a consequence of its utilization by bacteria as a source of energy and growth. This is an obvious fact of which account is taken in all formulations of biochemical reactions. Less obvious is the circumstance that, due to the selective action of successive generations of microörganisms, the more available food is attacked first, leaving the less readily available compounds for subsequent destruction. As a result, the rate of decomposition is subject to continual deceleration.

If, as in the key portions of the present studies, decomposition is measured by observing the rate of benthal oxidation, *i.e.* the amount of oxygen withdrawn in a given interval of time from the supernatant water by aerobic activities and oxidation reactions within the superficial layers of sludge deposits, the observed rates of oxygen utilization will decrease persistently (1) due to the combined effect of reduced quantity and selective availability of food supply and (2) due to the physical barriers imposed upon biochemical oxidation in the course of time by reduced rates of diffusion and transport of oxidizable substances into the surface zone: restrictions of availability that are markedly influenced by the process of consolidation (see Appendix to Part III).

Mathematical Formulation of the Progress of Decomposition.—In the mathematical formulation of certain biochemical changes that are confined (1) to short periods of time, (2) to the influence of a relatively few genera of bacteria and other microörganisms, and (3) to a relatively stable environment, it is possible to neglect, without appreciable error, changes in the availability of the organic substrate. In these circumstances, as shown by Phelps (8) for short-time aerobic biochemical oxidations, for example, the changes that accompany decomposition may, to a useful degree of approximation, be formulated in terms of a simple unimolecular equation. Here the rate of decomposition is assumed to depend solely upon the amount of organic matter remaining to be decomposed, and the availability of the substrate is presumed to be constant regardless of its physical condition and state of selective decomposition. It is obvious that this simple formulation is only a first approximation of the progress of benthal oxidation or the rate of stabilization of sludge deposits. So varied are both the chemical and physical environments during the slow course of benthal decomposition that the postulation of constant availability of food supply would lead to significant discrepancies between observed and fitted values. In order to adjust mathematical formulation to theory as well as measurement, while recognizing the fundamental usefulness of the unimolecular conception of reaction velocity, the simple unimolecular formulation may be elaborated to take into account the deterioration in the availability of the food supply in the course of time. This modification will be shown to correspond closely to experience.

If y = the amount of material decomposed or the oxygen demand exerted in time t;
L = the ultimate amount of decomposable material or ultimate oxygen demand;
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 (mineral matter, specific gravity, and depth of the deposit);
and a = the coefficient of retardation, depending upon the type of organic matter present and the condition of the physical environment,

then the requirement that the rate of decomposition, dy/dt, shall be proportionate to the amount of material remaining to be decomposed, $(L - y)$, and to the availability of this material, which decreases with time, may be expressed by the following relation:

$$\frac{dy}{dt} = \frac{k}{1 + at}(L - y). \tag{1}$$

Integration then yields the equation:

$$y = L[1 - (1 + at)^{-k/a}]. \tag{2}$$

In equation (1) the factor $(L - y)$ represents the amount of decomposable or oxidizable matter remaining in the substrate at any given instant, and the factor $k \div (1 + at)$ is a measure of the availability or rate at which a unit weight of remaining decomposable or oxidizable matter is stabilized. This rate factor decreases with time for positive values of a. When $t = 0$, $k \div (1 + at) = k$. The parameter k, therefore, measures the initial rate of reaction or availability. When $t = 1 \div a$, $k \div (1 + at) = \frac{1}{2}k$ and the reaction velocity has been cut in half after this period of time. When $a = 0$, the formulation becomes identical with the simple unimolecular equation:

$$\frac{dy_u}{dt} = k_u(L_u - y_u) \tag{1a}$$

and

$$y_u = L_u(1 - e^{-k_ut}), \tag{2a}$$

where the subscript u distinguishes between the constants and variables of the two formulations. For purposes of comparison, equations (2) and

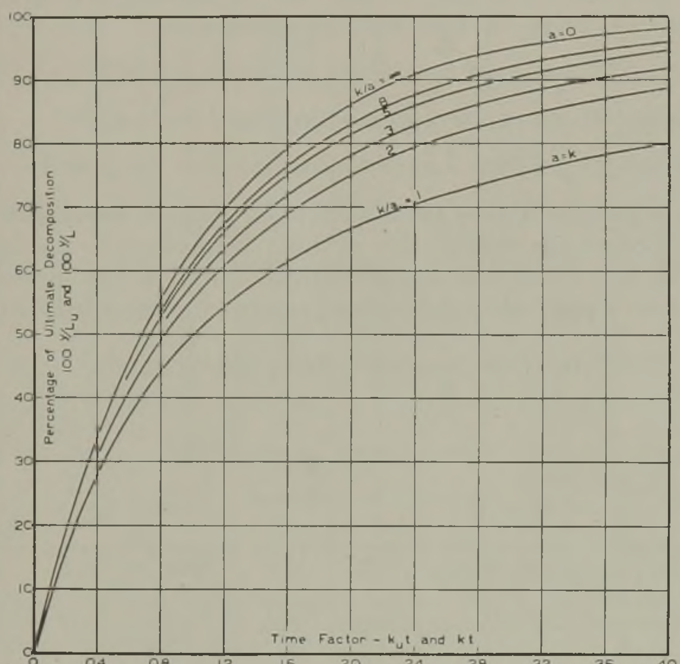

FIG. 3.—Course of decomposition traced by the retardant unimolecular curve. When the coefficient of retardation $a = 0$, $k/a = \infty$ and the retardant curves merges with the simple unimolecular curve. These curves facilitate the estimation of the proportion of decomposition completed in a given time.

(2a) have been plotted in dimensionless form in Fig. 3. Here increasing values of k/a depict, in a general way, the influence of the coefficient of retardation upon the progress of decomposition. Since equation (2) takes into account the decrease in rate of decomposition due to the reduction of availability as well as amount of remaining food supply, it may suitably be named the "retardant unimolecular equation." In order to fit the equation to observed values, a least-squares procedure, based on the differential form of the equation, has been developed (see Appendix to Part II of this paper). By means of this procedure it is possible to generalize the observed values of y and t in terms of the parameters L, k, and a.

It is not the opinion of the authors that this retardant form of the unimolecular equation represents the ultimate refinement in the analysis of long-time processes of decomposition. They do believe, however, that it provides an adequate and mathematically not inconvenient description of the stabilization of organic deposits while satisfying the requirements of the theory of the active processes as well as experimental findings.

If we are interested in the time needed to accomplish a given proportion of the ultimately expected amount of benthal decomposition, equation (2) may be solved for t as follows:

$$t = \frac{1}{a}\left[\left(1 - \frac{y}{L}\right)^{-a/k} - 1\right]. \qquad (2b)$$

For decomposition 50, 90 and 99 per cent completed, y/L equals 0.5, 0.9 and 0.99 and t is given by the following expressions:

Decomposition 50 per cent completed in time $t = 1/a(2^{a/k} - 1)$, $(2b_1)$

Decomposition 90 per cent completed in time $t = 1/a(10^{a/k} - 1)$, $(2b_2)$

Decomposition 99 per cent completed in time $t = 1/a(100^{a/k} - 1)$. $(2b_3)$

Mathematical Analysis of the Studies of the Royal Commission on Sewage Disposal.—Before discussing the authors' experiments on benthal decomposition, for which the mathematical methods just presented were developed, these methods will be tested against the recorded, but unformu-

TABLE II.—*Character of English River Muds (2)*

Sample No. and Date of Collection	Source	Depth of Mud—cm.	Total Solids—% of Wet Sediment	Volatile Solids—% of Total Solids	5-Day, 18° C., B.O.D.—Grams per kg. Volatile Matter	Total Nitrogen—N—	Total Iron—Fe—
						% of Volatile Solids	
304 10-12-1910	River Anker below Nuneaton Outfall	1.4	23.7	15.3	32.5	4.44	8.10
306 10-13-1910	River Avon above Coventry Outfall	1.2	24.6	11.7	13.4	4.11	8.81
308 10-13-1910	River Avon below Coventry Outfall at Bubbenhall	0.5	16.6	17.1	86.5	4.60	10.88
309 10-13-1910	River Avon below Coventry Outfall at Rock Spinney	1.2	22.2	12.8	102	5.09	14.31
123k 11-24-1910	South Delph above Lincoln Outfall	3.0	53.2	11.0	36.4	1.32	15.80
128k 1 -1 -1911	Canal below Berkhamsted Outfall	0.7	39.7	11.2	—	2.37	7.89

lated, results of three authoritative sanitary institutions: the Royal Commission on Sewage Disposal (2), the New Jersey Agricultural Experiment Station (7), and the Chicago Sanitary District (9).

Of classical importance are the studies of English river muds by McGowan, Frye and Kershaw (2) in which six samples of sediments of different origin, age, and depth were held at 18° C. in the Adeney apparatus

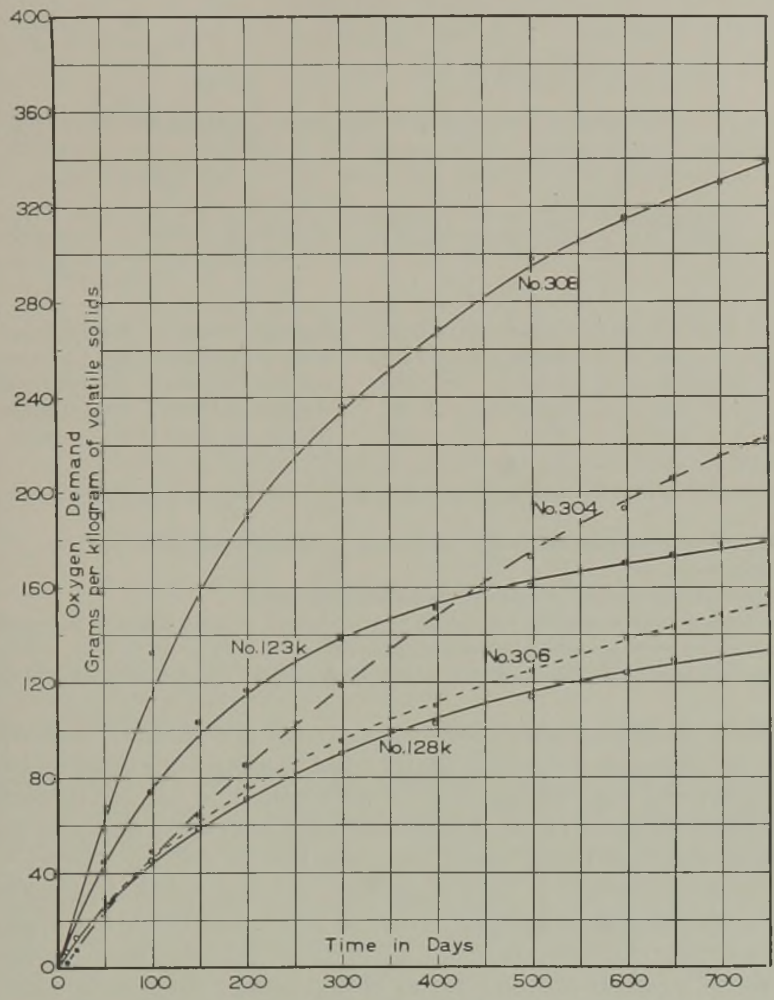

FIG. 4.—Course of oxygen demand exerted during decomposition by five English river muds. From observations by McGowan, Frye, and Kershaw (2) for the Royal Commission on Sewage Disposal. The observed points are fitted by retardant unimolecular curves.

(6), shown in Fig. 1. The properties of these muds are summarized in Table II, and the oxygen demands observed during 650 to 750 days, or about two years, when the demands were still active, are plotted in Fig. 4.

Analysis of the results yields the retardant unimolecular parameters of benthal oxygen demand listed in Table III and needed for the solution of equation (2). The retardant unimolecular curves calculated by means of these parameters have been drawn in Fig. 4. Agreement between observed and computed values is seen to be excellent over the entire range of experience. For purposes of comparison, the calculated simple unimolecular parameters, equation (2*a*), are added to Table III. The magnitudes of k_u, it will be noted, are consistently larger than those of k and the magnitudes of L_u consistently smaller than those of L. In line with theoretical considerations, these differences produce poorer agreement between observed oxygen demands and those computed by the simple unimolecular equation. For sake of clarity, however, the simple unimolecular curves are not shown in Fig. 4.

TABLE III.—*Mathematical Parameters of Benthal Decomposition of English River Muds*

Sample No.[1]	Approximate Depth—cm.	Volatile Matter—kg. per sq. m.	Specific Gravity [2]	Mathematical Parameters				
				Retardant Formulation			Simple Formulation	
				k [3]	a [3]	L [4]	k_u [3,5]	L_u [4]
304	1.4	0.570	1.12	0.00132	0.000333	378	0.00148	329
306	1.2	0.390	1.13	0.00244	0.00120	206	0.00269	174
128k	0.7	0.381	1.23	0.00295	0.00183	178	0.00396	136
308	0.5	0.153	1.08	0.00362	0.00188	418	0.00433	341
123k [6]	3.0	2.2	1.28	0.00523	0.00101	185	0.00534	177

[1] The results recorded for sample 309 are so irregular that they have not been included in this table.

[2] Estimated from average values for the density of volatile constituents and ash.

[3] On daily basis.

[4] Grams of oxygen per kg. of volatile solids initially present.

[5] This value is 2.303 times the magnitude of the reaction velocity constant as calculated by Phelps [8] and others from a modification of formula (2a): $y_u = L_u(1 - 10^{-k_u' t})$.

[6] Sample shaken during decomposition; conditions of test not comparable with other samples.

While the English observations were carried out on muds that were too different in character to permit strict quantitative comparisons between them, it is evident that the reaction velocity constant, k, and the coefficient of availability or retardation, a, decrease with increasing depth of mud or, more significantly, with the areal concentration of volatile matter.* The decrease in both k and a is to be expected, because benthal oxidation can take place only in the superficial layers of mud and the rate of reaction is reduced and increasingly retarded as vertical diffusion and transport of oxidizable materials from the interior of deposits to their surface are hampered by increasing depths. The values of k and a for the deep sample No. 123k are out of line with the rest because the potential influence of depth was eliminated by shaking the sample. The lack of trend in L with depth is explainable, since Table II shows that the different samples, as collected were nowhere near alike in composition or state of stabilization.

Perhaps the most striking evidence of the behavior of pollutional sediments, revealed by this mathematical analysis of a more than thirty-year old record of river muds, is the slow rate at which benthal oxidation

* Reasons for employing in place of depth the concept of areal concentration of volatile matter, which is expressed in Tables I and III in kg. per sq. m., will be given in Section III of this paper.

takes place in comparison with known rates of biochemical oxygen demand of organic materials that remain in suspension or solution in receiving waters. While a value of $k_u = 0.23$ is an accepted average for the rate of B.O.D. of polluted water incubated at 20° C., the initial rate of benthal oxidation of English river muds was approximately 1 to 5 per cent of this magnitude. This means that the same proportion of ultimate oxidation is accomplished only in a very much longer period of benthal exposure: months or years against days or weeks.

A better understanding of this element of time can be gained by substituting the values of the parameters a and k into equation (2b). Certain results are shown in Table IV. To some extent all of these findings anticipate those of the authors. It will become evident, however, that the conclusions so far reached gain in significance as they are implemented, rationalized or confirmed by the results of the authors' experiments which are yet to be discussed.

TABLE IV.—*Time Required for Benthal Oxidation of English River Muds*

Sample No.	$\frac{1}{a}$ [1]	$\frac{k}{a}$	Years to Reach Stated Completion [2]		
			50%	90%	99%
304	8.2	3.96	1.6	6.5	18
306	2.3	2.03	0.93	4.8	20
128k	1.5	1.61	0.81	4.8	25
308	1.5	1.93	0.63	3.3	15
123k [3]	2.7	5.18	0.39	1.5	3.9

[1] Years elapsing before reaction velocity has been cut in half.

[2] The time required for 50, 90 and 99 per cent completion of the 20° C. B.O.D. of polluted water is ordinarily 3, 10 and 20 days respectively.[8, 10]

[3] This sample was shaken.

Mathematical Analysis of the Studies of Rudolfs and Mohlman.—The experiments of McGowan, Frye and Kershaw (2) were performed in such a way as to evaluate, within limits, the benthal oxygen demand that may be expected to be exerted by river muds that are decomposing under relatively peaceful conditions of stream flow and sludge activity. In a broad sense, benthal oxygen demand, under these conditions, is a compound measure of the trend towards ultimate stabilization and so is governed, in its rate, by the velocity of the slowest constituent activity or combination of activities. The controlling processes in benthal oxidation appear to be those by which oxidizable substances are moved from the lower (anaerobic) to the upper (aerobic) layers of sludge (see Appendix to Part III).

The progressive reduction in the 5-day, 20° C., B.O.D. of sewage sludge or river mud stored under the conditions described by Rudolfs (7) and Mohlman (9) (see Part I) must not be confused with benthal oxygen demand. While the results of such tests do not measure the amount of oxygen that must gradually be abstracted from the receiving water, they do measure the fundamental, but not necessarily controlling, rate of natural purification of river muds and pollutional sediments. Paradoxical as it may seem, this fundamental rate of sludge stabilization—in all but very thin pollutional films—is fixed largely by the rate of anaerobic activity. How this rate compares in magnitude with that of benthal oxygen demand may be found by a mathematical analysis of Rudolfs' and Mohlman's results. The published data can be fitted quite precisely by a retardant unimolecular equation (Fig. 5), or less precisely by the simple unimolecular equation. As indicated in the thumbnail sketch included in Fig. 5, equations (2) and (2a) must be reoriented to suit the mirrored and

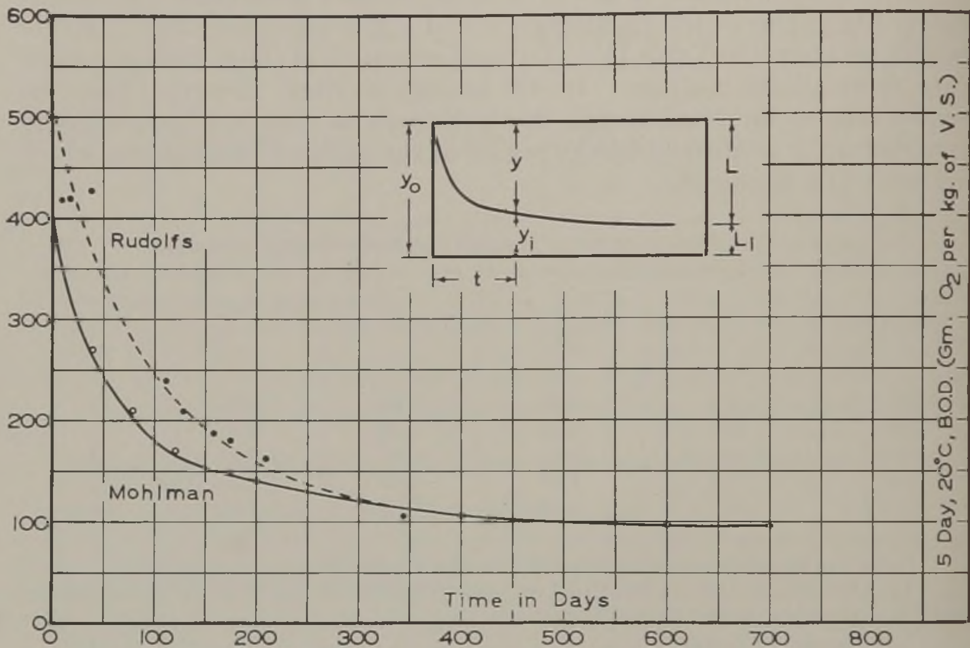

FIG. 5.—Progressive reduction in 5-day B.O.D. of stored sewage sludge and mud, observed by Rudolfs (7) and Mohlman (9). The observed points are fitted by retardant unimolecular curves.

inverted position of the curves of progressive reduction in 5-day B.O.D. Adjustment of equations (2) and (2a) to the new axes of reference (see Fig. 5), by substitution in these equations of $L = y_0 - L_i$ and $y = y_0 - y_i$, yields the following modified relations:

$$y_i = L_i\left[1 + \left(\frac{y_0}{L_i} - 1\right)(1 + at)^{-k/a}\right] \tag{2c}$$

and

$$y_{iu} = L_{iu}\left[1 + \left(\frac{y_0}{L_{iu}} - 1\right)e^{-k_u t}\right]. \tag{2d}$$

Here y_0 is the initial 5-day B.O.D. of the sludge, y_i the 5-day B.O.D. after time t, and L_i the residual 5-day B.O.D. apparently remaining after anaerobic decomposition has been completed. Fitting these equations to Rudolfs' and Mohlman's results, establishes the magnitudes of the parameters shown in Table V.

Examination of Table V and comparison of its figures with those of Tables III and IV shows that the fundamental rate of sludge stabilization is relatively much higher than that of benthal oxidation. The ratios of the respective reaction velocity constants are of the order of 5 to 10, and the ratios of the respective coefficients of retardation are of the order to 2 to 5. This means that the times required to reach a given proportion of the ultimate amount of decomposition are expressed conveniently in months instead of years. We shall not be surprised to find that the fundamental rate of sludge stabilization is substantially the same as the rate of anaerobic gasification of unseeded sewage solids, which is about one-tenth that of well-seeded sewage solids. Corroborating figures will be presented later in this series of papers.

TABLE V.—*Mathematical Parameters of, and Time Required for, Sludge Stabilization.* From Measurements by Rudolfs (7) and Mohlman (9)

		Mathematical Parameters				
	y_0 [1]	Retardant Formulation			Simple Formulation	
		k [2]	a [2]	L_i [1]	k_u [2,3]	L_{iu} [1]
Rudolfs [4]......	526	0.0126	0.0060	70	0.0105	96
Mohlman......	380	0.0181	0.0078	94	0.0122	102
	$\frac{1}{a}$ [5]	$\frac{k}{a}$	Months to Reach Stated Completion			
			50%		90%	99%
Rudolfs [4]......	5.5	2.1	2.1		10.9	43.3
Mohlman......	4.2	2.32	1.5		7.2	26.6

[1] 5-day, 20° C. B.O.D. in grams per kg. of volatile solids.

[2] On daily basis.

[3] This value is 2.303 times the magnitude of the reaction velocity constant as calculated by Phelps and others.

[4] Results of study employing intermittent decantation of supernatant liquid.

[5] Months elapsing before reaction velocity has been cut in half.

Taken by itself, measurement of the decreasing putrescibility of sludge deposits records, in addition to the fundamental rate of sludge stabilization, the potential oxygen requirements of the deposit in terms of its 5-day B.O.D. at a specific time. These requirements are set in motion, however, only in unusual circumstances, for example, when bottom sediments are lifted into the supernatant water. The rate of oxygen demand of these materials should then approach that normally anticipated by Phelps (8) and Theriault (10) for the biochemical oxygen demand of polluted waters. The amount of oxygen actually used up will vary with the time that elapses before the sludge solids are reprecipitated. Among causes for sludge rise are: (1) the gas-lifting of solids in warm weather and (2) flood scour. Of these, the warm-weather rise of bottom deposits is obviously the most immediately significant occurrence. The chemical oxygen requirement of the sludge may also be of importance in this connection. It should be emphasized again that the difference between the initial 5-day B.O.D. (y_0) and the final 5-day B.O.D. (L_i) of the deposit is not the amount of oxygen ordinarily abstracted by river muds and pollutional sediments from the water that flows or lies above them. Benthal oxygen demands are ordinarily much smaller, and benthal periods of oxidation are ordinarily much longer.

III. Effect of Sludge Depth upon Rate of Decomposition

Although the present section of this paper bears the heading "Effect of Sludge Depth," the simple linear measurement of depth, when taken by itself, does not differentiate adequately between the conditions of existence that obtain within pollutional sediments. Sludge depth is not constant but decreases due to consolidation of the deposit under its own weight (see Appendix to Part III) and destruction of organic matter as the deposit ages. Depth, moreover, does not reflect such important factors as the amount of organic matter present, the density of the sediment and the content of total solids. A better general yardstick of what we wish to express by the term depth is the areal concentration of volatile matter, m, in a sludge deposit. By this is meant the weight of organic or volatile solids accumulated beneath a unit area of benthal surface or sludge-water interface. This measure may be expressed conveniently in kg. of volatile solids per sq. m. in the metric system or in lb. per sq. ft. in the English system of measurement (see Tables I and III). Areal concentration of volatile matter is simple of determination and definite in meaning. Although not a unique measure, it does reflect the potential intensity of decomposition, and the authors have found it to be the most consistent and satisfactory single parameter of the conditions that are otherwise characterized only roughly by depth.

A limited amount of information on the effect of sludge depth upon rate of decomposition has been derived in Part II from a mathematical analysis of the results obtained by McGowan, Frye and Kershaw (2) for the benthal oxidation of a heterogeneous group of English river deposits. Additional information is available in a 35-day study of a sewage sludge carried on by Baity (1). It is the hope of the authors that the experiments to be recorded in this section of this paper will constitute a further contribution to our knowledge of the natural purification of river muds and pollutional sediments and their effects upon the quality of the waters that override them.

Experimental Procedures.—The apparatus employed is shown in Fig. 2 and has been described in Section I of this paper. The general properties of the sludge studied are summarized in Table I which shows that the mixture of sewage solids and inert materials that was prepared was representative of a freshly deposited pollutional sediment, with a 5-day B.O.D. per kg. of volatile solids comparable to that of fresh sewage solids. Different amounts of the mixture were measured into five carboys (Fig. 2)

TABLE VI.—*Observed Cumulative Benthal Oxygen Demand of Sludges of Varying Depth*
Grams of oxygen per kg. of volatile solids initially present

Temperature: 20 to 25° C. Surface Area of Sludge: 526 sq. cm.

Time in Days		Carboy No. I	II	III	IV	V
10		11	27	16	40	20
30		34	77	90	170	132
50		55	105	146	261	243
70		68	131	188	312	292
90		78	149	215	352	332
120		94	175	252	407	384
160		109	198	290	461	435
200		124	214	316	496	467
250		135	232	336	547	502
300		144	245	354	581	540
350		154	257	370	614	572
400		163	268	386	642	605
450		169	274	400	667	635
Areal Concentration of Volatile	*Initial*	3.77	1.38	0.513	0.188	0.188
Matter (kg. per sq. m.)	*Final*	1.37	0.640	0.261	0.101	0.102
Depth of Deposit (cm.)	*Initial*	12.2	5.4	2.7	1.5	1.5
	Final	8.2	4.1	2.4	1.34	1.35
	Mean *	10.2	4.75	2.55	1.42	1.42
Specific Gravity	*Mean* †	1.143	1.113	1.078	1.051	1.051

* ½ (depth at 3 days + depth at 450 days).
† Computed from density of materials added and mean depth:

$$1 + 0.001185\,\frac{\text{Total solids (grams)} - \text{Volatile solids (grams)}}{\text{Depth (cm.)}}$$

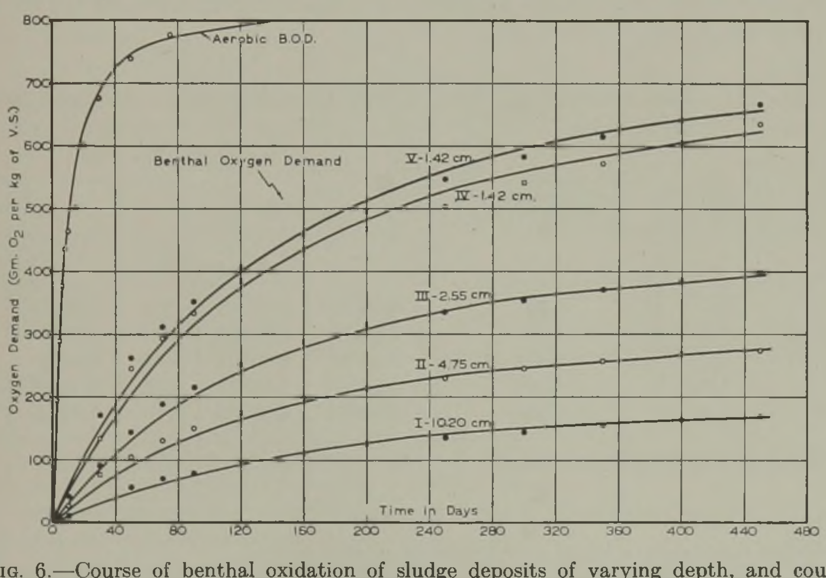

FIG. 6.—Course of benthal oxidation of sludge deposits of varying depth, and course of aerobic B.O.D. of the material originally deposited. Retardant unimolecular curves are fitted to the observed points.

and two anaerobic digestion flasks. The amounts introduced into carboys I to IV were chosen so that the weight of volatile solids (198, 72.7, 27, and 9.9 grams) would decrease in approximately geometric ratio for the purpose of spacing the expected benthal oxygen demands more or less uniformly over the range covered by the tests. Carboy V contained the same amount of volatile matter as carboy IV (9.9 grams) but differed from the rest in that, during the first month of operation only, the influent pipe terminated four inches instead of one inch above the surface of the sludge. The slight discrepancies between the results obtained from these two carboys are believed to be due to this temporary variation.

The changes taking place in the deposits were evaluated in a number of different ways that may be grouped conveniently as follows:

1. Measurement of (*a*) the oxygen absorbed from the supernatant water and the gases released by the sludge; (*b*) the aerobic oxygen demand, or long-time B.O.D., of the sludge at the beginning and end of the test; 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.

Results.—The chronology of the benthal oxygen demand exerted in 450 days by the five depths of sludge is listed in Table VI and plotted in Fig. 6. Fitting retardant and simple unimolecular equations to these data, yields the mathematical parameters shown in Table VII and the retardant curves of best fit drawn in Fig. 6. Calculations of the time required to complete 50, 90, and 99 percent of the ultimate benthal oxygen demand are recorded in Table VIII.

TABLE VII.—*Mathematical Parameters of Benthal Oxidation of Sludges of Varying Depth*

Carboy No.	Mean Depth cm.	Initial Areal Concentration of Volatile Matter kg. per sq. m. (m)	Mathematical Parameters				
			Retardant Curve			Simple Curve	
			k [1]	a [1]	L [2]	k_u [1,3]	L_u [2]
I	10.2	3.77	0.00628	0.00240	196	0.00674	172
II	4.75	1.38	0.00726	0.00245	309	0.0101	260
III	2.55	0.513	0.00750	0.00301	447	0.0103	377
IV	1.42	0.188	0.00762	0.00373	758	0.00869	641
V	1.42	0.188	0.00764	0.00369	710	0.0102	587
Long-time, 20° C. B.O.D. of Initial Sludge.....			0.1212	0.0791	818	0.103	715

[1] On daily basis.

[2] Grams of oxygen per kg. of volatile matter initially present.

[3] This value is 2.303 times the magnitude of the reaction velocity constant as calculated by Phelps and others.

TABLE VIII.—*Time Required for Benthal Oxidation and Areal Oxygen Demand of Sludge Deposits of Varying Depth*

Carboy No.	Mean Depth cm.	$\frac{1}{a}$ [1]	$\frac{k}{a}$	Years to Reach Stated Completion			Areal Oxygen Demand	
							Total	Initial Rate
				50%	90%	99%	L_s [2]	y_{s0}' [3]
I	10.2	1.1	2.61	0.33	1.6	5.5	739	4.65
II	4.75	1.1	2.96	0.30	1.3	4.2	426	3.09
III	2.55	0.91	2.49	0.29	1.4	4.9	227	1.70
IV	1.42	0.73	2.04	0.29	1.5	6.3	142	1.08
V	1.42	0.74	2.07	0.29	1.5	6.1	134	1.02
Long-time 20° C. B.O.D. of Initial Sludge		0.035	1.53	0.020	0.12	0.67	—	—

[1] Years elapsing before reaction velocity has been cut in half.
[2] $L_s = Lm$ = Grams of oxygen per sq. m. of sludge surface.
[3] $y_{s0}' = kLm$ = Grams of oxygen per sq. m. of sludge surface per day.

On the whole, there is remarkable agreement between the authors' results and those of McGowan, Frye and Kershaw (2). Comparable values of k, a, and k_u, however, lie nearer the second decimal than the third,

TABLE IX.—*Observed and Fitted Long-time B.O.D. of Sludge Before and After 450 Days of Benthal Decomposition and After 495 Days of Anaerobic Decomposition*

Temperature: 20° C. Demand: Grams of oxygen per kg. of volatile solids initially present.

Time—Days	Original Deposit	Carboy No.							Anaerobic Sample
		I [1]	I Upper	I Lower	II	III	IV	V	
2	195	21	19	24	19	9	6	7	63
4	290	38	37	40	27	19	9	14	143
6	376	51	46	55	42	31	14	18	204
8	434	65	54	77	55	43	19	23	235
10	463	76	62	92	66	52	21	28	277
15	501	119	126	111	89	71	28	35	344
20	602	139	151	127	103	81	33	43	386
30	677	—	—		—	—	41	50	428
50	738	—	—		—	—	—	—	455
75	768	—	—		—	—	—	—	—
L [2]	818	160	157	164	145	135	50	61	456
First-Hour Demand [3]	13	6	4	7	4	4	3	4	16
Total	831	166	161	171	149	138	53	65	472

[1] Average of values for upper and lower layers of sludge proportioned according to the volatile-solids content of these layers (0.512 of upper + 0.488 of lower).

[2] Calculated from retardant unimolecular curve of best fit for original deposits and for simple unimolecular curve for the remainder.

[3] Part of this amount, although small, may be due to interference of suspended matter with the dissolved-oxygen test (5). The azide modification with potassium fluoride to reduce interference by ferric salts was employed.

and comparable values of L and L_u are appreciably larger. The ratio k/a ranges between 2 and 3 as against 1.6 and 4. Most of these differences can probably be accounted for by the freshness of the sludge used by the authors and the variable age and origin of the English river muds. Age appears to decrease both the rate of decomposition and its potential amount. The time required to reach a significant degree of completion, however, remains a matter of months or years rather than days or weeks.

Comparing the simple with the retardant parameters in Table VII, we note, as in the analysis of the English studies, that the magnitude of L_u is smaller than that of L, and the magnitude of k_u is larger than that of k. For all but carboy I, indeed, the value of L_u falls short of the mark actually reached in 450 days. Also there is no consistent variation in k_u with depth.

