A Thesis in Two Parts

PART II

INVESTIGATION AND DISCUSSION OF PHENOMENA AFFECTING THE SETTLING CHARACTERISTICS OF "ACTIVATED SLUDGE" IN LIGHT OF CURRENT THEORY

by

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SCOPE

Many difficulties experienced in the operation of activated sludge plants center around the nature of the resultant sludge. Its condition directly affects the efficiency of the plant by governing the solids that may escape with the final effluent. Ease with which sludge is handled for final disposal is frequently affected by its physical characteristics.

When activated sludge has reached a certain abnormal condition, it is said to be "bulked". This term, as correctly applied, usually denotes the state of the sludge wherein there is noticeable failure to settle completely during its normal detention period in the clarifier. Sludge loses its compactness and particles of suspended matter may be completely diffused throughout the otherwise clear tank liquid. The effect may be to greatly increase the suspended matter that is retained in the final effluent, as well as to increase the volume of the sludge.

Certain conditions with similar effect have been erroneously described as bulking. Such condition is evidenced when sludge suddenly rises to the top of the settling tank or "turns over". The result is frequently a thick blanket of scum on the top of the clarifier, which condition is in some cases similar and certainly no more desirable than true bulking. The cause, however, may then be physical. It results in most cases from accumulations of sludge lodged in pockets on the bottom. Incipient septic action causes it to let loose and rise to the top.

The condition of true bulking having been experienced so generally in activated sludge plants both in this country and abroad, it is only natural that endeavors have been made to determine its cause. Some studies have been superficial but others have been exhaustive. Claims have been made that the underlying cause of sludge bulking has been determined, advice having been offered as to methods of control for all plants. Unfortunately, although methods for remedying or controlling this condition have proven practicable under certain conditions, there has as yet been no solution universal in its application. To most plant operators sludge bulking is still a serious problem.

CURRENT THEORIES

The factors to which the cause of sludge bulking has been attributed range in nature from development of minute symbiotic organisms to the purely mechanical condition of the elements contained in the sewage. The investigations and discussions of the entire phenomena of sludge function, requirements as to oxygen, and other sludge environmental factors, must be considered in obtaining an accurate picture of current theories. Some very valuable research has been carried on in this field.

Walter Scott[1], chemist of the Bury, (England) Activated Sludge Plant, has made experiments which seem to indicate that excessive amounts of carbohydrates in sewage cause rapid increase in the volume and consequently in the moisture content of activated sludge. He added milk wastes, starch, brewers' yeast and glucose to good activated sludge from the Bury treatment works. Yeast alone caused some increase in volume; but yeast plus 2000 P.P.M. glucose caused very pronounced bulking, - the volume increasing from 10 to 79 percent in eight days. In further tests the volume increased from 30 to 71 percent in one day.

H. W. Clark long ago showed that excessive amounts of carbohydrates prevent nitrification.

Results of the experiments by Walter Scott, and the contribution by H. W. Clark have been substantiated in a large measure by a summary of actual conditions experienced at the Des Plaines River Treatment Works of the Sanitary District of Chicago, as reported by E. H. Morgan and A. J. Beck[2]. They state that no serious difficulties in operation of the activated sludge process were encountered until the latter part of June, 1927, when the sludge began to bulk and flow over the effluent weirs, the oxygen demand of the sewage increased markedly, and nitrates almost disappeared in the effluent.

The sludge in this case changed visibly in appearance as well as in its physical properities. Instead of a well-formed, spongy floc, it became slimy and gelatinous in appearance and would not settle. It contained numerous small pellets surrounded by a slimy coating, which would settle fairly rapidly, but the bulk of the sludge was fluffy and like egg albumen in appearance.

Microscopic examination showed that the flocs were almost entirely masses of intertwined filaments. The small pellets mentioned above appeared to be more solidly agglomerated clumps of the organism and the sludge matter, entwined by continuous agitation in the aeration tank. The filaments did not grow from these balls but were merely entangled throughout them.

The organism was identified as sphaerotilus. Its growth was found to be encouraged in this instance by the addition to the sewage of large quantities of grain refuse, from illicit stills operating in that locality.

As reported by C. C. Ruchhoft and J. H. Watkins,[3] who are also connected with the Chicago Sanitary District, and working on the same problem, filamentous organisms similar to those present in the activated sludge of the Des Plaines Plant of the Sanitary District of Chicago, in the summer of 1927, have been noted as troublesome in sewage by sanitary engineers both in this country and abroad.

These reports usually refer to sphaerotilus and suggest various methods for its destruction or control, but describe neither the characteristics nor the microscopic appearance of the organism. Goudey[4] mentions growths of Beggiatoa and sphaerotilus in outfall sewers, but it is doubtful whether the latter plays a material part in the conditions described. Hull[5] experienced difficulties with growths of sphaerotilus natons and Leptomitus in a sewer receiving creamery wastes, and claimed that an application of about 2 P.P.M. of copper sulphate eliminated the growths. At Wakefield, England, Hoyle[6] reports difficulties with sphaerotilus growths in an activated sludge plant similar to those encountered by Morgan and Beck. He stated that he was able to conquer the difficulties by adding humus to the aeration tanks, but discussion of his remarks cast some doubt upon the permanence of his remedy.

Ruchhoft and Watkins made a microscopic examination of the organism identified as sphaerotilus. It is a straight filament, has no branches nor joints. No differentiation of any part is noted, the whole consisting of a continuous imperceptible sheath, enclosing homogeneous cells placed closely end to end and of a length but little greater than the diameter. Under the high power the cells appear as thin discs, which occasionally have separated, revealing the thin colorless sheath. A faint green is observed under the oil of emersion which cannot be seen under the low power. No granules or deposits are ever observed. The diameter of the filament is 2.0 - 3.0 micra, the length of the individual cells 2.0 - 4.0 micra. The filaments are seldom less than 1000 micra long and frequently are 5000 to 6000 micra in length. A stained slide of the filament reveals little more than an examination of the unstained material.

The cells are gram negative and appear merely as cells placed end to end. No production of motile conidia were shown even after isolation of the organism.

Whether the organism isolated by Ruchhoft and Watkins was the one commonly described as sphaerotilus was not known for certain at the time. There were certain points of difference.

Ellis[7] regards sphaerotilus as a variant of Cladothrix, and as such, one of the iron bacteria. No evidence has been obtained of a relation between the presence and absence of iron compounds in the medium and this organism. Because of this fact, and the fact that morphologically it resembles none of the common iron bacteria, it is believed by Ruchhoft and Watkins that the organism is not a member of this group.

Laboratory experiments by these same two men showed that prolonged aeration of the sludge up to 96 or 120 hours improved the settling quality of the sludge and greatly reduced the number of filaments, but did not eliminate them. Their experience checked the experience of Morgan and Beck whereby lime was found to be effective in treating the sludge. It was shown that in doses of 500 P.P.M. or over most of the filamentous organisms are dissolved or disintegrated in a short time. Doses of from 100 to 500 P.P.M. are also decidedly helpful in reducing the filaments but doses under 100 have little, if any, effect on the sludge.

Stress has been laid on this fact that sufficient aeration does not always prevent bulking, and that abundant air supply will not eliminate the diseased sludge. Moreover, excessive and prolonged aeration is said to be the cause of the dispersal of sludge particles, so that settlement of the sludge is hampered, thus creating conditions resembling the common bulking phenomenon.

In 1928 Kolwitz[9] states that the trouble was the result of a lack of equilibrium between the absorption and the regenerative power of the sludge, indicated by the development of this same sphaerotilus which disappears as soon as the equilibrium is reestablished. In other words, overloading of the sludge is the cause of bulking and there are no special constituents of the sewage that could be labeled as guilty.

Walter Scott was one of the first investigators to deny the exclusive influence of aeration and to emphasize the preponderating influence of certain substances in the sewage. He pointed out that damage to milk wastes cannot be cured by suitable aeration. A few years before, Kessener, describing his experiments at a milk factory at Vorden (Holland)[10] had ascribed the heavy bulking of the activated sludge solely to under-aeration. Without discussing air requirements, Back, in his letter to the Editor of the Surveyor[11] emphasizes his view that carbohydrates are the chief cause of bulking, they promote the growth of filamentous organisms belonging to the genus sphaerotilus.

To increase the limited knowledge of the phenomena already cited, Dr. Jan Smit[12] made a renewed study of its causes. The following are his conclusions regarding this subject.

"The phenomenon of bulking of activated sludge has proved to be materially influenced by the presence of carbohydrates. It is shown that glucose, sucrose, and lactose are particularly deleterious, while the influence of starch is much less. Notwithstanding the deterioration of the sludge, the carbohydrates are digested with rapidity. After the addition is stopped, renewing of sugar-free sewage being continued, a quick restoration of the sludge occurs, whereby the ability of the sludge to settle again reaches its original value.

A method for quantitative estimation of settling properties is indicated. The occurrence of carbohydrates in sewage is discussed and it is shown that the sugar content of Amsterdam sewages is far below the limit of harmfulness.