Variation of L with Depth.—All of the mathematical parameters of decomposition are seen to vary systematically with depth. Most striking, perhaps, is the rapid decrease in the ultimate benthal oxygen demand, L in grams per kg. of volatile matter, with increasing depth or areal concentration of volatile matter. There can be little doubt that anaerobic decomposition plays a larger part as deposits become deeper and decom-

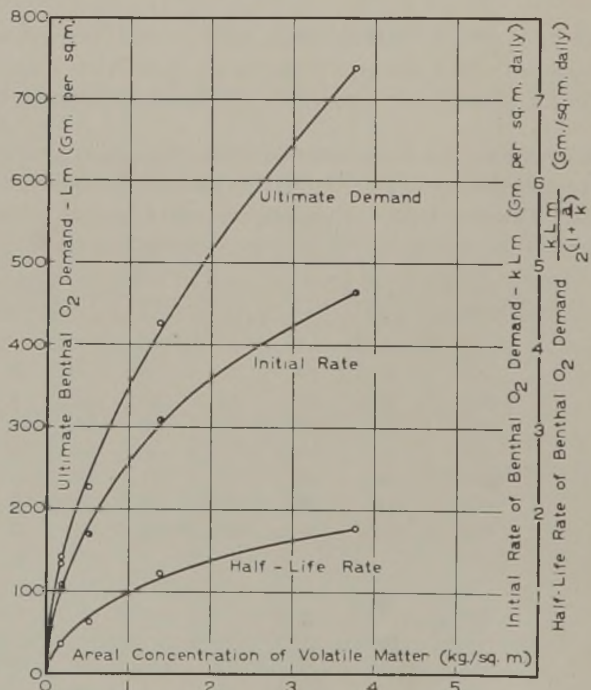

FIG. 7.—Observed variation of (1) ultimate, areal demand of benthal oxygen, (2) initial, areal rate of demand, and (3) half-life areal rate of demand with areal concentration of volatile matter (depth characteristic).

posable substances are farther removed from the sludge-water interface. Much of the potential oxygen demand is then destroyed anaerobically and escapes from the sludge in the form of methane. It must be expected, therefore, that the benthal oxygen demand, L, of deep deposits will approach a lower limiting value which is exerted by those residues that are not decomposed anaerobically. Well-digested sewage sludge, for example, still possesses a B.O.D. of 150 to 250 grams of oxygen per kg. of volatile

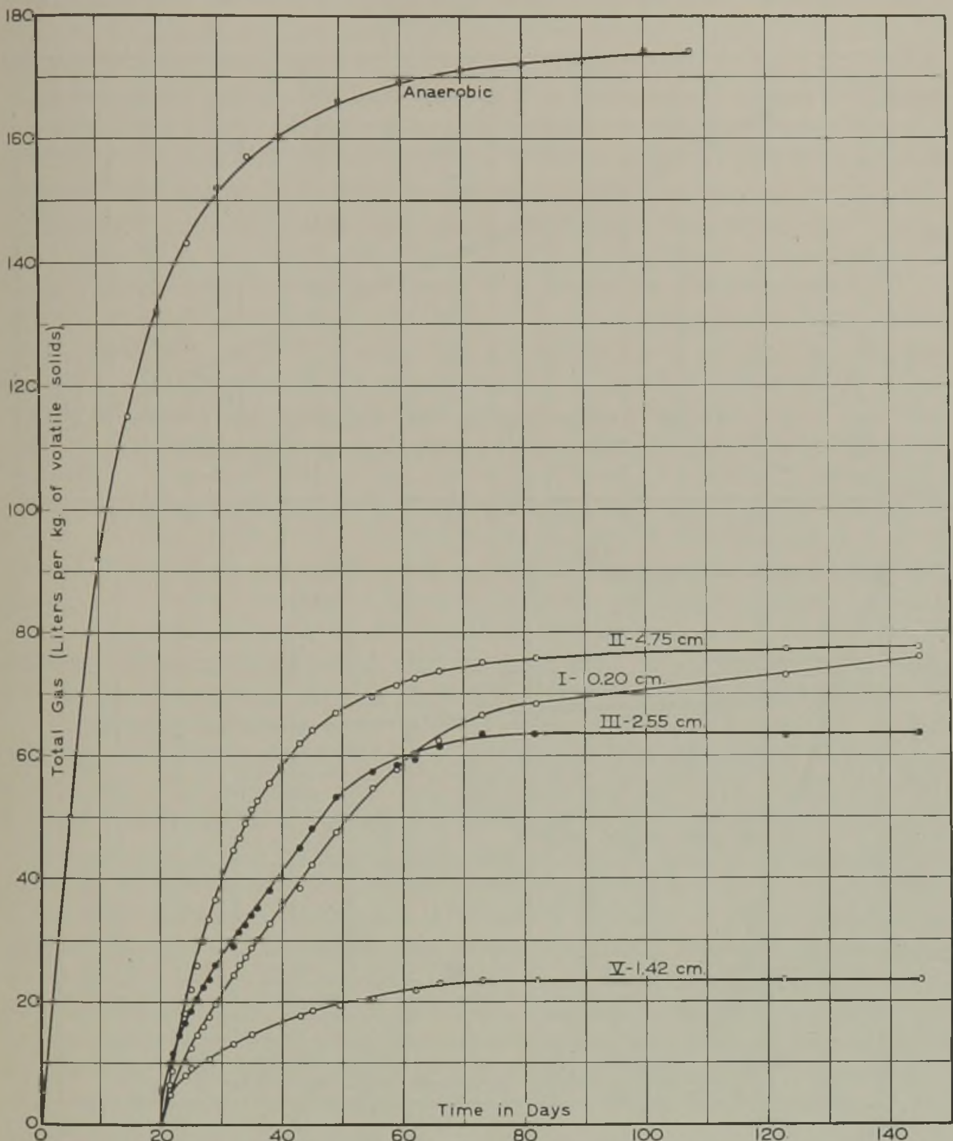

FIG. 8.—Volume of gas released by sludge deposits of varying depth, decomposing benthally. Observations were initiated 20 days after the start of the tests. The course of anaerobic gasification of the material originally deposited is shown for purposes of comparison. The curves are fitted by eye.

solids, and the lower limiting benthal demand of deep sludge deposits may well be of this order of magnitude. This statement is supported by the observed long-time biochemical oxygen demands of the deposits after 450 days of benthal decomposition (Table IX). The B.O.D. of the residues is seen to vary from about 60 grams per kg. of volatile solids for the shallowest samples to about 170 grams per kg. of volatile solids for the deepest one.

In spite of decreasing values of L, however, the total oxygen requirements of deeper deposits are greater than those of shallow ones because of

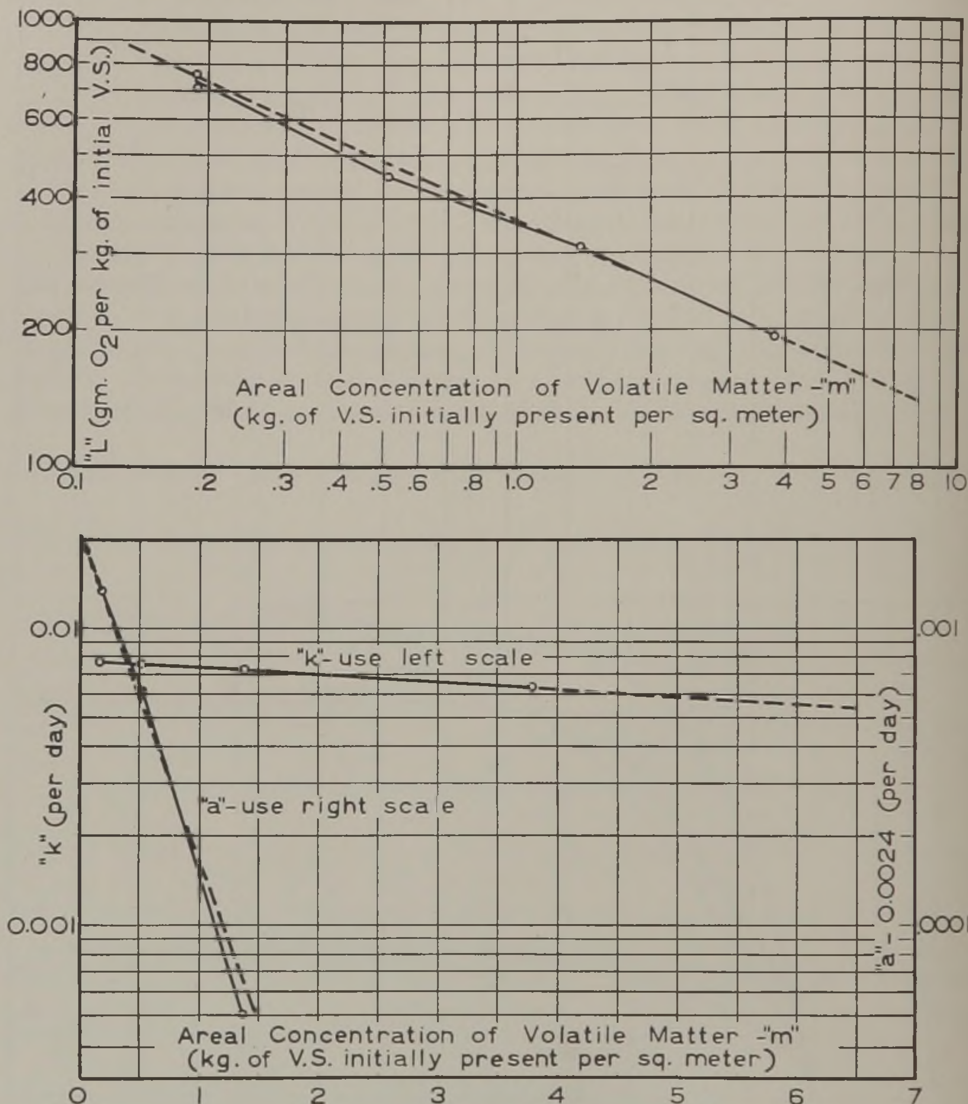

FIG. 9.—Decrease of ultimate oxygen demand, L, initial rate of demand, k, and coefficient of retardation, a, with areal concentration of volatile matter (depth characteristic). Straight lines facilitate estimation of the magnitudes of L, k, and a.

the larger amount of decomposable matter present. The daily oxygen demands, too, are greater even though the reaction velocity also becomes smaller with depth. The ultimate areal oxygen demands, calculated for the authors' results, are shown in Table VIII and traced in Fig. 7. The ultimate areal, or surface, demands for oxygen, $L_s = Lm$, are here expressed in grams of oxygen per sq. m. of sludge-water interface.

That anaerobic decomposition does become ascendant with depth can be seen also from Fig. 8, a record of the volume of gas liberated during benthal decomposition. Unfortunately, collection of this gas was not instituted until 20 days after the beginning of the tests. The preceding happenings, therefore, are quantitatively unknown. Excepting carboy I, gas production per unit weight of volatile matter initially present is seen to have increased with depth. The peculiar behavior of carboy I may be due to this very fact. For purposes of comparison, observations of the gas produced during strictly anaerobic decomposition of the deposit are included in Fig. 8. The rapidity of gas production and small volume collected are somewhat unusual, but it is probable that the admixture of inert materials and lime are responsible for this situation. The high B.O.D. of the digested sludge (Table IX) is a necessary corollary. The proportion of methane in the gas from all sources was close to 70 per cent.

If anaerobic conditions establish the lower limit of benthal oxygen demand, a full aerobic environment similarly fixes the upper limit. The course of the fully aerobic oxygen demand, or long-time B.O.D. of the fresh sludge used by the authors, was followed for 75 days by the "dilution method." Observed values are listed in Table IX and a fitted curve, based upon the retardant parameters included in Table VIII, is shown in Fig. 6. The ultimate B.O.D. of 818 grams per kg. of volatile matter is seen from Table VII to exceed the highest benthal oxygen demand (smallest depth) by about 60 grams per kg. of volatile matter and the lowest benthal oxygen demand (largest depth) by over 500 grams per kg. of volatile matter. Discussion of these relationships will be continued in a later section of this series of papers.

Variation of k and a with Depth.—As shown in Table VII and Fig. 9, the reaction velocity constant, k, decreases only slowly with depth, while the coefficient of retardation, a, is reduced more rapidly. The magnitude of both of these parameters of benthal oxidation is only a small percentage of the magnitude of the corresponding parameters for the B.O.D. of polluted waters. This is understandable when one considers the differences inherent in the respective environments. The rate of B.O.D. is a direct measure of the life activities of the organisms responsible for aerobic decomposition, while the rate of benthal oxygen demand is influenced, in addition, by the physical processes of diffusion and consolidation. No direct comparison can be made between the benthal oxidation and anaerobic decomposition observed in these tests, because of the unusual behavior of the anaerobic sample. Ordinarily one would expect the rate of anaerobic gasification to be somewhat more rapid than that of benthal oxidation, but much would depend upon so-called seeding effects. The rate of anaerobic gasification is a fundamental rate in the same sense as the rate of change in 5-day B.O.D. observed by Rudolfs and Mohlman ($k = 0.0126$ and 0.0181 respectively).

The influence of depth upon the daily oxygen requirements of sludge deposits is included in Table VIII and Fig. 7. These requirements are a function of reaction velocity as well as ultimate oxygen demand. They are conveniently expressed in grams of oxygen per sq. m. of sludge-water interface per day. Two rates of areal, or surface, oxygen demand are presented in Fig. 7: (1) the maximum areal rate, which obtains at the start of benthal oxidation, and (2) the half-life areal rate * which is reached after 50 per cent of the ultimate benthal oxygen demand has been exerted. Examination of equation (1) will show that the initial areal rate, y_{s_0}', and the half-life areal rate, y_{s_2}', must equal:

$$y_{s_0}' = kLm, \qquad (1b)\ \dagger$$

$$y_{s_2}' = \frac{kLm}{2^{1+a/k}}. \qquad (1c)\ \ddagger$$

The time when the half-life of the deposits has been reached ranges between 3 and 4 months (Table VIII). Intermediate rates are included in Fig. 10 which will be discussed in connection with the generalization of the experimental results. The areal, or surface, rates of oxygen demand are particularly useful concepts of benthal oxidation, because they can be translated directly into the amounts by which the dissolved-oxygen content of the supernatant water will be reduced in flowing over the bottom sediments. It follows directly from the simple relations of the metric system, for example, that each square meter of sludge surface will lower the dissolved-oxygen content of a flow of one cubic meter of water per day by y_s' parts per million. In the English system of units, correspondingly, each acre of sludge surface will remove y_s' parts per million of dissolved oxygen from approximately 1 m.g.d. of water.§ Whether y_s' is the initial, half, or any other rate of demand depends upon the particular circumstances.

This discussion of the effect of depth upon the initial rate of benthal oxidation would not be complete without reference to the pioneer studies of Baity (1). The initial benthal demands observed by Baity may be expressed in grams of oxygen per sq. m. of benthal surface per day and tabulated as follows:

Depth—cm	0.5	1.0	1.5	2.0	4.0
Areal concentration of volatile matter (m)—kg. per sq. m.	0.355	0.710	1.06	1.41	2.82
Initial rate of benthal oxygen demand (y_{s_0}')—grams of oxygen per sq. m. per day	1.84	2.89	3.45	3.77	5.17

Comparison of these rates with the ones recorded in Table VIII will show that they are approximately 30 per cent greater. In the absence of significant differences in temperature, this discrepancy may be due to variations in the character of the organic matter, but it is more probably

* Not to be confused with the half-rate at time $t = \frac{1}{a}$.

† For $t = 0$ and $y = 0$, $y' = \frac{dy}{dt} = kL$ and $y_{s_0}' = kLm$.

‡ For $\frac{y}{L} = 0.5$ in equation (2), $(1 + at) = 2^{a/k}$, and for $(L - y) = 0.5$ in equation (1),

$$y' = \frac{dy}{dt} = \frac{kL}{2^{1+a/k}} \quad \text{and} \quad y_{s_2}' = \frac{kLm}{2^{1+a/k}}.$$

§ More exactly, 1.07 m.g.d.

the result of the lower density and consequently greater mobility and benthal exposure of the sewage sludge studied by Baity. The initial

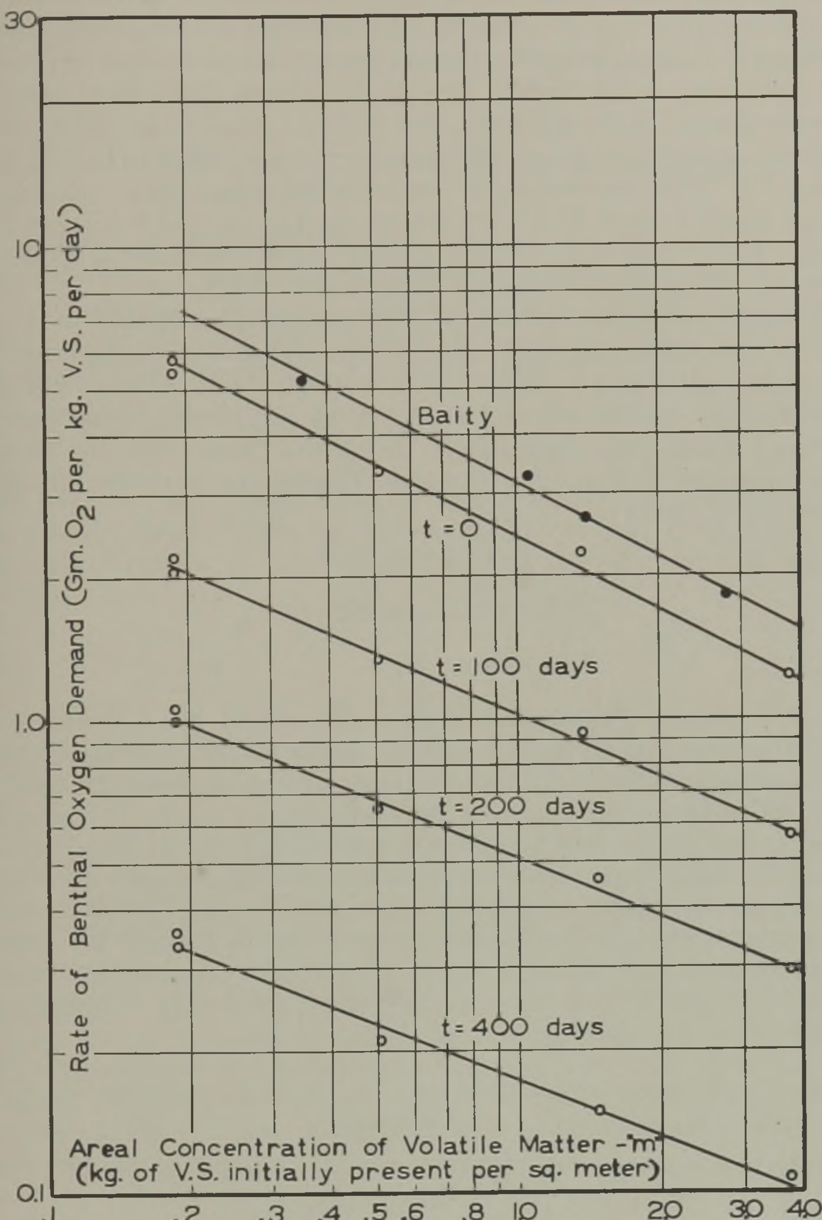

FIG. 10.—Decrease of rate of benthal oxygen demand in time and with areal concentration of volatile matter. Straight lines facilitate estimation of rates at given times and areal concentrations of volatile matter (depth characteristic).

density of this sludge is estimated from its analysis (Table I) to have been about 1.01, whereas the sludge deposit prepared by the authors had an estimated mean density of 1.05 to 1.14. It is evident that areal concentration of volatile matter falls short of being completely descriptive of the "depth factor" and that some other measure will have to be introduced when sufficient information has accumulated to permit its identification.* At the same time, it is clear that the discrepancies between Baity's results and those of the authors would become greatly exaggerated if comparisons were based upon depth itself. At a depth of 4 cm., for example, the areal concentration, m, of the sludge studied by Baity was 2.82 kg. per sq. m. and the initial rate of benthal oxygen demand, y_{s_0}, was found to be 5.17 grams per sq. m. The corresponding values interpolated from the authors' findings would be $m = 1.05$ kg. per sq. m. and $y_{s_0} = 2.55$ grams per sq. m. On this basis, therefore, Baity's values would be about 100 per cent greater than those of the authors, rather than 30 per cent.

Mathematical Generalizations.—The information collected by the authors on the relation between sludge depth and rate of benthal oxidation can be generalized in a number of different ways both within and outside the immediate mathematical framework of the retardant unimolecular equation. Remaining immediately within this framework, the variation of the parameters k, a, and L with the depth measure, m, can be formulated empirically as follows:

$$k = 0.0078e^{-0.0571m}, \tag{3a}$$

$$a = 0.0024 + 0.0021e^{-2.57m}, \tag{3b}$$

$$L = 355m^{-0.449}. \tag{3c}$$

Here, m is measured in kg. of volatile matter per sq. m., k and a are on a daily basis, and L is given in grams of oxygen per kg. of volatile matter. The relationships were derived by straight-line plotting of L, k and $(a - 0.0024)$ against m as shown in Fig. 9.

Going outside the immediate framework of the unimolecular equation, there are at least two generalizations that will relate the authors' observations of benthal oxygen requirements to sludge depth. The first of these follows from a straight-line (double-logarithmic) plotting of the information shown on natural scales in Fig. 7. For areal concentration of volatile matter in kg. per sq. m., the empirical equations that have been derived take the following form:

Ultimate benthal oxygen demand: (grams of oxygen per sq. m. of sludge) $L_s = 355m^{0.551}$, (4a)

Initial rate of oxygen demand: (grams of oxygen per sq. m. daily) $y_{s_0}' = 2.45m^{0.485}$, (4b) †

Half-life rate of oxygen demand: (grams of oxygen per sq. m. daily) $y_{s_r}' = 0.91m^{0.516}$. (4c)

* One might speculate that the rate of demand varies inversely as the square of the sludge density.

† A similar generalization of Baity's observation gives the equation

$$y_{s_0}' = 3.2m^{0.485}.$$

Equation (4*a*) is seen to equal equation (3*c*) multiplied by *m*. Since the oxygen demand must be satisfied by the supernatant water, the rates of demand, as explained before, also evaluate directly the rates at which oxygen is withdrawn from the water, provided these rates are stated in p.p.m. of dissolved oxygen per cu. m. of water per sq. m. of sludge, or p.p.m. of dissolved oxygen per m.g.d. of water per acre of sludge. Formulated:

P.p.m. of oxygen removed from supernatant water = Rate of benthal oxygen demand (y_s') × acres of sludge surface ÷ million gallons of flow per day.

The second generalization that lies outside the immediate framework of the retardant unimolecular equation is more ambitious in that it embraces time as well as rate of benthal oxidation and areal concentration of volatile matter. This generalization proceeds from a differentiation of equation (2) which results in the following variant of equation (1):

$$y' = \frac{dy}{dx} = \frac{k}{(1 + at)^{k/a+1}} L. \qquad (1d)$$

In this equation, the value of the fraction is substantially constant for a given value of time, *t*. Since equation (3) shows that *L* varies as some power of *m*, equation (1*d*) may be reduced to the following approximate relations:

$$y' = Am^{-v} \qquad (5a)$$

and

$$y_s' = Am^{1-v}. \qquad (5b)$$

If *m* is expressed in kg. of volatile matter per sq. m. of sludge surface, y' is the rate of benthal oxygen demand in grams daily per kg. of volatile matter, and y_s' is the corresponding areal rate of benthal oxygen demand in grams daily per sq. m. of sludge surface. Equations (4*b*) and (4*c*) are seen to represent special cases of equation (5*b*). Selecting specific values for the time, *t*, a series of straight lines on double logarithmic paper is obtained, as shown in Fig. 10. The intercepts, *A*, and slopes, *v*, of these lines decrease in magnitude with the age of the deposits, *t*. This decrease can be formulated,* but this is not sufficiently useful to be emphasized here. Baity's results are included in Fig. 10 and are seen to be parallel to, though 30 per cent higher than, the corresponding results of the authors for $t = 0$.

Sample Calculation of Benthal Oxygen Demand.—A sample calculation involving the use of many of the equations and figures will acquaint the reader with their relative merits and significance. Such a calculation must of necessity be confined to the special conditions of benthal decomposition that have been discussed so far in this paper. In practice, these conditions could be matched, for example, in a millpond fed by a stream that is not protected against pollution during the winter months because of seasonal (summer) operation of treatment works or tradewaste discharge. If such a pond covers an area of 10 acres and decomposable

* $A = 0.11 + 2.3e^{-0.00905t}$,
$v = 0.393 + 0.122e^{-0.0103t}$.

matter accumulates to a depth of about 2 in. during the winter, what are some of the characteristic benthal oxygen requirements to be expected at the onset of warm weather, assuming the deposited sludge contains 82 per cent of water and 15 per cent of the residue on evaporation is lost on ignition?

The specific gravity of such a deposit may be estimated to be about 1.11,* yielding an areal concentration of volatile matter,

$$m = 2 \times 2.54 \times 0.18 \times 0.15 \times 1.11 \times 10 = 1.5 \text{ kg. per sq. m.}$$

To evaluate k, a, and L, substitute this value of m in equations (3) or enter Fig. 9 with it.

a. $\log k = \log 0.0078 - 0.0571 \times 1.5 \times 0.4343 = 0.8549\text{–}3$ and $k = 0.00716$; checked in Fig. 9.

b. $\log (a - 0.0024) = \log 0.0021 - 2.57 \times 1.5 \times 0.4343 = 0.648\text{–}5$ and $a = 0.0024 + 0.00004 = 0.00244$; checked in Fig. 9; or $\frac{k}{a} = 2.93$.

c. $\log L = \log 355 - 0.449 \log 1.5 = 2.4711$ and $L = 296$; checked in Fig. 9.

These values may be substituted in equation (2), in order to find the oxygen demand at any time, t, and in equation (1) or (1*b*) if the rate of demand at any time, t, is wanted.

d. For $t = 200$ days, equation (2) states that

$$y = 296[1 - (1 + 0.00244 \times 200)^{-2.93}] = 0.682 \times 296,$$

and $y = 202$ grams per kg. of volatile matter.

This result can be checked in Fig. 3 for $kt = 0.00716 \times 200 = 1.432$ and $\frac{k}{a} = 2.93$. The areal demand for oxygen, therefore, is

$$y_s' = 202 \times 1.5 = 303 \text{ grams per sq. m.}$$

e. The rate of demand at 200 days, as given by equation (1), is

$$y' = \frac{0.00716}{1 + 0.00244 \times 200} (296 - 202) = 0.00497 \times 94,$$

and $y' = 0.467$ grams per kg. daily.

The areal rate, therefore, is

$$y_s' = 0.467 \times 1.5 = 0.70 \text{ grams per sq. m. daily.}$$

f. The ultimate areal demand for oxygen is

$$L_s = Lm = 296 \times 1.5 = 444 \text{ grams per sq. m. of sludge surface.}$$

g. The initial, or maximum, areal rate of demand is

* Specific gravity = 25,000 ÷ [250 × % water + % solids (2.5 × % volatile + % mineral)].

$y_{s_0}' = kLm = 0.00716 \times 444 = 3.18$ grams per sq. m. per day, or $3.18 \times 8.92 = 28.4$ lb. per acre per day. As shown by Imhoff and Fair (11), this rate of demand would probably exceed the rate of atmospheric reaeration of the pond under normal circumstances. If 20 m.g.d. of water flow through the pond, the concentration of dissolved oxygen in the water will be lowered, in the absence of reaeration, by $3.18 \div (20 \div 10) = 1.59$ p.p.m. at the outset of decomposition.

h. The half-life areal rate of benthal oxidation is given by equation (1*b*):

$$y_{s_2}' = \frac{3.16}{2^{1.341}} = 1.25 \text{ grams per sq. m. per day,}$$

and the time elapsing before it is reached is obtained from equation ($2b_1$):

$$t = \frac{1}{0.00244}(2^{0.341} - 1) = 110 \text{ days.}$$

i. According to equation ($2b_2$), decomposition will be completed 90 per cent in

$$t = \frac{1}{0.00244}(10^{0.341} - 1) = 490 \text{ days.}$$

As explained in the statement of the problem, the results listed under *f* and *g* have a meaning only because deposition is not continued after the onset of warm weather. The possibilities of evaluating the effects of continuous deposition will be considered in a later section of this series of papers.

2. To find the answers listed in 1 *f*, *g* and *h* more quickly but also more approximately, except for *L*, we can use equations (4), as follows:

f. $\log L_s = \log 355 + 0.551 \times \log 1.5 = 2.647$;
and $L_s = 444$ grams per sq. m. of sludge surface.
g. $\log y_{s_0}' = \log 2.45 + 0.485 \times \log 1.5 = 0.4747$;
and $y_{s_0}' = 3.0$ grams per sq. m. per day.
h. $\log y_{s_2}' = \log 0.91 + 0.516 \times \log 1.5 = 0.0498$;
and $y_{s_2}' = 1.1$ grams per sq. m. per day.

These values can also be read directly from Fig. 7.

3. Figure 10 can be used to approximate the results listed in 1*g* or 2*g*, and particularly for the purpose of finding the rate of oxygen demand at 100, 200 or 400 days or, by interpolation, at intermediate values (see also 1*c*).

g. For $t = 0$, read $y' = 20$ grams per kg. of volatile matter and find $y_s' = 2 \times 1.5 = 3.0$ grams per sq. m. of sludge surface per day.

e. For $t = 200$ days, read $y' = 0.45$ grams per kg. of volatile matter and find $y_s' = 0.45 \times 1.5 = 0.68$ grams per sq. m. of sludge surface per day.

The answers given are naturally circumscribed by the extent of the information so far available. It is to be hoped that it will be possible to place greater reliance upon calculations such as these, as the work of other experimenters and practitioners carries our knowledge farther. At the present time, the results given only indicate roughly the order of magnitude of benthal oxygen requirements.

Summary of Parts I to III and Conclusions

The natural purification of river muds and pollutional sediments is an important, often poorly understood, and inadequately controlled factor in the regimen of water courses and other bodies of water. Depending upon flows and currents, more or less of the pollutional load that is imposed upon water by the discharge of natural or man-made drainage is thrown to the bottom where it undergoes benthal decomposition and interacts in various and sundry ways with the supernatant water. About 30 per cent of the organic, decomposable, or oxygen-demanding, matter in raw sewage, for example, may be precipitated to form river muds or pollutional sediments. The amount of work to be done in stabilizing these substances, therefore, may reach a considerable proportion of the total that a receiving water is called upon to do. Whether or not this shift in locus of biochemical activity is of benefit or detriment to the receiving water must depend upon circumstances.

As shown in Parts I to III of this discussion of the natural purification of river muds and pollutional sediments, benthal decomposition must be expected to fluctuate widely in character, quantity and rate. Depth of deposit, or areal concentration of organic matter, as shown in Part III, may of itself align benthal stabilization with processes akin to the aerobic decomposition of flowing pollutional matters at the one extreme, or with processes akin to anaerobic sludge-digestion at the other. With reference to oxygen requirements, aerobic processes make the greatest demands per unit weight of decomposable matter, both in quantity and rate, while anaerobic processes make the least. Aerobic processes, in the very nature of things, however, are associated with thin and hence light layers of sludge, while anaerobic processes are maintained in thick and hence heavy sediments. The overall effect is a product of (1) rate of reaction, (2) amount of oxygen required for ultimate stabilization of a unit weight of decomposable matter, and (3) the weight of decomposable matter. We cannot overlook the possibility that the building of sludge banks may, under certain circumstances, be one of nature's ways of solving the problem of pollution and natural purification in the most efficient and least damaging manner.

As to the quantity of oxygen required, the upper, aerobic, limit appears almost to approach a value of weight for weight of volatile solids (kg. of oxygen per kg. of volatile matter, for example), while the lower, anaerobic, limit lies at about 10 per cent of this value. The rate at which this demand is initially exerted, in turn, seems to approach, at the upper, aerobic limit, the rate of the B.O.D. of polluted waters—*i.e.* 20 per cent of the ultimate demand is exerted in the first day—while the lower, anaerobic limit lies well below the rate of digestion of unseeded sewage solids—*i.e.* well below 1 per cent of the ultimate demand is exerted in the first day. Between these quantities and rates are arrayed the various conditions of benthal activity that produce some of the values recorded in connection with the studies of the authors and other workers. These are ultimately tied up with depth, and the rate of areal oxygen demand is shown to vary approximately as the square root of the areal concentration of volatile solids. In addition to areal concentration of volatile matter, however, specific gravity of the solid matter, permeability, and elastic properties of the deposit are shown to be important in determining the rate and eventual magnitude of benthal oxidation.

Rates of decomposition are seen to be variable in time, decreasing in such manner, as the deposit ages, that they are halved about every three months. This retarding factor has been recognized in the mathematical formulation of the progress of decomposition and establishes the "retardant unimolecular curve" as a curve of good fit. Methods of applying it to experimental data and simple field situations have been outlined.

The influence of temperature upon the reactions that have so far been considered will be taken up in a later section of this series of papers. Presentation of the problem of continuous deposition of solids awaits this discussion. Effects of benthal decomposition on the quality of the supernatant water, other than oxygen requirements, are also left for later treatment.

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Appendix to Part II

Least Squares Fitting of the Retardant Unimolecular Equation.—In applying the theory of probability to observed data, in order to obtain the parameters of the retardant unimolecular equation of best fit, the general method of approach parallels that found successful for equations of the simple unimolecular type in which the mathematical treatment is based upon the differential form of the equation (12). The differential form of the retardant equation is written as follows:

$$\frac{dy}{dt} = y' = \frac{k}{1 + at}(L - y) \qquad (A)$$

or

$$y' + ay't = kL - ky. \qquad (B)$$

The rate (y') may be calculated from the given values of y and t as follows:

$$y' = \frac{(y_i - y_{i-1})\dfrac{t_{i+1} - t_i}{t_i - t_{i-1}} + (y_{i+1} - y_i)\dfrac{t_i - t_{i-1}}{t_{i+1} - t_i}}{t_{i+1} - t_{i-1}}. \qquad (C)$$

Since it may be safely assumed that there is no appreciable error in the measurement of time, t, the lefthand side of equation (B) may be treated as a dependent function varying linearly with the independent variable y. The least squares criterion requires that the sum of the squares of the residuals, $R = kL - ky - y' - ay't$, be a minimum; that is

$$\sum R^2 = \sum(kL - ky - y' - ay't)^2 = \text{a minimum}. \qquad (D)$$

Therefore

$$\frac{\partial \sum R^2}{\partial (kL)} = 2\sum R \frac{\partial R}{\partial (kL)} = 0$$

and since

$$\frac{\partial R}{\partial (kL)} = 1,$$

$$\sum R = nkL - k\sum y - \sum y' - a\sum y't = 0, \qquad (E)$$

where n is the number of sets of observations y', y and t. Equation (E) provides the first one of three normal equations each of which is obtained by differentiating equation (D) with respect to one of its three parameters (kL, k, and a). Thus by applying the conditions $\frac{\partial \sum R^2}{\partial k} = 0$ and $\frac{\partial \sum R^2}{\partial a} = 0$, the remaining equations may be obtained as follows:

$$kL\sum y - k\sum y^2 - \sum yy' - a\sum yy't = 0, \qquad (F)$$

$$kL\sum y't - k\sum yy't - \sum y'^2t - a\sum(y't)^2 = 0. \qquad (G)$$

Equations (E), (F) and (G) involving the quantities $\sum y$, $\sum y'$, $\sum y^2$, $\sum yy'$, $\sum yy't$, $\sum y't$, $\sum y'^2t$, and $\sum(y't)^2$ calculated from the measured quantities y, y', and t provide the three conditions necessary for the determination of the parameters k, L, and a.

Summarizing, the steps in the least squares procedure are:

I. Given ($n + 2$) sets of experimental points y versus t, compute the n corresponding values of y' by means of equation (C).

II. From the n sets of values of y, y', and t, calculate the sums $\sum y$, $\sum y'$, $\sum y^2$, $\sum yy'$, $\sum yy't$, $\sum y't$, $\sum y'^2t$, and $\sum (y't)^2$.

III. Substitute the sums obtained in II in equations (E), (F) and (G). Solve these equations simultaneously for the parameters k, L, and a, of the retardant equation of best fit.

Appendix to Part III

Consolidation of Deposits and Upward Diffusion of Oxidizable Substances.—Two processes have been suggested by which the soluble oxidizable organic and inorganic substances that are found as the end products of anaerobic decomposition are transported from the interior of the deposit to the surface, or interfacial, zone of oxidation. These are the processes of consolidation and diffusion.

During consolidation of the deposit, an upward displacement of fluid through the interstices of the deposit is created by the internal excess hydrostatic pressure, h, that is due to the weight of the upper layers of sludge being partly carried by the fluid contained in the interstices. When upward flow relieves this pressure, the weight of the upper layers is transferred to the solid particles of the deposit. After this state has been reached, upward flow ceases and the deposit has become completely consolidated. The resulting decrease in depth of deposit is proportional to the total amount of flow that has taken place. The mathematical formulation of the process of consolidation proceeds from the well-known differential equation of hydrodynamics for streamlined flow in the unsteady state:

$$\frac{\partial h}{\partial t} = p^2 \frac{\partial^2 h}{\partial x^2}, \qquad (a)$$

where h = the excess hydrostatic pressure within the deposit at time t, and depth x below the surface,

and p^2 = a constant depending upon the permeability and the elastic properties of the deposit. ($p^2 = E_p k_p$; where E_p is the bulk modulus, and k_p the coefficient of permeability of the deposit.)

Taking into account the fact that the initial distribution of the excess hydrostatic pressure, h, throughout the depth of the deposit is triangular, with a value of zero at the top, equation (a) integrates into the following expression for the percentage of consolidation:

$$P = 100 \left[1 - \frac{32}{\pi^3} \sum_{n=1}^{n=\infty} \frac{(-1)^{n-1}}{(2n-1)^3} e^{-(2n-1)^3 K t} \right], \qquad (b)$$

where P = the per cent of the ultimate amount of consolidation (either settlement or flow) that has occurred up to time t,

and K = a constant depending upon the total depth of deposit D; $K = \dfrac{\pi p^2}{4D^2}$.

In the process of diffusion, an oxidizable organic compound is transported upward because of a gradient in the concentration of the compound that is created between the interior of the deposit and the surface zone where oxidation is taking place. In this process, depth and specific gravity of the deposit remain essentially unchanged and no flow occurs through the interstices, the movement of oxidizable products being limited to the slow process of molecular diffusion. Formulation of this process stems from the same differential equation that applies to the process of consolidation—as do all processes that depend fundamentally upon thermodynamic principles. Consequently the relation controlling the concentration, C, of a given dissolved constituent may be written as follows:

$$\frac{\partial C}{\partial t} = j^2 \frac{\partial^2 C}{\partial x^2}, \qquad (c)$$

where C = the concentration of a given dissolved substance at any time t and depth x below the surface

and j^2 = the coefficient of diffusion, depending, among other things, upon viscosity of the interior fluid and size of molecules being diffused.

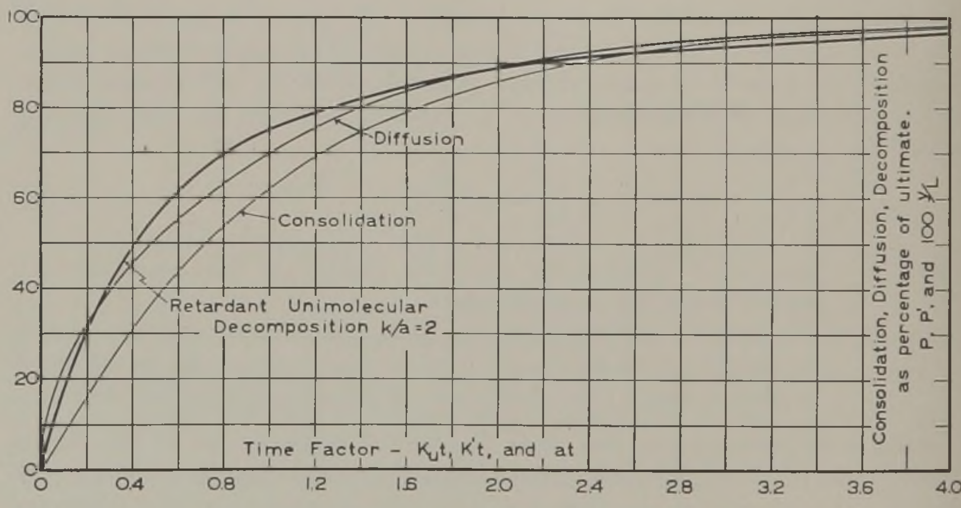

FIG. 11.—Progress of consolidation, diffusion, and retardant unimolecular decomposition, showing similarity of pattern in time.