It follows from the above specifications that the real cause of bulking in domestic sewage must lie elsewhere."

Results of investigations have indicated the effect of variations in the supply of air on settlement of sewage sludge. The study of active oxygen requirements of the sludge by Harris, Cockburn and Anderson[13], Jenks and Levine[14], and by Grant, Hurwitz and Mohlman[15] are valuable. In this connection Harris, Cockburn and Anderson claim that the time of treatment varies inversely as the amouht of sludge used, within rather wide limits, with a shortened period of aeration, however, the period of aeration of the sludge must be increased, for, as Harris, Cockburn and Anderson[13] put it, the "pollute" is transferred to the sludge.

Jenks and Levine[14] in connection with their studies of "stream-flow" aeration, have discussed the theoretical oxygen requirements of the activated sludge process on the assumption that the rate of air supply should be adjusted to the diminishing demand in proportion to the theoretical rate of satisfaction of oxygen demand as proposed by Phelps[16], and later more fully confirmed by Theriault[17]. The logarithmic nature of this rate curve is well known; as expressed by Phelps, "the rate of bio-chemical oxidation of organic matter is proportional to the remaining concentration of unoxidized substance, measured in terms of oxidizability". Jenks and Levine, in considering the 5-day demand, apportion the requirements for oxygen as follows:

Days	Per Cent	Per Day
1	60	60
2	84	24
3	94	10
4	98	4
5	100	2

The rate of B.O.D. satisfaction is assumed to correspond to the rate of aeration, directly as above if the aeration is 5 hours, or proportionately allocated if the aeration period is greater or less.

Realizing the scarcity of laboratory research on the oxygen requirement of the activated sludge process, Grant, Hurwitz and Mohlman made important contribution to this subject. They investigated chiefly the oxygen requirements of the sludge, and the sludge and sewage mixtures. In this case the primary biological nature of sewage purification was recognized, but it was kept in mind that clarification is a combination of biological and purely physical events. According to Grant, Hurwitz and Mohlman, the physical nature of clarification consists of the coagulation "or scrubbing out" of colloidal solids in the sewage liquor. If the process were entirely physical, however, high concentrations of activated-sludge in the aeration tanks would be desirable to secure maximum adsorption and clarification. There is a limit, however, to the amount carried, the oxygen requirements of which must be entirely satisfied.

Two stage processes have resulted from this consideration. In the first stage large amounts of sludge are used to secure maximum clarification, whereas in the second stage, small amounts of sludge are used to reduce the oxygen requirements.

The specific problem investigated by Grant, Hurwitz and Mohlman, was the correlation of daily determination of oxygen requirements of sludge with the actual weight of sludge in the aeration tanks, to develop a more rational basis for determination of the amount of sludge to be returned and maintained in the aeration tanks.

To determine absorption of oxygen by sludge, activated sludge from the North Side Treatment Works was used in their tests. Sludge was collected at the effluent end of the aeration tanks, concentrated by settling or diluted with water in the laboratory when necessary. The content of suspended solids from 1225 to 4850 P.P.M. was said to cover the range usually used in the North Side aeration tanks. The sludge was saturated with oxygen before starting each test, thus eliminating any immediate oxygen demand.

To determine absorption of oxygen by sludge and sewage, sewage and activated sludge from the North Side Treatment Works were used. The sewage was settled and rapidly filtered through glass wool in order to remove the coarser suspended matter. Activated sludge was added to the sewage in varying amounts, and the experiments performed as for the previous determination.

These experimenters summarize their results as follows: "Our experiments with activated sludge and sewage from the North Side Treatment Works indicate that:

1. The rate of absorption of oxygen by activated sludge in the amounts and periods of aeration commonly used, is fairly uniform and varies directly in proportion to the weight of the sludge.

2. The rate of absorption of oxygen varies, further, in proportion to the content of organic "volatile" matter in the sludge.

3. The rate of absorption of oxygen by North Side activated sludge averaged 7.0 milligrams of oxygen per gram of sludge per hour.

4. Mixture of sewage plus sludge absorbs oxygen in proportion to the weight of sludge, but with increasing amounts of sludge most of the oxygen-demanding material of the sewage is coagulated or adsorbed by the sludge, so that very little oxygen is required for the unadsorbed material in colloidal or true solution. The subsequent rate of oxidation of the coagulated material in the sludge is slow and comparatively uniform. The sludge passes through many cycles of aeration before it is removed, and during these successive aerations the organic matter is slowly oxidized.

5. Based on reduction of B.O.D. our results so far do not indicate that the period of aeration and amount of sludge vary inversely (that is, the period of aeration X per cent of sludge - constant) as claimed by Harris, Cockburn and Anderson, small amounts of sludge reduce the B.O.D. of the sewage almost as rapidly as large amounts. Re-aeration of sludge is indicated, however, when small amounts are used because of the shorter period of retention.

6. Adjustment of the rate of air supply should be governed by the amount of sludge in the aeration tanks; with large amounts a fairly uniform rate is desirable. Rates of aeration in proportion to the B.O.D. of sewage, as recommended by Jenks and Levine, are greatly modified by the oxygen requirements of the sludge".

Since temperature of liquids affect its viscosity and thus the rate of settlement of particles in suspension a complete investigation of factors relating to efficiency in clarification of activated sludge will include actual correlation between temperatures and the time for settling that results. To G. M. Ridenour[18] we are indebted for such a study. He used an apparatus consisting of 3 inch diameter cylindrical glass tubes, 36 inches long, with conical bottom. The outlet arrangement at the bottom of the cone permitted the settled solids to be drawn off at will. Temperatures were maintained by incubation. Settling tests were made at different temperatures from a composite sample secured from the Plainfield Plant. The solids settled at the end of predetermined intervals were drawn from the bottom of the settling tubes, dried and weighed. The suspended solids in the supernatant liquid were also determined at the end of each run. From this experiment the following conclusions were drawn:

"1. Temperature affects the rate of settling of sewage solids. The rate of settling increases slightly with corresponding increase of temperature up to 30° C. Near that point a critical temperature is encountered above which the rate of settling rapidly decreases.

2. Although temperature increases the rate of settling, its effect is of no practical importance in the usual range of temperatures encountered in sewage treatment.

3. The effect of temperature on the settling rate is most pronounced for settling periods of from 0-30 minutes.

4. The settling of finer particles was not influenced by temperature.

5. Temperature of sewage is of no importance in the settling efficiency of a sewage settling tank unless a combination of high temperatures above 30°C. and short detention period prevails.

6. At the end of two hours the removal of solids by settling is practically the same for all temperatures between 10°C. and 37°C.

7. Less floculation of sewage particles seems to occur at higher temperatures than at lower temperatures. At higher temperatures the sewage particles settle in a finely divided state. At the lower temperatures, below 30°C., a more pronounced floculation was noticed.

8. The change which caused the particles to be retarded in their settling rate at temperatures above 30°C., was not permanent. Sewage

which was heated to 33° or 37° C. and then cooled to the lower temperature of 7°C. assumed the same settling characteristics as those of sewage settled at 7°C. without heating."

In a paper presented at the Annual Summer Conference of the Association of Managers of Sewage Disposal Works at Lythano, St. Annes, July 7-9, 1932, presented by Clifford and Windridge, experiences relating to capacity of sludge to settle and exygen requirements of activated sludge as noted at Bio-Aeration Plants were recounted. These briefs refer particularly to the cause of bulking in individual plants in Great Britain. It was stated that at the Wolver Bio-Aeration Plant underaeration was held responsible for bulking, weak sewage in the aerators correcting the difficulty to a great extent. Tests on the rate of settling in cylinders indicated that the time required for settling increased with concentration but that equal weight increments of sludge concentration above a certain point increased the time element disproportionately. For all sludges examined it was found that an increase in the weight of sludge solids per 100 c.c. of liquid produced more than a proportionate increase in the volume of settled sludge for all periods of settlement up to six hours. Beyond a certain weight of sludge, roughly 25% on two hours settlement, a further small increase produced an enormous increase in volume. The conclusion was that the phenomenon of bulking may be largely a result of too much sludge, regardless of the condition of the sludge or its state of aeration.

Clifford and Windridge offer practical explanations for the observed results. They state that caution must be used in comparing results of settling in small cylihders to that obtained in large tanks. Depth has no effect on moisture content under quiescent conditions. Bulking may be controlled by keeping the sludge down to a certain volume indicated for the Wolverhampton Plant by definite data. Prolonged aeration has the same beneficial effect on bulking as reduction in weight concentration and could be used where an ample supply of air is available, although several days aeration of the same sludge may be required to produce any marked change.

Clifford and Windridge also state that "A certain residual volume of sludge should be maintained in settling tanks to allow concentrations but if this sludge volume exceeds the quiescent space of the tank, some sludge will be discharged with the tank effluent. In any event the larger amount of sludge maintained in circulation, the greater is the capacity of settlement tanks required and the greater the volume of sludge to be removed.