Taking into account the fact that the initial concentration of the dissolved substance is rectangular, being constant at all depths below the surface, the diffusion that has occurred at any time may be expressed as follows:

$$P' = 100 \left[1 - \frac{8}{\pi^2} \sum_{n=1}^{n=\infty} \frac{1}{(2n-1)^2} e^{-(2n-1)^2 K' t} \right], \qquad (d)$$

where P' = the per cent of the ultimate amount of diffusion taking place in time t; in other words, the per cent of the total amount of dissolved substance that has entered the surface zone of oxidation at time t

and K' = a constant depending upon depth of deposit, D; $K' = \frac{\pi^2}{4} \frac{j^2}{D^2}$.

Equations (b) and (d) have been plotted in Fig. 11, and it may be observed that they are in close agreement with the course of decomposition delineated by the retardant unimolecular equation plotted in this figure. A similarity may also be observed between the general shape of these theoretical curves and the actual curves of benthal oxidation presented in the body of this paper (Figs. 4 and 6). It is probable that both processes occur successively and that the oxidation actually accomplished depends upon the sum of their individual effects.

Industrial Wastes

CHEMICAL PRECIPITATION OF SULFUR DYE WASTES ON A PILOT PLANT SCALE *

By Ralph Porges, Robert K. Horton, and Harold B. Gotaas

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The application of laboratory results to plant operation is a factor often neglected. Various problems arise during plant operation which are entirely overlooked or are insignificant in the laboratory. For instance, such matters as odor concentration and the feasibility of batch or continuous operation are problems that must be decided with equipment larger than that necessary for laboratory studies. Laboratory experimentation permits adequate control, but the question arises as to whether the results so obtained can be duplicated by the plant operator working on a large scale. These difficulties may be overcome, in part, by correlating laboratory data to studies made on a pilot plant scale.

The processing wastes from textile mills are voluminous and when composited may exert a five-day 20° C. B.O.D. of approximately 500 p.p.m. or more. Under such conditions of compositing, the entire waste must receive special treatment, although the greater portion of the volume of the composite waste comes from wash waters which have negligible pollutional qualities. Under specific conditions, the strong and highly colored wastes can be separated from the wash waters. In this way, the wash waters can be discharged into domestic sewers without placing an undue burden on the domestic sewage treatment process, while only the concentrated discharges will have to be handled by industrial waste treatment processes. Although the cost of treating strong discharges is very high, it may be advantageous to treat the small volume of strong waste at a high unit cost rather than a large volume of composite waste at a low unit cost. With this objective in view laboratory studies on the precipitation of textile wastes have been reported (1). Many coagulants were employed to precipitate different types of wastes, including concentrated processing liquors. These studies indicated problems that may arise, some of which are stated below. The solving of these problems is important for the successful operation of a plant treating strong sulfur wastes.

Sulfur dye waste is most economically precipitated by strong acids; however, the production of malodorous hydrogen sulfide, which has toxic properties, should not be overlooked. Color removal is extremely sensitive to the chemical coagulant dosage; and hence proper control

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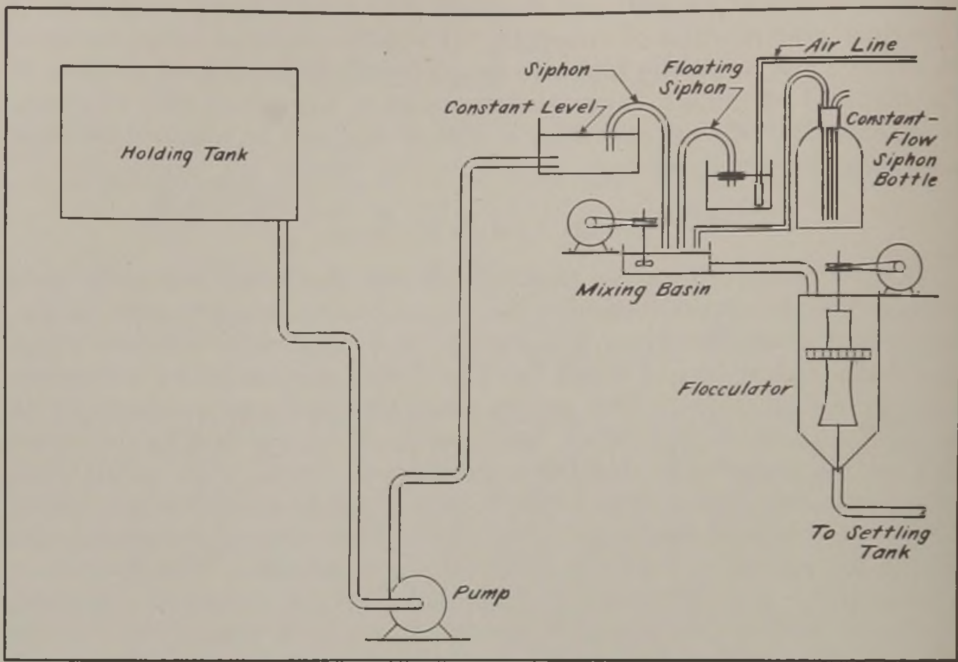
of the amounts of reagent and close pH adjustment are of importance. Chemical precipitation of concentrated wastes produces large volumes of sludge; and since the ultimate problem of any treatment process is the disposal of sludge, large sludge volumes aggravate this problem. It appears that efficient operation is difficult but may be attained through adequate plant control.

Apparatus and Material

A 4,000-gallon detention tank outside the dye house was used as a storage tank for the collection of the waste obtained from the dyeing machines. A drain line from this storage tank was connected to a pump that fed a siphon box in which the liquid was maintained at a constant head by a float valve. The siphon from this box was so arranged as to discharge the liquid either into a hydraulic-jump mixing device or to a mixing chamber containing a mechanical stirrer. Chemicals were added into the mixing device either by a constant head floating siphon or from a constant discharge bottle (2). When lime or copperas were added, air agitation kept the material in suspension. The flocculator consisted of a downward flow circular tank of 12-gallon capacity, equipped with a mechanically operated, variable speed, spirovortex mixer. The settling tank had a total capacity of 95 gal. of which 17 gal. was the volume within the sloping bottom and hopper. The volume of the hopper bottom was assumed to be the sludge capacity; while the remaining 78 gal. was the volume or capacity used as a basis for the calculation of all theoretical detention periods. The inlet trough contained bottom outlets thus causing downward flow. Equal distribution over the width of the tank was assured by a constant head of liquid over these bottom orifices. The supernatant liquor from the tank was discharged over the outlet weir to the waste line. The sludge was withdrawn from within a hopper in the center of the sloping bottom and was piped to sludge-drying sand beds (3). In addition, a series of 8-in. vitrified tile pipes filled with 6 in. of gravel covered with sand to a total depth of 18 in., were also used as sludge drying beds. The apparatus is shown diagrammatically in Fig. 1*a* and 1*b*.

The waste has been described in detail in a previous paper (1). The pigment consists of a sulfur compound and is usually applied onto the cloth with the addition of a solution agent, sodium sulfide. The waste contains the pigment, sodium sulfide, salt, a small amount of caustic soda, and other chemicals in minor amounts. Although the waste varied considerably during the period of experimentation, the analysis averaged approximately as follows:

Color	Deep blue black
Total alkalinity	18,000 p.p.m. as $CaCO_3$
Phen. alkalinity	10,000 p.p.m. as $CaCO_3$
B.O.D.	10,000 p.p.m. (5 day, 20° C.)
Total solids	9%
Volatile solids	23% of the total solids
pH	11.2



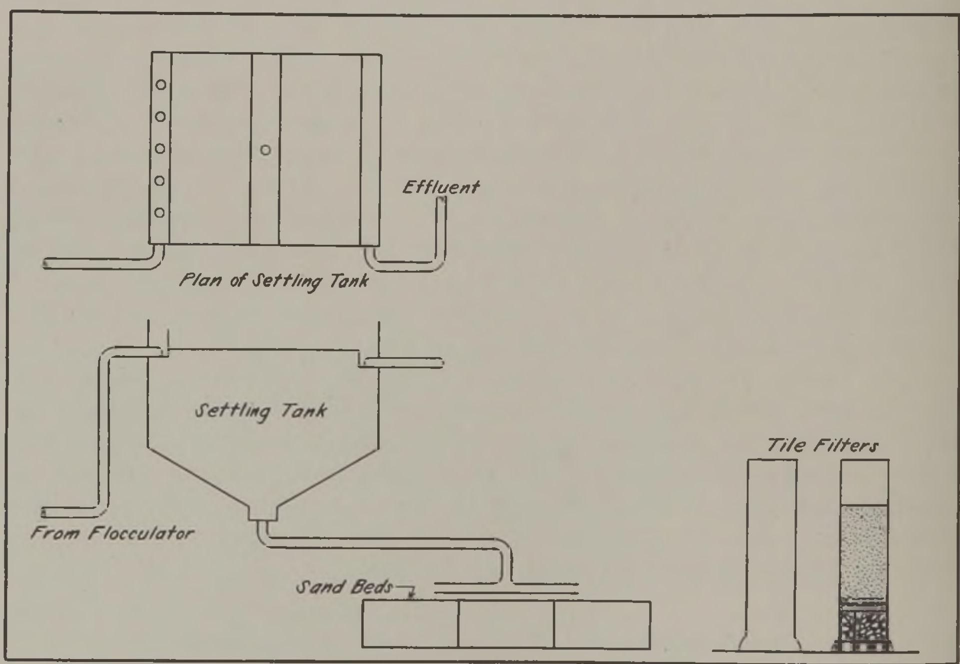


Fig. 1*a*, 1*b*.—Schematic presentation of pilot plant for the precipitation of textile wastes.

Since the materials in the dye bath are in solution, the suspended solids content of the waste is very low.

Procedure

The waste was pumped from the dyeing machines to the storage tank immediately after the processing of each roll of goods. After sufficient waste was accumulated, it was mixed and stored preparatory for use. The waste was pumped to the constant-head siphon box at which point a sample was taken for laboratory tests in order to determine the chemical dosage. Chemicals in convenient concentrations were added from the discharge siphons to the waste at the mixing device. All flows were adjustable.

An inclined channel involving a hydraulic jump was used at first for the mixing device. This method of mixing was discontinued because the froth which occurred at the jump ran over the sides of the channel. A mixing chamber with a mechanical stirrer was substituted. The mixture was flocculated and then settled; the effluent was discharged over a weir. The resulting sludge was drawn to sand beds to observe dewatering characteristics.

In these studies, the following tests were made on the indicated materials:

1. Raw waste: pH, total solids, alkalinity, B.O.D., color.
2. Flocculator effluent: pH, suspended solids, settling characteristics.
3. Sludge: pH, suspended solids, total solids, filtrability, sludge index.
4. Effluent: pH, color, suspended solids, B.O.D.

All analyses were performed according to *Standard Methods of Water and Sewage Analysis.* The hydrogen-ion concentration was determined by means of a Coleman glass-electrode electrometer. Filtrability of samples was determined by filtering in an 11 cm. Buechner funnel through No. 202 Reeve-Angel, rapid filtering paper. In all cases, 100 ml. samples were dewatered by maintaining a vacuum of 22 in. of mercury.

Results

Typical results obtained by the treatment on pilot plant scale of sulfur black dye wastes have been summarized in Tables I, II, and III. Table I shows flow characteristics and other pertinent data of the waste and coagulants used in these studies; Table II presents the characteristics of the effluents; while Table III gives data pertaining to the characteristics of the resulting sludges obtained with the coagulants.

In these studies, sulfuric acid was the first coagulant used for the precipitation of the dye waste. Frothing was violent in the mixing channel at the hydraulic jump. This froth, which was produced by all coagulants, was very persistent and foamed over the channel. Hydrogen sulfide was evolved in such large quantities at the point of mixing that it was uncomfortable to remain in the immediate vicinity

Table I.—*Coagulant, Waste, and Flow Data*

Coagulant		Sulfur Dye Waste		Coagulated Waste		
Name	Grains per Gal. of Waste	B.O.D.	Color	Rate of Flow g.p.m.	Detention Time in Minutes: Flocculator	Detention Time in Minutes: Settling
H_2SO_4	926	13,600	100,000	0.56	21.0	140
$Fe_2(SO_4)_3$	2,043	11,000	100,000	0.32	37.5	245
$Ca(OH)_2$ and $Fe_2(SO_4)_3$	241 1,850	5,600	100,000	0.83	14.5	94
$FeCl_3 \cdot 6H_2O$	2,035	8,000	100,000	1.07	11.3	74
$FeSO_4 \cdot 7H_2O$	2,840	8 000	100,000	0.62	19.5	125
$Ca(OH)_2$ and $FeSo_4 \cdot 7H_2O$	701 2,435	8,000	100,000	Batch Process		

of the pilot plant. Bulking of the sludge over the effluent weir made it impossible to operate continuously. However, the final sludge dewatered rapidly and formed a dry cake.

Aluminum sulfate (filter alum) produced results similar to those obtained with the use of acid. Large amounts of hydrogen sulfide were evolved, and the filtrability of the sludge was good.

Ferric sulfate (ferrisul) coagulated the waste without odor formation but again settling of the sludge was poor. In one case, the waste was allowed to settle over night and the sludge compacted to about 50 per cent. The following morning continuous operation was started, but, after 3.5 hours operation, the sludge bulked over the effluent weir. Sludge drawn to the sand beds to a depth of 10 in. gave a cake about 3 in. thick in five days and, in spite of heavy rains, it appeared satisfactory for removal. The dried sludge had a total solids content of 22.5 per cent. It is not necessary to dry this material to as high a degree as sewage sludge since readily decomposable matter and humus is absent. The poor settling qualities of the precipitated waste are evidently due to the high suspended solids content. A representative sample of the tank mix showed over 2.2 per cent suspended solids while settled sludge had 4.5 per cent suspended solids.

Table II.—*Effluent Characteristics from Treatment Shown in Table I*

Coagulant	pH	Color: Residual	Color: Removal Per Cent	B.O.D.: Residual P.p.m.	B.O.D.: Removal Per Cent	Suspended Solids P.p.m.	Remarks
H_2SO_4	4.1	300	99.7	2,960	78.2	273	Not filtered
$Fe_2(SO_4)_3$	8.4	1,000	99.0	1,000	89.0	43	
Lime and Ferrisul	8.6	900	99.1	1,100	80.5	16	
$FeCl_3$	8.4	1,100	98.9	1,100	80.5		
$FeSO_4$	9.0	1,200	98.8	800	90.0		
Lime and Copperas	7.1	600	99.4	1,500	81.0		Batch Process

Lime was then used in conjunction with ferric sulfate in an attempt to improve results. However, no improvement was evident, as may be noted in Table II. Sludge obtained from the conjugated lime-ferrisul treatment was applied onto the tile filters in depths of 4.6, 9.2 and 13.8 in., corresponding to 1, 2, and 3 gal. dosages. All sludges cracked overnight, that from the 4.6 in. dose being removable. All sludges were removable on the fourth day; the total solids of the dry samples being 43.1, 28.9, and 25.4 per cent for the 4.6, 9.2, and 13.8 in. depths, respectively. Poorer results were obtained in drying the sludges with the tile filters than with the larger sand beds as the tile filters protected the sludges from sun and wind.

An effort was made to operate continuously by constantly withdrawing sludge. Ferric chloride was used as the coagulant. It was impossible to prevent the rising of the sludge blanket although 50 per cent of the total flow was drained to the sand beds.

Continuous operation was then tried with the use of copperas, but, likewise, did not prove feasible. Difficulty arose in the filtering of the copperas sludge. Effluent from the flocculator applied to the sand beds drained through the filter in a few minutes, but the sludge was not retained and the filter effluent was highly colored. Copperas sludge after flocculation forms a very fine floc that can be retained by sand filters only after the formation of a sludge mat. Since previous laboratory results showed that flocculation may be detrimental (1), another filter was dosed with the waste obtained from the mixing chamber. In this case the sludge was retained and the filter effluent showed good color removal. Evidently, mixing in the flocculator may break up the floc and result in poor filtration.

Lime was then added together with copperas to aid in the formation of a good floc. Dewatering results showed marked improvement. Copperas-lime sludge was applied to three of the tile filters to depths of 4.6, 9.2, and 13.8 inches. The sludge remaining from the 4.6 in. depth dried overnight and left a removable cake. Sludges from the other two filters cracked overnight but were not removable until the fifth day. Unfortunately, rain was plentiful and interfered with the sludge drying tests; hence, one would expect dry weather to improve the drying results.

Discussion

The treatment of strong wastes, such as concentrated sulfur black dye liquor, necessitates close control of all variable factors to obtain economical operation. Maximum color removal is obtained within narrow limits of coagulant dosages and any variation in the flow of strongly alkaline or acid wastes or in the dosage of the relatively concentrated coagulants will upset the chemical balance for optimum precipitation. Since a holding tank is necessary to composite the variable strength sulfur dye wastes, and since difficulties arise in accurately controlling the flow rates of both the waste and the chemical coagulant when using continuous operation, it appears that the batch process is the more satisfactory method for treating strong, concentrated wastes. The holding tank may be used as a settling tank and the proper amount of coagulant may be added to a known volume of known-strength waste.

The large sludge volumes that occur with these wastes present another difficulty. Optimum precipitation of sulfur dye wastes was shown to depend, according to laboratory tests (1), upon mixing, flocculating, and the proper addition of chemicals, especially if settling of the sludge is to be considered. Similar results were obtained in the pilot plant studies. A short rapid mix, followed by little or no flocculation forms the most compact sludge.

TABLE III.—*Sludge Characteristics from Treatment Shown in Table I*

Coagulant	pH	Suspended Solids P.p.m.	Dewatering Time Seconds (Buechner Funnel Test)	Sludge Index	Remarks
H_2SO_4	5.1		55		
$Fe_2(SO_4)_3$	8.6	45,490	45	22	Settled to 50 per cent
Lime and Ferrisul	8.9	22,590	99	44	
$FeCl_3$	8.5	21,570	45	47	
$FeSO_4$	9.1	7,780	58	128	
Alum	5.1	12,148	70	82	

In Table III are given values for the sludge index of this coagulated waste. The index used is that as defined by *Standard Methods* and is equal to the volume occupied by one gram of sludge. Even though some settling occurred in the half-hour time interval required in making a sludge index analysis, the values given in the table were calculated on the assumption that no settling occurred, and that the sludge volume was equal to the total volume of waste. In the case of activated sludge, a sludge index of 100 or less shows a satisfactorily settling material. This is in accordance with Donaldson (5), whose index was equal to a hundred times the reciprocal of the present index, and who found that in general a sludge index of less than 1.0 indicated an undesirable condition from the standpoint of sludge bulking. Hence, it is seen that even without any settling a quite compact sludge is present.

The addition of coagulating salts increases the weight of the resulting sludge over that obtained by the use of acid alone, as may be noticed in Table IV. Although the increase varied from 82 to 128 per cent in weight, no great difference in the rate of settling in one hour was noticed. Overnight settling showed greater variation, although not so much as would be expected. With the waste used in this experiment, sludge settled overnight to 50 per cent of the total volume. Advantage may be taken of this fact when holding tanks are used to composite the daily waste. The batch can be precipitated and settled overnight, and a swinging effluent line may be used to withdraw the supernatant liquor.

It may be possible, provided a holding tank is used to composite the waste, to treat a given volume continuously. The chemical dosage may then be arranged to precipitate the given waste. A good mixing, followed by filtration should prove satisfactory, since it appears from the results that flocculation may not be necessary and that settling is unsatisfactory. Settling can be practiced only in cases where the necessary inclusion of rinse waters dilutes the waste, because the coagulated solids settle rapidly in dilute wastes where there is little or no effect of compaction. Hence, settling may be practical when the coagulated waste contains less than 6000 to 8000 p.p.m. suspended solids.

TABLE IV.—*Per Cent Increase in Weight of Sludge Produced by Various Coagulants—Acid Sludge Considered as Unity*

Coagulant	Per Cent Increase in Weight of Sludge	Per Cent Sludge to Total Volume	
		1 Hour Settling	Overnight Settling
H_2SO_4	0	81.5	30.3
$Al_2(SO_4)_3$	114	95.0	54.5
$FeCl_3$	87	82.8	41.6
$Fe_2(SO_4)_3$	82	80.0	37.0
$FeSO_4$	128	89.0	58.3

In the case of strong wastes, filtration is very important since the maximum concentration of the sludge by settling is 50 per cent of the total flow. Dewatering is very rapid and no difficulties should be experienced. In view of the rapid filtration of the sludge, it appears possible, when treating strong concentrated wastes, to dewater the entire waste on vacuum filters or sand beds and eliminate the settling tank.

Acid and alum should not be used to precipitate sulfur dye waste unless special precautions are taken to remove the evolved malodorous and toxic hydrogen sulfide. The toxic effects are appreciable as the authors noticed the ill effects caused by the hydrogen sulfide even with the small quantities of waste treated. Control of odors is often overlooked in waste treatment. (At least one plant comes readily to mind where acid and alum used in the treatment of a waste containing sulfur dye liquor created a nuisance because of odors. It is not the best policy to prevent one nuisance and in doing so create another.)

Iron salts coagulate the sulfur wastes very satisfactorily without the production of odors. Evidently a non-volatile sulfide is formed. Lime used in conjunction with the coagulants may aid in the production of a floc.

Previous laboratory results predicted the present findings very closely (1). The main discrepancy was in the color removal data. Better results were obtained in the laboratory, which fact can be accounted for probably by the ability to control conditions more accurately. Possibly better results may be achieved on a large scale basis than on a pilot plant basis, as control may be better in the former. Another consideration is that a composite dye waste discharged by a mill will not be quite so strong as the waste handled in this experiment because of the inclusion of the highly-colored, first rinse waters.

The large amounts of chemicals required for coagulation and the large sludge volumes produced indicate the interesting possibilities of recovering and re-using the coagulants and the dye. Preliminary studies on the re-use of sludges have been made. Acid precipitates the pure dye and excellent results are obtained on re-using the dye. The other coagulants interfere with the dyeing process but this difficulty is eliminated by removing the coagulants from the sludge. The reclaimed chemical coagulants can be re-used to precipitate more waste. Rudolfs and Kessener (4) describe a plant which treats textile waste and sewage, wherein the sludge is treated with acid to recover the alum. More economical treatment of those industrial wastes that require large amounts of coagulants is possible if recovery and re-use of materials is practiced. Should the hydrogen sulfide difficulty in acid precipitation be overcome, the acid treatment of the dye waste with the re-use of the precipitated dye may be an acceptable method of treating sulfur dye wastes. Some of these problems have been investigated and are being prepared for future presentation.

Summary

Pilot plant studies on the chemical precipitation of sulfur dye waste were inaugurated in order to correlate laboratory studies to plant operation and to determine the difficulties that may arise from large scale operation.

It appears that laboratory studies give a close indication of plant operation. Laboratory results may be slightly better than pilot plant studies because of the possibility of more accurate control. An example of this is color removal.

The fill-and-draw method of operation appears to be more feasible than continuous operation when precipitating strong wastes.

Continuous operation may be practical when treating a waste that has been diluted several times with wash water, as this type of waste will have less suspended solids and settling is satisfactory.

Acids and alum should not be used to precipitate sulfur wastes unless precautions are taken to control the hydrogen sulfide.

Iron salts such as ferrisul, ferric chloride, and copperas can be used with this type of waste without the evolution of hydrogen sulfide. Flocculation is detrimental to the copperas floc and must be kept to a minimum. Lime aids in the production of a floc with copperas.

Dewatering is important because of the large sludge volumes. Maximum sludge concentration was approximately 50 per cent. The high content of suspended solids of the treated liquor preclude further compaction. Filtering the entire coagulated mixture appears satisfactory, especially since dewatering is rapid.

The large chemical dosages required and the large volumes of sludge produced indicate that recovery of both the coagulant and the dye may be practical. Preliminary studies of the re-use of precipitated dye and the recovery of the coagulants confirm these indications.

Acknowledgment

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Operators' Reports and Suggestions

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SEWAGE PUMPING INSTALLATIONS AND MAINTENANCE *

By Newell L. Nussbaumer

This discussion approaches the subject of design more from the operator's standpoint than the engineer's, and calls attention to features which, if incorporated in the design, will facilitate proper operation. There is a great need, particularly in small plants, for cooperation between operators and engineers in preparing designs.

The cause for pumping in a sewer system or at a treatment plant is, of course, obvious: to lift sewage from a lower to a higher level to permit outfall to some final point of disposition.

For strictly sanitary or domestic sewage, the fluctuations in flow are not too great and can be reasonably calculated by the designer. When storm flow is also involved, the calculations cannot be as exact, the fluctuations are far greater, the maximum being possibly thirty times the dry weather flow. The third case is the worst, when storm flow is permitted to enter a sanitary system where neither the sewers nor the pumps were intended for such service. In such a case, a by-pass is probably the most frequent solution.

The New York State Department of Health now has some rather rigid requirements for pumping installations which are in the operators' interests, among which are the following:

(*a*) Main pump stations must have at least three pumps.

(*b*) With the largest pump out of service, the other two must be able to pump the maximum flow.

(*c*) Sizes should be proportioned to anticipated flows.

(*d*) Power should be available from two sources where electric power is subject to interruption.

(*e*) Secondary lift stations should have duplicate equipment.

(*f*) Screening devices should, in general, be placed ahead of the pumps.

(*g*) Pumps should be located in a dry well.

If these requirements are all observed, a very good start has been made towards a good pump station. However, there are many stations in this district which were built before these regulations were in force.

* Presented at Meeting of Western New York Section, New York State Sewage Works Association, Dec. 14, 1940.

It is interesting to comment on some of these, and from the mistakes observed, formulate further principles of good practice.

A pumping installation to be inclusive should be considered jointly with such structures or equipment as affect the quality of sewage to be pumped, and the efficiency of the pumps themselves, which includes screen and grit removal facilities.

Basket screens and bar screens, located so as to be very difficult to clean, were frequently installed. These screens have two principal objections: They clog easily, often because the operator cannot clean the screen and dispose of the screenings without unusual exertion.

Therefore, let us say:

A bar screen, or other screening device, should be located to permit ready cleaning, and some easy way provided to dispose of screenings. Where the size of installation warrants the expense, mechanically raked screens with grinders, or a comminutor installation, is recommended.

A grit chamber ahead of pumps reduces wear on the pumps, particularly in a combined sewer system. However, if the invert elevation is rather deep in the ground, say twenty feet or more, the economics of additional wear on the pumps as against cost of the grit chamber installation should be studied. There are recent installations of both types near here which have been operated satisfactorily. When the grit chambers are placed after the pumps, the wearing rings on the pumps should be made of hardened steel, and water under pressure used in the stuffing boxes. It would be advisable when buying the pumps to inform the pump manufacturer of the conditions. Adequate facilities should also be provided for removing grit to a point of final disposal, such as craneways, or mechanical grit removal devices. In many of the older installations, the wet wells were designed too large, so that large quantities of grit and organic matter deposited in them. It is important that the velocity in a grit chamber be controlled by proportional weirs, a following Parshall flume, or other device.

From the grit chamber, sewage flow generally enters the pump wet well in which the pump suctions are located. Where three or four pumps, or more, are to be installed, probably the wet well should be divided into two sections which can be used jointly or separately to facilitate cleaning and repairs. The size of the wet well should be such as to permit pump operation without too frequent stopping and starting, and at the same time not provide a sedimentation basin. We have encountered several where the period of detention in the wet well was even greater than in the primary sedimentation tanks at the sewage treatment plant. The floor of the wet well should be sloped toward the pump suctions. If an operator has a well with a flat bottom, this can be corrected easily by installing a fillet of concrete. The wet well should also provide sufficient depth so the pumps will be primed at average pumping level in the wet well.

The pump operation will probably be controlled by a float switch operating from the levels in the wet well. This float tube should be located in such a way that the float and cable can be replaced if necessary. A float and cable of non-corrosive material is advisable to avoid frequent replacements. It is quite helpful to an operator to have a wet well depth indicator near his control panel. This may be a part of the float switch, or a separate instrument.

Proper ventilation should be provided for a wet well to prevent condensation, and to remove foul odors and corrosive gases. There is one case nearby where oils and gasoline are frequently found in the entering sewage in objectionable amounts. In such cases, where an explosive mixture might develop, ventilating, or other equipment, should all be provided with explosion-proof electrical motors and starters. Adequate lighting should also be provided in a wet well and a safe means of access. Too frequently a narrow, steep, ladder, which is frequently wet and slippery, is the only means of descending to a screen platform.

The discussion of pumping equipment will be limited to centrifugal pumps as practically all sewage pumps in use in this district are of this type.

The major portion of present installations, except for a few of the larger plants, are all vertical, submerged pumps in a dry pit, driven through shafting by a motor located on the ground floor level of the pump station. In a number of cases, the shafting is twenty-five or more feet in length, requiring a large number of intermediate supports. Again, a fairly safe way to develop rules for good installations is to discuss the faults found in some of the older ones which have proved difficult and expensive to operate.

In some cases, the shafting has not been sufficiently rigid to prevent whip, or the bearings have worn to allow it. The bearings have been oil lubricated, and generally the oil applied too freely. The result is a well oiled pump room from top to bottom. There are several things which can be done to improve this kind of an installation:

(*a*) The motors can sometimes be lowered to a level above high water which is considerably below ground floor level, thereby reducing the shaft length.

(*b*) Grease lubrication can be substituted for oil lubrication. In this connection, it is further found to be more satisfactory to provide access for inspection to the point of lubrication, rather than a length of tubing with a pressure type grease fitting at some remote point.

(*c*) In some cases, heavier shafting of the Watson-Spicer or Dodge type can be installed with a reduction of points of intermediate support and number of intermediate bearings.

A clean-out hand hole should be provided in the pump or suction elbow so that clogging material can be removed.

Pumps should be located so that they will prime when starting. However, it may happen that due to turbulence in the wet well, or other reasons, the pump may become air bound or lose its prime. An air release valve should be provided at a high point in the casing to permit the release of air.

Gauges on the suction and discharge side of the pump are helpful in watching the operation, and may be the means of quickly indicating a clogging of the piping or falling off in efficiency of the pumps. An operator should have on hand a set of pump curves for the pumps under his care, so he may observe the pump operation for variations from intended performance.

Of course, a high efficiency is desired in a pump. However, this may sometimes be obtained at the expense of free openings and tight clearances so that a pump will clog more easily. A pump in sewage service should give steady and reliable operation primarily. If the pump must be removed from service, often due to characteristics producing high efficiency, then a less efficient but more reliable pump would be preferred.

Slow speed pumps, particularly in the larger sizes are desirable. To reduce the size of the motors and the cost, sometimes geared motors are used, which operate at several times the pump speed. It goes without saying that the pump should be designed for the proper heads, and the size chosen to conform with the anticipated flows. However, sometimes due to lack of knowledge, or an attempt to use an old pump for a new purpose, or the changing of the cycle of a motor without changing the pump impeller for the change in speed, or other reasons which may occur to you, an improper pump is installed. This pump, in the interest of economy, should be replaced with a proper unit.

In an effort to provide maximum flexibility of pump capacity with a minimum of units, and to eliminate the stopping and starting of the pumps, two speed or multiple speed motors are used so that after a pump is placed in operation, by increasing or decreasing the speed, its capacity can be altered to fit closely with the rate of flow.

Where a second source of power is required, a gasoline engine is frequently provided directly connected to the pump shaft through a right-angle gear drive unit so that either the motor or engine can be used by operating a clutch.

In other cases, a separate pumping unit is provided with a gas engine drive. On the Niagara Hudson system near Buffalo, the interruptions to service are so infrequent that generally a second source of power is not deemed necessary.

There is now an increasing tendency to use vertical lift, horizontal type pumps with some sort of vacuum priming. While there are not many in this district, some of the larger and more recent pumping installations are of that type. Examples are Gary, Indiana, and the Blue Plains plant at Washington, D. C. Situations where the suction lifts do not exceed 15 ft. are particularly adapted to this type of pump. The advantages are the ability to place the pumps and motors direct connected above high water, the reduction in space required at a lower level, greater ease in maintenance.

Ejectors are now also finding increased use where the handling of screenings would be difficult, and the heads are not high or the capacities large. Very good performance can be expected under 30 ft. head and up to 350 g.p.m.

Piping to and from the pumps is important. The piping itself should be properly sized. Couplings in strategic locations should be provided to assist in dismantling the piping in case of repairs. No air pockets should be formed in the suction lines. A check valve of the non-slam type on the discharge side should be provided with free opening equal to the main pipe size. Gate valves should be placed in the suction and discharge lines to permit removing the pump from service without interfering with the other pumps. Adequate supports should be provided for the piping so that the load is not transmitted to the pumps.

Where the valve location makes operation difficult, special means such as chain falls, cat walks, or extension operating stems, should be provided to assist the operator in turning the valve, and an indicator should be provided to show the position of the valve opening.

A sump pump should be provided in the pump room to keep the floor dry. This pump can also be used to dewater the wet well in case of repairs, if the proper pipe connections are made.

We recommend that the pump room should be well ventilated, painted a light color which will reflect light, and can be easily cleaned, and should be well lighted. In addition, wall plugs should be located at convenient points for trouble light use or electric tool operation.

An operator should know the volume of flow pumped by his equipment. This knowledge can be secured in a number of different way. Two of the most common are the Venturi meter and the Parshall Venturi flume. Both have their advantages. The Venturi throat placed in a pipe line, particularly where adequate screening has not previously been provided, is very likely to clog particularly in the smaller sizes. If the lengths of pipe required ahead of the throat are such as not to give accurate measurement, and straightening vanes are used, they too will probably clog. The Venturi flume is a larger structure, is usually placed above ground, and to its advantage rarely clogs, but if such occurs, is readily cleaned. The recording of flows will probably be on an instrument mounted on or near the control panel. We recommend the type with recording, integrating, and indicating features so that an operator can secure information for making out reports, and readily check operation with a minimum of time and effort.

The control of pump operation is, of course, accomplished with the electrical control equipment. This is much more satisfactory, and frequently very little more expensive, if mounted on a panel where all the equipment and instruments can be together. Often, in smaller plants, the operator is not a skilled electrician. Operation is, therefore, safer in this type of plant by pushbuttons with indicating lights than the pulling of various starters and breakers. In case of trouble, a proper mechanic can be called to make the repairs. The panel is probably most convenient if located on the ground floor, with a good light, and not too close to a lane of common travel. Any high voltage equipment should be safely screened off. The control room will present a pleasing appearance if finished with floor tile, and interior brick which will not require painting. The cost should not be excessive. Much time and expense in maintenance is saved with this type construction. If a building presents a pleasing appearance in the beginning, then there is a better chance of maintaining it in good condition in the future.

Safety protective devices and guards should be installed where needed such as around shafting at an intermediate floor. A telephone in the pump station is convenient in case of breakdown so the operator can make a report at once. Where a station is placed on automatic operation, some device should be provided so as to notify the proper parties in case of a failure. Lacking such a device, fairly frequent inspection should be provided. Overload and undervoltage protection should be provided for the motors. As a further protection, it is well to have the motor of such size that it will not be overloaded at any point in the pump curve by over 10 per cent.

Cranes, hoists, or other similar equipment should be provided, and access to openings allowed so that various items of equipment can be installed in the first place and removed later for repairs.

Where there are many small pipes in use, such as heating, hot and cold water, vacuum lines, etc., a schedule of colors for the pipes is helpful.

There are on the market now a number of special designs of pumps for particular circumstances. The mixed flow pump is a centrifugal pump particularly adapted for pumping large capacities at low heads with high efficiency. The screw propeller pump is a pump combining a feature to chew up rags and solids in the sewage before the flow enters the pump. There are now on the market several pumps with built-in vacuum priming systems.

In buying new pumps, it is advisable to specify that the unit shall have had a factory test, so that it is known that the various parts of the unit will fit together.

This discussion has outlined the major points considered in a pumping installation. Some operators have in their charge all of the facilities mentioned. Others have some, and would, no doubt, have better operation with the inclusion of those features which they lack. Some details in pump construction have been purposely omitted because the discussion of this paper is to be led by Mr. Allen Hopper of the Turbine Equipment Company whom I know is exceptionally well qualified to advise you on the details of construction.

Discussion

Mr. Hopper pointed out the advantages of wearing sleeves in the casing and on the impellers. These sleeves are readily replaced at little cost and materially increase the life of the pump. He further pointed out that the reason a customer frequently gets an unsatisfactory pump is because the specifications are inadequate. Pump manufacturers are anxious to sell their pumps. When the selection is to be made on a price basis, they, of course, bid on their cheapest line, and omit all but the bare essentials, even though they have a more suitable pump, which over a period of years might prove more economical, even though the first cost is high.

The pump manufacturer would much prefer to sell the best pump for any particular situation. Therefore, it is urged that in taking bids for pumping equipment:

First: A fairly complete description be given under which the pump is to operate, and

Second: A description of the type of pump, together with drive and control equipment, be included.

Mr. Hutcheson—Operator in Charge-of-Plant, Newark, New York

Mr. Hutcheson inquired as to how far a description of the pump should go. His feeling was that if too much were included, the specifications would be limited to a comparatively few, or possibly only one manufacturer.

Mr. Hopper answered that the best way was to include, in general, only those points which involve good construction and without which a pump would not be considered satisfactory.

Mr. Youngs—Operator at Town of Tonawanda No. 2 Plant

The question was asked as to arrangement of piping on suction side of pump, particularly with regard to reduction in pipe size. The answer was to use an eccentric reducer to eliminate air pockets.

Mr. Velzy—Works Superintendent, Buffalo, New York

Engineers, when drawing specifications, particularly in regard to existing plant extensions where an operator is in charge, should consult with the operator regarding requirements and equipment to be supplied. He also advocates the periodic checking of all equipment operation.

SPRINGFIELD SANITARY DISTRICT'S ANNUAL REPORT FOR 1939

By C. C. Larson, *Chemist*

In 1929, the Springfield sewage plant was placed in operation. Ten years later, in the annual report, are shown photographs of the plant in 1929 and in 1939. Some of these are reproduced, herewith.

A nine year summary of data is shown in Table I, and Table II gives a log of important events.

TABLE I.—*Statistical Summary*

Yearly Totals	1931	1932	1933	1934	1935	1936	1937	1938	1939
Connected population	70,000	70,000	70,000	70,000	72,000	75,000	75,000	80,000	85,000
Population equivalent	67,975	74,268	66,700	72,525	62,104	74,166	79,362	70,373	74,717
Sewage treated—in million gallons	2,308	2,811	2,396	2,303	2,471	2,316	3,066	2,779	2,677
Air consumed—in million cubic feet	1,424	2,445	1,922	2,133	1,850	1,933	1,820	1,906	2,011
Solids added to digesters—in million pounds	2.25	3.27	2.77	3.50	3.10	3.99	4.70	3.82	3.81
Volatile solids added to digesters—in million pounds	1.40	2.00	1.78	2.25	1.93	2.64	3.09	2.39	2.50
Dry sludge produced—in tons (50% moisture)	1,025	1,475	1,178	770	959	1,114	1,075	1,470	1,182
Gas produced—in million cubic feet	14.86	13.79	14.82	19.66	18.36	22.35	20.12	21.37	22.58
B.O.D. in raw sewage—p.p.m.	187	168	152	181	128	188	151	159	170
B.O.D. % removal	67	90	91	91	94	92	91	91	91.6
Miscellaneous Factors									
Gas—in cubic feet per capita per day	.58	.54	.58	.77	.71	.83	.74	.73	.73
Gas—in cubic feet per million gallons of sewage treated	6,477	4,906	6,184	8,535	7,582	9,650	6,562	7,690	8,434
Gas—in cu. ft. per pound of solids added to digesters	6.62	4.22	5.36	5.61	6.04	5.60	4.28	5.60	5.92
Gas—in cu. ft. per lb. of vol. solids added to digesters	10.62	6.90	8.23	8.72	9.71	8.46	6.51	8.95	9.03
Per cent reduction of suspended solids in digesters	42.5	26.6	38.7	32.7	37.2	36.2	45.3	30.1	31.4
Per cent reduction of volatile solids in digesters	64.6	47.9	59.4	52.0	60.9	58.0	65.6	51.1	52.9
Suspended solids in raw sewage, lb. per capita per year	48.8	53.7	42.8	54.1	45.9	55.8	66.9	51.3	48.0
Suspended solids in pounds per million gallons of sewage	1,483	1,356	1,250	1,643	1,338	1,807	1,636	1,476	1,523
Cost—per million gallons of sewage treated	$14.45	$12.11	$12.61	$11.93	$12.16	$13.36	$11.91	$16.88	$15.90
Cost—per capita per year	$ 0.48	$ 0.53	$ 0.41	$ 0.39	$ 0.42	$ 0.41	$ 0.49	$ 0.59	$ 0.50

TABLE II.—*Log of Important Events*

Jan. 9. Established a new record for gas production; 114,400 cubic feet.

Jan. 25. Flooded our sunken garden with digested sludge in an effort to fertilize the grass. Am afraid we overdid it.

Jan. 30. Very heavy snowfall. All roads blocked.

Feb. 24. Due to poor gas production we were forced to turn in an electric blower for the first time in four months.

Mar. 1. A bad flash over on the electric switch board ruined several current transformers and caused serious damage to other equipment. There are too many automatic features about this board.

Mar. 6. Took first sludge of the season from the drying beds.

Mar. 12. High water in Spring Creek backed up into our main outfall. On the one occasion in ten years that we had use for the valve closing off the outfall it refused to close. Plant by-passed for 24 hours.

Apr. 15. One of the main drag chains in the Link Belt secondary tank broke and was replaced by a new chain. These chains have been in service 7½ years.

June 8. Activated sludge is behaving badly.

July 10. Sewage Works dedicated ten years ago today.

June 27. Burned out a bearing on large electric blower, due to failure of oil pump. Small electric blower back in service after flash over on March 1.

Aug. 1. Trustee J. A. Van Nattan resigned from Board and Roger E. Chapin was appointed to fill the vacancy.

Sept. 7. Activated sludge is very bulky and the sludge blanket rose to the weir crests of the secondary tanks today.

Sept. 18. Reduced flow to aerators to improve the activated sludge.

Sept. 20. Drew two beds of sludge using alum as an experiment.

Sept. 26. Drag chains in Link Belt Primary tanks No. 2 and 3 broke and were replaced by new chains. These chains have been in service 10 years.

Oct. 2. Switch board blew up again. This is getting to be a habit.

Oct. 8. Heavy rain today broke a 47 day drought. Needless to say it was welcome.

Nov. 9. Replaced main traction wheel on Dorr primary tank.

Nov. 20. Sludge index is down to 80 after a prolonged period of bulking.

General view of treatment works when placed in operation.

Same view after ten years.

Main building in 1929.

Main building, ten years later.

Editorial

A MORE USEFUL FEDERATION

The reorganization of the Federation is now well under way and the various member associations are considering the new Constitution and By-laws as they affect the local groups. The most important change to be considered by each local group relates to the classification of its members as active members of the Federation, whose dues will be three dollars per year in 1942. Each association is given the privilege of determining the number of its members who wish to continue to be active members of the Federation. They will receive all publications of the Federation and may serve on its Committees and vote in its elections. Affiliate members remain members of the local association, and pay their local dues, but are members of the Federation in name only.

Active members must therefore pay three dollars per year after 1941, in place of the $1.50 they are paying this year.

The Federation plans to offer considerably more service to active members than has heretofore been possible. Our new and capable Executive Secretary, Mr. Wisely, is bending every effort to make the Federation's services more valuable to the average plant operator. He is planning to broaden the Operators' Section in the SEWAGE WORKS JOURNAL, so that it will be of increased interest and value to the operator. He is soliciting information from operators all over the country as to their problems and experiences. He plans to visit as many meetings as possible in order to obtain first-hand information on operators' problems.

For several years the Federation officers have stressed the need for economic aid to the operators of small plants. State boards of health have been trying for years to raise the status, both technically and financially, of sewage works operators; local associations have also sought to improve the stability and economic independence of their operators; now the Federation will add its influence to standardize and equalize, as far as possible, the status of operators throughout the country.

The Federation plans to extend its committee activities and will publish, from time to time, reports of the Research, Standard Methods, and Sewage Works Manual Committees. Other committees might well be organized, possibly on Cost Data, Operators' Ratings, Annual Reports, and Maintenance of Sewerage Systems.

It is the intention to make the functions of the Federation so much more attractive to operators that they will be glad to pay the slight additional fee of $1.50 per year, in order to remain as active members, to whom all publications and benefits of the Federation will be available. It is too bad that in many parts of the country operators of small sewage works are paid so little that any expense beyond the necessities of life is a sacrifice. It is to be hoped that the concerted efforts of the Federation, the local associations, and the state departments of health will result in improved status and increased salaries for these men.

The Federation, as a more closely integrated organization, now faces a new duty, namely, to give consideration to the problems of defense and military development within the next few years. Sewage disposal is second only to water supply as a national public health problem, and the Federation should prepare to make its influence felt more strongly than heretofore in the country's defense plans.

In order to carry on the fine record of development of the Federation to date, officers of local associations should do everything possible to keep the members of their local associations in the Federation as active members. It will take time to demonstrate the value of the plans now under way to improve and enlarge the functions of the Federation, but in future years those who have remained with the Federation will not regret it.

F. W. Mohlman

Proceedings of Local Associations

IOWA SEWAGE TREATMENT CONFERENCE AND IOWA WASTES DISPOSAL ASSOCIATION

Twenty-second and Fourteenth Meetings, Respectively

Iowa State College, Ames, Iowa, November 7–9, 1940

The twenty-second Iowa Sewage Treatment Conference was held in Ames on November 7, 8, 9, 1940, under the auspices of the Iowa State College and the Public Health Engineering Division of the State Department of Health. One hundred and ten superintendents and operators of sewage works, municipal and sanitary engineers, and city officials were present from fifty-one municipalities.

The program opened Thursday morning, November 7, with Conference Director L. J. Murphy presiding. A. H. Wieters, Director of the Public Health Engineering Division of the State Department of Health, gave an interesting and informative discussion of the present sewage treatment situation in Iowa together with the trends and new developments in the field. The problem of handling and disposing of grit was discussed by Paul Winfrey, superintendent of the Des Moines Sewage Works, and Charles Wilson, superintendent of the Waterloo Sewage Works. The matter of "Eliminating Health Hazards at Sewage Treatment Works" was then discussed by Paul Houser, Assistant Engineer of the Public Health Engineering Division of the State Department of Health with a great deal of interest to everyone present.

The afternoon program opened with the presentation of a topic of general concern to Iowa Municipalities, "The Nuisance Liability of Cities," by Alan Loth, Attorney of Fort Dodge. The rest of the afternoon was devoted to a practical study of "Sewage Settling Tank Performance" led by Earle L. Waterman, Professor of Sanitary Engineering, State University of Iowa; "Sludge Digestion Tank Operation" by Charles D. Mullinex, Public Health Engineering Division, State Department of Health; and "Methods of Sludge Disposal" by John C. McIntyre, superintendent, Cedar Rapids Sewage Works.

An interesting discussion of "Mechanical Devices in Treatment" by C. P. Lewellen, of the H. R. Green Co., Cedar Rapids, B. K. Hartman, Link Belt Co., Chicago, and W. B. Marshall, Chain Belt Co., Milwaukee, opened the Friday morning program. This was followed by a talk on "Hydraulic Problems in Sewage Disposal" by W. E. Galligan, Civil Engineering Department, Iowa State College. Dr. Max Levine, Professor of Bacteriology and Sanitary Bacteriologist of the Engineering Experiment Station, then presented a scholarly paper on "The Role of the Trickling Filter in Sewage Treatment." Research tests on "The

Efficiency of Rotary Sewage Distributors'' were discussed by Professor Earle L. Waterman with interest to the group.

''Sludge Gas Utilization'' was the topic first on the list in the guided discussions of the afternoon. This was started by T. R. Lovell, Superintendent of the Fort Dodge Sewage Works, and Charles Wilson, Superintendent of the Waterloo Sewage Works. W. H. Wisely, Engineer-Manager of the Urbana-Champaign Sanitary District, then directed a lively discussion on ''Nuisances—Flies, Weeds, Odors, Pooling.'' A common-sense, informative talk on ''Maintaining Good Public Relations'' concluded the afternoon program.

Saturday morning was devoted to a series of practical discussions on plant operation problems. W. H. Wisely directed the exchange of ideas on ''Maintenance—Keeping the Plant in Operation'' with real benefit to the group. The possibilities of ''Garbage Disposal in Conjunction with Sewage Treatment'' were presented by Professor B. A. Whisler of the Iowa State College Civil Engineering Department. Helpful ideas on ''Landscape Treatment of Sewage Works'' were brought out in an illustrated talk by Professor John R. Fitzsimmons of the Iowa State College Landscape Architectural Department. The Conference concluded with a round table discussion of ''Sewage Plant Tests and Results'' under the direction of George C. Ahrens of the Public Health Engineering Division of the State Department of Health.

The Fourteenth Annual Convention of the Iowa Wastes Disposal Association opened with a Dutch Lunch and Smoker, Thursday Evening, November 7, following the first day's sessions of the Iowa Sewage Treatment Conference.

The annual business meeting was called to order Friday afternoon, November 8, at 3:30 P.M., by President Elmer E. Dye. The reports of the Secretary-Treasurer were read and approved. Financial reports of the business of the Association during the past year were passed out to the members.

The proposed reorganization of the Federation of Sewage Works Associations was then introduced for consideration of the members. The two Iowa representatives to the Board of Control, Max Levine of Ames, and Earle L. Waterman of Iowa City, had both attended the October 5 meeting of the National Federation in Chicago, and they were asked to report. They explained the financial and business status of the Federation and gave the reasons for reorganization. Proposed changes in the Constitution and organization of the Federation were taken up and discussed item by item. The matter of a raise in Federation, and thus State, dues was discussed at length with many feeling that an increase might have a serious effect on the membership in the Association of representatives from the smaller communities. It was agreed that dues to these members should be kept as low as possible. On motion the Association voted to approve the proposed reorganization as contained in the new Constitution with revisions as suggested by Dr. Levine's Committee. The Executive Committee of the Iowa Wastes

Disposal Association was instructed by a second motion to revise the Constitution and By-laws of the State Association to conform to revised Federation requirements.

The Committee on Licensing, through T. R. Lovell, made a comprehensive report of its investigation of Licensing of Sewage Works Operators in other states. They stated that in general the results have been good. The report was highly commended, and upon motion the Committee was continued and asked to bring in definite recommendations on Licensing of Operators in Iowa Plants.

The selection of officers for the coming year then followed with the following being unanimously elected:

President	George C. Ahrens, Des Moines
Vice-President	T. R. Lovell, Fort Dodge
Director	Paul Winfrey, Des Moines
Director	R. G. Miller, Vinton
Representative to the Board of Control, Federation of Sewage Works Associations	Earle L. Waterman, Iowa City (To serve until reorganization of Federation)
Representative to the Board of Control, Federation of Sewage Works Associations	Max Levine, Ames (To continue as Iowa Association representative)

The business meeting then adjourned.

The annual dinner was held Friday Evening, November 8, at the Iowa State College Memorial Union. Guest speaker was Colonel E. B. Bush of Ames, who spoke interestingly on the topic, "Sanitation in and about Army Camps."

LINDON J. MURPHY,
Secretary-Treasurer

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Thirteenth Annual Meeting, New York, N. Y., January 16–18, 1941

The thirteenth annual meeting of the New York State Sewage Works Association was held in New York City, January 16–18, 1941, with headquarters at the Hotel McAlpin. Over 300 members and guests were registered.

Professor M. L. Malcolm, Director of the School of Civil Engineering at Cornell University, Charles R. Velzy, Works Superintendent of the Buffalo Sewer Authority at Buffalo, and Lawrence L. Luther, Commissioner of Sanitation at Freeport, were elected to the Executive Committee for a period of three years. Mr. Herbert H. Wagenhals of

Syracuse was elected President and Mr. Robert C. Wheeler of Albany Vice-President. Mr. A. S. Bedell of the State Department of Health, Albany, was reappointed Secretary-Treasurer. Mr. J. C. Brigham and Mr. Arthur W. Eustance of Albany were appointed Assistant Treasurer and Assistant Secretary, respectively, for the ensuing year.

The program was arranged so that the members of the Sewage Works Association were able to attend all the Thursday sessions of the Sanitary Engineering Division of the A. S. C. E. And in like manner the members of the A. S. C. E. attended the technical sessions of the N. Y. S. S. W. A. on Friday and the joint inspection trip on Saturday.

At the general business meeting on Friday it was noted that the Association now has a membership of over 700 and that the Executive Committee had approved the formation of the Central New York Section, making a total of five local sections in the state. The reports of the activities of these sections and of the various standing committees were presented and considerable interest evinced.

At the technical sessions on Friday morning Mr. Earl Devendorf, Assistant Director of the Division of Sanitation of the New York State Department of Health, presented a paper on "Achievements in Sewage Treatment in New York State During the Past Decade." This paper gave a wealth of statistical and interesting construction data but time did not permit much discussion.

At the luncheon Messrs. George E. Symons and William L. Torrey of the Buffalo Sewer Authority were presented with the Kenneth Allen Memorial Award for 1940 for the most meritorious paper of a technical and research nature.

Mr. Nicholas Miljevic of Lackawanna was presented with a similar bronze plaque for the most meritorious paper covering the solution of certain operating problems at the City of Lackawanna sewage treatment plant.

Mr. C. George Andersen, the retiring President, was presented with a gold key bearing the emblem of the Association.

In the afternoon session Gordon M. Fair, Professor of Sanitary Engineering of Harvard University, presented a very scholarly paper on "The Effects of Sewage Sludge Deposits on the Quality of Streams," which aroused considerable discussion and is the forerunner of a series of studies. Following this, Charles R. Velzy, Works Superintendent of the Buffalo Sewer Authority, presented a paper on "Public Relations in the Construction and Administration of Sewerage Works," and Rodney E. Cook, Sanitary Engineer of the Suffolk County Department of Health, gave a paper on "Operating Experiences at the Riverhead Activated Sludge Sewage Treatment Plant."

In preparation for the inspection trip on Saturday, Mr. Richard H. Gould, Acting Deputy Commissioner of the Department of Public Works of New York City, spoke on "Present Status of Sewage Treatment in the Boroughs of Queens and Brooklyn," which was illustrated with many lantern slides.

Friday evening the members of the N. Y. S. S. W. A. and of the Sanitary Engineering Division of the A. S. C. E. enjoyed their usual annual banquet and were greeted very graciously by Frederick H. Fowler, President-elect of the A. S. C. E.

After the dinner the group listened spellbound to the experiences in the war zones of Europe as related by Robert C. Campbell, representing the Dorr Company in Holland, and S. R. Williams, representing the Worthington Pump and Machinery Company in France and Spain.

On Saturday a joint inspection trip was made by 130 persons in some 40 private cars and cars furnished by the city. This was a quick trip through the Midtown Tunnel, a comprehensive view of the marginal areas of Brooklyn and Queens, Owls Head Sewage Treatment Plant site, Shore Drive, Coney Island Plant, 26th Ward Plant site, Jamaica Plant, Cross Island Parkway, and Tallman's Island Plant.

Following luncheon at LaGuardia Airport a visit was made to the Pan-American Airways offices and hangar.

The Spring Meeting of the Association will be held in Niagara Falls on June 19–21, 1941.

A. S. Bedell, *Secretary*

Federation of Sewage Works Associations

CONSTITUTION AND BY-LAWS

CONSTITUTION

Article I

Name

The name of this organization shall be the Federation of Sewage Works Associations, hereinafter designated as the Federation.

Article II

Objectives

The objects of this Federation shall be: The advancement of fundamental and practical knowledge concerning the nature, collection, treatment and disposal of sewage and industrial wastes; the design, construction, operation and management of treatment works; the study, promotion and encouragement of improved sanitation of waterways; the correlation and strengthening of regional and state sewage works associations or conferences within or without the United States of America; the publication of a journal; and other relevant activities.

Article III

Membership

The membership of the Federation shall consist of regional or state associations or conferences, either within or without the territory of the United States of America, hereinafter designated as Member Associations, whose objectives and constitutions are in harmony with the purposes of this Federation, and of individuals or corporations as specified in the By-Laws, subject to the conditions and limitations prescribed in the Constitution and By-Laws of the Federation.

Article IV

Organization

Section 1. The affairs of the Federation shall be conducted by a Board of Control (hereinafter designated as the Board), under such rules as the Board may determine, subject to the specific conditions of this Constitution and By-Laws.

Section 2. The officers of the Federation shall be a President, a Vice-President, a Secretary, a Treasurer, and an Editor.

Section 3. The Board shall consist of:

(*a*) The President of the Federation.
(*b*) The Vice-President of the Federation.
(*c*) The Treasurer of the Federation.
(*d*) One Director to be appointed by and to represent each Member Association.
(*e*) Six Directors-at-Large, of whom three are to be elected by the Executive Committee of the Sewage Works Division of the Water and Sewage Works Manufacturers' Association, and three by the Directors representing the Member Associations.
(*f*) The latest living Past President of the Federation.
(*g*) The Chairman of the Organization Committee.
(*h*) The Chairman of the Publications Committee.
(*i*) The Chairman of the Sewage Works Practice Committee.
(*j*) The Chairman of the Research Committee.

Section 4. After the Annual Meeting of October, 1941, the terms of office of the President, Vice-President, and Treasurer shall be one year, and the Directors three years, which terms shall start at the beginning of the last session of the Annual Meeting of the Board at which they are elected and continue until a successor qualifies. The Secretary and the Editor shall be appointed by the Board for the terms of office stated in the By-Laws. In the case of a vacancy in the office of President, the Vice-President shall act in his place for the unexpired term. In case the Vice-President cannot act, the latest living Past President shall do so. In the case of a vacancy in the office of Treasurer or of any Director-at-Large, the Executive Committee shall appoint an Active Member to fill such office for the unexpired term.

Section 5. The President, the Vice-President, and the Directors of the Federation will not be eligible for reelection for consecutive terms.

Section 6. The President of the Federation shall be the Presiding Officer of the Board.

Section 7. A quorum of the Board shall consist of a majority of its members. Absent members may vote by proxy, all such proxies being counted in determining a quorum.

Article V

Nomination and Election of Officers and Directors

Section 1. The annual meeting of the Board in 1941 shall be held in January. Thereafter, it shall be held on the first Saturday of October in each year, or such other day in October as may mark the closing of the Annual Convention of the Federation.

At the annual meeting the Directors representing the Member Associations shall meet under the Chairmanship of the President of the Federation and shall by a majority vote of all such Directors, elect a President, Vice-President, Treasurer, and one Director-at-Large. Absent Directors may vote by proxy. Any candidate so elected shall be an Active Member of some Member Association and shall signify willingness to serve. Any candidate elected as President or Vice-President shall at some time previous to such election have been a member of the Board of Control.

The President, Vice-President and Treasurer, elected at the meeting of the Board in January, 1941, shall hold office until the beginning of the last session of the meeting held in October, 1941. Thereafter, the terms of office shall be as provided in Article IV, Section 4, of this Constitution.

Section 2. One Director on the Board of Control to represent each Member Association shall be elected by each Member Association. Each Director so elected shall be an Active Member of the respective Member Association and in good standing at the time of his election.

After the annual meeting of October, 1941, the term of each Director so elected shall be for three (3) years beginning with the last session of the Board immediately following his election, excepting that the terms of Directors to be elected by the various Member Associations to take office in January, 1941, shall be as follows:

By lot at the January, 1941, meeting, the directors then taking office shall be divided into three groups, A, B, and C. Group A shall hold office until the beginning of the last session of the October, 1941, meeting. Group B shall hold office until the beginning of the last session of the October, 1942, meeting. Group C shall hold office until the beginning of the last session of the October, 1943, meeting. The three Directors-at-Large, elected by the Board, shall be divided among these groups as shall the three Directors representing the Water and Sewage Works Manufacturers' Association. As the term of office of each group expires, the term of office of their successors shall be as provided in Article IV, Section 4, of this Constitution.

In the case of any director, representing a Member Association, retiring for any cause before his term is completed, the governing board of the Member Association shall designate his successor, who shall serve for the unexpired portion of his term.

Article VI

Except as specifically mentioned herein, this Constitution shall take effect immediately upon its adoption by the Board of Control.

Article VII

Amendments

Amendments to this Constitution may be made by a two-thirds vote of the total membership of the Board, notice of the proposed amendment having been given to each member of the Board and to the Secretary of each Member Association not less than sixty days in advance of the meeting, at which the said amendments are to be voted upon.

BY-LAWS

Article I

Member Associations

Section 1. Any regional or state sewage works association or conference, or other organization whose objectives and constitution are in harmony with those of the Federation, may be granted membership in the Federation by a majority vote of the Board; provided, that the constitution of the applicant association or conference has been examined and certified by the Board as being in accord with Article III of the Constitution of this Federation; and provided further, that certification shall be made by the association seeking admission to membership that the Constitution and By-Laws of the Federation are accepted by it.

Section 2. Any Member Association may withdraw from the Federation at the end of any fiscal year by giving three months' notice of such intention, provided that the dues of such Member Association in the Federation are fully paid up to the time of withdrawal.

Section 3. Any Member Association may be excluded from this Federation, at the pleasure of the Board, for non-payment of dues, as hereinafter provided, or for any change in its constitution that may bring it into conflict with the Constitution or By-Laws of the Federation.

Section 4. Any change in the existing constitution or by-laws of a Member Association shall be reported in full to the Secretary of the Federation within thirty days after its adoption by said Member Association.

Article II

Classification of Members

Section 1. Membership of the Federation shall be composed of Member Associations, Honorary Members, Associate Members, and Sustaining Members. Membership of the Member Associations shall consist of Active Members and Corporate Members only.

Section 2. An Active Member shall be a superintendent, manager, operator, or employee of a sewage or industrial wastes system or treatment works; a professional engineer; a chemist, bacteriologist, biologist, or any qualified person professionally engaged or interested in the advancement of knowledge relating to the disposal or treatment of sewage and industrial wastes or improved sanitation of waterways. Present membership in any Member Association is to be taken as sufficient evidence that the individual is so qualified for as long as he continues to be a member in good standing.

Section 3. A Corporate Member shall be a Sewerage Board, Department or Commission; Sanitary District; Department of Public Works handling sewerage; National, State, District or Municipal Board or Department of Health; or other body, corporation or organization engaged or interested in at least one of the stated objectives of the Federation, and shall be entitled to one representative whose name shall appear on the roll of members and who shall have all the rights and privileges of an Active Member. This representative may be changed at the convenience and pleasure of the Corporate Member on written notice to the Secretary of the Member Association to which the Corporate Member is accredited.

Section 4. An Honorary Member shall be a person of acknowledged eminence in one or more fields of activity within the scope of the stated objectives of the Federation. Candidates may be nominated by any Member Association but can be elected only by a majority vote of the Board. There shall not be more than ten living Honorary Members at any time. No candidate for Honorary Membership shall be an elective or appointive member of the Board at the time of his nomination. Honorary Members shall be elected for life and shall receive, without cost, all the publications of the Federation that are distributed to its members.

Section 5. An Associate Member shall be a person, firm, or corporation engaged in the manufacturing or furnishing of supplies, materials, or equipment for the construction, operation, or maintenance of sewerage works and shall be elected by affirmative vote of a majority of the Board after consideration of written application duly made to the Secretary.

Section 6. A Sustaining Member shall be an individual or a corporation interested in the general objectives of the Federation.

Article III

Dues

Section 1. The dues established by Member Associations, as applied to their members, shall be as determined by the Member Association.

Sction 2. (*a*) The dues paid by the Member Associations to the Secretary of the Federation shall be Three Dollars per annum for each Active Member in the Member Association on December 31st.

(*b*) For each Corporate Member the annual dues shall be Ten Dollars, payable to the Secretary of the Federation by February 1 of each year.

(*c*) For each Sustaining Member the annual dues shall be not less than Twenty-five Dollars, payable to the Secretary of the Federation by February 1 of each year.

(*d*) For each Associate Member the annual dues shall be Twenty Dollars, payable to the Secretary of the Federation by February 1 of each year.

(*e*) Corporate Members, Sustaining Members, or Associate Members whose dues remain unpaid on March 1 of any year may be dropped from membership on action of the Executive Committee.

(*f*) The dues for Member Associations outside the United States of America and its territorial possessions shall be greater than the amounts hereinbefore specified by an amount to be fixed annually by the Board as equivalent to the added cost for mailing the Journal to such associations as compared with the average cost for mailing to members residing within these limits.

(*g*) Active and Corporate Members of Member Associations, and Associate and Sustaining Members of the Federation, in good standing, shall be entitled to one copy each of all publications that are distributed by the Federation to its members.

Section 3. The fiscal year of the Federation shall begin on January first, and annual dues shall be collectible on that date and shall have been paid before February first. If the dues of any Member Association shall not have been paid by February first, fifteen days' notice of the dues in arrears shall be given to that association, after which time, if the dues remain unpaid, that association may be dropped from the rolls of the Federation on action by the Board, as provided in Article I, Section 3, of these By-Laws.

Section 4. Any member, newly elected before June 30, shall pay full dues and shall be entitled to all of the publications of the Federation that are distributed to its members during the year. Members elected after June 30 shall pay one-half the regular dues for that year, and shall be entitled to all of the publications distributed during the half year beginning July 1.

Section 5. In transmitting dues to the Federation, each Member Association shall forward with them a certified list of the names and correct mailing addresses of all members of all classes of the said association who are in good standing and are entitled to receive the Journal or other distributed publications of the Federation during the ensuing year.

Section 6. For the year 1941 dues for Active Members shall be at the rate of One Dollar and Fifty Cents per annum, as fixed under the previous By-Laws.

Dues for Corporate Members, Sustaining Members, and Associate Members for the year 1941 shall be at the rates fixed by these By-Laws.

Article IV

Duties of Officers and Directors

Section 1. The President shall have general supervision of the affairs of the Federation, and shall preside at all conventions of the Federation and meetings of the Board. In his absence, he shall designate a Presiding Officer to act in his stead at such conventions or meetings. The President shall be, ex-officio, a member of all committees.

Section 2. The Vice-President shall assist the President in the performance of his duties, and act in his stead when required.

Section 3. The Board of Control shall be the legal representative of the Federation, and as such shall manage its affairs subject to the conditions and limitations prescribed in the Constitution and By-Laws; direct the investment and care of funds of the Federation; make appropriations for specific purposes; appoint employees and fix their compensation; take measures to advance the interests of the Federation; and generally direct its business. The Board shall not incur indebtedness beyond the funds in the hands of the Treasurer and the Secretary. The Board shall hold a meeting during the Annual Convention. Other meetings shall be held at the call of the President, or on petition addressed to the Secretary and signed by ten or more members of the Board representing not less than seven Member Associations. Notice of all meetings shall be issued by the Secretary at least fifteen days in advance of such meetings to all members of the Board and to the Secretary of each Member Association.

At the Annual Meeting the Board shall appoint a Secretary to serve for a term of two years, and an Editor to serve for a term of three years, unless removed for cause by the Board.

Except as otherwise provided in the Constitution and By-Laws, all questions before the Board shall be decided by a majority vote.

Section 4. The Treasurer shall have charge of the funds of the Federation and custody of its investments, if any. He shall pay bills against the Federation when certified by himself and the Secretary. He shall make a report for each calendar year at the Annual Meeting of the Board, showing receipts from the Secretary and other sources, the expenditures, the investments and other assets, and the liabilities of the Federation. He shall make such other reports as may be required by the Board.

He shall be bonded at the expense of the Federation, and to an amount to be determined by the Board.

He shall perform such other duties as may be assigned to him by the Board.

Section 5. The Secretary shall be an Active Member and, under the direction of the President and the Board of Control, shall be the executive officer of the Federation. It shall be his duty to attend all conventions and meetings of the Board, prepare the business and duly record the proceedings thereof. He shall see that all monies due the Federation are carefully collected and without loss transferred to the custody of the Treasurer. He shall scrutinize all expenditures, shall certify to the accuracy of all bills and vouchers on which money is to be paid, and shall countersign checks drawn by the Treasurer against the funds of the Federation when such drafts are known by him to be proper and duly authorized by the Board. Once every three months he shall forward to each member of the Board a financial summary of receipts and disbursements, and at the annual meeting of the Board shall present a balance sheet of his books as of the 31st of December and as of the 30th of September preceding the meeting, together with a report of the activities of his office.

He shall have charge of the books and records of the Federation, including lists of members of the Federation and subscribers to the Journal. He shall have charge of the mechanical production and distribution of the Journal and other publications of the Federation, and shall handle all financial matters connected therewith.

He shall be bonded at the expense of the Federation, and to an amount to be determined by the Board.

He shall perform such other duties as shall be assigned to him by the Board.

The books of the Federation shall be audited annually at the expense of the Federation by public accountants to be appointed by the Board.

Section 6. The Editor shall be the literary agent of the Board and shall receive all manuscript copy and prepare it for publication. He shall have the authority to return to the author for correction, or to reject entirely, any manuscript which may be in bad condition, illegible, or clearly deficient in respect to composition, subject matter or supporting data, or otherwise conspicuously deficient or unfit for publication. He shall also have the authority to reject any manuscript which is designed to promote commercial interests. He shall be a member of the Publications Committee and of the Committee on Sewage Works Practice. Decisions of the Editor relative to rejection of manuscripts shall be subject to appeal to the Publications Committee.

Article V

Conventions of the Federation

The Annual Convention of the Federation shall be held at a time and place to be selected by the Board, preferably in the month of October. All conventions and meetings shall be conducted according to "Roberts Rules of Order."

Each member and guest present at any of the conventions of the Federation shall pay a registration fee of such amount as may be determined by the Executive Committte.

Article VI

Committees

Section 1. There shall be an Executive Committte of five members consisting of the President and four Directors. This committee shall be chosen by the Board at its annual meeting. The President of the Federation shall be Chairman, and the Secretary of the Federation shall act as Secretary of the committee. In the absence of the President, the committee shall choose a temporary Chairman from its members. The duties of this committee shall be to direct the administrative work of the Federation and carry out the policies of the Board between meetings of the latter. The Executive Committee shall present at the annual meeting of the Board a budget of estimated expenses of the Federation, including publications, for the ensuing year. On the adoption of the budget by a majority vote of the Board, the expenses of the Federation shall be limited, as far as may be practicable, within the amounts prescribed in the said budget. A quorum of the committee shall be three members.

Section 2. A General Policy Committee of seven members consisting of the latest living Past President, who shall serve as Chairman, three Directors and three Members-at-Large, appointed at the outset for terms of one, two, and three years, and thereafter for three-year terms, shall be appointed by the Board at its annual meeting. Three of the seven members of the committee shall be operators of sewerage systems or sewage or industrial wastes treatment plants.

The committee shall study and recommend to the Board upon matters of general policy affecting the well-being and usefulness of the Federation and its Member Associations; matters of public relations; the advancement of the professional and social status of members, and such other matters of similar nature as shall be referred to it by the Board.

Section 3. A Publications Committee shall be appointed by the Board at its annual meeting. It shall consist of the Editor and at least four additional Members-at-Large. Its Chairman shall be, ex-officio, a member of the Board. The Publications Committee shall arrange the technical programs for the annual convention of the Federation and shall have general supervision of the publications of the Federation and of the performance of contracts and expenditures connected therewith. The committee shall prepare general rules which, after approval by the Board, shall control the preparation, presentation, acceptance and publication of papers and shall have general supervision of such other matters of similar nature as the best interests of the Federation may require.

Section 4. An Organization Committee of at least three Members-at-Large shall be appointed by the Board at the annual meeting, and its Chairman shall be, ex-officio, a member of the Board. The Organization Committee shall examine and report to the Board on applications for membership in the Federation and also shall serve in the encouragement of the formation of new regional or state associations or conferences eligible for membership, as well as serving in an advisory capacity in other matters of a similar nature as the best interests of the Federation may require.

Section 5. A Sewage Works Practice Committee Consisting of the Editor and at least four Members-at-Large shall be appointed by the Board at the annual meeting, and its Chairman shall be, ex-officio, a member of the Board.

Any resolution, report or publication which undertakes to establish, in the name of the Federation, professional or technical standards, shall be submitted to this committee, and it shall direct such matters on behalf of the Federation.

It shall give notice by publication to the membership of all such proposed standards and report its approval or disapproval of such to the Board.

It shall appoint such sub-committees as it may deem necessary properly to carry on its work.

Section 6. There shall be a Research Committee of at least five Members-at-Large. The Chairman shall be appointed by the Board, and the other members of the Committee may be appointed by the Chairman, by and with the consent of the President of the Federation. The Chairman shall be, ex-officio, a member of the Board.

The Research Committee shall be charged with the duty of stimulating and coordinating research work among the various Member Associations, and of cooperating with other organizations in the promotion of research work.

Section 7. The Board shall appoint such other committees as may be necessary to carry on the work of the Federation.

Section 8. The reports and recommendations of all committees of the Federation shall be subject to approval by the Board.

Section 9. Members-at-Large are Active Members who are not members of the Board.

Article VII

Publications

All publications of the Federation shall be issued under the direction of the Board and shall be copyrighted as far as is practicable and proper.

Article VIII

Amendments

The Board of Control may amend these By-Laws in any manner not inconsistent with the Constitution by the two-thirds vote of those voting at any meeting of the Board or by sealed letter ballot, provided that a copy of such proposed amendment has been mailed by the Secretary to each member of the Board and to the Secretary of each Member Association at least thirty days prior to such meeting or letter ballot.

Federation Affairs

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

An important event in the history of the Federation of Sewage Works Associations occurred on January 15, 1941, in New York City, when the Federation was put on a sound and national footing.

The reorganization was carefully arranged and so constituted as to try to benefit all concerned.

The local sections are still the bulwark of the Federation but their more active participation in the entire Federation has been the aim of the new organization.

In order that all members of our organization may know what occurred at this historic meeting the minutes of meetings of the Board of Control, directors, and newly reorganized Board of Control are presented here, together with the new Constitution.