"From experimental data it is concluded that for short settlement periods the heaviest sludge is obtained by settling the liquid containing the smaller quantity of sludge, although for periods of 24 hours' settlement the thickest sludge is obtained from the most concentrated liquid."

The beneficial effect of prolonged aeration as noted by Clifford and Windridge is contrary to the experience of Walter Scott[1], and Ruchhoft and Watkins[3] as previously noted in connection with bulking which was attributed to sphaerotilus.

Discussions by plant operators at this same Conference, brought out diversity of opinion as to the effect of underaeration on bulking. It was the opinion of most operators that the cause of bulking was a complexity of factors. The experience of F. W. Harris of Glascow, that if by increased sludge concentration the dissolved oxygen in the supernatant liquid was reduced, bulking invariably followed. Mr. W. H. Hoyle of Wakefield believes sugar in the sewage created a culture medium for the filamentous growths associated with bulking. He stated that he could tell by microscopic examination of the sludge for filamentous growths whether sludge was bulking or not.

Recent literature on activated sludge includes a paper that is inclusive in its consideration of biological and oxidative phenomena of the sludge and mixed liquor, and their relation to sludge bulking and clarification. T. R. Haseltine,[20] Superintendant at the Salinas Activated Sludge Plant took advantage of difficulties encountered during the first year or more of operation to experiment with certain treatment units in order to reduce operating problems. During the comparatively short period of operation bulking, short circuiting, poor clarification, and loss of nitrification had been experienced at times, while on other occasions a clear stable effluent resulted.

The sewage treated was chiefly domestic in origin, but very strong and containing considerable grease. Its strength varied, being greatest in November and least in March. Average monthly figures for suspended solids and ammonia nitrogen ranged from 260 to 450 P.P.M. and from 25 to 45 P.P.M., respectively. The high grease content was said to be augmented by frequent discharges of kerosene and lubricating oil. The sewage reached the plant in fairly fresh condition although occasionally as much as 2.0 P.P.M. of hydrogen sulphide was detectable on arrival.

The Salinas plant combines separate sludge digestion with the activated sludge process.

The plant was first put in operation May 27, 1930. After a good activated sludge was developed it was reported "possible to aerate about 400,000 gallons per day and to produce a very excellent effluent, but whenever an attempt was made to treat more sewage the dissolved oxygen dropped and the sludge bulked. The bulking resulted in a very slimy, slow settling, floc that would not compact to a dense return sludge. As a result the sludge levels in the final clarifiers built up to the point where the floc passed out with the effluent. Greatly reducing or eliminating the flow to the aeration tanks for three to six days eliminated bulking temporarily." It was estimated that 3.4 cu.ft. of air per gallon of sewage and a 9.5 hour aeration period were being used.

Changes were made in the sludge handling facilities to remove the sludge at a rate fast enough to keep the level in the clarifier below the point where it would flow out with the effluent. It was also desired to increase the period of reaeration at the sacrifice of part of the time of aeration. A study of the results indicated to Mr. Haseltine the following:-

1. The sludge density did not simply drop to a certain minimum at which point it would remain constant, but apparently it would con-

tinue to decrease until it became so low that there was very little separation of the floc from the liquor. Therefore the increased sludge return capacity was of little or no benefit. Extremely high rates of return sludge were probably harmful because they decreased the sludge aeration period and, to a lesser extent, the aeration period of the mixed liquor.

2. "Sludge aeration was of some benefit in retarding bulking. This indicated that if the reaeration period could be increased without further decreasing the aeration period of the mixed liquor considerably more benefit would be realized. This showed the necessity of obtaining a return sludge of higher solid content.

3. "Either more air, or more efficient aeration, or both were required. Because of limited blower capacity, air had been supplied at a uniform rate, which meant that although the daily averages ranged from 1.9 to 2.6 cu.ft. of air per gallon of sewage, the actual air supplied ranged from 1.3 cubic feet per gallon on peak flow to 4.7 cubic feet per gallon on low night flow. It was thought that additional air in peak flows was particularly necessary."

Experiments were therefore undertaken to determine (a) means of increasing the efficiency of the aeration, (b) means of increasing the solid content of the raw sludge, and (c) how much air was required and how it should vary with sewage flow.

The efficiency of the aerators was increased twenty-five percent by installing baffles to reduce short circuiting resulting from the spiral flow aeration.

Practical means to increase the solids content of the raw sludge were found to include increasing the amount of suspended matter in the mixed liquor, increasing the depth of sludge in the clarifiers, and decreasing the rate of withdrawing sludge. Air requirements would increase by increasing the solid content of the mixed liquor, which was undesirable at this plant.

Experience at Salinas was said to indicate that bulking occurred more rapidly when greater depths of sludge were carried in the clarifiers, thus agreeing with the experience of others; Harris, Cockburn and Anderson[13] had previously stated that, "undue detention in the settlement tanks lowers the density of the sludge and increases its volume." Tests on the Dorr clarifier indicated that lowering the rotating speed tended to increase the density of the sludge removed.

Reaerating the sludge appeared to have little if any effect on the air requirements, but reaeration together with baffling in the aerators increased the treating capacity about sixty per cent.

Tests made were also said to show: (1) "That the hourly variation in amount of air used should be much less than that in the amount of sewage treated; (2) that when large amounts of sludge were used, ... the air should be applied at a uniform rate, but that when smaller amounts were used ..... some reduction in air could be made during the night; (3) that the condition of the sludge had a marked effect on the amount of air required." These conclusions confirm the results obtained by Grant, Hurwitz and Mohlman[15] as previously related in this paper.

Proper distribution of air between the various parts of the aeration and reaeration tanks was given attention. The statement made by Harris, Cockburn and Anderson[13] was kept in mind that their experiments "proved that the dissolved oxygen adsorbed by the sludge is a constantly decreasing amount from its contact with the inflowing sewage to its discharge from the reactivation channels (aerators). The starting point of the process of reactivation (biological oxidation) may be accepted as the point nearest the inflow of the aeration tank at which dissolved oxygen appears. The degree of reactivation (biological oxidation) that takes place in the aeration tank is dependent upon the balance maintained between the supply of and the demand on the dissolved oxygen and the period of detention as timed from the determined starting point." The distribution of air to the various parts of the tank was so adjusted that (1) there was an appreciable amount of dissolved oxygen in the reaeration compartments; (2) there was at least a small amount at the inlet of the aeration compartments; and (3) the dissolved oxygen gradually increased toward the outlet of the aeration compartments. It was found at this plant "that when these conditions were all satisfied considerably more sewage could be treated when distributing the air uniformly throughout the aerators, although the dissolved oxygen was slightly lower. It was found necessary to use from 55 to 70 per cent of the air on the inlet side of the aerators to satisfy these conditions; the percentage increases somewhat with increased sewage flow, decreased air supplies or bulked sludge and vice versa."

Frequent microscopical examinations at the outlet of the aeration tanks disclosed the invariable presence of sphaerotilus in a bulked or poor sludge.

The conclusions reached by Mr. Haseltine from the Salinas experience and from current literature are as follows:

"1. There is considerable short circuiting in the ordinary spiral-flow aeration tanks; it appears that the incoming sewage and sludge follow a spiral course around a central core of nearly quiescent liquor. Increasing the surface velocity of the liquor increases the diameter of the central core and hence increases the amount of short circuiting. This condition is probably more serious in aerators in which the flowing-through channels are nearly square, and in which large volumes of air are used, than it is in normal aerators. Diagonal baffles so placed as to deflect part of the rising column of air and liquor toward the center of the tank are effective in reducing the diameter of the core and hence the amount of short circuiting. This would indicate that the practice of introducing the air through porous tubes paced several feet above the tank floor with vertical baffles extending down nearly to the floor so as to produce an air lift action, such as has been used at some recent plants, might favor the creation of a very large central core and hence severe short circuiting.

2. At Salinas the practice of sludge reaeration did not make it possible to reduce the amount of air used per gallon of sewage, but that practice together with the baffling of the aerators made it possible

to treat about sixty per cent more sewage in the same tank capacity when using the same amount of air per gallon of sewage.

3. At Salinas it is necessary to use about 3.4 cu.ft. of air per gallon of sewage to avoid bulking. This high air requirement may be caused by the abnormally high fat content of the sewage as well as by its high oxygen demand and concentrated nature.

4. The Salinas experiences show that the hourly variations in amount of air used should be much less than those in the amount of sewage treated. When larger amounts of sludge are carried in the aerators the air should be supplied at a uniform rate throughout the day, but when smaller amounts of sludge are used some reduction may be made in the amount of air used during the low night flow of sewage.

5. It appears that in order to get the most good from the air used it should be divided between the various parts of the aeration and reaeration tanks in such proportions that there is an appreciable amount of dissolved oxygen in the reaeration tanks, some at the inlet of the aeration tanks, and a gradually increasing amount toward the outlet of the aerators.