REPORT OF SECRETARY-TREASURER FEDERATION OF SEWAGE WORKS ASSOCIATIONS FOR THE YEAR ENDING DECEMBER 31, 1940

The past year has been a busy one for the Federation. The proposed Expansion and Reorganization was given official impetus by the appointment of a Committee, authorized at the January, 1939, Board Meeting, to consider methods for strengthening the Federation and to provide some plan for its further development. Its Progress Report was accepted by the Board at its January, 1940, meeting and the Committee continued.

At this same meeting it was decided to hold a Convention within a year. Committees were appointed to make necessary arrangements. An invitation was extended by the Central States Sewage Works Association, and after months of intensive planning and preparation the First Annual Convention of the Federation of Sewage Works Associations was held in Chicago on October 3–5, 1940. It was outstandingly successful and the details have already been published in the November, 1940, issue of Sewage Works Journal.

A feature of the Convention was the Business Meeting of the Federation on October 5, 1940, and the Special Meeting of the Board of Control held that evening and at which all Member Associations were represented except the two in England and the one in Argentina. Minutes of both meetings have been published in the November, 1940, issue of Sewage Works Journal, and relate the various matters considered. Possibly the most important was the approval of the Report proposed by the Committee on Expansion and Reorganization on Revised Constitution and By-Laws, and a recommendation that the Board of Control at its January, 1941, meeting should adopt and declare these in effect.

William W. Buffum, the Federation's Business Manager from its inception, died on June 22, 1940. By letter ballot the Board of Control adopted an appropriate resolution, copies of which were sent to the family of the deceased and to The Chemical Foundation, and published in the July, 1940, issue of SEWAGE WORKS JOURNAL.

Mr. Arthur A. Clay, who succeeded Mr. Buffum as Treasurer and General Manager of The Chemical Foundation, was designated by The Foundation as the new Business Manager of the Federation and, by letter ballot, was elected to fill the unexpired term of Mr. Buffum as Member-at-Large on the Board of Control.

The Secretary, by questionnaire, received from Association Secretaries data classifying membership in their several groups. These,

	Gross Membership	Dual Mems.	Gross New Mems. and Re-instatements	Did not Renew	Membership	
					Increase	Decrease
Arizona S. and W. W. Assn.	28	—	17	14	3	—
California S. Wks. Assn.	280	1	60	46	14	—
Cent. States S. Wks. Assn.	503	6	77	85	—	8
Dak. W. and Sew. Wks. Conf.						
North Dakota	7	—	—	9	—	9
South Dakota	23	—	7	12	—	5
Federal S. Research Assn.	64	1	9	5	4	—
Ga. W. and Sew. Assn.	27	—	6	7	—	1
Iowa Wastes Disp. Assn.	44	1	13	6	7	—
Kansas W. and S. Wks. Assn.	21	—	6	20	—	14
Md.-Del. W. and S. Assn.	24	—	1	2	—	1
Michigan S. Wks. Assn.	136	—	28	42	—	14
Missouri W. and S. Conf.	10	—	3	13	—	10
New England S. Wks. Assn.	187	12	31	11	20	—
New Jersey Sew. Conf. Gr.	68	—	14	7	7	—
N. Y. State S. Wks. Assn.	629	21	96	66	30	—
N. Carolina S. Wks. Assn.	80	1	20	11	9	—
Ohio S. Wks. Conf. Gr.	106	—	13	17	—	4
Oklahoma W. and S. Conf.	1	—	—	3	—	3
Pacific NW. S. Wks. Assn.	80	—	23	9	14	—
Pennsylvania S. Wks. Assn.	213	9	30	22	8	—
Rocky Mt. Sew. Wks. Assn.	38	—	12	10	2	—
San. Engr. Div. of the Arg. Society of Engrs.	2	—	—	10	—	10
Sew. Div.-Tx. Sec., S.W.W.A.	28		13	12	1	—
Can. Inst. on Sew. and San.	123	2	9	9	—	—
Inst. of Sew. Purif.—Eng.	97	—	18	30	—	12
Inst'n of San. Engrs.—Eng.	54	—	1	3	—	2
	2873 −54	54	507	481	119 −93	93
	2819 Net Mems.				26 Incr.	

nearly complete, showed by far the greatest number classified as sewage works superintendents and operators. Next in order were municipal and consulting engineers, with equipment men in third place. Incidentally, it is worthy of note that this information, as well as routine correspondence, was received from the two English associations, both with headquarters in London; another bit of evidence of the invincible fortitude of our British colleagues.

At the close of 1940 there was a gross membership of 2,873, less 54 dual memberships, leaving a net total of 2,819, or an increase of 26 in the past year. Membership was not renewed by 481, which was 74 more than in the preceding year. Details are shown in the table on page 343.

Dues received by the Secretary-Treasurer and forwarded to the Business Manager totaled \$3637.75 as against \$3685.75, a decrease of \$48.00. Petty cash expenditures of the Secretary-Treasurer for stamps and miscellaneous expenses amounted to \$24.25. Dues received are detailed below:

	For 1938	For 1939	For 1940	For 1941	Total	Refund
Arizona S. and W. Wks. Assn.	(Paid dues direct to Business Manager)					
California S. Wks. Assn.			\$ 423.00		\$ 423.00	\$1.50
Cent. States S. Wks. Assn.			745.50		745.50	
Dak. W. and Sew. Wks. Assn.			36.00	\$16.50	52.50	1.50
Federal S. Research Assn.			79.50		79.50	1.50
Georgia W. and S. Assn.	(Paid dues direct to Business Manager)					
Iowa Wastes Disp. Assn.		\$3.00	60.00	15.00	78.00	1.50
Kansas W. and S. Wks. Assn.			33.00		33.00	
Md.-Del. W. and S. Assn.			36.00		36.00	
Michigan S. Wks. Assn.		1.50	204.00		205.50	
Missouri W. and S. Conf.	(Paid dues direct to Business Manager)					
New England S. Wks. Assn.			264.50		264.50	1.50
New Jersey Sew. Conf. Gr.			102.00		102.00	
New York St. S. Wks. Assn.	\$1.50	25.50	904.25		931.25	1.50
N. Carolina S. Wks. Assn.			118.50		118.50	
Ohio S. Wks. Conf. Gr.			159.00		159.00	
Oklahoma W. and S. Conf.	(Paid dues direct to Business Manager)					
Pacific NW. S. Wks. Assn.	(Paid dues direct to Business Manager)					
Pennsylvania S. Wks. Assn.		1.50	308.00		309.50	
Rocky Mt. Sew. Wks. Assn.			57.00		57.00	
San. Engr. Div. of the Arg. Society of Engrs.	(Paid dues direct to Business Manager)					
Sew. Div. Tx. Sec., S.W.W.A.			41.50	1.50	43.00	
Can. Inst. on Sew. and San.	(Paid dues direct to Business Manager)					
Inst. of Sew. Purif.—Eng.	(Paid dues direct to Business Manager)					
Inst'n. of San. Engrs.—Eng.	(Paid dues direct to Business Manager)					
	\$1.50	\$31.50	\$3571.75	\$33.00	\$3637.75	\$9.00

H. E. MOSES,
Secretary-Treasurer.

FEDERATION OF SEWAGE WORKS ASSOCIATIONS

MINUTES OF THE ANNUAL MEETING OF THE BOARD OF CONTROL

Hotel Pennsylvania, New York City, January 15, 1941

The Annual Meeting of the existing Board of Control of the Federation of Sewage Works Associations was held at the Hotel Pennsylvania, New York City, on January 15, 1941. C. A. Emerson, Chairman, presided and convened the session at 3:30 P.M. The roll call indicated representation as follows:

Present in Person

Name of Affiliate	*Represented By*
California Sewage Works Association	Charles G. Hyde
Central States Sewage Works Association	W. W. DeBerard
Central States Sewage Works Association	George J. Schroepfer
Federal Sewage Research Association	F. J. Maier
Federal Sewage Research Association	A. P. Miller
Georgia Water and Sewage Association	Van P. Enloe
Georgia Water and Sewage Association	G. R. Frith
Iowa Wastes Disposal Association	Max Levine
Iowa Wastes Disposal Association	Earle L. Waterman
Maryland-Delaware Water and Sewerage Association	Harry R. Hall
Michigan Sewage Works Association	N. G. Damoose
Missouri Water and Sewerage Conference	George S. Russell
New England Sewage Works Association	F. W. Gilcreas
New Jersey Sewage Conference	Willem Rudolfs
New York State Sewage Works Association	Arthur S. Bedell
New York State Sewage Works Association	N. L. Nussbaumer
North Carolina Sewage Works Association	H. G. Baity
North Carolina Sewage Works Association	W. M. Piatt
Pacific Northwest Sewage Works Association	John W. Cunningham
Pennsylvania Sewage Works Association	C. A. Emerson
Pennsylvania Sewage Works Association	H. E. Moses
Member-at-Large	Arthur A. Clay
Member-at-Large	Linn H. Enslow
Member-at-Large	Charles G. Hyde
Member-at-Large	Wm. J. Orchard

Present in Person, Acting as Proxy

Name of Affiliate	*Represented By*
Arizona Sewage and Water Works Association	A. M. Rawn (for Phil J. Martin)
Arizona Sewage and Water Works Association	A. M. Rawn (for Bernard Schiller)
Dakota Water and Sewage Works Conference	Morris M. Cohn (for Lloyd K. Clark)
Dakota Water and Sewage Works Conference	H. E. Moses (for W. W. Towne)
Kansas Water and Sewage Works Association	F. W. Mohlman (for Earnest Boyce)
Maryland-Delaware Water and Sewerage Association	Harry R. Hall (for Abel Wolman)
Michigan Sewage Works Association	N. G. Damoose (for E. F. Eldridge)
Missouri Water and Sewerage Conference	George S. Russell (for W. Scott Johnson)

New Jersey Sewage Conference	Willem Rudolfs (for Richard C. Smith)
Ohio Sewage Works Conference Group	M. W. Tatlock (for Frank W. Jones)
Ohio Sewage Works Conference Group	M. W. Tatlock (for C. D. McGuire)
Oklahoma Water and Sewage Conference	W. H. Wisely (for H. J. Darcey)
Pacific Northwest Sewage Works Association	John W. Cunningham (for W. P. Hughes)
Sewage Division, Texas Section, S. W. W. A.	Charles R. Velzy (for V. M. Ehlers)
Sewage Division, Texas Section, S. W. W. A.	G. E. Symons (for W. S. Mahlie)
Member-at-Large	Albert L. Genter (for H. W. Streeter)

By consent, reading was dispensed with of the Minutes of the Special Meeting of the Board held at Chicago, Illinois on October 5, 1940, they having been printed in the November, 1940, SEWAGE WORKS JOURNAL.

Chairman Emerson and Secretary Moses each made brief verbal reports. Arthur A. Clay, Business Manager, who succeeded the late William W. Buffum, abstracted briefly his very comprehensive report on income and expenditures of the Federation for the year ending December 31, 1940, his report including a balance sheet as of December 31, 1940 and a tabulated statement of income and expenditures for the following periods: July 31, 1928 to December 31, 1939; January 1, 1940 to December 31, 1940; and July 31, 1928 to December 31, 1940. He reported a profit for 1940 of $1,368.52, exclusive of the excess of income over expenditures from the 1940 Convention of $1,449.83. This comprises a Journal operating profit of $768.37 and a 1940 profit on sale of copies of *Modern Sewage Disposal* of $600.15. On hand there are 389 copies of this publication and 5,304 copies of various back numbers of SEWAGE WORKS JOURNAL, these having an unestimated sale value.

On December 31, 1940, the assets of the Federation were $5,091.41, including cash in bank amounting to $3,588.01. The liabilities include accounts payable amounting to $1,389.69, advance subscriptions of $621.94, and suspense account of $4, leaving a surplus of $3,075.78.

In the tabular statement of income and expenditures for the year 1940, the actual printing and mailing cost of the Journal was shown to be $9,866.04; editorial, abstract and Secretary's office expense was $2,-124.06; and the Business Manager's office expense was $278.37. Other expenses, including those in connection with the reorganization committee work, totaled $624.46.

It was pointed out that the actual printing and mailing cost of the Journal, aside from editorial and other necessary management expenses, amounted to approximately $3 for each member and non-member subscriber.

Mr. Clay's verbal report was approved by the Board, which automatically constitutes approval of the written report, which written report has since been carefully examined and found to be correct.

On behalf of the convention committee, George J. Schroepfer, Chairman, presented the following report which, on motion and duly seconded, was accepted and ordered filed:

"Mr. Emerson: Jan. 15, 1941
Members of the Board of Control:

"With the First Annual Convention of the Federation of Sewage Works Associations some months behind us, and expressions of appreciation having been offered to all who played a part in its arrangements, the General Convention Committee considers its work completed.

"The report of the Committee presented at the annual meeting, and the statement in the recent issue of the SEWAGE WORKS JOURNAL, summarize the views of this Committee and constitute the record of this event.

"As a result of its contacts with a representative proportion of the membership both before and during the convention, and of its considerations since that time, the Committee makes the following recommendations:

1. That for the purpose of maintaining continuity and of taking advantage of the experience gained, one member of the general convention committee be retained on the committee to arrange for the next subsequent convention.
2. That the value of publicity continue to be emphasized, as was done in the 1940 convention, and that public relations constitute an essential part of the activities of the Federation.
3. That recognition of the highest type be accorded Mr. C. A. Emerson, Chairman of the Federation during this period, among other reasons, for his unselfish efforts in the interest of the Federation for more than a decade, which assumed still greater proportions during the past year. The Committee suggests as fitting recognition, that he receive the first honorary membership in the Federation.

"The Committee reiterates the statement in its report to the First Annual Convention that it is heartily in favor of the reorganization and revitalization of the Federation and its members pledge themselves individually to perform any additional service for which they may be called upon.

"For the opportunity of participating in the arrangements for the First Annual Convention, the Committee expresses its appreciation.

Respectfully submitted,
MORRIS COHN,
F. W. GILCREAS,
F. W. MOHLMAN,
WM. J. ORCHARD,
B. O. POOLE,
GEO. J. SCHROEPFER, *Chairman*"

Mr. Orchard presented the 1940 Convention Finance Committee report, which showed income from registration and sale of tickets of $2,600.50, and an advance from the Water and Sewage Works Manufacturers' Association of $1,500.00, or a total of $4,100.50. The total expenses amounted to $2,650.67, leaving a balance in the Finance Committee's bank account of $1,449.83. Upon motion made, seconded and carried unanimously, this report was accepted, and it was authorized that the Convention Finance Committee account in the Northern Trust Company of Chicago for the 1940 Convention, be certified by the proper resolutions which were in the hands of Mr. Orchard.

Mr. Emerson traced the history of the work done by the Committee on Reorganization and Expansion, stressing the large volume of correspondence, the number of committee meetings held, and the considerable work entailed. He then called on Mr. Orchard to read Item No. 8 of the report of the Committee on Motivation entitled: "Affiliate Members of Member Associations." This suggests a procedure for retaining the membership of low-income sewage works operators, a matter reported to be troubling nearly every Member Association, especially in anticipation of the increased dues contemplated under the revised Constitution and By-Laws. General discussion ensued, and finally by a motion which was seconded and carried, the matter was referred to the Executive Committee for further consideration and report, and then to be submitted to the Board for action by ballot.

Under the head of New Business, it was moved and seconded that the revised Constitution and By-Laws be adopted. These were distributed in printed form on October 16, 1940, by order of Chairman Emerson, to officers and members of the Board of Control and to members of the Committee on Reorganization and Expansion of the Federation, and to all secretaries, officers and directors of Member Associations of the Federation. After a prolonged discussion participated in freely by nearly all Board members present, the motion was unanimously carried and the suggested revisions of the Constitution and By-Laws were adopted.

Mr. Emerson stated that the Constitution and By-Laws just adopted provided for one Director for each Member Association. He asked the Secretary to call the roll to ascertain which of the two former representatives would remain on the Board as hold-over Directors. The list follows:

Arizona S. and W. W. Assn.	Phil J. Martin (A. W. Rawn, *proxy*)
California S. W. Assn.	Charles G. Hyde
Central States S. W. Assn.	Georgt J. Schroepfer
Dakota W. and S. W. Conf.	W. W. Towne (H. E. Moses, *proxy*)
Federal S. R. Assn.	A. P. Miller
Georgia W. and S. Assn.	Gilbert R. Frith
Iowa W. D. Assn.	Max Levine
Kansas W. and S. W. Assn.	Earnest Boyce (F. W. Mohlman, *proxy*)

Maryland-Delaware W. and S. Assn.	Harry R. Hall
Michigan S. W. Assn.	N. G. Damoose
Missouri W. and S. Conf.	George S. Russell
New England S. W. Assn.	F. W. Gilcreas
New Jersey S. Conf.	Willem Rudolfs
New York State S. W. Assn.	N. L. Nussbaumer
North Carolina S. W. Assn.	Wm. M. Piatt
Ohio S. W. Conf. Group	F. W. Jones (M. W. Tatlock, *proxy*)
Pacific Northwest S. W. Assn.	John W. Cunningham
Pennsylvania S. W. Assn.	H. E. Moses
Rocky Mountain S. W. Assn.	Chas. A. Davis
Sewage Div., Texas Sec., S. W. W. A.	V. M. Ehlers (H. E. Moses, *proxy*)

At the time of the Board meeting the following Member Associations had not furnished the names of their hold-over Directors:

Oklahoma Water and Sewage Conf.
Sanitary Engineering Division of Argentine Society of Engineers
The Can. Inst. on Sewage and Sanitation
The Inst. of Sew. Purif.—England
The Inst'n. of San. Engrs.—England

Article V, Section 1, Paragraph 2 of the new Constitution was read, this providing for the election of officers, and an invitation was extended by Chairman Emerson to the directors who retired from the Board and to all others present, to meet with the hold-over Directors at the meeting of the reorganized Board of Control immediately following the interim meeting for election of officers. He called upon the hold-over Directors to meet at once as an Election Committee, and stated that a meeting of the new Board of Control would convene as soon as the Election Committee report was ready.

Upon motion made, seconded and carried, the Board adjourned *sine die* at 4:51 P.M.

H. E. Moses,
Secretary-Treasurer

MINUTES OF A MEETING OF THE DIRECTORS OF MEMBER ASSOCIATIONS OF THE FEDERATION OF SEWAGE WORKS ASSOCIATIONS AS AN ELECTION COMMITTEE

Hotel Pennsylvania, New York City, January 15, 1941

This meeting was called to order by Mr. Emerson at 4:52 P.M., immediately following the meeting of the existing Board of Control, which had adopted the revised Constitution and By-Laws putting into effect this meeting. Mr. Emerson presided and explained the action of the Motivation Committee in preparing for this meeting, whose purpose was to effect organization under the revised Constitution and By-Laws. He then requested W. J. Orchard, Secretary of the Motivation Committee, to read the Committee's recommendation with reference to the election of officers. This was done, and the following were recommended for election:

President: C. A. Emerson, New York City
Vice-President: A. S. Bedell, Albany, N. Y.
Treasurer: W. W. DeBerard, Chicago, Ill.

(The foregoing to serve from January 15, 1941, to election of their successors at the Board of Control meeting October 11, 1941.)

Director-at-Large: Langdon Pearse, Chicago, Ill. (Term expires October, 1941.)
Director-at-Large: Linn H. Enslow, New York City. (Term expires October, 1942.)
Director-at-Large: A. M. Rawn, Los Angeles, Calif. (Term expires October, 1943.)

By motion, seconded and carried, the report was accepted and the foregoing names were placed in nomination. There were no further nominations, and on motion which was seconded and carried, the nominations were closed. By *viva voce* vote these nominees were unanimously declared elected.

Upon motion the meeting then adjourned.

H. E. Moses,
Secretary-Treasurer

MINUTES OF A MEETING OF THE REORGANIZED BOARD OF CONTROL (WITH NEWLY ELECTED OFFICERS) OF THE FEDERATION OF SEWAGE WORKS ASSOCIATIONS

Hotel Pennsylvania, New York City, January 15, 1941

This meeting followed immediately after the meeting of the hold-over Directors under the new Constitution, which elected as officers to serve until October, 1941: C. A. Emerson, President; A. S. Bedell, Vice-President; and W. W. DeBerard, Treasurer.

Roll call was dispensed with in view of the preceding roll call to determine the hold-over Directors.

The action of the new Constitution (Article V, Section 2) pertaining to the election by lot of the length of service of the new Directors, was read. The question was raised about a three-year service on the Board of a Director of a Member Association who would be elected by that Member Association for only one year. It was pointed out that the Executive Committee would have to make some provision in the Member Association for a greater length of office for Directors, and that bringing the Member Associations' Constitution into a line with the new Federation Constitution would accomplish this.

The drawing by lot established tenures of office as follows:

The Institution of Sanitary Engineers—October, 1941
Pennsylvania Sewage Works Assn.—October, 1943
Michigan Sewage Works Assn.—October, 1943
Sanitary Engineering Division of the Argentine Society of Engineers —October, 1943
Georgia Water and Sewage Assn.—October, 1941
Maryland-Delaware Water and Sewerage Assn.—October, 1942
Kansas Water and Sewage Works Assn.—October, 1942
New York State Sewage Works Assn.—October, 1942
The Canadian Institute on Sewage and Sanitation—October, 1943
The Institute of Sewage Purification (England)—October, 1941
New England Sewage Works Assn.—October, 1942
Missouri Water and Sewerage Conference—October, 1942
Ohio Sewage Works Conference Group—October, 1942
Arizona Sewage and Water Works Assn.—October, 1943
New Jersey Sewage Conference—October, 1943
North Carolina Sewage Works Assn.—October, 1943
California Sewage Works Assn.—October, 1941
Central State Sewage Works Assn.—October, 1942
Dakota Water and Sewage Works Conference—October, 1943
Rocky Mountain Sewage Works Assn.—October, 1942
Sewage Division, Texas Section, S.W.W.A.—October, 1942
Pacific Northwest Sewage Works Assn.—October, 1941
Federal Sewage Research Assn.—October, 1941
Iowa Wastes Disposal Assn.—October, 1941
Oklahoma Water and Sewage Conference—October, 1941

Mr. Orchard, at the suggestion of Mr. Emerson, read the report of the Committee on Motivation in its entirety. The adoption of the report and its recommendations was made by items as numbered in the report, as follows:

Item 1—Cessation of support of The Chemical Foundation. "The Committee recommends the establishment of a central office and the employment of a part-time Executive Secretary immediately. This is necessary because the Chemical Foundation, from whose largess the Federation has greatly benefited in years gone by, has informed the Committee that it will be unable to carry on as it has in the past after March 31st, 1941." Adopted as read.

Item 2—Location of central office. Your Committee recommends establishment of a central office in the Chicago area not later than March 1, 1941. Adopted as read.

Item 3—Appointment of Executive Secretary.

A motion was made, seconded and carried that this item be adopted, reading as follows:

"3. *Appointment of Executive Secretary.*

"Your Committee recommends the appointment of Mr. W. H.

Wisely as Executive Secretary to work on a half-time basis until the October, 1941, meeting of the Board of Control. Your Committee recommends that Mr. Wisely be paid a salary not exceeding the rate of $2500.00 per annum for this half-time employment, plus expenses approved by the Executive Committee."

Item 4—Extension of Editorial service. "Your Committee recommends that the Executive Committee make arrangements with Dr. Mohlman to continue as Editor of the JOURNAL in co-operation with Mr. Wisely until the October, 1941, meeting of the Board of Control or at a time to be agreed upon by Mr. Wisely and Dr. Mohlman with the approval of the Executive Committee." Adopted as read.

Item 5—Place of 1941 Annual Meeting. Recommends that the October, 1941, Annual Meeting be held in New York City on October 9, 10 and 11. Discussion of this item brought forth an invitation from Mr. Nussbaumer to have the 1943 Convention of the Federation in the City of Buffalo, New York. Mr. Emerson ordered this invitation filed with the Secretary, and explained that the tentative setting of New York City as the place of the 1941 Convention at the October, 1940, Board meeting had resulted in voluminous committee work and the making of a great many arrangements. Invitations had been received for the 1941 and other Conventions from Tulsa, Cleveland, and many other cities. Item 5, it was moved, seconded, and carried should be adopted as read.

Item 6—Increasing scope of JOURNAL. "Your Committee feels that it is essential that there be every effort made to make the JOURNAL more attractive to and interesting for the average sewage works plant operator." Adopted as read.

Item 7—Budget for 1941 and indicated budget for 1942. Action temporarily deferred.

Item 8—Affiliate members of Member Associations. This item dealing with affiliates of Member Associations, will require an amendment of the By-Laws. It was moved, seconded and carried that this item be adopted as read and that the recommendation of the Committee on Motivation be submitted to the Executive Committee for study and prompt report to the Board of Control. The recommendation was as follows: "Your Committee recommends the amendment of Section 1, Article II of the By-Laws, 'Classification of Members,' to permit Member Associations to have affiliates for whom the Member Associations will make no payment to the Federation and which affiliates will not receive the JOURNAL. Your Committee recommends that the procedure adopted by the New York State Sewage Works Association be used by the Member Associations as a guide. Section 6, Article III, of the proposed Constitution of the New York State Sewage Works Association reads as follows: '*Affiliates.* Sewage plant operators in the Grade III or lower classifications and sewerage maintenance men in the smaller communities *may* upon their specific request and with the approval of the Executive Committee become Affiliates of this association. Such Affiliates may become members of Local Sections of the N. Y. S. S. W. A., but shall not have voting privileges in the Parent Body and will not receive the publications of the Federation.' "

Item 9—Contribution from Water and Sewage Works Manufacturers' Association. There was considerable discussion on this item, and it was finally decided that the offer of the Manufacturers was one in good faith, that they would gain by the arrangement as the Federation would gain and would do nothing to, as it were, "foul their own nest." A motion was made, seconded, and carried that Item 9 be adopted, reading as follows:

"9. *Contribution from Water and Sewage Works Manufacturers' Association.*

"Your Committee has received a proposal from the Water and Sewage Works Manufacturers' Association offering to contribute $5000.00 per year to the general funds of the Federation to be used as the Federation sees fit in advancing its interests. In return, the Manufacturers request the privilege of taking charge of the exhibits at the Annual Meetings of the Federation. Your Committee recommends the acceptance of this contribution from the Water and Sewage Works Manufacturers' Association on the basis indicated; that is, on a mutually agreeable basis to be worked out by the Executive Committee and the Manufacturers' Association."

Item 10—Incorporation of the Federation. Provides for incorporation in the State of Illinois as an association not for profit. Adopted as read.

Mr. Orchard interjected a remark at this point, stating that in view of the action on Item 9 as above, the Treasurer of the Federation had at his disposal, when he asks for it, $5000.00 from the Manufacturers' Association. He stated, further, that the Directors-at-Large designated by the Executive Committee of the Sewage Works Division of the Water and Sewage Works Manufacturers' Association were as follows:

Term expiring October, 1942—Mr. L. E. Rein, Pacific-Flush Tank Company

Term expiring October, 1943—Mr. Wm. J. Orchard, Wallace & Tiernan Co., Inc.

Term expiring October, 1941—Mr. D. S. McAfee, The Dorr Company, Inc.

A motion was made, seconded and carried that these Directors-at-Large be accepted.

The Board then proceeded to consideration of the budget, Item 7, of the Committee's report. This was read and explained by Mr.

Orchard, and it was moved, seconded and carried that the budget as drawn by the Committee be adopted.

On motion duly made and seconded, it was unanimously

> RESOLVED, That the Federation, through its Secretary, tenders its sincere thanks to the Chemical Foundation for its help and co-operation in years past; and
>
> FURTHER RESOLVED, That Chemical Foundation, Inc., be requested and authorized to continue its present relations and functions as Business Manager of the Federation until March 31, 1941, or until such earlier date as may be mutually agreed between the officers of Chemical Foundation, Inc., and the President and Treasurer of the Federation of Sewage Works Associations, at which time the Chemical Foundation is instructed to deliver to the aforesaid officers of the Federation with proper accounting, all books, records and funds of the Federation which may be in its charge and custody. Such accounting and delivery shall automatically relieve Chemical Foundation, Inc., of all responsibility to the Federation of Sewage Works Associations.

The recommendations of the Motivating Committee with respect to Committee Memberships to October, 1941, were read, and after certain changes agreed to by the Board the recommendations were adopted on motion duly made, seconded and carried. The committees thus established are as follows:

Executive Committee (President and four Directors)
- A. S. Bedell (New York)
- Wm. J. Orchard (Manufacturers)
- Wm. M. Piatt (North Carolina)
- C. G. Hyde (California)

General Policy Committee (Latest Living Past President as Chairman, three Directors, and three Members-at-Large. Three of the total number to be operators)

Directors:
- H. E. Moses (Pennsylvania)
- Harry R. Hall—operator (Maryland)
- Linn H. Enslow (New York)

Members-at-Large:
- Carl E. Green (Oregon)
- George J. Schroepfer—operator (Minnesota)
- L. L. Luther—operator (New York)

Publications Committee (Editor and at least four Members-at-Large)
- Editor
- F. W. Gilcreas—Chairman (New England)
- LeRoy W. Van Kleeck (Connecticut)
- F. C. Roberts (Arizona)
- Chas. Velzy (New York)
- Rolf Eliassen (New York)

James L. Ferebee (Wisconsin)
W. W. Towne (South Dakota)

Organization Committee (At least three Members-at-Large)
H. W. Streeter—Chairman (Federal)
Earnest Boyce (Kansas)
N. G. Damoose (Michigan)

Sewage Works Practice Committee (Editor and at least four Members-at-Large)
Editor
F. W. Mohlman—Chairman (Illinois)
J. J. Wirts (Ohio)
Geo. H. Craemer (Connecticut)
Morris Cohn (New York)
Gail P. Edwards (New York)
B. A. Poole (Indiana)
C. E. Keefer (Maryland)

Research Committee (At least five Members-at-Large)
Willem Rudolfs—Chairman (New Jersey)

Upon motion made, seconded and carried, it was unanimously

RESOLVED, That Wm. J. Orchard should at his early convenience turn over to the Treasurer of the Federation the funds remaining in the account of the 1940 Convention Finance Committee; and

FURTHER RESOLVED, That the Treasurer and Secretary be bonded at the Federation's expense as stated in the new Constitution and By-Laws; and

FURTHER RESOLVED, That the Treasurer be, and he hereby is, authorized to open a bank account for the Federation in a bank of his choosing in Chicago; that he is further authorized to complete and submit to the Secretary for transmittal to the bank the necessary resolutions required by the bank for the account; and that the signatures required for withdrawal shall be those of the President, Vice President, or Treasurer of the Federation when countersigned by either the Secretary or Treasurer of the Federation.

Upon motion duly made, seconded, and carried unanimously, it was

RESOLVED, That in recognition of the many years of faithful service of Mr. H. E. Moses to the Federation, Mr. Moses be made Honorary Secretary of the Federation with his present compensation continued to June 1, 1941.

FURTHER RESOLVED, That the Motivation Committee considers the Federation very fortunate that Dr. Mohlman is agreeable to continue as Editor on a basis to be determined by the Executive Committee. The Executive Committee is authorized to make such arrangements. Mr. Wisely is to be, and he hereby is, instructed to assist Dr. Mohlman as Managing Editor.

Upon motion duly made, seconded and carried, it was unanimously

> RESOLVED, That a Convention Management Committee, consisting of the Chairman, two members of the Federation, and two members of the Manufacturers' Association, be created.

Upon motion made, seconded and carried unanimously, a vote of thanks was tendered to the Committee on Motivation for the fine work it had done in expediting the work of the day's meetings.

The Secretary was instructed to write a letter of thanks to the Hotel Pennsylvania in New York City for their cooperation in furnishing a room for the meeting.

There being no further business the meeting adjourned at 6:37 P.M.

H. E. MOSES,
Secretary-Treasurer.

Reviews and Abstracts

EXPERIENCES IN OPERATING A CHEMICAL–MECHANICAL SEWAGE TREATMENT PLANT

By George J. Schroepfer

Proceedings, A. S. C. E., 67, 61 (Jan., 1941)

The Minneapolis-St. Paul sewage treatment plant has been in operation since June 1, 1938. The author presents data on the performance of the plant and the cost of operation and maintenance, as well as on the improvement of the Mississippi River during the course of the first two years of operation. The plant has a design capacity of 134 M.G.D. and has the flow sheet of a chemical precipitation plant, plus magnetite filters for the effluent, and vacuum filters and incinerators for the sludge. The plant was designed so that treatment by a variety of processes could be provided to meet varying river requirements. Operation during the first two years indicated that with all of the units in operation, the following removals could be expected:

Treatment Process	5-day B.O.D.	Suspended Solids
Sedimentation only	40 to 45%	70 to 75%
Flocculation plus sedimentation	45 to 50%	75 to 80%
Flocculation and sedimentation, plus effluent filtration	50 to 55%	80 to 85%
Flocculation with chemicals, sedimentation, and effluent filtration (dependent upon quantities of chemicals)	55 to 70%	85 to 95%

With an average detention period of only 1.5 hours, the average removal of suspended solids was 69 per cent and of 5-day B.O.D. 38 per cent. During four months of 1939 and 1940, detention periods averaging 2.4 hours were used and the removal of suspended solids averaged 74.4 per cent and the B.O.D. 42.9 per cent. By using all of the settling tanks, a detention period of 3.2 hours could be obtained at present flows, which should result in still higher removals. These are not desired until further plants are constructed along the Mississippi River to care for wastes from neighboring communities. Difficulty was experienced in the handling of scum. The suction and discharge lines of the scum pumps frequently became clogged and required the addition of large quantities of water to transport it. After four months of operation, the scum discharge line had been reduced to one-tenth of its original area by grease incrustations. After consideration of a number of methods of handling, the ejection method was selected because of its possibilities of handling relatively dry scum, assisting in the final disposal. No difficulties were experienced with freezing of sewage in the settling tanks or effluent filters during the winter months when temperatures went as low as 25° F. below zero. Sewage temperatures dropped only about 4° F. through the plant. By careful control of sludge pumping, it has been possible to remove sludge from the tanks averaging between 7–8 per cent solids. In order to handle heavy sludge without frequent stoppages, it was found necessary to make provisions for blowing back suction lines with plant effluent or compressed air. Except under conditions of storm flow, the usual practice is to operate the sludge pumps three times daily, continuing pumping as long as the sludge remains heavy. As a means of maintaining as concentrated a sludge as possible, specific gravities are determined by weighing calibrated containers of sludge periodically during the pumping period. In connection with combined sewers, it was found that settling tank and sludge pumping difficulties were encountered when flows greater than 250 per cent of the average were taken into the plant. Samples taken at half-hour intervals before, during, and after rains in the early summer indicated suspended-solids strength up to 6000 p.p.m., compared with averages of approximately 275 p.p.m.

Operation of the vacuum filters over the two year period showed that an average filter rate of 4.87 lb./sq. ft./hr. could be maintained. In the early period of operation, filter cloths generally had to be removed after about 150 hours of use. Lime-blinding necessitated higher chemical dosages and more frequent washings, and ripping or rotting at seams required the use of a large number of tin patches, (as many as 30 to 40 on a filter) even with this short life. With reduced lime dosage, the economical cloth life has been increased to somewhat more than 300 hours and as much as 500 to 600 hours for several months. Beyond this time increased chemical feed is required, incommensurate with the cost of cloth replacement. Chemical dosages of approximately 2 per cent ferric chloride and 5 per cent lime are now being used.

Incineration of the sludge brought to light several interesting facts. The original estimate showed that approximately $2,500 worth of fuel oil a month would be required to support combustion. Instead, it was found that under practically all conditions of operation an excess of heat existed and no fuel was required for actual incineration. It was found necessary to dissipate more than 6,000,000 B.T.U. per hour per incinerator. The manufacturers first attempted to accomplish this by introducing water into the furnace through sprays. This was unsatisfactory to the Sanitary District, and a by-pass was finally installed to conduct pre-heated air direct to the stack. In this way, air at room temperature could be used for combustion, and the water would be reduced to reasonable quantities and its addition required on less frequent occasions. A total of 182,097 tons of filter cake were incinerated during the first two years. The average B.T.U. per pound of combustible solids in the sludge was 10,800 and the average volatile solids in the sludge cake was 58.5 per cent, with a moisture content of 65.1 per cent. The sludge cake was reduced by incineration to an ash containing less than 2 per cent volatile matter. The guaranteed capacity of each incinerator was 60 tons of dry solids per 24 hours. During the test run as much as 78.5 tons were incinerated in 24 hours. Experiments were made on the production of partly dried material by removal of a portion of the sludge from the top parts of the incinerator, using the heat of the remainder of the sludge incinerated for drying purposes. Studies are now being carried out at the Agricultural College of the University of Minnesota on uses of the sludge cake, dry sludge, or ash. The cost analysis shows that filtration and the conditioning cost $2.56 per dry ton and incineration costs $1.01 per dry ton, giving a total of $3.57 per ton of solids on a dry basis, or an average cost of $11,260 per month to handle 3,150 tons of dry sewage solids.