6. The oxygen-demanding material in the sewage is adsorbed on the activated-sludge floc surfaces and then biologically oxidized. Oxidation may progress in two phases, liquefaction and gasification. The relation between the dissolved solids in the sewage and those in the mixed liquor shows the progress of liquefaction, while the time required for the sludge in the mixed liquor to rise in suitable containers under

semi-controlled conditions serves as a rough measure of gasification. Gasification appears to be more important than liquefaction in the oxidation of adsorbed nitrogenous matter. These two phases of biological oxidation may be depending upon different flora and require slightly different environmental conditions for optimum progress.

7. The balance between adsorption and biological oxidation within the sludge must be maintained. Excessive adsorption is the primary cause of bulking, while excessive oxidation results in poorer clarification. Variations in the ash content of the sludge serve as a rough measure of the balance between adsorption and oxidation; increasing ash content indicates an increase in oxidation over adsorption and vice versa. The density of the sludge tends to follow variations in its ash content.

8. Occasional discharges of oil in the sewage upset the adsorption-oxidation balance so that they are always accompanied by decreases in the ash content of the sludge, but they do not cause serious bulking unless the ash content of the sludge has been falling for some time previous to the receipt of the oil. Because of the deleterious affect of the oil on the adsorption-oxidation balance it is desirable to increase the amount of air used for a few hours after receiving the oil discharges.

9. *Sphaerotilus* growths in the sludge may be a secondary cause of bulking sludge. The sludge may be constantly seeded with these organisms, but unless oxidation lags behind adsorption for several days the sludge

is not a suitable medium for their development. Sugars in the sewage may contribute, but are not essential, to their development. The application of large amounts of lime appears to be a better means of eliminating these organisms once they have gained a foothold than is prolonged aeration or greatly increased amounts of air, but it does not follow that it should be relied upon instead of either increasing the air supply or the aeration period sufficiently to prevent the development of the organisms in the first place. Much less air is required to prevent the development of the organisms than is required to eliminate them after they have developed within the sludge.

10. At Salinas bulking may be avoided by regulating the amount of air used so that the dissolved solids in the mixed liquor are maintained slightly higher than, or equal to, those in the sewage; likewise the ash content of the sludge, as determined daily at a given hour, should not be subject to a continuous decline.

11. A preponderance of flaggellates over ciliates in the sludge may indicate a poor sludge, as is claimed by many investigators, but, at Salinas at least, a preponderance of ciliates over flagellates does not necessarily indicate a good sludge.

12. The Salinas experiences show that it is not necessary to carry large amounts of sludge in the aerators in order to produce a well purified, stable effluent. The use of small amounts of sludge make possible a saving in air required, but makes necessary the maintenance of very active biological oxidation processes which apparently entails rather complete nitrification."

Mr. A. P. Banta, Assistant Engineer with the Los Angeles County Sanitation District, from observations of conditions experienced at the Wilmington Plant, makes certain comments on Mr. Haseltine's theory regarding the cause of variations in ash content, and the effect of this variation on sludge density. To restate a portion of Mr. Haseltine's theory, "variations in the ash content of the sludge serve as a rough measure of the balance between adsorption and oxidation; increasing ash content indicates an increase in oxidation over adsorption and vice versa. The density of the sludge tends to follow variations in its ash content."

It is conceded by Mr. Banta that the sludge density and hence the bulking effect, tends to follow variations in the ash content of the sludge; however, it is his contention that the underlying cause for such variations of the ash (or volatile) content of the sludge is due to corresponding variations in the raw sewage, and not to any oxidation balance effect. In other words, the volatile content of the sludge is in reality a measure of what the volatile content of the raw sewage solids has been. It is his contention that the strength of the raw sewage as measured by the volatile content or the B.O.D. is a determining factor in the sludge density characteristics and variations in the circulating load of activated sludge exert an influence similar to that of the variations in strength of the raw sewage.

It is seen that although similar in effect, these two theories are at variance in principle. The first theory attributes changes in the sludge to the ability to adsorb or oxidize the organic load. The second theory attributes changes in the activated sludge to changes in the raw sewage.

RESTATEMENT OF PROBLEM

Examination of these recorded results of research on activated sludge phenomena and the observations and opinions of investigators in this field discloses a great variety of information, some contradictory, but largely of value in arriving at increased efficiency for operation of individual plants.

As directly pertaining to the condition known as bulking there seems to be a great diversity of opinion. In some cases the disagreemànt is as to whether the conditions observed bear a primary or secondary relation to bulking. Corrective measures reported as helpful at one plant have been tried and found to be of no avail when repeated elsewhere. The use of lime as suggested by Goudy and proven successful at the Griffith Park Plant, Salinas and previously at Chicago, was only mildly effective or entirely inoperative when tried at Phoenix, Pasadena, and the Joint Disposal Plant at Wilmington.

The opinion held by some that bulking in activated sludge is caused by a complexity of factors is substantiated by part of the information presented. However a great deal of weight must be attached to the association of sphaerotilus with bulking. A logical conclusion, is that bulking is not always caused by the same factors, but that the development of sphaerotilus due to a favorable environment may directly cause the sludge to lose its normal characteristics and thus result in bulking. Two distinct types of sludge bulking may then exist; one caused by the development of sphaerotilus due to favorable environment; the second due to causes other than biological which may produce the same effect.

To determine the effect of requirement and satisfaction of functions of the activated sludge process, has been the attempt of the investigators as heretofore stated. Some have advanced probable correlations with the sludge density. The entire cause of variations in sludge density or index is not definitely known, but having determined the principles involved the factor or combination of factors may soon become apparent or at least more fully understood.

Future research should eliminate disagreement as to interpretation of various component processes involved in the activated sludge type of treatment. It would clarify present thought on the subject if proof or disproof could be advanced concerning the numerous theories that have been cited herein. On completion of this phase, final treatment of the problem will be unencumbered by unessential or unrelated ideas.

The purpose of the statistical analysis undertaken in this study has been to check the correlation of certain foregoing theories with actual operating conditions (as found in one or more local plants) rather than to formulate additional factors which may be involved in sludge bulking.

DATA AVAILABLE

Investigation of activated sludge phenomena for correlative purposes should include a diversity of data. To secure comprehensive results attempts were made to acquire information pertaining to operating results from plants in the southwest, including those at Phoenix, Salinas, Pasadena, Pomona, and the Los Angeles County Sanitation District's plant. Records were made available and used from Pasadena and Wilmington; Pomona as yet does not make daily tests; at Salinas the analysis of the raw sewage is not sufficiently complete, for the purpose, and at the Phoenix Plant the data on the activated sludge does not contain the tests necessary for the study.

METHOD OF ANALYSIS

In making this investigation recognition was taken of the fact that the treatment program normally followed in the activated sludge process is inflexible. Variability in flow of the raw sewage is in such cases not counteracted by a changing proportion of air supplied or of detention time. Rate of return for the activated sludge frequently remains constant. Fluctuation in sludge characteristics must, therefore, be attributed to basic phenomena and cannot be connected with operating conditions. An exception is noted where return sludge is effected by the rate of withdrawal of excess sludge.

Frequently investigations on activated sludge treatment relate in someway to the density or settling characteristics, of the sludge. Since sludge density is a relation between the amount of dry solids and the settling ability of the sludge, there is, therefore, no standard practice for determining this ratio. As defined at the Pasadena Activated Sludge Plant, sludge density (or sludge index) refers to the percent of total dry solids, expressed as a percentage, in the aeration tank to the percent volume of the same sludge recorded in a standard cylinder after one-half hour of settling. At the Joint Disposal Plant of the Los Angeles County Sanitation Districts, sludge density refers to the per cent suspended solids in reaeration tanks, expressed in P.P.M., divided by the percentage volume of sludge after one-half hour of settling. The essential difference lies in the fact that for Pasadena the sample is taken from the aeration tanks and total solids are determined whereas at the Wilmington Plant the suspended solids are used and the sample is taken from the reaeration tanks.