A marked improvement in the physical, bio-chemical, and bacteriological condition of the Mississippi River was noted. Through the Twin Cities, the floating scum, sleek and large masses of sludge, which in former summers covered as much as 50 per cent of the water surface in some areas, had practically disappeared. Foul odors of past years were no longer in evidence and game fish were returning. Recreational uses such as boating and fishing were in evidence. The river below the Twin Cities has shown an improvement, although it is still seriously affected by the untreated sewage and packing plant wastes from South St. Paul and Newport, having a population equivalent of from 200,000 to 400,000, depending upon the animals killed. The data taken at the Twin City Lock and Dam on the Mississippi River show that dissolved oxygen averaged 6.6 p.p.m. during 1939, whereas in 1935 it averaged as low as 1.7 p.p.m. The B.O.D. of the river at this point averaged 1.85 p.p.m. as against values above 4 previously. The total bacteria count per ml. showed an average of 11,000 as against 400,000 or over, previously. River bottom analyses were also made. A complete evaluation of the recovery of the Mississippi River will not be possible until the other communities install treatment plants. The author had previously made calculations on which the degree of treatment decided upon was based. It is hoped that these calculations can be checked by actual observation and a determination made of several factors affecting deoxygenation and reaeration. Preliminary calculations which have been made indicate that the type of treatment selected will meet maximum requirements of the Mississippi River and at the same time will permit variations of treatment to cope with different river dilution conditions and requirements.

ROLF ELIASSEN

WORLD'S LARGEST SEWAGE DISPOSAL PLANT WILL BE DOUBLED IN SIZE

Engineering News-Record, 125, 698 (Nov. 21, 1940)

The completion of the program for the complete treatment of all sewage from Chicago and neighboring communities will be brought about by the expansion of the Southwest sewage treatment plant of the Sanitary District of Chicago. The present capacity of 400 M.G.D. will be increased to provide activated sludge treatment for 900 M.G.D. of sewage.

To provide further purification of the Imhoff tank effluent at the West Side sewage treatment plant, studies were carried on over a period of four years on six different processes to determine the best method. After review by an independent board of engineers, a decision was reached to treat the effluent by the activated sludge process. Cost studies showed that it would be more economical to accomplish this treatment by an addition to the Southwest plant rather than building a separate activated sludge plant at the West Side. The elevation of the Imhoff tanks above the water surface of the aeration tanks at the Southwest plant will provide adequate head for gravity flow through 4,100 ft. of conduits, meters, and gates.

The contemplated enlargement to 900 M.G.D. capacity will be made in two stages. The first stage includes the installation of one turbo-blower of 100,000 c.f.s. capacity, the construction of 16 final settling tanks and 4 sludge concentration tanks, the enlargement of the sludge disposal plant, and the addition of facilities for handling screenings, scum, grit, coal, and fertilizer. Completion of this work will bring the rate of capacity to 500 M.G.D. and provide sludge disposal equipment for the ultimate 900 M.G.D. to be treated. The second stage will include the construction of a conduit from the West Side works with meter vaults and gate house. Eight aeration tanks, similar to those now in use, twenty-four final settling tanks, two additional blowers, operating galleries, service tunnels, effluent conduits, and appurtenances will be constructed.

Storm runoff equivalent to 50 per cent of normal dry-weather sewage flow will receive primary sedimentation, but only that part equivalent to 115 per cent of dry-weather flow will receive complete treatment. Excess solids will be stored for short periods in the aeration system by increasing the concentration of the mixed liquor as high as 4500 p.p.m. to smooth out the storm maxima and reduce the amount of sludge disposal equipment that would be required to remove solids as fast as they are received. The mixing of Imhoff tank effluent with the settled sewage of the Southwest plant will also smooth out the large variations in strength of the latter due to the periodic discharge of highly concentrated wastes from the stockyards and packing houses.

Rolf Eliassen

HEAT TREATMENT AS AN AID TO SLUDGE DEWATERING

By C. Lumb

The Surveyor, 98, 287–291 (Dec. 6, 1940)

The author describes the installation, operating troubles, ten months' full scale operating results and operating costs of an installation at Halifax, England, for pretreating humus (from settling tanks following trickling filters) and waste activated sludge prior to dewatering by filter pressing methods. The process is known as the "Porteous" heat treatment process and is designed to deal with 25,000 gallons of raw sludge, containing approximately 5 to 1 by weight of dry humus to activated sludge solids, respectively, in an 8-hour day.

The process is as follows: raw sludge from a storage tank is pumped through a heat exchanger against steam pressure into cooking vessels in which the preheated sludge is cooked for 15 minutes at a temperature of 360 deg. F. at 150 lb. pressure. The sludge is then settled and decanted, the supernatant liquor drawn off and the settled residue piped to a thickened sludge storage tank. The thickened, heat treated sludge is filtered in filter presses. The decantate and press filtrate are settled in a separate tank known as an effluent tank. The settled effluent is returned to the raw sewage; the sludge is pumped to the thickened sludge storage tank.

The heat exchanger comprises eighty-eight 25-ft. lengths of concentric double steel tubes. The inner tube is 2½ in. in diameter with the outer tube providing a ¾ in. annular space around the former. The tubes are set vertically in a steel shell and coupled together in series so that cold raw sludge enters the outer space at one end of the system and hot treated sludge enters the central core at the other end and the two sludges pass in countercurrent through these sections for about ½-mile to effect heat exchange. Velocity of the sludge in the inner tube is about 3 ft. per second and about 5 ft. per second in the outer tube.

The cooking vessels are of steel, each of gross capacity of 1500 gals., but intended to treat about 800 gal. per charge. Steam is passed into the vessels during the time they are filled and emptied. Sludge is not withdrawn until it has been cooked for 15 min. at 360 deg. F.

The heat treated sludge is decanted in two steel tanks having hopper bottoms. Each tank has a capacity of 14,000 gallons, equivalent to about four hours' production of treated sludge.

The thickened sludge storage tank is of reinforced concrete, circular in plan, and equipped with a stirring device.

The effluent tank used to settle decantate and press filtrate is of reinforced concrete having a capacity of 32,000 gallons.

There are three filter presses, by S. H. Johnson & Co., Ltd., of 2800 to 2900 lb. capacity each per discharge. The filter press cake is further dried in a shed heated by unit heaters.

The steam plant comprises two water-tube boilers each rated at 3,000 lb. of steam per hour at 180 lb. per square inch. The boilers are stoker-fired with recovered cinders, of calorific value 8,000 to 10,000 B.t.u. per pound, from the Corporation's refuse disposal works. One boiler only is used at a time, the other serving as stand-by.

The contract cost was £22,000.

Main operating troubles were due to difficulties in emptying the cooking vessels to synchronize with sludge pumping schedule, clogging of the sludge pumps and loss of output capacity due to inability to attain desired temperatures in the cooking vessels in the normal operating period. This latter difficulty was bound up with questions of boiler pressure and of gas liberated from the sludge on cooking. Low grade fuel makes it difficult to maintain boiler pressure and it has at times been necessary to shut down the process to wait for the boiler pressure to pick up. Gas vented from the cooking vessels caused some odor when exhausted through the chimney stack. This difficulty was eliminated by burning the gas under the boilers.

Operating results for the period, December, 1939 to September, 1940, inclusive are briefly as follows:

TABLE 2.—*Moisture Content*

Month	Raw Sludge	Thickened Sludge after Heat Treatment and Decantation
	Per Cent	Per Cent
December, 1939	94.7	87.6
January, 1940	94.8	90.2
February, 1940	94.7	88.0
March, 1940	94.9	88.7
April, 1940	95.0	87.9
May, 1940	94.9	89.8
June, 1940	95.5	91.4
July, 1940	94.7	89.4
August, 1940	93.9	88.7
September, 1940	94.0	90.5
Weighted average over full period	94.7	89.3

Results on dewatering the thickened sludge in the presses have been as follows:

TABLE 3.

	Average Pressing Time (Hours)	Average Cake Moisture	Average Age of Press Cloths	Nature of Press Cloths
		Per Cent	Weeks	
December	3.9	46.7	3.0	Cotton
January	5.2	43.4	6.5	Cotton
February	6.3	45.8	10.0	Cotton
March	4.2	42.5	2.0	Cotton and jute
April	4.3	40.1	4.1	Cotton and jute
May	3.9	37.4	2.5	Jute
June	4.0	37.6	2.7	Cotton and jute
July	4.1	42.3	2.5	Cotton
August	3.9	41.8	2.5	Cotton
September	4.0	40.6	2.5	Cotton
Weighted average	4.2	41.3	All states of cloths	

TABLE 4.—*Average Analyses of Sludges (Dry Basis)*

	Original Raw Sludge Received	Dried Cake Leaving Site (Final Product)
	Per Cent	Per Cent
Organic and volatile matter	63.6	51.2
Total nitrogen, as N	3.88	2.00
Phosphoric acid, as P_2O_5	3.33	4.26
Potash, as K_2O	0.31	0.23

TABLE 5.—*Steam Consumption and Heat Recovery*

	Overall Figure, Including Warming-up Each Morning		Net Operating Figure Not Including Warming-up	
	Steam Consumption, Lb. per Gallon Sludge Treated	Percentage Heat Recovery	Steam, Lb. per Gallon	Percentage Heat Recovery
		Per Cent		
December	1.26	66.8	—	—
January	1.24*	68.4	—	—
February	1.06	72.6	—	—
March	0.85	77.4	—	—
April	0.80	78.3	0.67	81.8
May	0.78	78.5	—	—
June	0.69	80.7	—	—
July	0.62	82.4	—	—
August	0.60	83.0	—	—
September	0.68	81.0	—	—

* First fortnight not included, readings not available.

TABLE 6.—*Average Analysis of Decantate and Press Liquor*

	Parts per 100,000
Total solids	1,135
Total solids, ash	165
4 Hours oxygen absorbed	301
5-day B.O.D.	422
Albuminoid nitrogen	46.5
Kjeldahl nitrogen	163

Over the full period, the volume of liquor has averaged 0.21 per cent of the sewage flow, although the ratio during actual hours of pumping (approximately 100 hours weekly) has exceeded this value.

Personnel employed to operate the plant comprise a plant superintendent, a boiler attendant and three laborers. Operating costs per ton are stated as follows:

	Cost per Ton, Pence
Wages, including running repairs	9.5
Power, including effluent pumping	1.6
Fuel, including cake drying	4.0
Press cloths	2.0
Water, including boiler conditioning	0.6
Sundry material and stores	1.0
	18.7
Less revenue from dried cake	3.5
Net cost per ton	15.2

K. V. HILL

CITY OF WORCESTER, MASSACHUSETTS, DEPARTMENT OF PUBLIC WORKS, BUREAU OF SEWERS

Annual Report of the Superintendent of Sewers for the Year Ending December 31, 1939

SEWAGE TREATMENT WORKS

No changes were made in the general method of operation of the sewage treatment works. Continued progress is made each year in maintenance work so that aside from poor paint condition of the iron walks and railings at the Imhoff tanks, in particular, the Works can be considered as being in excellent condition.

Sewage Flow. The total sewage flow during 1939 was 7472.52 million gallons; a daily average of 20.47 million gallons. It is interesting to note that the maximum sewage flow for any day, 7 A.M. to 7 A.M., during 1939 was only 44.55 million gallons. The normal figure generally falls between 50 and 58 million gallons.

Grit Chambers. Each grit chamber was flushed and cleaned seven times during the year. From 7472.5 million gallons of sewage there were deposited 876.6 cubic yards of material, which were removed from the chambers. This represents an average of 3.17 cubic feet of material per million gallons of sewage. The total cost of cleaning the chambers was $339.90, an average of 38.8 cents per cubic yard of material removed.

The sand filter on to which these flushings are discharged was cleaned in August. The Barber-Greene loader, our own two trucks and welfare labor were used. The cost of removing 1090.7 cubic yards of material to a low area, 700 to 1000 feet distant, was $715.37, an average of 65.6 cents per cubic yard.

Screening of Sewage. Both screen installations received needed overhauling of the raking mechanism. In addition to new chains and upper sprocket wheels, the lower wheels were replaced and the chain runs, both upper and lower, were refitted with lower plates or bottoms. The latter repair was the first of its kind made since the rakes were installed in November, 1930.

There were removed from 7472.5 million gallons of sewage, a total of 13,920 cubic feet of screenings, representing an average of 1.86 cubic feet per million gallons of sewage screened.

The cost of screen operation according to the Works payroll was $1148.11. This represents $3.14 per day; 8.2 cents per cubic foot of screenings removed to a low area 500 feet away; 15.2 cents per million gallons of sewage screened.

Imhoff Tanks. The Imhoff tanks have given no difficulties concerning their operation. The quantity of sewage treated by the tanks was 7376.82 million gallons, a daily average of 20.21 million gallons. The average detention period of the sewage was 2.9 hours.

The grease accumulation removed from the tanks amounted to 4,563 cubic feet; this is the largest yearly accumulation since 1934. The grease is run to diked areas and buried.

The sludge production during this past year totalled 12,841,810 gallons, or almost four million gallons more than in 1938. The tank influent totalled almost 900 million gallons less in 1939 than in 1938. The facts are (1) part of the sewerage system is on the combined plan, (2) the annual rainfall of 1939 was 3.2 inches less than normal, (3) industrial activities increased considerably during the latter half of the year and (4) normally, the sewage contains a daily average of from three to four million gallons of industrial waste liquors. Operation data pertaining to the sewerage system and to sewage treatment, if practiced, are valuable when considering the problem of sewage treatment.

The sludge drawn from the tanks had a specific gravity of 1.028; percentage dry solids, 6.52 and pH 6.7. The density of the sludge was about the same as in past years; the pH dropped from 6.8 to a new low of 6.7 with apparently no ill effect upon sludge digestion.

The sludge was well digested; the percentage of volatile matter in the dried solids averaged 44.10. The percentage of nitrogen increased nearly 0.5 per cent as compared with the past two years. The percentage of iron decreased to 3.69.

The data in Table I indicate that tank treatment of the stronger sewage of 1939 produced an effluent containing less settleable and suspended solids than that of 1938. The suspended solids content of the tank effluent averaged 88 parts per million. The biochemical oxygen demand of the effluent averaged 115.8 parts per million, an increase of 14.2 parts, as compared with 1938.

Dosing Tanks. No difficulties have been encountered with dosing tank operation throughout the year. Replacements were made of the poorest sections of dosing tank covers as a part of an annual program for uniform maintenance expenditures.

Trickling Filters. The trickling filters treated 7136.12 million gallons of Imhoff tank effluent; an average of 19.55 million gallons daily. The average rate of filtration was 1.50 million gallons per acre per day.

The usual filter flooding for fly control was practiced from May to September and no complaints were received concerning filter flies. Nozzle clogging was more prevalent than usual during the last two months of the year owing to continued high winds, day after day.

In the 1938 report, it was stated that filter unloading had been almost entirely absent during the fall months. Filter unloading occurred from April through August, 1939, an unusually long period and during November and December, it has been greater than in 1938, despite this marked unloading earlier in the year.

Analysis of all of the data concerning trickling filter operation is shown in Table I and is summarized as follows:

Stronger sewage and Imhoff tank effluent placed a heavier load of organic matter upon the filters; consequently, the filter effluent contained more organic matter than in 1938. The same statement is true concerning the iron content of the effluent.

During January and February there was a period of fifteen days when all end nozzles were out owing to low atmospheric temperature. The influent discharged from the end nozzles was not purified. The cold temperature caused ice formation over the entire filter area and the influent discharged upon the filters was not well purified. Mention has been made that March and April, 1939, were colder than the corresponding months of 1938. All of these conditions resulted in filter effluent of increasing deterioration of quality during the first four months of 1939.

Although filter unloading early in the year continued for an unusually long time, the quality of the filter effluent improved quickly upon obtaining warmer atmospheric temperature and decreased rate of filter operation.

The filters successfully treated stronger influent demonstrating that filter ice conditions and low atmospheric temperature are the factors affecting winter results of operation.

The results of filter operation during December, 1939, when it was necessary to remove end nozzles for 48 hours during a period of eight days of low atmospheric temperature showed a drop in effluent stability and increased organic content of the effluent. The duration of this cold spell, December 23 on, was not long enough to affect the dissolved oxygen and nitrate nitrogen contents of the effluent during December.

Secondary Tanks. The secondary settling tanks handled 7136.12 million gallons of trickling filter effluent, an average of 19.55 million gallons daily. The average detention period of the trickling filter effluent in the secondary or final settling tanks was 2.1 hours.

Efficient operation of the final settling tanks shows that the average suspended solids of the filter effluent, 126 parts per million, was reduced to 60 parts. The biochemical oxygen demand reduction was from 24.9 to 17.8 parts per million. The dissolved oxygen content of the filter effluent was but slightly reduced during its detention in the final settling tanks. The relative stability of the final effluent averaged 91 + per cent or the same as that of the filter effluent.

Sludge was pumped from the tanks once each week; during the summer, to the sludge concentration tanks and then to the small drying beds and during the remainder of the year to the winter bed area.

TABLE I.—*Suspended Solids, Biochemical Oxygen Demand*

	Susp. Solids P.P.M.				Per Cent Removal		B. O. D. P.P.M. 5 Days 20° C.				Per Cent Removal	
	Sew.	Imhoff Eff.	Tr. Fil. Eff.	Sec. Tk. Eff.	Imhoff Treat.	Sec. Tr.	Sew.	Imhoff Eff.	Tr. Fil. Eff.	Sec. Tk. Eff.	Imhoff Treat.	Entire Plant
January	183	85	85	55	53.5	69.9	170.6	115.3	25.8	23.9	32.4	86.0
February	213	85	93	61	60.1	71.4	161.4	110.1	28.2	24.0	31.8	85.2
March	163	82	90	59	49.7	63.9	140.9	99.1	26.2	20.1	29.7	85.8
April	146	69	122	70	52.7	52.1	114.7	80.8	20.1	13.7	29.5	88.0
May	224	95	213	78	57.5	65.2	186.8	124.8	30.4	20.1	33.2	89.3
June	258	99	213	66	61.6	74.4	193.4	137.0	36.7	23.7	29.2	87.8
July	236	79	172	59	66.5	75.0	211.6	134.4	24.3	14.9	36.5	93.0
August	253	100	136	60	60.5	76.3	200.0	117.2	18.2	11.8	41.4	94.1
September	264	100	98	47	62.1	82.2	208.1	123.6	12.0	8.1	40.6	96.1
October	279	96	82	44	65.6	84.2	210.9	122.6	20.2	11.5	41.9	94.6
November	251	82	114	53	67.3	78.9	209.7	127.1	27.4	19.4	39.4	90.8
December	278	97	120	58	65.1	79.2	198.8	127.5	27.3	19.6	35.9	90.2
1939	223	88	126	60	60.5	73.1*	178.5	115.8	24.9	17.8	35.1	90.0
1927	288	127			55.9		150.5	88.6	31.1	27.0	41.1	82.1
1928	275	114	120	77	58.6	35.9	152.9	98.6	20.4	18.8	35.4	87.8
1929	317	118	142	84	62.8	40.8	178.5	114.0	22.6	17.8	36.2	90.1
1930	291	117	165	86	59.8	47.9	211.6	142.5	31.0	24.4	32.6	88.5
1931	229	101	140	64	55.9	54.3	196.0	136.5	29.7	22.2	30.4	88.7
1932	219	94	143	62	57.1	56.6	211.5	140.0	34.0	22.7	33.8	88.3
1933	224	97	118	53	56.7	55.0	213.5	139.6	34.4	23.8	34.6	88.9
1934	240	95	97	55	60.4	43.3	241.0	147.6	43.9	35.8	38.7	85.2
1935	233	96	105	52	58.8	50.5	200.5	123.0	33.5	25.6	38.7	87.2
1936	256	97	92	55	62.2	40.2	207.2	129.5	36.9	29.1	37.5	86.0
1937	264	100	104	55	62.1	47.1	204.0	122.9	30.7	24.0	39.7	88.3
1938	207	89	100	54	57.0	73.9*	162.5	101.6	20.9	15.7	37.5	90.3
1939	223	88	126	60	60.5	73.1*	178.5	115.8	24.9	17.8	35.1	90.0

* Entire Plant.

Sludge Disposal. The sludge drying bed area is in three parts; summer Imhoff tank sludge is dried on 21 one-quarter acre beds; summer secondary tank sludge after concentration is dried on 32–18 × 110 ft. beds and during the winter, both sludges, the secondary without concentration, are pumped to 43 old one acre beds. The entire area is composed of former sand filters used for intermittent filtration of sewage.

Welfare help working with trucks have been employed throughout the season cleaning beds in the first two areas; in addition, sludge was removed from quite a few of the winter beds. From September 14 to December 14, three months, about 10 to 12 temporary laborers were employed cleaning winter beds. Funds for sludge removal were limited as well as the amount of available welfare help. At this time, there are fourteen one-acre beds from which the sludge was not removed.

The summary of costs of sludge removal is as follows:

Welfare	Cubic Yards	Cost		Total	Cubic Yard
		Trucks	Labor*		
Imhoff sludge	6694.2	$1212.86	$2658.63	$3871.49	$ .578
Secondary sludge	793.3	232.05	434.77	666.83	.841
Winter sludge	4753.5	959.47	2139.32	3098.79	.652
Temporary:					
Winter sludge	6822.0	1454.64	3168.60	4623.24	.677
Total	19,063.0	$3859.02	$8401.32	$12,160.34	.643

* No foreman charge. All labor at 50 cents per hour.

Why handle secondary tank sludge on small beds after concentration instead of on the winter beds at less cost per cubic yard of dried sludge for removal? The total of approximately 800 cubic yards of dried sludge represents the drying of almost the entire sludge production from April to December on 1.5 acres of bed area. Flexibility of bed operation; sludge drying and removal of the dried sludge and reservation of one-acre beds for winter sludge disposal represent $160.00 well expended.

Cost of Sewage Treatment

The cost of sewage treatment is summarized as follows:

	Total	Per Million Gallons
Grit Chamber	$ 716.14	$0.09
Screen	2,237.11	0.30
Imhoff Tanks	8,524.64	1.14
Trickling Filters	8,620.81	1.15
Secondary Tanks	5,687.86	0.76
Sludge Disposal	11,023.90	1.48
Laboratory	5,175.98	0.69
	$41,986.44	$5.61
Real Estate	980.25	
	$42,966.69	

The expenditure of $41,986.44 represents a cost of $5.61 per million gallons of sewage treated by the Works. The cost per capita served was approximately 22.1 cents for the year—1.84 cents per month.

Welfare labor is not included in these figures. The cost of removal of dried sludge from the beds by welfare labor was $5,232.72, using 50 cents per hour as the rate. All other costs are included in the figure above. The cost of welfare labor increases the treatment cost per million gallons of sewage to $6.31.

PROCEEDINGS OF THE FOURTEENTH ANNUAL CONFERENCE OF THE MARYLAND-DELAWARE WATER AND SEWERAGE ASSOCIATION

The Biofiltration System as a Means for Varying the Degree of Sewage Treatment. By A. J. Fischer, pp. 11–27. This article gives a description of various applications of the biofiltration system, together with a discussion of factors influencing design and operation, B.O.D. loading, recirculation, clarifier design, dosing rates, filter bed design and distributors. Ten drawings and photographs and nine tables of operating data giving dosing rates, B.O.D. loading and per cent reductions are used to supplement and support the author's discussion.

The author concludes as follows:

1. The degree of treatment of sewage may be varied over a wide range by the use of the biofiltration system.

2. The single-stage process in which one filter and one clarifier is used, will effect B.O.D. reductions of 50–60 per cent.

3. The single stage complete system, using one filter and two clarifiers will give B.O.D. reductions of 75–80 per cent.

4. In the two-stage system where two filters and two clarifiers are used, B.O.D. reductions of 90–95 per cent may be effected.

5. The chief factors that influence the design and operation of all types of biofilter plants are B.O.D. loading on the filter, the volume of recirculated flow, and the clarifier overflow rate and detention.

6. The capacity of a filter for removing B.O.D. apparently varies with the strength and characteristics of the applied sewage. With normal strength domestic sewage, a maximum of 2.0 lb. of B.O.D. per cu. yd. of filter medium per day can be removed.

7. Recirculation of filter effluent back to the detention tank is of material aid in controlling the degree of purification obtained. In general the recirculation ratio should be increased in proportion to the increase in strength of the raw sewage. In the case of normal strength sewage this ratio should be about 2.0 for single stage intermediate treatment, 1.5 for single stage complete treatment and 1.0 for two-stage treatment.

8. The detention tank design becomes increasingly more important as B.O.D. load on the filters is increased. The average clarifier overflow rate should not exceed 800–1000 gallons per square foot per 24 hours in the case of the two-stage plants. Average clarifier detentions should not be less than 1.5–2.0 hours.

9. Within a range of about 8.0 to 100 m.g.a.d. dosing rates apparently do not affect the action in the filter bed as long as the B.O.D. load is not excessive.

10. Increasing the filter bed depth beyond 3 feet gives only a slight improvement in results.

11. The biofilter system may be applied for the pre-treatment of very strong industrial wastes. In the case of distillery wastes having a B.O.D. of about 20,000 p.p.m. over 90 per cent reduction in B.O.D. may be effected in a single-stage 3 ft. depth filter.

12. In the treatment of strong wastes such as distillery waste, very high B.O.D. loadings may be applied to the filters without seriously affecting their efficiency. In the case

of distillery waste, B.O.D. loadings of 18–20 lb. per cubic yard per day were applied. The removals in the filters were 15–18 lb. per cubic yard per day.

Discussion. By F. S. Friel, pp. 28–32. Further discussion of the design, operation and application of the biofiltration system is given. The influence of temperature on filter efficiency is emphasized.

Digestion tanks for the plant employing biofiltration should be larger than those employed for the standard trickling filter plant since no digestion occurs in the filter proper and the moisture content of the biofilter sludge is higher than that from the standard filter. Digestion space between 3 and 4 cu. ft. per capita is recommended.

Experiments with High-Rate Trickling Filters at Baltimore, Maryland. By C. E. Keefer and Herman Kratz, Jr., pp. 33–42. Discussion, Linn H. Enslow, pp. 42–44. A small portion of the existing trickling filters at the Baltimore plant was used for the experiments. These filters contain trap rock varying in size from 1 in. to 2.5 in. and are 8.5 ft. deep. At the start of the experimental work the filter stone was in good condition with no evidence of clogging. Two eight-arm rotary distributors each 47.5 ft. in diameter were erected on the filter. Throughout the experiments a portion of one of the existing filter beds adjacent to the experimental units was operated at a rate of 3 m.g.a.d. as a control.

The sewage applied to the filter had passed through bar screens with 0.75 in. clear openings and had been settled in primary tanks equipped for mechanical sludge removal. The primary tanks have an average theoretical detention period of two hours. Samples of the filter influent and effluent were collected hourly, composited for a 24 hour period and analyzed. The filter effluent samples were thoroughly stirred before analysis so that the analyses would be representative of the entire effluent.

Three groups of experiments were carried out. Experimental data are presented in tables and by means of graphs.

Based on the experimental evidence the following conclusions which apply particularly to Baltimore conditions were reached.

1. There is no reason to believe that ponding will occur at any rate of flow from 6.5 to 30 m.g.a.d.

2. As the rate of flow increases, a gradual increase in the B.O.D. of the effluent and a decrease in nitrification can be expected. This decrease in B.O.D. removal was not marked even when the flow was 10.0 m.g.a.d.

3. Even at high rates of application (26 m.g.a.d.) a reduction of approximately 30 per cent can be expected in the B.O.D. in winter and 70 per cent or more in summer.

4. A considerable portion of the B.O.D. can be removed in summer by shallow filters varying from 2 to 4 ft. deep when the rate is as high as 10 m.g.a.d. The removal would undoubtedly be less in winter.

5. If an effluent is to be better than that from sedimentation tanks and inferior to that from a low-rate trickling filter, a high rate filter may serve. Treatment comparable to chemical precipitation or sedimentation and magnetite filters can be obtained by sedimentation and high-rate trickling filters. The degree of treatment depends upon the rate of applying the sewage and the depth of the filters.

Inexpensive Contrivances Which Have Improved the Operation of a Small Sewage Treatment Works. By C. G. Weber, pp. 78–89. This is a summary of experiences at the Annapolis, Maryland, sewage treatment plant with chlorination, grit removal, sludge filtration and elutriation. Eight sketches and photographs illustrate methods and equipment. The improvements which were conceived and carried out by plant personnel have resulted in substantial savings in operating costs and improved plant performance.

This paper is discussed by H. R. Hancock and A. L. Genter, pp. 90–97.

The Effect of the Washington Sewage Disposal Plant on the Potomac River. By Paul D. McNamee, pp. 61–70. This paper presents a summary of a study made of the bacteriological and chemical quality of the Potomac River during 1938 and 1939. Sampling points corresponded to those used in surveys by the U. S. Public Health Service before the plant was installed. The data are compared with the results of the prior surveys and correlated with stream flow and temperature. The plant has been of value in raising the dissolved oxygen concentration in the section of the river which needs it most. Approximately 20 tons of 5-day B.O.D. and 12 tons of heavy solids are removed daily by the treatment plant.

Discussion. By Ralph E. Fuhrman, pp. 70–73. A discussion of certain characteristics of the Potomac River which affect its ability to absorb the imposed sewage load. Of particular importance are the tidal flats which, through the agency of the vegetative growths, furnish large amounts of oxygen to the water.

Discussion. By R. E. Tarbett. Past studies by the U. S. Public Health Service indicated that the Potomac River tidal flats produced oxygen during the summer period at a rate of 17.7 pounds per acre per day.

The author notes that physical changes taking place in and around the Washington area, particularly those affecting the flats, will eventually have a considerable effect upon the river pollution problems and will make it difficult to show by future studies just what effect the treatment of the Washington sewage has had upon river conditions.

The problem of water pollution control within the District is one that must be considered mainly from the standpoint of recreational use of the stream.

Paul D. Haney

FLASH DRYING OF SLUDGE

Chemical and Metallurgical Engineering, 48, 108–111 (January, 1941)

A brief discussion of the flash-drying system employed by the Chicago Sanitary District is given. Twelve actual photographs of the Southwest sewage treatment plant are used to supplement the plant flow sheet which shows diagrammatically the various steps in the entire sewage treatment and sludge disposal processes.

Paul D. Haney

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Briggs, O. L., Sr. North Carolina.
Brigham, Harold L. New England.
Brigham, John C., Jr. New York.
Brigham, J. C. New York.
Briggs, Raymond J. Pacific Northwest.
Britt, C. E. Ohio.
Brockman, C. J. Georgia.
Broderick, Joseph A. New York.
Brody, James. Central States.
Broestl, Andrew J. Ohio.
Brook, Harry. Central States.
Brookman, H. R. California.
Brooks, John H., Jr. New England.
Brower, James. Central States.
Brower, J. Singleton. New York.
Brown, C. U. Michigan.
Brown, Edward J. New York.
Brown, George L. Central States.
Brown, Glen V. Pennsylvania.
Brown, Ike F. Arizona.
Brown, John L., Jr. North Carolina.
Brown, Kenneth W. California.
Brown, R. F. California.
Brown, W. Fillingham. England (I. S. E.).
Browne, Floyd G. Ohio, Central States.
Bruden, C. O. Central States.
Brule, Abundius A. New England.
Brumbaugh, W. V. New York, Pennsylvania.
Brumm, Allen S. Michigan.
Brunner, Paul L. Central States.
Bryant, C. T. Ohio.
Bryant, H. M. New England.
Bryce, W. F. M. Canada.
Buchholz, Richard. Central States.
Buck, George H. New York.
Buck Hill Falls Co. Pennsylvania.
Buck, Robinson D. New England.
Buck, W. H. Dakota.
Budd, Chester B. Ohio.
Bugbee, Julius W. New England.
Bugbee, Raymond C. New England.
Bumstead, John C. New York.
Bunger, Fred C. Central States.
Bunker, F. L. North Carolina.
Burack, W. D. New Jersey.
Burchard, Edwin Day. North Carolina.
Burczak, William J. New York.
Burden, Harry P. New England.
Burdoin, Allen J. New England.
Burger, A. A. Ohio.
Burgeson, J. H. Central States.
Burgess, Harold. New York.
Burlingame, Hitchcock & Estabrook. Central States.
Burnet, J. G. England (I. S. E.).
Burnett, A. H. Canada.
Burnett, J. A. Canada.
Burnite, T. B. Rocky Mountain.
Burnside, Lewis E. Pennsylvania.
Burnson, Blair I. California.
Burns & McDonnell. Kansas.
Burr, George H. New York.
Burr, R. S. New England.
Burrell, Robert. New England.
Burrin, Thomas J. Central States.
Bushee, Ralph J. Central States.
Bush, Bernard S. Pennsylvania.
Butler, A. D. Pacific Northwest.
Butler, Emmet. Michigan.
Butterfield, C. T. Federal.
Byble, Duane. New York.
Byram, Arthur T. Canada.
Byxbee, J. F. California.

Caccia, Pio. Central States.
Caine, Richard. Iowa.
Caird, James M. New York.
Caldwell, David H. Central States.
Caldwell, H. L. Central States.
Calderara Orall J. New England.
California Corrugated Culvert Co. California.
California Packing Corporation. California.
Calkins, Lyle W. Ohio
Callen, Loy A. Central States.
Calvert, A. England (I. S. P.).
Calvert, C. K. Central States.
Cameron, A. B. Ohio.
Cameron, Geo. New Jersey.
Camp, Thomas R. New England.
Campbell, Arthur T. New England.
Campbell, Harry M. Central States.
Campbell, John. Pennsylvania.
Campbell, J. L. England (I. S. P.).
Campbell, M. S. Pacific Northwest.
Campbell, Wm., Jr. New Jersey.
Capalbo, James. New Jersey.
Capen, Charles H., Jr. New York.
Carbone, Edward A. New York.
Cardwell, Edward C. Central States.
Carey, James L. New York.
Carey, Wm. N. Central States.
Carl, Charles E. Dakota.
Carlson, H. R. Federal
Carmichael, David W. New York.
Carnahan, Charles T. Federal.
Carney, George. Michigan.
Carollo, John. Arizona.
Carpenter, Carl B. Central States.
Carpenter, George D. New York.
Carpenter, Harry C. New York.
Carpenter, Howard F. New England.
Carpenter, J. D. Pennsylvania.
Carpenter, William T. New York.
Carrique, Carlos S. Argentine.
Carson, Caryl. New England.
Carter Co., Ralph B. New York.
Cary, Willis E. New England.
Case School of Applied Science. Ohio.

Casey, City of. Central States.
Casey, John J. California.
Casey, William. Canada.
Castello, W. O. California.
Caster, Arthur. Central States.
Castro A. J., Jr. California.
Cederberg, C. R. Rocky Mountain.
Ceriat, Eugene. California.
Cerny, Paul J. New York.
Chambers, Cecil W. Federal.
Chamberlain, L. H. Central States.
Chamberlin, Noel S. New Jersey.
Chamberlain, Wm. T. New York.
Chambersburg, Boro of. Pennsylvania.
Chapman, Clarke. California.
Charlton, David. Pacific Northwest.
Chase, E. Sherman, New York, New Jersey.
Chase, H. W. Pacific Northwest.
Cheadle, Wilford G. Central States.
Chiarolla, Frank V. California.
Chicago Pump Company. New York.
Chisholm, Colin B. New York.
Christian, James B. New York.
Cipriano, Anthony G. New York.
Clapp, Milton Jr. North Carolina.
Clare, H. C. Pacific Northwest.
Clark, E. S. Central States.
Clark, H. W. England (I. S. E.).
Clark, H. W. New England.
Clark, John A. California.
Clark, J. C. California.
Clark, L. K. Dakota.
Clark, M. S. Central States.
Clark, Robert N. New York.
Clarke, V. B. New England.
Cleary, Edward J. New Jersey.
Cleland, Ralph R. Pennsylvania.
Clement, R. C. Maryland-Delaware.
Clementi, Paul T. New York.
Clements, Paul N. California.
Cleveland, E. A. Canada.
Cliff, D. P. Canada.
Clifford, W. England (I. S. P.).
Clift, M. A. New York.
Clodfelter, Howard T. Central States.
Clouser, L. H. Pennsylvania.
Clover, I. N. Ohio.
Cloyes, W. J. Pacific Northwest.
Clubb, William C. Pacific Northwest.
Coates, John J. New York.
Cobb, Edwin B. New England.
Coberly, Carroll H. Rocky Mountain.
Coblentz, J. M. Iowa.
Coburn, S. E. New England.
Cochrane, W. F. South Dakota.
Cockroft, T. N. England. (I. S. P.).
Cohen, Stuart. Federal.
Cohn, Morris M. New York, Central States.
Cole, Charles W. Central States.
Cole, E. Shaw. New York.
Colitz, Michael J. Pennsylvania.
Collard, A. E. England (I. S. E.).
Collier, H. England (I. S. E.).
Collier, James. Ohio.
Collins, A. Preston. California.
Collins, W. D. Federal.
Collins, W. H. Canada.
Collyer, Joseph C. New York.
Combs, Harold F. Central States.
Compton, C. R. California.
Comstock, Walter C. New York.
Conger, Charles C. California.
Conklin, Chester A. New York.
Connell, C. H. Texas.
Consoer, Arthur W. Central States.
Cook, Horace J. New England.
Cook, Lawrence H. California.
Cook, Max E. California.
Cook, Rodney E. New York.
Cooke, P. N. Canada.
Cooley, E. C. California.
Coombs, E. P. England (I. S. E.)
Copeland, William R. New England.
Copley, Charles H. New England.
Copple, Isaac, Pennsylvania.
Corbett, Walter E. New England.
Cordell, Miss Mona. New York.
Corey, R. H. Pacific Northwest.
Cornilsen, C. K. Central States.
Corr, Ray H. Central States.
Corrao, Joseph. California.
Corrington, C. E. Central States.
Corrington, Kingsley. Central States.
Corson, B. I. New Jersey.
Corson, H. C. Michigan.
Cortelyou, H. P. California.
Costello, John J. New York.
Cotterell, G. T. England (I. S. E.).
Cotton, Harry E. Central States.
Cottrell, H. S. New York.
Cousineau, A. Canada.
Covill, R. W. England (I. S. P.).
Cowell, John E., New York.
Cowing, Roy T. Central States.
Cowles, M. W. New Jersey.
Cox, C. R. New York.
Coy, Arthur H. New England.
Coy, Burgis. Rocky Mountain.
Craemer, George H. New England.
Craig, Clifford. Central States.
Craig, Robt. H. Pennsylvania.
Craig, W. Allan. New England.
Crane, H. R. California.
Crask, Rex. Central States.
Craun, J. M. Ohio.
Crawford, H. V. New York.
Crawn, R. D. Michigan.
Creears, T. H. California.
Critser, W. H. Ohio.
Crockett, V. P. Texas.
Crohurst, Harry R. Federal.
Croll, J. B. England (I. S. P.).
Cromer, Lyle. California.
Cromwell, Edward C. Maryland-Delaware.
Croom, Thomas G. Michigan.
Cropsey, W. H. Central States.

Cullison, Eugene F. New York.
Culp, King. Pacific Northwest.
Cummings, G. J. California.
Cummins, Walter. Ohio.
Cunningham, A. C. New England.
Cunningham, H. L. Pennsylvania.
Cunningham, John W. Pacific Northwest.
Curfew, L. S. California.
Currie, C. H. Iowa.
Currie, David H. California.
Currie, Frank S. California.
Cushing, Robert. Arizona.
Cushman, S. P. Central States.
Cutler, Charles E. Central States.
Cutting, Merritt E. New England.
Cyr, Rene. Canada.

Dallavia, Louis. Central States.
Damon, Nelson A. New England.
Damon, Wayne F. New England.
Damoose, N. G. Michigan.
Daniels, F. E. Pennsylvania.
Dappert, Anselmo F. New York.
Darby, George M. New England.
Darby, W. A. New England.
Darling, E. H. Canada.
Darling, Fred A. New England.
Darling, Orrin M. Central States.
Darnell, F. M. California.
Davey, H. W. California.
Davids, E. M. California.
Davidson, F. G. New York.
Davidson & Fulmor. California.
Davidson, Philip. Central States.
Davis, Charles A. Rocky Mountain.
Davis, E. Watson. Pennsylvania.
Davis, H. F. North Carolina.
Davis, J. H. Pacific Northwest.
Davis, P. D. North Carolina.
Davis, Walter S. New York.
Dawson, F. M. Central States.
Dawson, Lafayette Wm. Pennsylvania.
Dawson, Thomas T. Pennsylvania.
Dayton, Alfred E. New York.
Deberard, W. W. Central States.
Debrito, Jr., F. Saturnino. New York.
Debrun, John W., Jr. Central States.
Dechant, F. D. Pennsylvania.
Decker, E. P. New Jersey.
Decker, Walter. Central States.
Deckert, Christ. Central States.
Degroat, Frank N. New York.
Dehaas, Nicholas. New England.
Dehooge, Bernard A. Michigan.
Dejarnette, N. M. Georgia.
Delano, Huntley. Michigan.
De Leon, Gregorio. California.
Deleuw, C. E. Central States.
Demartini, Frank E. Federal.
Deming, Harold A. New York.
Demunn, E. M. New York.
Denise, Wm. D. New York.
Denison, W. R. Arizona.
Dennis, C. E. New York.
Depoy, A. G. Central States.
Derby, Ray L. California.
Desmarais, R. J. Canada.
Des Moines, City of. Iowa.
Deuchler, Walter E. Central States.
Devendorff, Earl. New York.
Devoe, Kermit. New Jersey.
Diamond Alkali Co. Central States.
Dick, Robert. Central States.
Dickman, Dorian H. Michigan.
Dickson, D. B. Texas.
Dickson, Harvey. Michigan.
Dickson, W. K. North Carolina.
Dieffendorf, Fred G. Pennsylvania.
Diehl, H. B. New York.
Dietrich, Paul. Central States.
Dietz, Jess C. Central States.
Dietz, John. Central States.
Dilles, Paul F. New York.
Dion, Clarence K. New England.
Disario, G. M. New England.
Dixon, C. S. Central States.
Dixon, G. Gale. Ohio.
Doane, Ercell J. Michigan.
Doan, Norman D. North Carolina.
Dobson, William T. New York .
Dobstaff, Robert, Jr. New York.
Dobstaff, Robert W., Sr. New York.
Dodge, H. P. Michigan.
Dodson, Roy E., Jr. California.
Doerr, Earl. Dakota.
Doggett, F. G. North Carolina.
Dolomite Products Co. New York.
Doman, Joseph. New York.
Domke, L. C. Central States.
Dommes, Sid F. California.
Domogalla, Bernhard. Central States.
Donaldson, Wellington. New York.
Donnell, Geo. M. Rocky Mountain.
Donohue, Jerry. Central States.
Doonan, R. E. Iowa.
Dopmeyer, A. L. Federal.
Dornbush, Don. Michigan.
Dorr, Company, Inc., The. Rocky Mountain.
Dorr, Fred M. Michigan.
Doubleday, Arnold R. Central States.
Dougherty, James E., Jr. New York.
Dougherty, Richard J. New York.
Douglass, R. M. Pennsylvania.
Dowd, Ira. Michigan.
Downer, Wm. J. Central States.
Downes, John R. New York.
Doyle, Thomas J. Michigan.
Drake, James A. Central States.
Dresselt, Edward L. New York.
Drexel, Frederick. New York.
Driscoll, Timothy J. New York.
Drummond, A. H. England (I. S. P.)
Duane, John M. New York.
Dudley, Charles E. Central States.
Duerr, Arlie. Ohio.
Dufficy, Frank J. New York.

Duffy, John J. New York.
Dumonte, Robert. Ohio.
Duncan, Roland F. California.
Dundas, Wm. A. Central States.
Dunnam, Herman. Arizona.
Dunne, E. R. New York.
Dunstan, Gilbert H. California.
Durand, Edwin M. Michigan.
Durham Water Dept. North Carolina.
Durrant, W. K. F. Canada.
Duvall, Arndt J. Central States.
Duxbury, S. England (I. S. P.).
Duy, C. Central States.
Dyckman, Warren W. New York.
Dye, Elmer E. Iowa.
Dyer, Samuel. New England.

Eager, Vernon. New York.
Early, Fred J., Jr. California.
Early, Mart. Pacific Northwest.
Easdale, W. C. England (I. S. E.).
Eastburn, W. H. Pennsylvania.
Eastman, T. F. California.
Ebaugh, G. M. Central States.
Ebert, R. E. North Carolina.
Ecusta Paper Corp. North Carolina.
Eddy, Harrison P., Jr. New England.
Edge, L. C. Georgia.
Edgecomb, George. Michigan.
Edgehoffer, Albert. New York.
Edgerley, Edward. Pennsylvania.
Edinger, Harry F. New York.
Edmonds, W. R. Canada.
Edmondson, J. H. England (I. S. P.).
Edward, William L. New York.
Edwards, B. E. Iowa.
Edwards, Gail P. New York.
Edwards, H. L. California.
Egan, J. H. California.
Eggert, E. G. Georgia.
Ehle, Virgil. New York.
Ehler, John A. New York.
Ehlers, Ralph B. Michigan.
Eich, Henry F. New York.
Eldridge, E. F. Michigan.
Electro Refractories & Alloys Corp. New York.
Eliassen, Rolf. New York.
Ellinger, Morris. California.
Elliot, S. F. Rocky Mountain.
Ellis, Albert. Central States.
Ellis, Norman T. Michigan.
Ellms, J. W. Ohio.
Ellsworth, Samuel M. New England.
Ely, E. H. England (I. S. E.).
Emerson, C. A. Pennsylvania.
Emigh, William C. Pennsylvania.
Englewood Sewerage Company. New Jersey.
English, C. C. Ohio.
English, James A. North Carolina.
English, W. B. Georgia.
Enloe, V. P. Georgia.
Enoch Pratt Free Library. Maryland-Delaware.
Enslow, L. H. New York.
Epler, J. E. Central States.
Eppley, Robert G. Pennsylvania.
Epstein, Harold. New York.
Erdle, Gardner F. New York.
Erdwurm, Emil. New York.
Erickson, Carl V. Central States.
Erickson, Una H. California.
Eriksen, Arne. Pacific Northwest.
Erzen, C. A. Central States.
Etheridge, W. England (I. S. P.).
Ettinger, M. B. Federal.
Eustance, Arthur W. New York.
Eustance, Harry W. New York.
Evans, David A. Pennsylvania.
Evans, F. M. New Jersey.
Evans, R. W. Central States.
Evans, S. C. England (I. S. P.).
Evans, Wm. J. North Carolina.
Evansky, Frank J. New York.
Everson, Mfg. Co. Central States.
Everts, C. M., Jr. Pacific Northwest.
Everts, W. S. California.

Faber, Harry A. New York.
Faccinia, Frank. California.
Fah, C. Thum. England (I. S. E.).
Fair, Gordon M. New England, New York.
Fairbanks, E. G. California.
Fairfield State Hospital. New England.
Fales, Almon L. New England.
Falls, O. M. Canada.
Fargo Engineering Co. Michigan.
Farmer, J. E. England (I. S. E.).
Farnham, Arthur B. New England.
Farnsworth, George L., Jr. Central States.
Farrant, James. New Jersey.
Farrar, J. H. California.
Farrell, Eugene J. New York.
Farrell, Michael. New York.
Farries, Gerald E. Central States.
Fassnacht, George G. New York.
Faulkner, T. G. England (I. S. E.).
Feltz, Fred C. Central States.
Fenaughty, Thomas. New York.
Fenger, J. W. New York.
Fenton, John V. New York.
Ferebee, James L. Central States.
Ferguson, G. H. Canada.
Ferguson, Gerald. New Jersey.
Fernandez, John U. New York.
Ferris, James E. New York.
Fidler, G. C. England (I. S. P.).
Field, W. T. New York.
Finch, J. England (I. S. P.).
Finch, Lewis S. Central States.
Finck, G. E. Maryland-Delaware.
Firth, E. W. New York.
Fischer, Anthony J. New York.
Fischer, Philip C. New York.
Fiscus, A. E. California.

Fishbeck, Kenneth. Michigan.
Fisher, Homer C. Central States.
Fisher, F. P. Ohio.
Fisher, L. M. Federal.
Fitch, T. A. California.
Fitzgerald, J. A. New York.
Fitzgerald, J. E., Jr. New England.
Fitzsimons, Richard H. New York.
Five, Helge. New York.
Flanagan, Jr., Joseph E. Federal.
Fleet, Gerald A. New York.
Fleming, M. C. Pennsylvania.
Fleming, Paul V. New England.
Flickinger, Lloyd H. Central States.
Flood, Frank L. New England.
Flower, G. E. Ohio.
Flowers, E. England (I. S. P.).
Foley, William M. New York.
Follett, Eli. Arizona.
Fontenelli, Louis. New Jersey.
Foote, Kenneth E. New England.
Forbes, Albert F. New York.
Ford, Curry E. Ohio.
Ford, Robert. Central States.
Foreman, Merle S. California.
Forsbeck, C. D. Pacific Northwest.
Forsberg, Ole. Central States.
Forster, M. H. New York.
Fort, Edwin J. New York.
Fortenbaugh, J. Warren. New York.
Forton, R. G. Michigan.
Foster, Herbert B., Jr. California.
Foster, Norman. Pennsylvania.
Foster, William Floyd. California.
Fowler, G. England (I. S. P.).
Francis Hankin & Co., Ltd. Canada.
Francis, Geo. W. Michigan.
Frank, Leslie C. Federal.
Franklin, W. M. North Carolina.
Franzozo, Anthony. New Jersey.
Fraschina, Keeno. California.
Fraser, Charles E. Canada.
Frawley, Daniel. New York.
Frazier, R. W. Central States.
Fredson, Anthony. Central States.
Freeborn, W. F. England (I. S. P.).
Freeburn, H. M. Pennsylvania.
Freeland, B. H. Central States.
Freeman, A. B. Federal.
French, R. Del. Canada.
Frenchman, J. L. New Jersey.
Frerking, A. G. Kansas.
Freund, J. P. Pennsylvania.
Frick, A. L. California.
Frick, Edward J. Ohio.
Frickstad, Walter N. California.
Friel, F. S. Pennsylvania.
Frisk, Paul W. North Carolina.
Frith, Gilbert R. Georgia.
Froehde, F. C. California.
Fuchs, A. W. Federal.
Fuhrman, Ralph E. Federal.
Fuller, Andrew J. New York.
Fuller, N. M. New York.
Fulmer, F. B. California.
Fulmer, Frank E. Central States.
Fulton, E. A. Central States.
Funk, John B. Maryland-Delaware.
Furphy, H. G. England (I. S. P.).

Gadomski, Albert J. New Jersey.
Gahagan, H. B. Michigan.
Gail, A. L. Central States.
Galata, Richard L. New York.
Ganshaw, Elmer. New York.
Gardner, George W. New York.
Gardner, R. T. California.
Garland, Chesley F. Maryland-Delaware.
Garner, J. H. England (I. S. P.).
Garrison, Peter L. Central States.
Garthe, E. C. Federal.
Gartner, W. H. Central States.
Garwood, Kirk. Iowa.
Gates, Justin F. New York.
Gates, Lloyd R. Michigan.
Gauntt, W. C. Texas.
Gavett, Weston. New York.
Gearhart, John C. Pacific Northwest.
Gehm, Harry Willard. New Jersey.
Gelbke, Arthur W. New York.
Gelder, R. W. Rocky Mountain.
General Electric Company. California.
Genter, Albert L. Maryland-Delaware.
Gerard, F. A. Central States.
Gerardi, Angelo P. New York.
Gerdel, W. E. Ohio.
Gere, William S. New York.
Gerecke, Edward R. New York.
Germond, Earl. New York.
Geupel, Louis A. Central States.
Geyer, John C. Maryland-Delaware.
Gibbons, M. M. New Jersey.
Gibeau, H. A. Canada.
Gidley, H. K. Pennsylvania.
Giesey, J. K. Central States.
Gifford, J. B. Central States.
Gilbert, A. J. Arizona.
Gilbert, Joseph J. Pennsylvania.
Gilcreas, F. Wellington. New Jersey, New York
Giles, J. Henry L. New England.
Gilkey, A. E. California.
Gill, A. F. Canada.
Gill, J. Francis. New York.
Gill, Paul. Pennsylvania.
Gillard, J. E. England (I. S. P.).
Gillespie, C. G. California.
Gillespie, Jr., Robert L. New York.
Gillet, R. T. England (I. S. E.).
Gilman, Floyd. New York.
Gilman, N. A. Pacific Northwest.
Ginsberg, S. D. Central States.
Gisborne, Frank R. New England.
Glace, I. M. Pennsylvania.
Gladding, Charles. California.
Gladue, Donat J. New England.

Glynn, William J. New York.
Gneagy, Harold. Central States.
Goff, James S. New England.
Goff, William A. Pennsylvania.
Goforth, W. W. Canada.
Goldenberg, Charles N. Rocky Mountain.
Goldsmith, Philip. New York.
Goldthorpe, H. H. England (I. S. P.).
Golly, M. R. Central States.
Gooch, E. W. Pacific Northwest.
Goodenough, Frank H. New York.
Goodman, Arnold H. Central States.
Goodridge, Harry. California.
Gordon, J. B. Federal.
Gorman, R. C. New York.
Gorman, William A. Pennsylvania.
Gotaas, Harold B. North Carolina.
Gottschalk, Harry. Central States.
Goudey, R. F. California.
Gough, T. England (I. S. P.).
Gould, Richard H. New York.
Grabbe Construction Co. Central States.
Grabowski, John J. Pennsylvania.
Grace, C. F. Pennsylvania.
Grace, Francis J. New York.
Grady, Robert H. North Carolina.
Graemiger, Joseph A. New England.
Graham, Edward J. New York.
Graham, J. A. England (I. S. P.).
Graham, James E. Michigan.
Gran, John E. Georgia.
Grand Junction, City of. Rocky Mountain.
Grant, Arthur J. California.
Grassie, C. A. Canada.
Gray, D. M. Ohio.
Gray, Harold F. California.
Gray, Odell W. Georgia.
Greek, Edward B. Central States.
Greeley, Samuel A. Central States.
Green, Carl E. Pacific Northwest.
Green, Herbert. New England.
Green, Howard R. Iowa.
Green, R. A. Michigan.
Green, Tom C. Texas.
Greendale, Village of. Central States.
Greenleaf, John W., Jr. New England.
Greenlee, J. L. North Carolina.
Greenwich Sewer Commission. New England.
Gregory, L. L. England (I. S. E.).
Gregory, Robert W. North Carolina.
Gregory, Ted R. California.
Greig, John M. M. New York.
Grelick, David. New York.
Grieff, Victor C. New York.
Griffen, F. T. New York.
Griffin, Guy E. New England.
Griffin, Ralph J. Central States.
Grinnell Co., Inc. North Carolina.
Groeu, Michael A. Michigan.
Gross, Carl D. Central States.
Gross, Dwight D. Rocky Mountain.
Grossart, L. J. H. Pennsylvania.
Grosshans, Edward W. Central States.
Grover, R. H. New York.
Growdon, Howard C. Ohio.
Grunsky, Eugene L. California.
Gruss, A. W. California.
Gulden, H. B. Pennsylvania.
Gustafson, Ivar. Michigan.
Gwin, Lewis L. Pennsylvania.
Gyatt, W. P. New York.

Haberer, John C. New York.
Habermehl, C. Austin. Michigan.
Haddock, Fred R. Pennsylvania.
Haemmerlein, Victor E. New York.
Hageman, Roy C. Central States.
Hager, Fred. Central States.
Hagerty, L. T. Ohio.
Hagestad, Herman T. Central States.
Hahn, Howard. Central States.
Hale, Arnold H. New York.
Hall, Claude R. Pacific Northwest.
Hall, G. Albro. Ohio.
Hall, G. D. Pacific Northwest.
Hall, Frank H. New York.
Hall, Fred B. New York.
Hall, Hilliard D. Arizona.
Hall, Harry R. Maryland-Delaware.
Hall, M. G. Iowa.
Hall, W. H. North Carolina.
Hallden, John T. Central States.
Hallock, Emerson C. New York.
Halm, Ernest W. New York.
Halpin, John. New York.
Halstead, Douglas M. New York.
Hambleton, F. T. England (I. S. P.).
Hamel, Edouard. Canada.
Hamilton, R. F. Pacific Northwest.
Hamlin, C. H. England (I. S. P.).
Hamm, William C. New York.
Hammond, F. D. Central States.
Hammond, F. G. New York.
Handley, L. W. Georgia.
Haneman, A., Jr. Texas.
Hanenberg, A. L. Canada.
Haney, Joseph E. Central States.
Haney, Paul. Kansas.
Hanke, Carl C. Central States.
Hanrath, William J. New England.
Hansell, Wm. A. Georgia.
Hansen, August E. New York.
Hansen, Paul. Central States.
Hansford, Albert E. Canada.
Hanson, George I. New England.
Hanson, John R. New York.
Hapgood, E. P. California.
Hardenbergh, W. A. New York.
Harding, J. C. New York.
Harding, Robert G. California.
Hardinge, Company. New York.
Hardman, Thomas J. Central States.
Hardy, W. R. Texas.
Harley, Frank E. New Jersey.
Harmeson, D. K. Central States.
Harmon, Jacob A. Central States.

Harmon, Judson A. California.
Harper, Charles E. Central States.
Harper, M. J. New England.
Harrington, J. H. California.
Harris, C. H. Ohio.
Harris, George C. Central States.
Harris, R. C. Canada.
Harris, Roy M. Pacific Northwest.
Harrison, Bert. Pacific Northwest.
Harrison, Edward F. New York.
Harroun, F. E. Ohio.
Hart, Charles G. New York.
Hart, W. B. Pennsylvania.
Hartman, B. J. Central States.
Hartman, Byron K. Central States.
Hartung, N. E. Central States.
Hartzell, E. F. Pennsylvania.
Harvey, Carl. New York.
Harvey, J. R. Pennsylvania.
Harwell, A. A. Arizona.
Haseltine, T. R. Pennsylvania.
Hasfurther, William A. Central States.
Haskins, Chas. A. Missouri.
Haste, J. R. Central States.
Hatch, B. F. Ohio.
Hatch, G. M. Texas.
Hatfield, W. D. Central States.
Hathaway, A. S. Central States.
Hauck, Charles F. Ohio.
Hauer, G. E. Michigan.
Havens, William L. Ohio.
Hawken, Dalton. Michigan.
Hawley, Arthur A. New York.
Haworth, J. Victor. Pennsylvania.
Haworth, W. D. England (I. S. E.).
Hawtrey, R. O. Canada.
Hay, Julian A. Central States.
Haydock, Chas. Pennsylvania.
Hayes, John A. New York.
Hayler, Geo. R. California.
Hayward, Homer. Michigan.
Haywood, R. W., Jr. North Carolina.
Hazen, Richard. New York.
Healy, William A. New England.
Heaslit, Walter. Rocky Mountain.
Hedgepeth, L. L. Pennsylvania.
Hedges, Horace P. New York.
Heeg, Herman H. Michigan.
Heffelfinger, D. D. Ohio.
Heger, Harold. Central States.
Heider, Robert W. Central States.
Hein, Walter E. Central States.
Heinemann, B. New Jersey.
Heiple, Loren R. Central States.
Heisig, Henry M. Central States.
Heiss, Edward A. Pacific Northwest.
Helland, H. R. F. Texas.
Henderlite, J. H. North Carolina.
Henderson, Chas. F. New York.
Henderson, C. N. New Jersey.
Hendon, H. H. New York.
Hendrie & Bolthoff Mfg. & Supply. Rocky Mountain.
Hendrix, George K. Central States.
Heneghan, George P. Central States.
Henel, Wm. F. New York.
Henkel, George E. New Jersey.
Henn, Donald E. Central States.
Henry, Augustine. New York.
Henry, B. F. California.
Herberger, Arthur Henry. New York.
Hermann, Frank. Central States.
Herr, H. N. Pennsylvania.
Herrick, T. L. Central States.
Herringer, Elmer J. Federal.
Hersig, S. B. Central States.
Hesford, L. England (I. S. E.).
Hess, Joseph C., Jr. Pennsylvania.
Hess, Seth G. New York.
Hetherington, W. G. Central States.
Heubi, Thomas. New York.
Heukelekian, H. New Jersey.
Hewitt, A. C. Pennsylvania.
Heydon, F. G. Central States.
Heyward, T. C. North Carolina.
Hibschman, Charles A. Pennsylvania.
Hicks, Geo. W. Central States.
Hicks, R. England (I. S. P.).
Higgins, William J. New York.
Highberger, W. W. New York.
Hilborn, Gerald. Pennsylvania.
Hill, Frank C. Rocky Mountain.
Hill, G. Everett. New York.
Hill, K. V. Central States.
Hill, Theo. C. Pennsylvania.
Hill, W. R. Pacific Northwest.
Hiller, Paul W. New England.
Hilton, Elton M. California.
Hinman, Jack J. Iowa.
Hinyard, J. N. Texas.
Hircock, Chas. W. Arizona.
Hirschel, Leslie. New York.
Hitchcock, Simon E. Canada.
Hitchner, A. H. California.
Hoad, William C. Michigan.
Hoak, Richard D. Pennsylvania.
Hobson, N. C. Canada.
Hockley, C. P. Pacific Northwest.
Hodge, W. W. Pennsylvania.
Hodges, H. E. W. England (I. S. E.).
Hodgin, S. W. Central States.
Hodgson, E. England (I. S. P.).
Hodgson, H. J. N. England (I. S. P.).
Hoeflich, G. C. Pennsylvania.
Hoefling, Wm. L. New York.
Hoey, John B. New York.
Hoff, Clarence W. Pennsylvania.
Hoffert, J. R. Pennsylvania.
Hogan, J. W. T. New York.
Hogan, William J. New York.
Hoganson, Lester O. Central States.
Hogg, Alex M. Canada.
Holbrook, A. R. New York.
Holden, E. G. Rocky Mountain.
Holderby, J. M. Central States.
Holderman, John S. Central States.

Holland, Frank H. New York.
Hollis, L. M. Federal.
Holloway, Frank M. New York.
Holmes, Glenn D. New York.
Holmes, Harry E. New England.
Holmgren, Richard F. New England.
Holmquist, Chas. A. New York.
Holroyd, A. England (I. S. P.).
Holst, J. S. Dakota.
Holter, A. L. Pacific Northwest.
Holtkamp, Leo. Iowa.
Holway, O. G. Central States.
Hommon, H. B. Federal.
Honens, R. W. Central States.
Honigman, Elkono G. New York.
Hoover, C. B. Ohio.
Hoover, Charles R. New England.
Hopkins, E. S. Maryland-Delaware.
Hopkins, L. S. R. New York.
Hopkins, O. C. Federal.
Hopper, Allen O. New York.
Horne, Ralph W. New England.
Horton, F. C. California.
Hoskins, J. K. Federal.
Hoskins, Nandy. England (I. S. E.).
Hoskinson, Carl M. California.
Hotchkiss, H. T., Jr. New York.
Hoth, Fred. Central States.
Houlihan, J. E. England (I. S. P.).
Houser, C. S. Ohio.
Houser, George C. New England.
Houston, W. J. Georgia.
Howard, C. M. Pacific Northwest.
Howard, N. J. Canada.
Howard, P. F. New England.
Howarth, J. P. England (I. S. P.).
Howe, Ben V. Rocky Mountain.
Howell, Eugene M. Rocky Mountain.
Howland, W. E. Central States.
Howson, J. T. New York.
Howson, L. R. Central States.
Hoy, J. R. Georgia.
Hoydar, A. L. Pacific Northwest.
Hoyle, W. H. England (I. S. P.).
Hromada, Frank M. Central States.
Hubbard, Winfred D. New York.
Hubel, J. H. Canada.
Huber, Harold J. New York.
Huckeba, W. L. Georgia.
Hudson, Laverne D. Central States.
Huebner, Ludwig. California.
Hughes, W. P. Pacific Northwest.
Hulak, S. M. New York.
Hull, S. P. Central States.
Hults, William S., Jr. New York.
Humphrey & Sons, Howard. England (I. S. P.).
Hunt, L. W. Central States.
Hunter, A. England (I. S. P.).
Hunter, Harry. Central States.
Hupp, John E., Jr. Central States.
Hurd, Charles H. Central States.
Hurd, Edwin C. Central States.
Hurley, J. England (I. S. P.).
Hurst, William C. New York.
Hursting, R. C. Central States.
Hurwitz, Emanuel. Central States.
Hutchins, Will A. Central States.
Hutcheson, H. D. New York.
Huth, Norman A. California.
Hyde, Charles Gilman. California.
Hynes, H. A. Pennsylvania.

Illig, Louis. New York.
Illinois Dept. of Public Health. Central States.
Imbt, M. Russell. Pennsylvania.
Indiana State Board of Health. Central States.
Industrial Chemical Sales Co. Inc. New York.
Inertol Company. New York.
Ingols, Robert. New Jersey.
Ingram, Fred R. California.
Ingram, Wm. T. California.
International Filter Co. Central States.
Irwin, G. M. Canada.
Iscol, George. New York.

Jack, D. Canada.
Jack, Grant R. Canada.
Jacka, S. C. Michigan.
Jackson, J. Frederick. New England.
Jackson, James A. Central States.
Jackson, R. B. Michigan.
Jackson, T. B. Pacific Northwest.
Jackson, T. L. Michigan.
Jacobs, L. L. Georgia.
Jacobson, John. California.
Jarrett, J. M. North Carolina.
Jarvis, Alec C. England (I. S. P.).
Jeffrey, H. H. California.
Jellema, John F. Michigan.
Jenckes, J. Franklin, Jr. New England.
Jenks, Glen. Rocky Mountain.
Jenks, Harry N. California.
Jenne, Lyle L. Pennsylvania.
Jennings, A. England (I. S. P.).
Jennings, L. R. Michigan.
Jensen, Emil C. Pacific Northwest.
Jepson, C. England (I. S. P.).
Jeup, Bernard H. Central States.
Jewell, H. W. California.
Jewett, Herbert A. California.
Johns-Manville Corp. New York.
Johnson, Arthur H. Central States.
Johnson, Clement. New York.
Johnson, Earle P. Pennsylvania.
Johnson, Eskil C. New England.
Johnson, Floyd E. Central States.
Johnson, Francis M. North Carolina.
Johnson, Harry B. Pennsylvania.
Johnson, Herbert O. New York.
Johnson, John W. New York.
Johnson, L. J. Central States.
Johnson, Lloyd M. Central States.

Johnson, R. J. Central States.
Johnson, Verner C. California.
Johnson, W. T. Central States.
Johnson, Warren W. Kansas.
Johnson, W. H. England (I. S. P.).
Joiner, W. H. Texas.
Jonas, Milton R. Central States.
Jones, C. B. O. England (I. S. P.).
Jones, Daniel. New York.
Jones, Everett M. Pennsylvania.
Jones, Frank. Michigan.
Jones, Frank Woodbury. Ohio.
Jones, Howard H. Central States.
Jones, S. Leary. Federal.
Jones, T. A. Georgia.
Jones, Wayland. California.
Jordan, Edward C. New England.
Jordan, Harry B. New York.
Jorgensen, Homer W. California.
Joy, C. Fred, Jr. New England.

Kachmar, John F. Federal.
Kachorsky, M. S. New Jersey.
Kafka, John. Central States.
Kaiser, William B. New York.
Kaler, P. E. Kansas.
Kalste, Arthur. Central States.
Kammerling, Lane. Michigan.
Kane, James I. Central States.
Kappe, S. E. Pennsylvania.
Karalekas, Peter C. New England.
Karsa, William J. New York.
Kasperski, Frank E. Pennsylvania.
Kasser, Victor H. Central States.
Kass, Nathan I. New York.
Kay, L. A. Canada.
Kearney, E. W. North Carolina.
Keatly, C. R. Pennsylvania.
Kee, William J. New Jersey.
Keefer, C. E. Maryland-Delaware.
Keefer, R. K. Pennsylvania.
Keeler, J. Harold. New York.
Kehoe, Daniel J. New York.
Kehr, Robert W. Federal.
Kehr, Wm. Q. Missouri.
Keirn, K. A. New York.
Kelleher, Joseph A. New York.
Kelleher, Joseph A. New Jork.
Keller, Jacob. New York.
Keller, Lyndon M. New York.
Kelley, R. E. Michigan.
Kellogg, Clarence E. New York.
Kellogg, James W. North Carolina.
Kelly, Clarence. New York.
Kelly, Earl M. California.
Kelsey, Walter. Pennsylvania.
Kempkey, A. California.
Kemp, Harold A. New York.
Kennedy, C. C. California.
Kennedy, D. R. California.
Kennedy, R. R. California.
Kennedy, William. New York.
Kennedy, W. R. New York.
Kenney, Norman D. Maryland-Delaware.
Keown, Roy L. Georgia.
Kepner, Dana E. Rocky Mountain.
Kershaw, Arnold. England (I. S. P.).
Kessener, Ir. H. England (I. S. P.).
Kessler, Lewis H. Central States.
Ketcham, Charles G. New York.
Ketcham, Joseph M. New York.
Kewer, J. F. Central States.
Keyes, Harmon Edward. Arizona.
Kiker, John E., Jr. New York.
Kilcawley, Edw. J. New York.
Killam, E. T. New Jersey.
Killmar, C. M. Michigan.
Kimball, Jack H. California.
Kimberly, A. E. Ohio.
Kimler, Alexander. New York.
King, Henry R. Central States.
King, Kenneth K. Federal.
King, Richard. Central States.
King, William B. North Carolina.
Kingsbury, N. H. Central States.
Kingston, Paul S. Central States.
Kin, Stephen R. New York.
Kinney, E. F. Central States.
Kinney, J. B. Canada.
Kinsel, H. L. Pennsylvania.
Kinsey, L. B. Central States.
Kinsman, Frederick. California.
Kirchoffer, W. G. Central States.
Kirkpatrick, John W. Central States.
Kirsner, Charles. New York.
Kivari, A. M. California.
Kivell, W. A. New York.
Kjellberg, G. California.
Klang, Marvin. Michigan.
Klassen, C. W. Central States.
Klegerman, M. H. New York.
Kleiser, Paul J. Central States.
Klemme, Wm. W. New York.
Klinck, Frank. New York.
Kline, H. S. Ohio.
Klingbeil, Ray J. Ohio.
Klippel, Floyd. Iowa.
Knapp, H. A. Georgia.
Knechtges, O. Central States.
Knez, Cosmo M. New York.
Knight, Ray R. Canada.
Knittel, E. A. Pacific Northwest.
Knoedler, H. A. California.
Knowlton, Kenneth F. New England.
Knowlton, W. T. California.
Knox, Stuart K. New Jersey.
Knox, W. H. Ohio.
Koch, Philip L. Central States.
Kochin, Milton. Pennsylvania.
Kochititzky, O. W., Jr. Federal.
Koebig & Koebig. California.
Koetz, Lester. Central States.
Kolb, Fred W. California.
Koon, Ray E. Pacific Northwest.
Koplowitz, Sol. New York.
Korfmacher, John A. Central States.

Kozma, Albert B. New York.
Kraft, George M. Central States.
Kramer, David. Iowa.
Kramer, Harry P. Central States.
Kratz, Herman. Maryland-Delaware.
Kraus, L. S. Central States.
Krell, A. J. New York.
Kremer, Robert W. Pennsylvania.
Kressly, Paul E. California.
Kretschmar, G. G. Pacific Northwest.
Kreutter, Clarence. New York.
Kriegel, Paul O. New York.
Kronbach, Allan. Michigan.
Krohn, William. California.
Krum, Harry J. Pennsylvania.
Krumm, Harry J. Pennsylvania.
Krunick, M.D. Ohio.
Kuhl, F. A. Central States.
Kulberg, Abraham J. New York.
Kulin, Harvey J. Central States.
Kulisch, Harry. Central States.
Kuhner, Frank G. Central States.
Kunowski, Peter. New York.
Kunsch, Walter. New England.
Kunze, Albert T. Michigan.
Kupper, C. J. New Jersey.
Kyte, W. O. California.

Lackey, J. B. Federal.
Ladue, Charles J. Michigan.
Lafreniere, Theo. J. Canada.
Lakeside Engineering Corp. Central States.
Lamb, Clarence F. New England.
Lamb, Miles. Central States.
Lamb, P. England (I. S. P.).
Lambert, Francis J. New York.
Lamoureux, Vincent B. Federal.
Lamson, B. F. Canada.
Lanigan, John A. Michigan.
Lang, Lloyd. Central States.
Langdon, L. E. Central States.
Langdon, Paul E. Central States.
Lange, John F. New York.
Langelier, Wilfred F. California.
Langford, Leonard L. New York.
Langwell, Louie. Central States.
Lannon, William. New England.
Lanphear, Roy S. New England.
Larkin, W. H. New York.
Larsen, Earnest A. New York.
Larsen, Stanley J. Central States.
Larson, C. C. Central States.
Larson, Keith D. Central States.
Larson, L. L. Central States.
Lassiter, Leroy Irving. North Carolina.
Lauer, Charles N. Pennsylvania.
Laughlin, W. C. New York.
Lauster, K. C. Dakota.
Lavalley, Edward C. New York.
Laverty, Francis J. New York.
Lawlor, Jerome N. New York.
Lawrence, John. New York.
Lawrence, William H. New York.
Lawson, W. S. Canada.
Lawton, George. Michigan.
Lea, J. E. England (I. S. P.).
Lea, Wm. L. Central States.
Lea, W. S. Canada.
Leach, Walter L. Ohio.
Leahy, S. James. New York.
Lebetkin, George. New England.
Lebosquet, M., Jr. Federal.
Leclerc, Arthur B. North Carolina.
Ledford, George L. New York.
Ledwith, James J. New York.
Lee, Charles H. California.
Lee, Oliver. Central States.
Leemaster, J. F. Michigan.
Lefebvre, Fabian J. New York.
Lefever, R. W. California.
Leh, Willard. Pennsylvania.
Lehman Sewer Pipe Co., Inc. New York.
Lehmann, Arthur F. New Jersey.
Lehmker, William. Central States.
Lehner, Walter J. Michigan.
Lehr, Eugene L. New England.
Leiby, F. E. New York.
Leigh, H. G. England (I. S. P.)
Leist, Ervin F. Ohio.
Leitch, John C. Georgia.
Leland, Ben J. Central States.
Leland, Raymond I. Central States.
Lendall, Harry N. New Jersey.
Lenderink, Andrew. Michigan.
Lenert, Louva G. Georgia.
Lentfoehr, Charles E. Central States.
Leonard, O. M. Central States.
Leonard, W. V. Pacific Northwest.
Leonhard, Harold M. Michigan.
Lesher, C. E. Michigan.
Lesher, Carl. Ohio.
Lessig, D. H. Central States.
Lesslie, John N., Jr. North Carolina.
Levan, J. H. Federal.
Levine, Max. Iowa.
Levy, Harry W. New York.
Lewis, Clay W. Kansas.
Lewis, E. S. Arizona.
Lewis, John V. New York.
Lewis, R. K. Central States.
Lewiston, City of. Rocky Mountain.
Liddle, E. G. Michigan.
Lieber, Maxim. New York.
Limestone Products Corp. of America. New York.
Lind, A. Carlton. Central States.
Lind, Gunner W. Central States.
Lindell, O. V. Missouri.
Linders, Edward. Federal.
Lindsten, H. C. North Dakota.
Link Belt Company. New York, Pennsylvania, Central States.
Lingo, H. L. Kansas.
Linsley, Scott E. Central States.
Lippelt, Hans B. New York.
Littman, M. L. New Jersey.