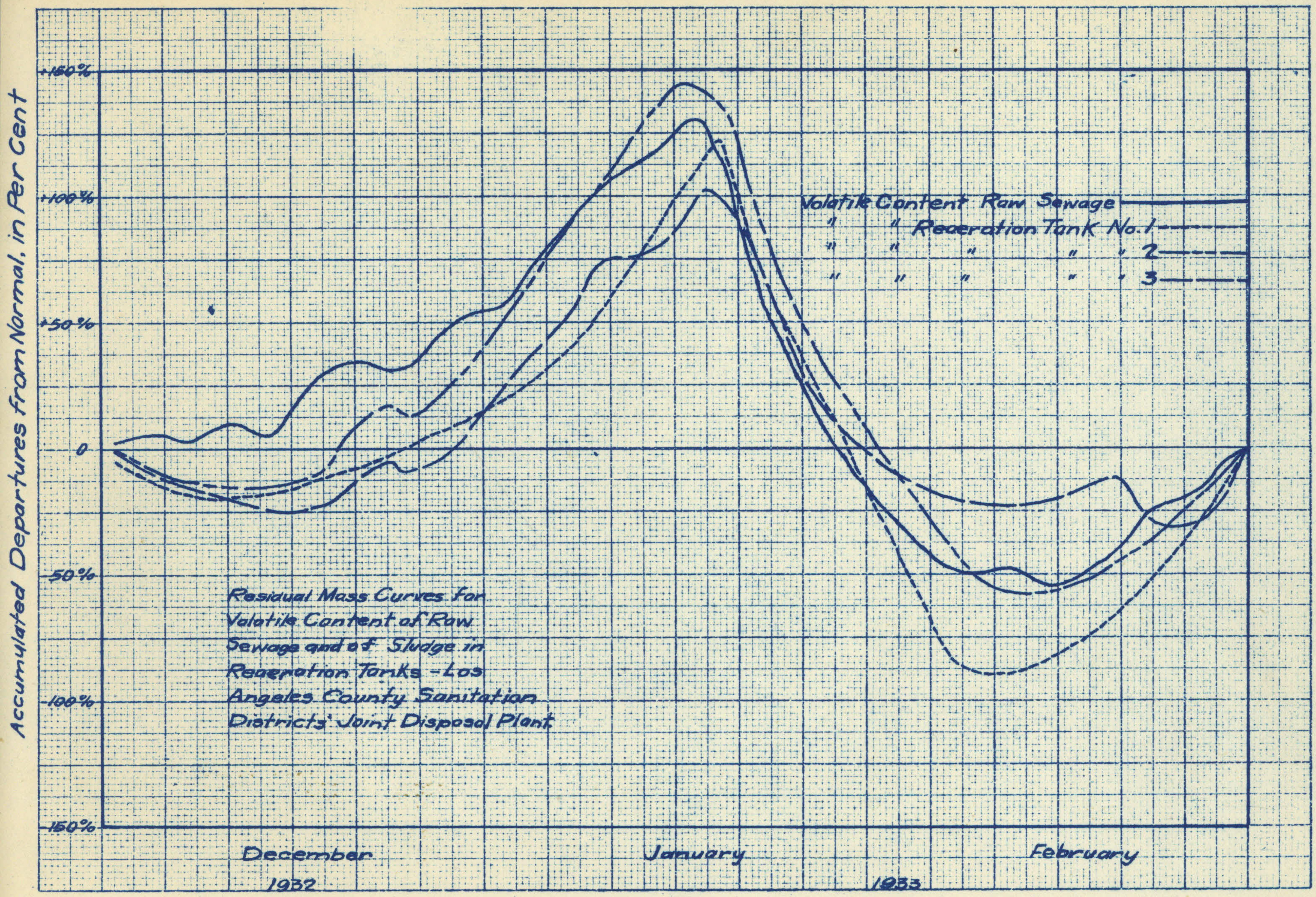
At both of these plants densities are particularly significant since when below unity for extended periods bulking results.

With the data obtained from the Los Angeles County Sanitation Districts' Wilmington Plant and the Pasadena Activated Sludge Plant as series of residual mass curves was plotted, in the first case for a three months period, and for the Pasadena Plant partly for three months and the remainder for one full year. The residual mass curves indicate accumulated departures from the normal of the period investigated. A rising curve indicates above average characteristics, a falling curve indicates that results are below average. Attention is called to the division of the Wilmington Plant into three units, each consisting of aeration, reaeration, and clarifier tanks. For this reason that portion of the plant consists essentially of three distinct plants, but having an identical raw sewage.

RESULTS

Plate No. I. shows the results obtained by plotting the volatile content of the raw sewage against the volatile content of the sludge in each of the reaeration tanks at the Wilmington Plant. It will be noticed that the resulting residual mass curves show a very close correlation, although it is also apparent that the volatile content of the sludge in the reaeration tanks tends to lag a few days behind that of the raw sewage. This would indicate that the characteristics of the circulating load as indicated by the volatile content of the sludge are dependent on the changing characteristics of the incoming raw sewage. There is no obvious dependence on the rate of oxidation of the sludge itself. This is in conformity with the conclusion drawn by Mr. Banta as previously stated.

The diagrams on Plate No. II. were drawn to make comparison of statistical data on the volatile content of the raw sewage, (5-day) B.O.D. load in pounds per day of the raw sewage, (and the sludge density,) at this same plant. It will be noted that the B.O.D. load curve is drawn as the inverse of actual data. In other words, when the



Accumulated Departures from Normal, in Per Cent
+150%
+100%
+50%
0
-50%
-100%
-150%
Volatile Content Raw Sewage
" " Reaeration Tank No. 1
" " " " " 2
" " " " " 3
Residual Mass Curves for Volatile Content of Raw Sewage and of Sludge in Reaeration Tanks - Los Angeles County Sanitation Districts' Joint Disposal Plant
December
1932
January
1933
February

I

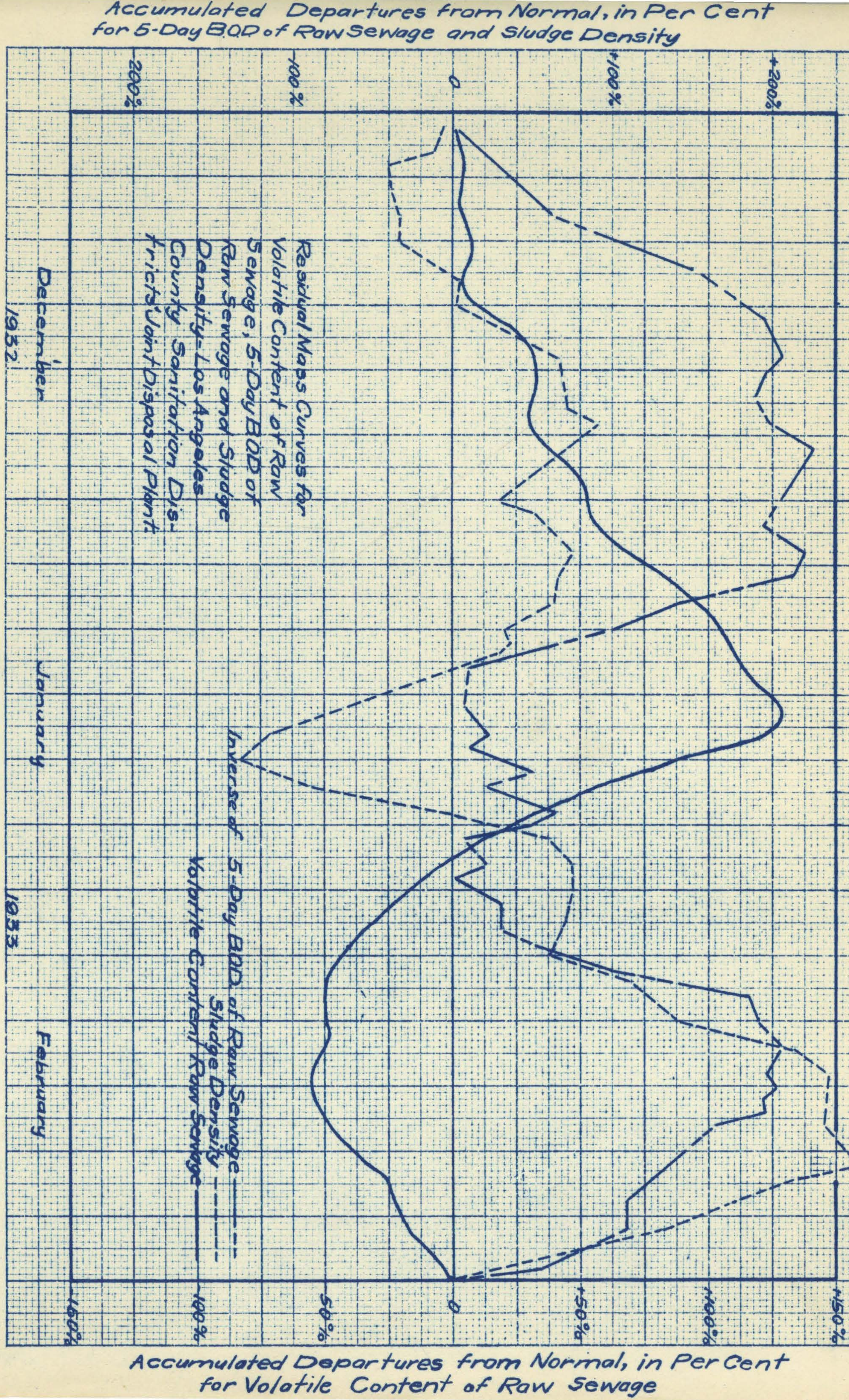
B.O.D. is above average the curve has a falling characteristic. Attention is first drawn to the correlation between the curve for the volatile content of the raw sewage and the sludge density. It will be noted in this connection that the sludge density curve is in reality an average of the results for each of the three Plant units - weighted twice for unit No. III., which is actually two units combined.