Livingston, L. E. Texas.
Lock Joint Pipe Co. Rocky Mountain.
Locke, Edwin A. New England.
Lockett, W. T. England (I. S. P.).
Long, H. Maynard. Central States.
Long, George S. Pennsylvania.
Long, James C. New Jersey.
Loomis, Harry E. New York.
Lord & Burnham Co. New York.
Lord, Herbert O. Central States.
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Lose, Charles, III. New York.
Lose, Charles, Jr. New York.
Losee, James R. New York.
Louis, Leo. Central States.
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Lovejoy, W. L. Pacific Northwest.
Lovell, M. L. North Dakota.
Lovell, Theodore R. Iowa.
Lovett, M. England (I. S. P.).
Lowe, Thomas M. Georgia.
Lower, J. R. Ohio.
Lowther, Burton. California.
Lozier, William S. New York.
Lubow, Louis A. North Carolina.
Lubrecht, Frank S. Pennsylvania.
Lucas, W. R. Michigan.
Ludwig, Harvey F. California.
Luebbers, Ralph H. Missouri.
Lueck, Bernard F. Central States.
Luff, Reginald. Pennsylvania.
Luippold, G. T. California.
Lumb, C. England (I. S. P.).
Lund, Ralph F. California.
Lustig, Joseph. Central States.
Luther, L. L. New York.
Luther, Robert W. North Carolina.
Luton, Max. Rocky Mountain.
Lutz, Howland G. Pennsylvania.
Lynch, Daniel E., Jr. New York.
Lynch, James T. New York.
Lyndes, H. E. Rocky Mountain.
Lyon, A. S. North Carolina.

McAdoo & Allen Welting Co. Pennsylvania.
McAllister, Paul J. Pennsylvania.
McAnlis, Chauncey R. Central States.
McBreen, Charles. New York.
McBride, J. L. California.
McCall, Joseph F. New England.
McCallum, G. E. Federal.
McCannel, D. A. R. Canada.
McCarthy, J. J. Central States.
McCarthy, Justin J. New York.
McCarthy, William F. New York.
McCleary, E. L. Pacific Northwest.
McClenahan, W. J. Central States.
McClintock, H. C. Rocky Mountain.
McClure, Ernest. Central States.
McCoy, M. H. Central States.
McCrae, K. C. England (I. S. E.).
McDill, Bruce M. Ohio.
McDonald, John. New England.
McDonald, Michael D. New York.
McDonald, N. G. Canada.
McDonald, Roland G. New York.
McDonnell, George H. New York.
McDuell, John W. California.
McFarlane, W. D. Michigan.
McFaul, W. L. Canada.
McGrath, C. P. Michigan.
McGuire, C. D. Ohio.
McGuire, M. H. Pacific Northwest.
McIlvaine, Wm. D., Jr. Central States.
McInerney, Gerald J. New York.
McIntyre, Frank J. Ohio.
McIntyre, John C. Central States.
McKee, Frank J. Central States.
McKee, Jack E. New England.
McKeeman, Edwin C. New York.
McKenna, Harold R. Michigan.
McKinlay, Daniel. California.
McLaughlin, Carroll W. New York.
McLaughlin, R. M. New York.
McLean, Clement. New York.
McLean, R. F. Pacific Northwest.
McMahon, Walter A. New England.
McMenamin, C. B. New Jersey.
McMillan, Donald C. California.
McMorrow, Bernard J. California.
McNamara, W. P. Pacific Northwest.
McNamee, Paul D. Federal.
McNeal, Leonard. Ohio.
McNiece, L. G. Canada.
McPhail, James L. New York.
McRae, John. Michigan.
McShea, James. New York.
McWilliams, D. B. Canada.
MacAbee, L. Cedric. California.
MacCallum, C. New York.
MacLeod, Myron. New England.
MacCrea, J. M. New York.
MacDonald, G. A. Canada.
MacDonald, Hugh H. California.
MacDonald, J. C. Central States.
MacDowell, R. F. Ohio.
MacIntire, Kenneth. Pacific Northwest.
MacKenzie, C. J. Canada.
MacKenzie, Vernon G. Federal.
MacKin, John C. Central States.
MacLachlan, Angus. Ohio.
MacLean, J. D. Canada.
MacLaren, J. F. Canada.
MacLaren, L. A. Canada.
MacMurray, L. C. Maryland-Delaware.
MacNicol, N. Canada.
Madison, James W. Central States.
Magee, George W. New York.
Mahlie, W. S. Texas.
Maier, F. J. Federal.
Malcolm, Wm. L. New York, Canada.
Malick, Anthony J. New York.
Mallalieu, W. C. New Jersey.
Mallmann, W. L. Michigan.
Mallory, Edward B. New York.
Malloy, Howard. Michigan.

Malone, J. R. North Carolina.
Malony, W. L. Pacific Northwest.
Makepeace, W. H. England (I. S. P.).
Maguire, Chas. C. New England.
Mann, Alfred H. New York.
Mann, Uhl T. New York.
Mannes, Arthur S. Dakota.
Mannheim, Robert. New England.
Manning, P. Canada.
Mansfield, M. G. Pennsylvania.
Manteufel, Lawrence A. Central States.
Manz, Erwin C. Pennsylvania.
Mariner, W. S. New England.
Marrs, Paul. New York.
Marsh, H. M. Canada.
Marshall, E. A. New York.
Marshall Field Co. North Carolina.
Marshall, J. C. Michigan.
Marshall, Leslie S. New York.
Marshall, W. B. New York.
Martens, L. P. Central States.
Martin, A. E. New York.
Martin, Alexander G. New York.
Martin, Edward J., Jr. New York.
Martin, George C. Central States.
Martin, Geo. H., Jr. New York.
Martin, Phil J. Arizona.
Martin, Sylvan C. Central States.
Martin, Warren S. New York.
Marx, Frank. New York.
Maryland State Dept. of Health. Maryland-Delaware.
Marzec, E. J. Iowa.
Mason, Clarence A. Central States.
Mather, Edward K. Dakota.
Mathers, George. New York.
Matthew, R. P. California.
Mathews, E. R. Dakota.
Mathews, Frank E. Pacific Northwest.
Mathews, Henry M. Georgia.
Mathews, L. R. Central States.
Mathews, Richard. Michigan.
Mathews, W. W. Central States.
Mathis, Alice. Arizona.
Matter, L. D. Pennsylvania.
Mattheis, Clarence. Central States.
Mattimoe, George E. California.
Mattson, Walfrid I. Central States.
Mauldin, P. L. California.
Maurer, Peter J. Central States.
Max, John. Michigan.
Maxwell, G. E. Canada.
Maxwell, W. E. New York.
May, D. C. Michigan.
May, Harold L. California.
Meade, F. Griffith. Arizona.
Meadors, L. B. Central States.
Meats, G. R. E. England (I. S. P.).
Mechler, Louis W. California.
Meeker, Robert H. Kansas.
Megregian, Stephen, Jr. Federal.
Meiers, Walter W. New York.
Menantico Sand & Gravel Company. Pennsylvania.
Mendelsohn, I. W. New York.
Menefee, J. H. Missouri.
Meneke, K. E. Central States.
Mengel, Carl W. North Carolina.
Menzies, D. B. Canada.
Menzies, J. Ross. Canada.
Markel, Paul P. Pennsylvania.
Meron, L. A. New York.
Merrill, Walter E. New England.
Merritt, Will D. North Carolina.
Merryfield, Fred. Pacific Northwest.
Merwin, Willard. Central States.
Merz, H. Spencer. Central States.
Meserva, Charles. Michigan.
Metz, Roy L. Central States.
Meyer, Carl F. New England.
Meyer, Louis. California.
Michaels, John M. E. New York.
Mick, K. L. Central States.
Mickle, Chas. T. Central States.
Middleton, Francis M. Federal.
Miick, Fred E. California.
Miles, Henry J. New Jersey.
Milinowski, Arthur S. Central States.
Miljevic, Nicholas. New York.
Miller, A. J. Central States.
Miller, A. P. Federal.
Miller, A. Stuart. England (I. S. P.).
Miller, Alden W. Arizona.
Miller, David R. Central States.
Miller, E. P. Central States.
Miller, Fred M. New York.
Miller, J. John. Pennsylvania.
Miller, L. A. Central States.
Miller, Robert G. Iowa.
Miller, Roy. Pennsylvania.
Miller, W. C. Canada.
Miller, Wallace T. New York.
Milligan, Francis B. Pennsylvania.
Milliken, H. E. New York.
Milling, Martin A. Central States.
Mills, S. W. Canada.
Minneapolis-St. Paul San. Dist. Central States.
Mitchell, Ansel N. Kansas.
Mitchell, Geo. W.
Mitchell, Louis. New York.
Mitchell, Robert D. South Dakota.
Mittelstaedt, R. E. California.
Moat, C. P. New England.
Mock, Alvin M. Ohio.
Mogelnicki, Stanley J. Michigan.
Moggio, Wm. A. North Carolina.
Mohlman, F. W. Central States.
Molitor, Paul. California.
Moloney, Grant. Canada.
Monn, Edgar P. Pennsylvania.
Monroe, Lowell W. Pennsylvania.
Monroe, S. G. Federal.
Monsell, Harry M. New York.
Montagna, S. D. Pennsylvania.

Montes, Jose Garcia, Jr. England (I. S. E.).
Montgomery, J. Robert. Michigan.
Montreal Sewers Comm. Canada.
Mooney, Earl E. New York.
Moor, W. C. Texas.
Moore, Charles A. Pennsylvania.
Moore, Edward W. New England.
Moore, F. Owen. England (I. S. E.).
Moore, G. W. New York.
Moore, George S. North Carolina.
Moore, Herbert. Central States.
Moore, R. B. Central States.
Moore, W. A. Federal.
Morgenroth, Fritz. New York.
Morehouse, W. W. Ohio.
Morey, Burrows. New York.
Morgan, Edward F., Jr. New England.
Morgan, L. S. Pennsylvania.
Morgan, P. F. Central States.
Morkert, Kenneth. Central States.
Morrell & Company, John. Iowa.
Morrill, Arthur. Michigan.
Morris, Arval. California.
Morris, Lee. Dakota.
Morris, Paul J. Pennsylvania.
Morrison, C. B. California.
Morrow, Ben. Central States.
Moseley, Harry H. Ohio.
Moses, H. E. Pennsylvania.
Moss, F. J. Federal.
Mott, C. A. Canada.
Mount Penn, Borough of. Pennsylvania.
Mountfort, L. F. England (I. S. P.).
Mowbray, George A. New York.
Mower, Stanley E. New York.
Mowry, Robert B. Pennsylvania.
Mudgett, C. T. Michigan.
Muegge, O. J. Central States.
Mulcahy, James P. New York.
Muldoon, Joseph A. New England.
Mulvaney, M. B. Central States.
Munding, Germaine G. New York.
Mundt, Charles H. New York.
Munford, G. England (I. S. P.).
Munro, A. D. England (I. S. E.).
Munroe, E. H. Canada.
Munroe, W. C. Maryland-Delaware.
Munson, Laura A. California.
Murdock, Charles R. Canada.
Murdock, William. Pennsylvania.
Murphy, John A. Central States.
Murphy, Lindon J. Iowa.
Murphy, Reginald A. New York.
Murray, A. E. Scott. England (I. S. E.).
Murschel, Jacob. Dakota.
Musgrove, Robert. Michigan.
Muskegon, City of. Michigan.
Myatt, H. England (I. S. P.).
Myers, Harry L. Central States.

Nadin, Joe W. Central States.
Nagel, W. B. Ohio.
Nance, E. N. North Carolina.
Nash, D. A. Central States.
Nasi, Kaarlo. Pacific Northwest.
National Aluminate Corp. Central States.
Naylor, William. New England.
Nazareth Sewerage Company. Pennsylvania.
Necker, C. E. Canada.
Neiman, W. T. Central States.
Nelle, Richard S. Central States.
Nelson, Ben O. Pennsylvania.
Nelson, C. L. Central States.
Nelson, Frederick G. Ohio.
Nelson, George I. Central States.
Nemmers, W. P. Iowa.
Nesbit, George H. New York.
Nesheim, Arnold. Federal.
Nesin, Benj. C. New York.
Netto, J. P. De Lemos. New York.
Neves, Lourenco Baeta. New York.
Neville, Jabez E. California.
Nevitt, I. H. New York.
Newell, Town of. Iowa.
Newland, Stewart H.
Newlands, James A. New England.
Newlund, Walter W. Central States.
New Mexico Bureau of Public Health. Rocky Mountain.
Newsom, Reeves. New York.
Newton, R. O. Georgia.
Nichol, Gordon B. New Jersey.
Nichols, V. R. Pacific Northwest.
Nichols, Arthur E. New York.
Nichols, M. Starr. Central States.
Nicholas, Forrest A. Central States.
Nicholson, C. P. New York.
Nicklin, H. S. Canada.
Nicoli, Frank A. New England.
Nielsen, A. F. New York.
Niemi, Arthur G. Central States.
Niles, A. H. Ohio.
Nisbet, George A. Rocky Mountain.
Nisnevitz, Oscar. New Jersey.
Nolan, George H.
Nolte, Fred W. Pacific Northwest.
Norcom, George D.
Nordell, Carl H. Central States.
Norgaard, John.
Norris, Finlay J. California.
Norris, Francis I., Jr. Federal.
Norris, Harold E.
Noth, Melvin J. Central States.
Nugent, Franklin J. Pennsylvania.
Nussbaumer, Newell L. New York.
Nussberger, Fred. New York.

Obma, Chester A. Central States.
O'Brien, Earl F. New York.
O'Brien, James E. New York.
Ocean City Sewer Service Co. New Jersey.
Ockershausen, R. W. Central States.
O'Connell, Wm. J. California.
O'Connor, William F., Jr. New York.
O'Dell, W. H. New York.
O'Donnell, Frank. New York.

O'Donnell, R. Pennsylvania.
Oeffler, W. A. Central States.
Oehlke, Henry E. Michigan.
Oeming, L. F. Michigan.
O'Flaherty, Fred. Ohio.
Ogden, Henry. New York.
Ogle, Harry B. California.
O'Hara, Franklin. New York.
Ohr, Milo F. Michigan.
Ojai, City of. California.
Oke, Ernest E. W. Canada.
Okun, Abraham H. New York.
Okun, Daniel A. Central States.
Okun, W. H. New York.
Old, H. N. Federal.
Older, Fred. Michigan.
O'Leary, William A. New York.
Oleri, Frank J.
Olewiler, Grant M. Pennsylvania.
Olmsted, C. Henry New England.
Olney, H. Ross. California.
Olsen, Wm. C. North Carolina.
Olson, Frank W. Central States.
Olson, Herbert A. Michigan.
O'Mara, Richard. Central States.
O'Neill, Ralph W. California.
Ongerth, Henry J. California.
Orchard, W. J. New Jersey.
Ortiz, Pedro C.
Orton, J. W. Michigan.
Orwicz, Bernard. Central States.
Osage, City of.
Osborn, L. C. Rocky Mountain.
Owen, Mark B. New York.
Owings, Noble L. Maryland-Delaware.

Pacific Flush Tank Co. Central States, Rocky Mountain.
Pacific Foundry Company, California.
Packard, O. E. Michigan.
Page, R. W. Central States.
Paige, F. O. Central States.
Painter, Carl E. California.
Pallo, Peter E.
Palmer, Benjamin M. New England.
Palmer, Fred C. Canada.
Palmer, Gilbert. Pennsylvania.
Palmer, Harold K. California.
Palmer, I. Charles. Pennsylvania.
Palmer, John R. Central States.
Palmer, Ralph M. Central States.
Palocsay, Frank S. Ohio.
Pardee Engineering Co., Inc. New York.
Parkes, G. A. Calif.
Parker, Charles F. New York.
Parker, J. C. North Carolina.
Parker, R. J. England (I. S. P.).
Parks, W. J., Jr. North Carolina.
Parr, James. California.
Parsons, F. W. California.
Parsons, Norman W.
Parsons, R. H. Canada.
Patterson, W. E. Canada.
Patterson, Orville W. Central States.
Patterson, Richard L. California
Patterson, Roy K. New York.
Patriarche, John M. Michigan.
Paul, Lewis C. New York.
Paulette, R. J. Kansas.
Payrow, Harry G. Pennsylvania.
Payton, Lyle. California.
Pearce, Geo. W. Arizona.
Pearse, Langdon. Central States.
Pearson, S. R. Pennsylvania.
Pease, Maxfield. Ohio.
Peart, Robt. Kansas.
Peck, E. M. Central States.
Peck, Lawrence J. New York.
Pecker, Joseph S. Pennsylvania.
Peirce, W. A. Central States.
Peirson, Nat. D. North Carolina.
Pekin, City of. Central States.
Peller, Leo R. Central States.
Pennsylvania Salt Mfg. Co. New York.
Pensinger, L. C. Kansas.
Perkins, J. L. North Carolina.
Perlstein, Edward. New York.
Perrine, J. F. New York.
Perroni, Joseph. New York.
Perry, A. H. Canada.
Perry, Earl R. New England.
Peterson, Earl L. New York.
Peterson, Ivan C. Central States.
Peterson, J. H. California.
Peterson, Myhren C. Central States.
Peterson, R. W. Central States.
Petrie, William P. New England.
Pettit, Charles. Ohio.
Pfeifer, Willard. Central States.
Pfeiler, L. F. Central States.
Pfreimer, Harold A. Pennsylvania.
Phelps, B. D. California.
Phelps, E. B. New York.
Phelps, E. K. New York.
Phelps, Geo. Canada.
Phelps, T. I. California.
Philadelphia, City of. Pennsylvania.
Philion, W. I. New York.
Phillips, H. N. New York.
Phillips, Roy L. Pennsylvania.
Phillips, R. S. North Carolina.
Piatt, Wm. M. North Carolina.
Pickett, Arthur G. California.
Pierce, C. L. California.
Pierce, George O. Central States.
Pierce, W. E. Michigan.
Pierron, Wm., Sr. Pacific Northwest.
Pierson, Otto J. Michigan.
Pincus, Sol. New York.
Pinkney, Glenn E. New York.
Pinney, F. W. North Dakota.
Pitkin, Ward H. New York.
Pittsburgh Equitable Meter Co. New York.
Placek, O. R., Jr. Federal.
Plamondon, Sarto. Canada.
Pleasanton, Town of. California.

Pledger, A. England (I. S. P.).
Plummer, Raymond Benton. Central States.
Poindexter, G. G. Central States.
Polakov, Nicholas N. New York.
Pollock, John M. New York.
Pollock, John M. North Carolina.
Pomeroy, Clarence. Michigan.
Pomeroy, Richard. California.
Pontbriand, P. N. Canada.
Ponto, Willard. Michigan.
Pool, Charles L. New England.
Poole, B. A. Central States.
Poole, S. B. England (I. S. P.).
Pope, Lester. New Jersey.
Popp, W. L. California.
Porges, Ralph. New Jersey.
Porteous & Company, W. K. England (I. S. E.).
Porter, Harold. California.
Porter, William, New York.
Post, Fred W. California.
Poston, R. F. South Dakota.
Potter, Alexander. New York.
Potter, R. E. Canada.
Pottingham, W. P. Central States.
Potts, Clyde. New York.
Potts, Harry C. Michigan.
Powell, A. R. New York.
Powell, J. C. Central States.
Powell, S. T. Maryland-Delaware.
Powell, W. B. New York.
Powell, W. L. Texas.
Powers, Thos. J. Michigan.
Pratt, Gilbert H. New England.
Pratt, Jack W. California.
Price, Charles R. South Dakota.
Price, D. H. A. England (I. S. P.).
Price, R. C. Central States.
Primmer, B. J. California.
Pringle, H. L. Canada.
Proctor, J. W. England (I. S. P.).
Proudman, Chester F. New England.
Prough, Fred K. Central States.
Provost, Andrew J., Jr. New York.
Puffer, Stephen P. New England.
Purdie, David J. New York.
Purdy, William C. Federal.
Purser, John R., Jr. North Carolina.

Quaely, Martin F. New York.
Queens Borough Public Library. New York.
Queen's University Library. Canada.
Quigley, T. T. Central States.
Quinn, Francis T. New England.
Quinn, Thomas A. New England.

Racek, L., Jr. Central States.
Raisch, William. New York.
Raiter, Clifford R. Central States.
Ralston, George E. Central States.
Ralston, Wilmer R. Pennsylvania.
Ramseier, Roy E. California.
Ranagan, Fred E. California.
Randall, C. C. North Carolina.
Randall, Odie L. Arizona.
Randolph, Verdun. Central States.
Rankin, R. S. Central States.
Rantsma, W. F. California.
Rath, Henry M. New York.
Rawn, A. M. California.
Rawson, E. Otto. Canada.
Raymond, Herbert E. New England.
Raymond, Nelson I. Michigan.
Ray, Frederick. Central States.
Read, Homer V. Central States.
Ream, Edward F., Jr. Central States.
Reardon, Joseph F. New York.
Reardon, Wm. R. Central States.
Redding, Harry P. North Carolina.
Redfern, W. B. Canada.
Red Wing Sewer Pipe Corp. Central States.
Reed, Geo. D. Federal.
Reed, J. H. Pennsylvania.
Reed, Paul W. Central States.
Reed, Ralph. South Dakota.
Reedy, Timothy D. Michigan.
Rees, N. B. Central States.
Regan, T. H. Central States.
Regelsen, Alfred E. New York.
Regester, Robert T. Ohio.
Reilly, John J. Pennsylvania.
Rein, L. E. Central States.
Reinke, Edward A. California.
Reinoehl, Don. California.
Reisch, Eugene A. New York.
Reisert, Michael J. New York.
Renfrew, J. Harvey. England (I. S. E.).
Requardt, G. J. New York.
Reuning, Howard T. Pennsylvania.
Reybold, D. C. Central States.
Reynolds, A. V. England (I. S. P.).
Reynolds, Leon B. California.
Reynolds, M. W. Michigan.
Rhoads, Edward J. Pennsylvania.
Rhyne, C. E. North Carolina.
Ribal, Raymond Robt. California.
Ribbius, F. J. England (I. S. P.).
Ribner, Morris. New York.
Rice, John M. Pennsylvania.
Rice, Lawrence G. New York.
Rice, Lawrence H. New York.
Rice, Palmer J. North Carolina.
Richards, P. W. Central States.
Richardson, Charles G. New England.
Richardson, Charles S. New England.
Richey, C. E. Iowa.
Richgruber, Martin. Central States.
Richmen, W. F. Central States.
Richter, Paul O. Central States.
Rickard, Grover E. New York.
Ricker, W. H., Jr. Pennsylvania.
Ricketts, Allan T. Federal.
Riddick, Thomas M. New York.
Ridenour, G. M. New Jersey.
Riedel, John C. New York.
Riedesel, Henry A. Central States.

Riehl, W. H. Canada.
Riley, Harley M. New York.
Riordan, James T. New York.
Ritter, Bruce. Michigan.
Roab, F. H. Central States.
Robb, Charles G. New England.
Roberton, L. T. Canada.
Roberts, C. R. New York.
Roberts, F. C., Jr. Arizona.
Roberts, Jack. New York.
Roberts, L. M. New Jersey.
Roberts, W. C. California.
Robinson, B. Canada.
Robinson Clay Products Co. New York.
Robinson, George L. New York.
Robinson, I. F. Canada.
Robinson, J. C. South Dakota.
Robinson, T. C. North Carolina.
Robinson, Willis S. California.
Robins, Maurice L. Central States.
Robles, George C. California.
Rocco, John. New York.
Roche, Edward C. New England.
Roche, J. P. New England.
Rocker, Christian G. New York.
Rockne, T. B. Central States.
Roe, Frank C. New York, Central States, Canada.
Rogers, Allan H. New York.
Rogers, D. Paul. Pennsylvania.
Rogers, Harvey G. Central States.
Rogers, H. L. Pennsylvania.
Rogers, John A. New England.
Rogers, M. W. Canada.
Rogers, W. H. Central States.
Rohlich, Gerald A. Central States.
Roland, Robert J. Central States.
Romaine, Burr. Central States.
Rooks, C. P. Michigan.
Rosemeyer, Alfred. Central States.
Rosengarten, W. E. Pennsylvania.
Ross, John T. Pennsylvania.
Ross, W. E. Central States.
Rostenbach, Royal Edwin. Iowa.
Roth, B. F. Ohio.
Rowan, Thos. C. New York.
Rowen, R. W. Central States.
Rowinski, N. M. Central States.
Rowntree, Bernard. California.
Roznoy, Louis W. New Jersey.
Ruble, E. H. Central States.
Ruchhoft, C. C. Central States, Federal.
Ruck, Franklin. Ohio.
Rudd, Wm. C. Michigan.
Rudolfs, Willem. New Jersey.
Rugdal, H. T. Central States.
Rule, Harry A. Central States.
Rumsey, James R. Michigan.
Rupp, Daniel H. Ohio.
Rush, Dewitt E. New Jersey.
Rush, Frank O. Central States.
Russell, Don B. Iowa.
Russell, George. Missouri.
Russell, J. H. Central States.
Russell, J. P. Canada.
Ruth, Leo. W., Jr. California.
Rutter, Lee D. Pennsylvania.
Ryan, Joseph P. Central States.
Ryan, J. Samuel. New York.
Ryan, T. J. Texas.
Ryan, Wm. A. New York.
Ryon, Henry. New York.

Saetre, Leif. New York.
Sage, Howard D. New York.
Sageman, Norman. Michigan.
Sager, John C. New England.
Sakellariou, Evans N. Central States.
Salle, Anthony. New York.
Salvato, Joseph A., Jr. New York.
Sammis, L. A. New York.
Sampson, J. A. Iowa.
Samson, Channel. New York.
Sanborn, J. F. New York.
Sanders, M. D. Central States.
Sanderson, W. W. New York.
Sanford, Chester. New Jersey.
Santilli, Frank. New York.
Sargent, H. H. Central States.
Savage, Edward. New York.
Saville, Thorndike. New York.
Sauer, Victor W. California.
Saunders, James B. Arizona.
Sawyer, Clair N. Central States.
Sawyer, Robert W., Jr. New England.
Sciver, A. England (I. S. E.).
Schade, Willard F. Ohio.
Schaetzle, T. C. Ohio.
Schaefer, Edward J. New York.
Schaller, Norbert C. Central States.
Schapp, A. California.
Schaut, George G. Pennsylvania.
Scheak, H. M. Canada.
Scheffer, Louis K. Pennsylvania.
Scheidt, Burton A. Central States.
Scheller, Geo. M. New York.
Schenk, E. E. Iowa.
Scherer, Paul. New York.
Schier, Lester C. Central States.
Schildmann, W. H. Central States.
Schiller, Bernard. Arizona.
Schirk, J. M. Rocky Mountain.
Schlenz, H. E. Central States.
Schliekelman, R. J. Iowa.
Schmidt, Otto J. Central States.
Schmidt, William F. New York.
Schmuller, Frederick M. New York.
Schneider, J. J. Central States.
Schnupp, Leonard J. Pennsylvania.
Schrack, Bert. Iowa.
Schreiner, W. R. New York.
Schriner, P. J. Central States.
Schroeder, A. W. Central States.
Schroeder, W. L. South Dakota.
Schroepfer, George J. Central States.
Schulz, E. H. South Dakota.

Schwark, Wm. A. Central States.
Schwartz, H. L. Pennsylvania.
Schwartz, Louis. New York.
Schwartz, Oswald. Central States.
Schwob, Carl E. Central States.
Scott, Cliffton A. Central States.
Scott, Guy R. Federal.
Scott, R. D. Ohio.
Scott, Roger J. Central States.
Scott, Rossiter S. New York.
Scott, Roy D. New York.
Scott, W. England (I. S. P.).
Scott, Warren J. New England.
Scott, Walter M. New York.
Scott, W. M. Canada.
Scouller, W. D. England (I. S. P.).
Scovill, John R. New York.
Scudder, Aubrey P. New York.
Seaman, Henry. North Carolina.
Searight, Geo. P. Pennsylvania.
Searls, Glenn. New York.
Seely, Geo. A. Arizona.
Sedlacek, A. J. Iowa.
Segel, A. California.
Seid, Sol. New Jersey.
Seifert, William P. New York.
Seltzer, J. M. Pennsylvania.
Semon, H. G. New York.
Senseman, Wm. B. California.
Setter, Lloyd R. New Jersey, Pennsylvania.
Seufer, Paul E. Pacific Northwest.
Sexton, J. P. Arizona.
Seydel, H. New Jersey.
Shapiro, Charles M. New York.
Shapiro, Robert. New York.
Shaw, George H. Pennsylvania.
Shaw, Frank R. Federal.
Shaw, Paul A. California.
Shea, Walter J. New England.
Shearer, A. B. California.
Sheen, Robert T. Pennsylvania.
Sheets, W. D. Ohio.
Shelley, Harry. Pennsylvania.
Shelton, Edw. N. Georgia.
Shelton, M. J. California.
Shephard, W. F. Michigan.
Sheppard, Frederick. New York.
Shera, Bryan. Pacific Northwest.
Sheridan, City of. Rocky Mountain.
Sheridan, Thomas J. New York.
Sherman, Leslie K. New England.
Shertzer, J. H. Pennsylvania.
Shete, V. G. England (I. S. E.).
Shick, V. R. Ohio.
Shiffer, J. Paul. Pennsylvania.
Shirley, Donald L. Pacific Northwest.
Shockley, Homer G. New York.
Shook, H. E. California.
Shook, Howard R. Canada.
Shubart, C. A. Central States.
Shupe, S. Canada.
Sibbald, Charles T. A. New York.
Sibila, Rocco. New Jersey.
Sickler, Archie H. New York.
Sidle, R. S. England (I. S. P.).
Sidwell, Clarence G. Central States.
Siebert, Christian L. Pennsylvania.
Sieg, J. G. Central States.
Sieverding, O. C. New England.
Signor, C. V. Pacific Northwest.
Sigworth, E. A. New York.
Silberbauer, Walter R. California.
Simmerman, John S. New Jersey.
Simon, Samuel S. New York.
Simonton, Lewis. Georgia.
Simplex Ejector & Aerator Corp. Central States.
Simplex Valve and Meter Co. New York.
Simpson, R. W. New York.
Simpson, Jr., George. Rocky Mountain.
Simson, Paul W. New York.
Singer, L. P., Jr. California.
Skinner, J. F. California.
Skinner, W. V. California.
Slagle, E. A. New Jersey.
Slagle, Elmer C. Central States.
Slausson, J. B. Michigan.
Slee, Angus E. Rocky Mountain.
Sleeger, Warren H. Central States.
Slocum, Adelbert I. New York.
Slough, John. New York.
Small, R. L. Pacific Northwest.
Smalley, R. T. Arizona.
Smallhorst, David. Texas.
Smedberg, C. W. North Carolina.
Smigel, Walter A. Ohio.
Smiley, Paul E. Ohio.
Smith Company, A. H. Ohio.
Smith, Alva J. California.
Smith, B. G. Pacific Northwest.
Smith, Benjamin L. New York.
Smith, Charles E. Iowa.
Smith, Chester A. California.
Smith, Dell. Central States.
Smith, E. A. Cappelen. New York.
Smith, Edward J. New York.
Smith, E. E. Ohio.
Smith, Frank E. California.
Smith, Fred J. Central States.
Smith, G. C. England (I. S. P.).
Smith, H. G. California.
Smith, Harold. New York.
Smith, Harold. Michigan.
Smith, Harvey J. Pacific Northwest.
Smith, J. F. California.
Smith, J. Irwin. Central States.
Smith, Levi B. Kansas.
Smith, L. R. New York.
Smith, Marvin L. Pennsylvania.
Smith, Merlin D. Pennsylvania.
Smith, P. A. New Jersey.
Smith, Paul L. Maryland-Delaware.
Smith, Ralph A. Central States.
Smith, R. C. New Jersey.
Smith, Robert J. Michigan.
Smith, Russell S. Federal.

Smith, R. Trumbull. Central States.
Smith, S. H. Michigan.
Smith, Waymon, North Carolina.
Smith, Walter B. Michigan.
Smith, Walter R. New York.
Smith, Wendell H. Pacific Northwest.
Smith, W. T. E. Canada.
Smithwick, John J. New England.
Snapp, Russell G. Federal.
Snedeker, L. Laverne. Michigan.
Snell, J. R. New England.
Snelsire, William. Pennsylvania.
Snow, Donald L. Central States.
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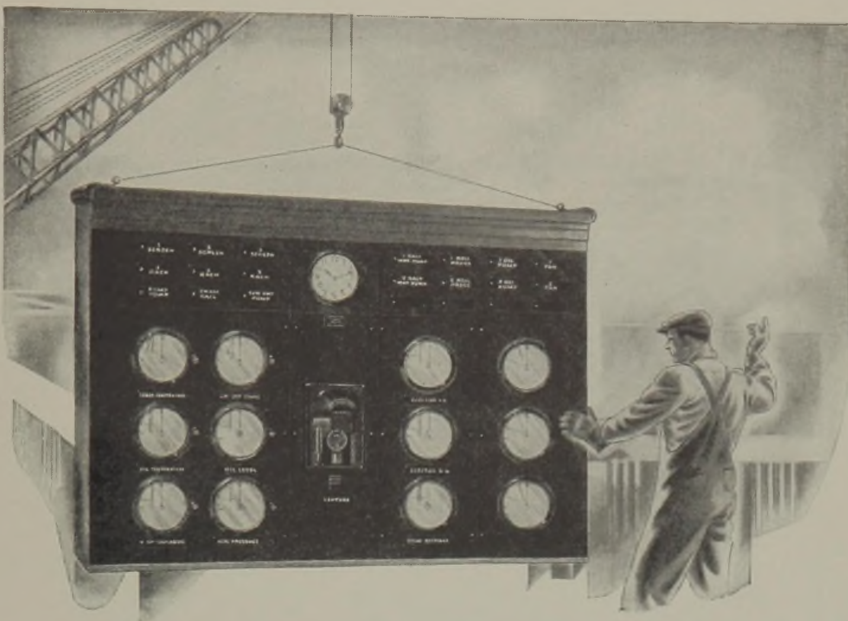

HOW "FLUSH-KLEEN" SYSTEM PREVENTS PUMP CLOGGING

Rags and Other Coarse Sewage Matter Do Not Pass Through Impellers.

Pumps Handle Strained Sewage Only.

While one pump is operating, sewage flows into basin through idle pump.

FILLING WET WELL

① Sewage flows through inlet pipe.

② Coarse sewage matter is retained by strainer.

③ Strained sewage flows through idle pump to basin.

PUMPING

③ Strained sewage is pumped from basin.

② Coarse sewage matter is backwashed from strainer.

④ Special check valve closes; sewage and coarse matter are pumped to sewer.

Both pumps operate under peak flows.

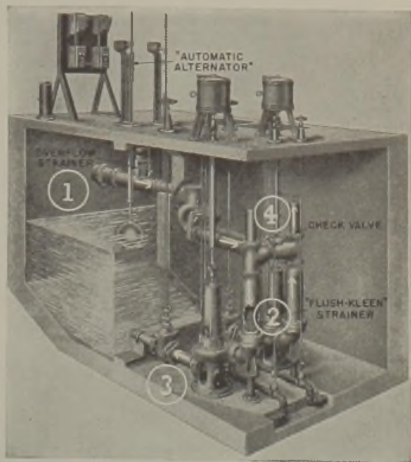

Fig. 2037—"Flush-Kleen" Sewage Pumping Station. While one pump is operating, sewage flows into the basin through the idle pump, as indicated by arrows. Coarse sewage matter is retained by the "Flush-Kleen" strainer in the idle pump (2). Only strained sewage passes through impeller to wet basin. When the idle pump operates, the coarse sewage matter in the strainer chamber is flushed out through the discharge pipe with the strained sewage from the wet basin. The check valve prevents operating pump from discharging back through the inlet line. In the meantime, sewage flows into the wet basin through the idle pump. Automatic Alternator transfers operation from one pump to the other. Both pumps may operate during peak flow, at which time sewage inflow is through overflow strainer.

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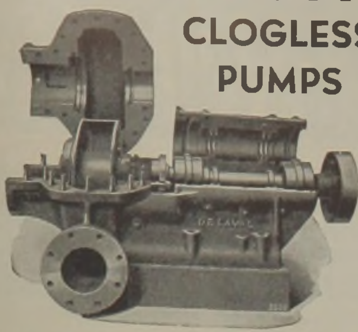

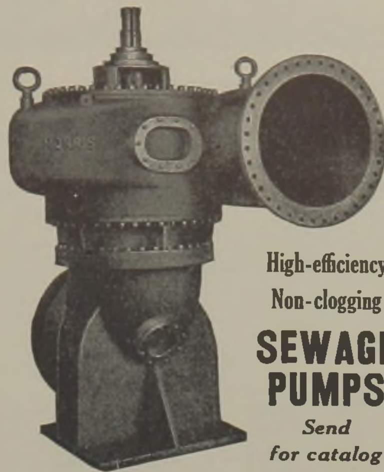

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