Comparison of the two curves indicated shows a tendency for the sludge density to vary inversely as the volatile content, or directly as the ash content of the raw sewage. This is most apparent where the volatile content increases or decreases rapidly. During the first ten days of the month of December the volatile content was somewhat higher than average, and sludge density somewhat below average. For the next twenty-five days the sludge density increased to above average, then leveled off to average at the same time that the volatile content of the raw sewage was increasing rapidly. This would suggest that some tendency other than that indicated by the volatile content of the raw sewage exerts an influence on the density of the sludge. From the end of the first week in January to the last of the period investigated there is a very marked tendency for the sludge density to vary inversely as the volatile content of the raw sewage.

Since the volatile content of the raw sewage has been shown to govern the volatile content of the sludge in the reaeration tanks, results for the Wilmington Plant are in agreement with the conclusions drawn by Mr. T. R. Hazeltine that "density of the sludge tends to follow variations in its ash (or volatile) content," even although the supporting reasoning is incorrect (for this plant).

Inspection of Plate No. II. discloses a tendency for the B.O.D. load as expressed by the inversely plotted curve, to vary directly as the sludge density. Inconsistancy is apparent, however, since variations in B.O.D. do not correlate inversely with sludge density for each period.

It thus appears that to get the full relation between the B.O.D. load of the raw sewage and sludge density, and between the strength load, as expressed by the percent volatile in the raw sewage, and the sludge density, that all three characteristics must be considered simultaneously. Closer study of the diagram emphasizes this point. An extended period with B.O.D. load below normal as indicated by the rising characteristic of the first portion of the curve is seen to be followed by a period of higher sludge density, indicated by the rising characteristic of the sludge density curve. During the latter half of December when the B.O.D. daily load curve levels off to about average, the percent volatile content of the raw sewage is clearly above average, whereas the sludge density begins to decline gradually (which, of course, indicates that the density of the sludge is somewhat below average for the period). Attention is called to the effect on the sludge index when the B.O.D. load decreases rapidly at the same time that the percent volatile of the raw sewage is relatively high. Inspection reveals in this period a fast declining curve for sludge density, which is abruptly


Accumulated Departures from Normal, in Per Cent
for 5-Day B.O.D. of Raw Sewage and Sludge Density
-200%
-100%
0
+100%
+200%
Residual Mass Curves for
Volatile Content of Raw
Sewage, 5-Day B.O.D. of
Raw Sewage and Sludge
Density-Los Angeles
County Sanitation Dis-
tricts' Joint Disposal Plant.
December
1932
January
1933
February
Inverse of 5-Day B.O.D. of Raw Sewage
Sludge Density
Volatile Content Raw Sewage
-150%
-100%
-50%
0
+50%
+100%
+150%
Accumulated Departures from Normal, in Per Cent
for Volatile Content of Raw Sewage

II

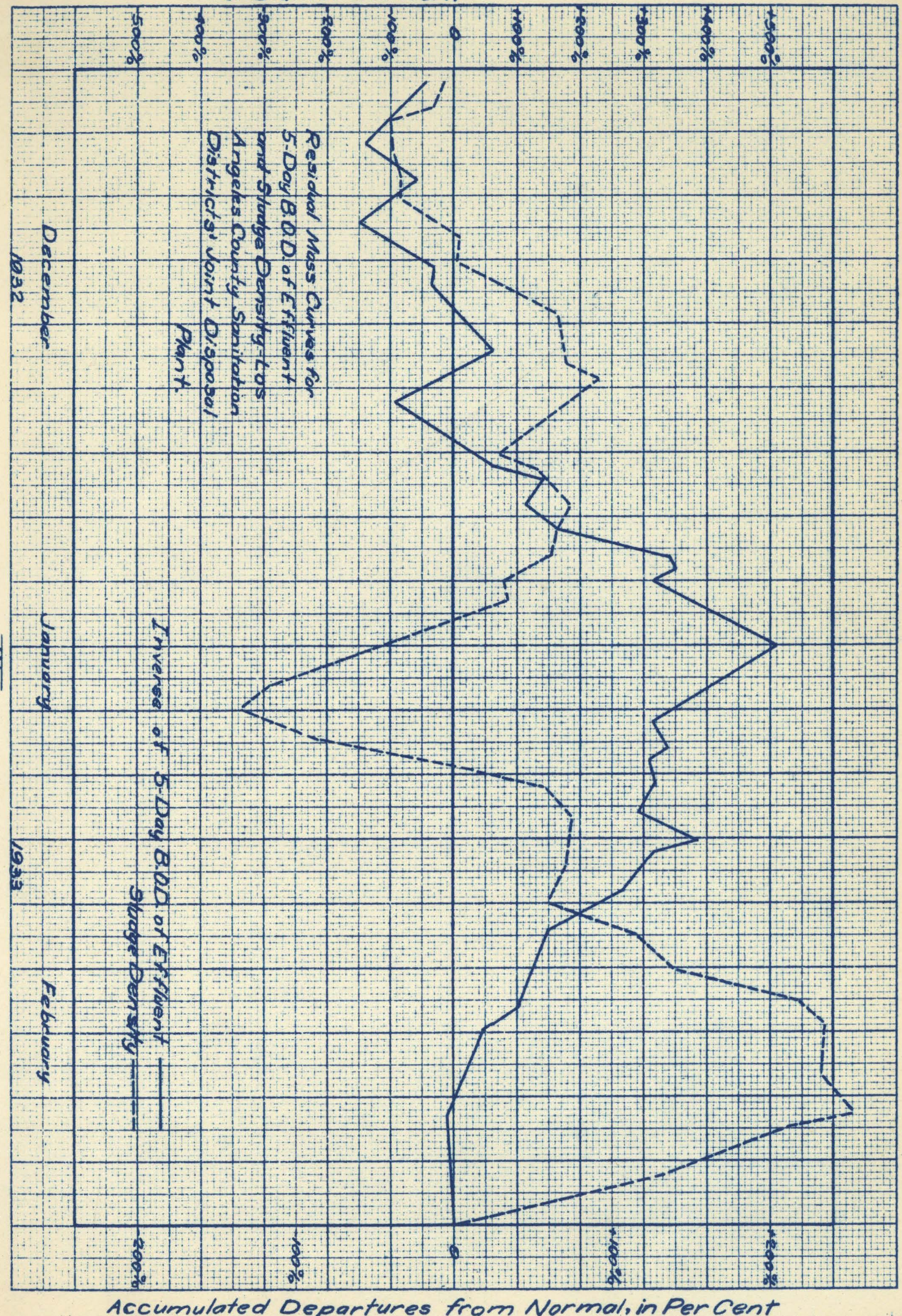
checked when the B.O.D. daily load drops to normal for the period, and the curve for volatile content declines slightly. The lag noted between the changes in volatile content of the raw sewage and variations in sludge density is, of course, to be expected, since as stated, the theory considers variations in sludge density to follow variations in the volatile content of the sludge itself. Plate No. I. discloses the lag between curves expressing the volatile content of the sludge, and the curve for volatile content of the raw sewage.

The sudden decline to below normal experienced by the volatile content of the raw sewage during the latter part of January is paralled by a sudden rise in the curve for sludge density. At the same time the B.O.D. load of the raw sewage is shown to be about average. The sludge density as indicated by the rising curve, increases for a period of slightly over one week, and then declines for a little longer period. The decline following a small increase in B.O.D. daily load.

The results for the first half of the month of February are characterized by a declining curve for volatile content of the raw sewage, a rising curve for B.O.D. load (decrease in B.O.D. load) and a resultant very great increase in the sludge density. During the latter part of February the reverse holds true; that is, increase in volatile content of the raw sewage, increase of B.O.D. load in pounds per day, and a resultant decrease in sludge density.

Inspection of these curves indicates the general rule for the Wilmington Plant at least, that the sludge density is influenced

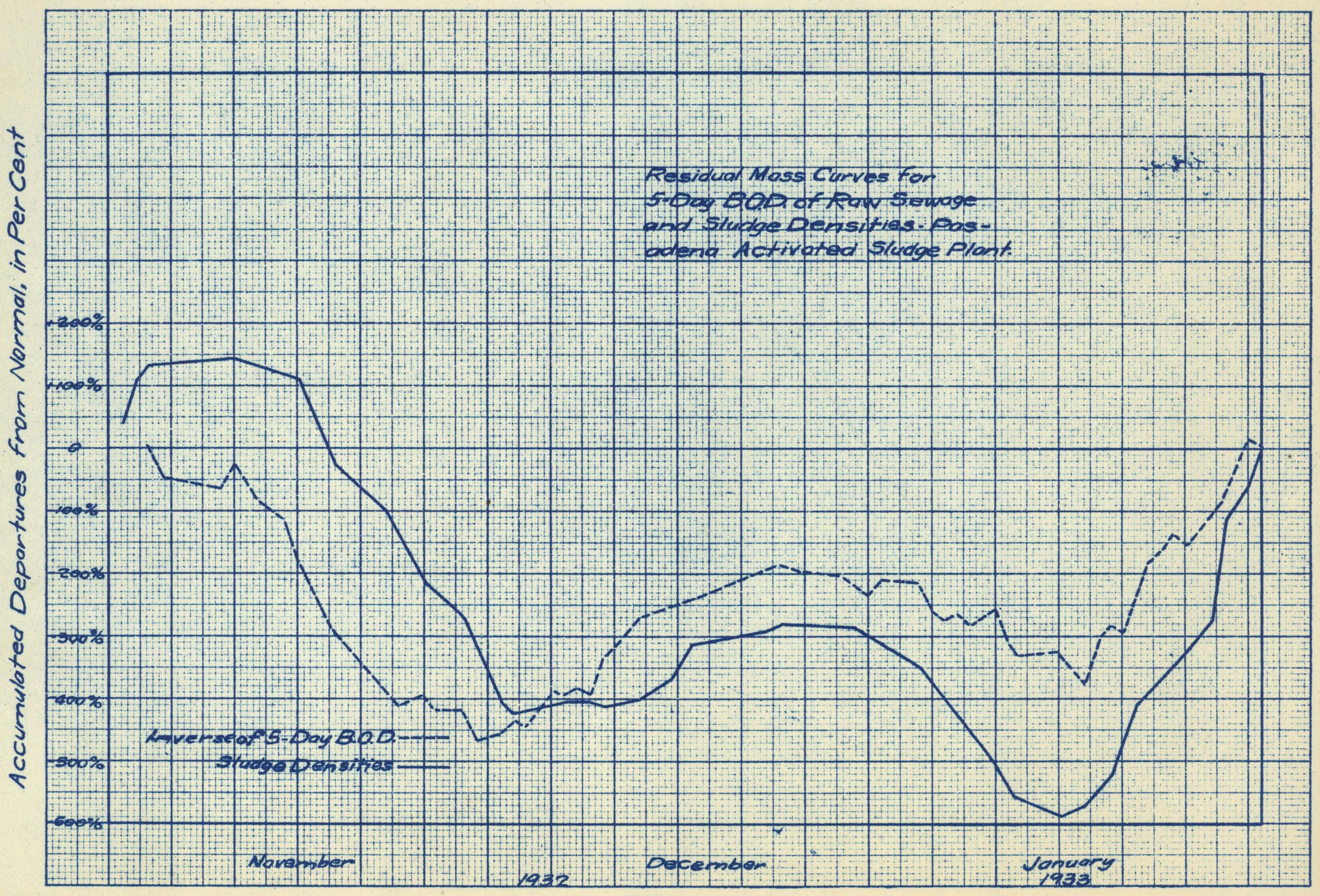
Accumulated Departures from Normal, in Per Cent for B.O.D. of Effluent



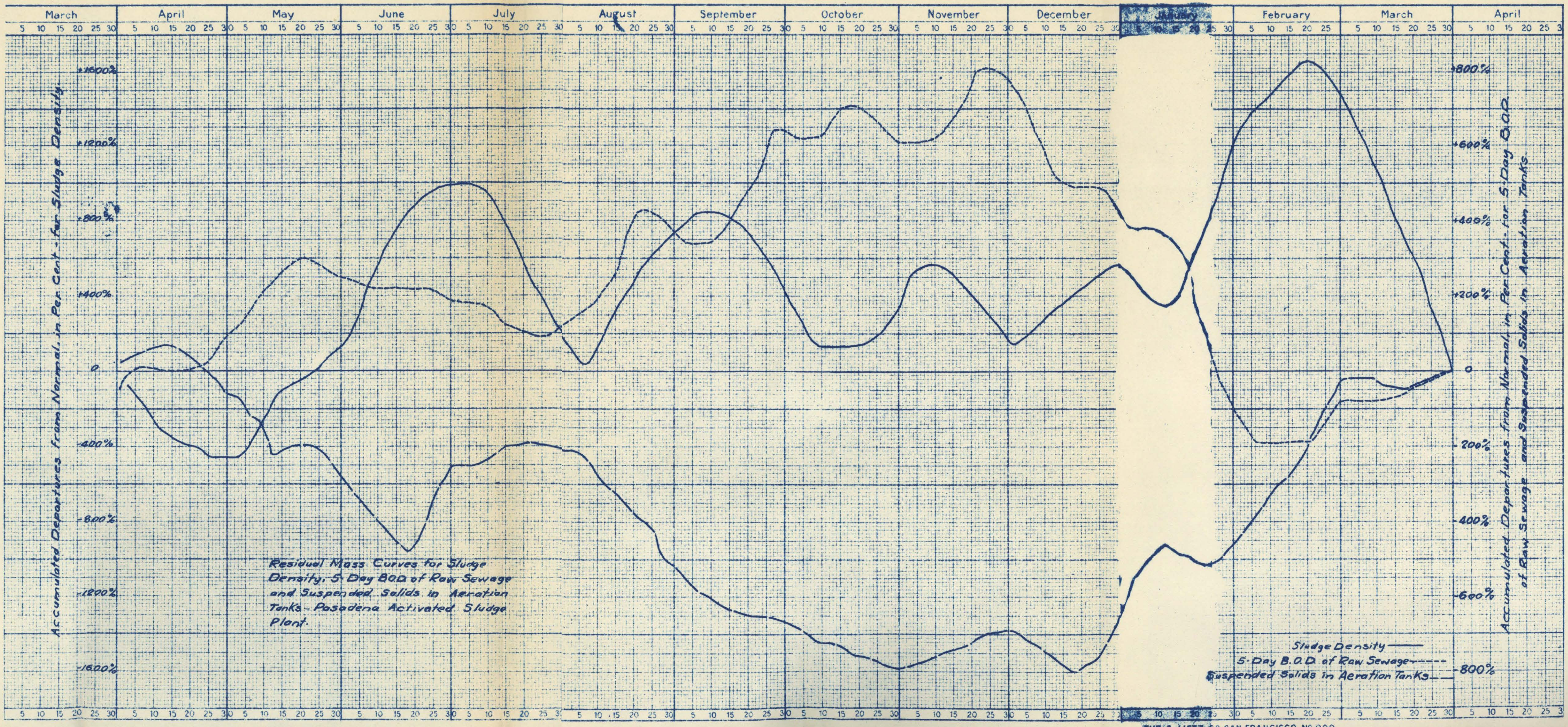
Accumulated Departures from Normal, in Per Cent for Sludge Density markedly by a combination of the factors indicated by the B.O.D. load of the raw sewage in pounds per day and by the volatile content of the raw sewage expressed as a percent; a period in which the B.O.D. load is above normal at the same time that the volatile content of the raw sewage is also above normal is characterized by a fall in sludge density. A very rapid decline in the load factor as expressed by per cent volatile of the raw sewage apparently exerts more influence than a similar decline in the load as indicated by the (5-day) B.O.D. of the raw sewage.

Plate No. III. indicates a comparison between the density of the sludge and the 5-day B.O.D. of the effluent. The significant aspect of these curves is the fact that for a period when the sludge density is below average, as indicated by the declining curve, the B.O.D. of the effluent becomes and remains higher than normal for the period. The contrary is also apparent. This would indicate that the efficiency of the plant as measured by the 5-day B.O.D. of the efflueht is dependent upon the settling characteristics of the sludge. Actual bulking, which is indicated by the period of low sludge density, would tent to allow suspended matter to flow out with the effluent, thus causing an increased oxygen demand. This relation is not conclusive for the entire period, however, and may depend to some extent on the quantity of suspended solids carried in the aerators.

On Plate No. IV. is shown an analysis of data obtained from the Pasadena Activated Sludge Plant which affords comparison between sludge


Residual Mass Curves for
5-Day B.O.D. of Raw Sewage
and Sludge Densities - Pas-
adena Activated Sludge Plant.
Accumulated Departures from Normal, in Per Cent
+200%
+100%
0
-100%
-200%
-300%
-400%
-500%
-600%
Inverse of 5-Day B.O.D.
Sludge Densities
November
1932
December
January
1933

IV


March
April
May
June
July
August
September
October
November
December
January
February
March
April
Accumulated Departures from Normal, in Per Cent - for Sludge Density
+1600%
+1200%
+800%
+400%
0
-400%
-800%
-1200%
-1600%
+800%
+600%
+400%
+200%
0
-200%
-400%
-600%
-800%
Accumulated Departures from Normal, in Per Cent - for 5-Day B.O.D. of Raw Sewage and Suspended Solids in Aeration Tanks
Residual Mass Curves for Sludge Density, 5 Day B.O.D. of Raw Sewage and Suspended Solids in Aeration Tanks - Pasadena Activated Sludge Plant.
Sludge Density
5-Day B.O.D. of Raw Sewage
Suspended Solids in Aeration Tanks
THE A. LIETZ Co SAN FRANCISCO No 909.

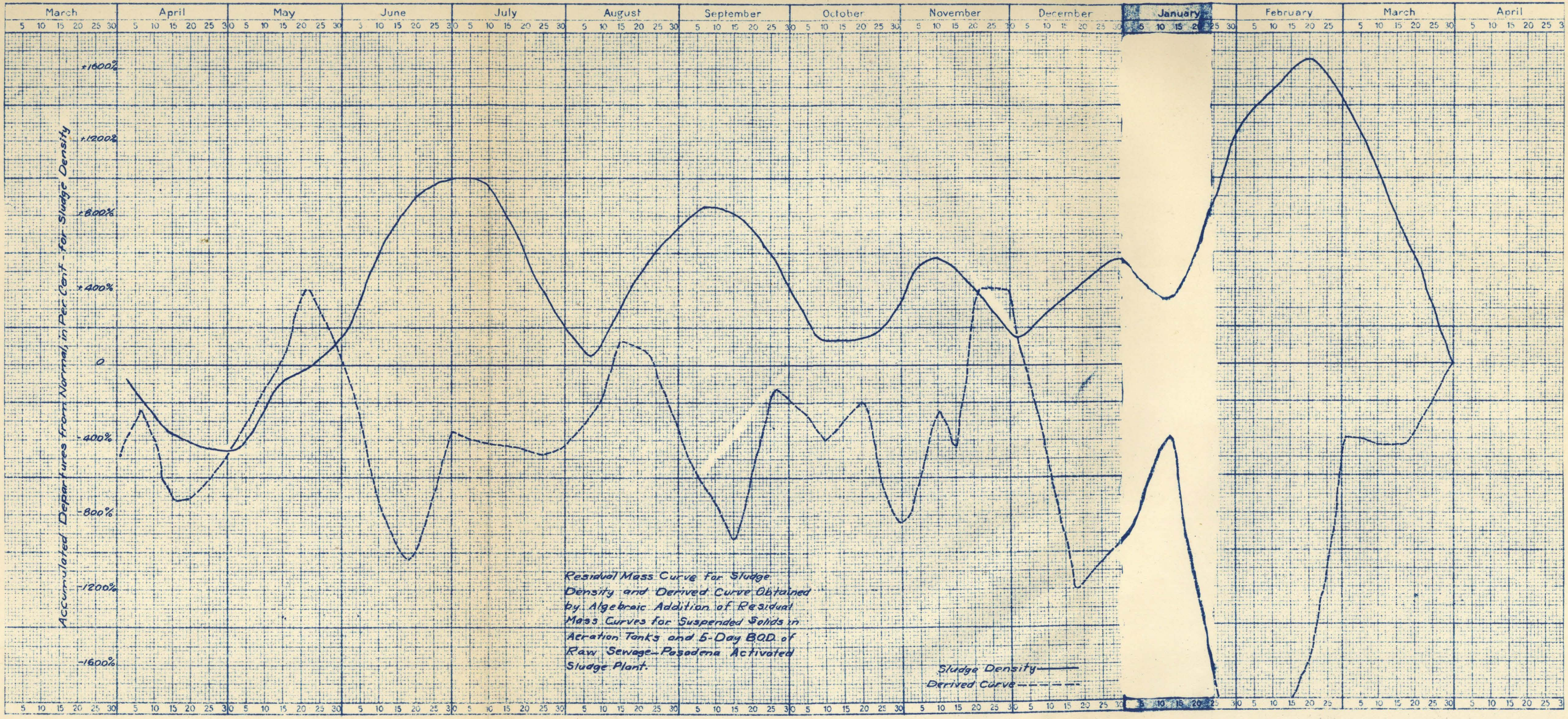
density (or index) and the inverse of the 5-day B.O.D. load expressed as hitherto in pounds per day. For the three month period shown, selected at random, there is an inverse correlation between these two factors at every point, except that the sludge density, as indicated by the curve, lags behind the B.O.D. load, as shown by the inverse plotting.

This indicates that for the period selected, when the load, as expressed by the 5-day B.O.D. of the raw sewage, increases, the sludge density decreases, and when the B.O.D. load is above normal for an extended period the sludge density drops below normal.

On Plate No. V. is plotted an analysis of similar data from this same Plant but covering an entire year (including the three months previously investigated). In addition there is included a curve for suspended solids in the aeration tanks.

The curve for the 5-day B.O.D. load of the raw sewage is in this case plotted directly rather than as an inverse function, as on Plate IV.

There are three features of importance disclosed by this diagram. The first significant fact to be noted is that for the year taken as a whole the inverse correlation between sludge density and the 5-day B.O.D. load of the raw sewage is not always evident. This would indicate that there must be factors other than the B.O.D. load which exert an influence on sludge density. This correlates with the results obtained from analysis of data secured from the Wilmington Plant, where it was found that the factors indicated by the percent volatile content of the raw sewage working in coordination with the elements indicated by variations


March
April
May
June
July
August
September
October
November
December
January
February
March
April
Accumulated Departures from Normal, in Per Cent for Sludge Density
+1600%
+1200%
+800%
+400%
0
-400%
-800%
-1200%
-1600%
Residual Mass Curve for Sludge Density and Derived Curve Obtained by Algebraic Addition of Residual Mass Curves for Suspended Solids in Aeration Tanks and 5-Day B.O.D. of Raw Sewage—Pasadena Activated Sludge Plant.
Sludge Density
Derived Curve

in B.O.D. load of the raw sewage to have a direct effect on sludge density. (See Plate II.)

Such correlation could not be checked for the Pasadena Activated Sludge Plant, since the volatile content of the raw sewage or of the sludge is not determined regularly.

The second significant feature to be noted from Plate No. V. is that the curve for (5-day) B.O.D. load of the raw sewage bears an inverse correlation to the suspended solids content of the aeration tanks. This fact cannot be explained since it is to be expected that the B.O.D. of the raw sewage is at least a rough indication of its solids contents.

It is also natural to expect that variability in characteristics of the raw sewage will be reflected in a change of similar nature in the circulating load. The inverse correlation thus noted between the B.O.D. of the raw sewage and the suspended solids in the aeration tanks can be explained only by variations in removal of excess sludge.

The third point referred to as being disclosed by Plate No. V. is perhaps of even greater significance than the other two. Inspection of curves for suspended solids in the aeration tanks and for the 5-day B.O.D. of the raw sewage reveals on first glance that apparently the curves bear an inverse relation to each other, consistant for all periods.

Closer study, however, discloses that there is a tendency for these two curves to vary at intervals independently of each other. Notice was taken of the fact that these points of independent variation correlated with changes in the sludge density consistantly throughout the year.

On Plate No. VI. is to be seen the curve for sludge density compared with a combined curve, the latter derived by algebraic addition of the B.O.D. load curve for raw sewage and the curve expressing suspended solids in parts per million in the aeration tanks. The scale for this composite curve was exaggerated to make full comparison with the curve for sludge density.

The inverse correlation between the derived curve and that for sludge density is very close. Interpretation will be aided by a clear understanding of the significance of the derived curve.

Consider first the periods wherein accumulated deviations from the normal for the B.O.D. load of the raw sewage are equal and opposite in sign to that for the suspended solids in the aeration tanks, expressed in parts per million. The algebraic total of these two curves at such a point will then be zero, which will represent the ordinates on the derived curve. If then the B.O.D. load increases at the previous rate, whereas the suspended solids content decreases more rapidly than for the preceding period the derived curve will be characterized by a negative slope equal to the difference between the other two curves. The same effect would be evidenced in the second period provided the suspended solids content did not change, whereas the B.O.D. in the raw sewage decreased. In either case the derived curve would exhibit a falling characteristic. The opposite effect, or a rising curve is caused by similar reverse characteristics in the suspended solids content and the B.O.D. load.

Interpretation may now be made regarding the significance of the inverse correlation between the derived curve and that for sludge density. It appears to be conclusive that for this plant sludge density is effected by a combination of characteristics indicated by the B.O.D. load of the raw sewage expressed in pounds per day and by the suspended solids content of the reaeration units expressed in parts per million. An increase in suspended solids is counteracted if there is an equivalent decrease in the B.O.D. A decrease in suspended solids is nullified in its effect on the sludge density by a like increase in B.O.D. load factor.

SUMMARY AND CONCLUSIONS

Sludge density factors indicated by the statistical data herein presented may be summed up as follows:-

1. Characteristics of the circulating load as indicated by the volatile content of the sludge are dependent on the corresponding characteristics of the incoming raw sewage (at least for the Wilmington Plant). There is no obvious dependence on the rate of oxidation of the sludge itself. This is in conformity with the conclusions presented by Mr. A. P. Banta.

2. At the Wilmington Plant sludge density tends to follow directly variations in the ash content (or inversely as the volatile content) of the raw sewage. A rapid change in the volatile content appears to have more effect than the actual percentage noted. This is in conformity with the conclusion drawn by Mr. T. R. Haseltine that "density of the sludge tends to follow variations in its ash (or volatile) content," even although the supporting reasoning is shown to be incorrect (for this plant).

3. Sludge density, at the Wilmington Plant, tends to follow inversely variations in the B.O.D. of the raw sewage, although not conclusive for the entire period investigated.

4. A general rule for the Wilmington Plant at least is that the sludge density is influenced markedly by a combination of the factors indicated by the B.O.D. load of the raw sewage in pounds per day and by the volatile content of the sewage expressed as a per cent; a

period during which the B.O.D. load is above normal, at the same time that the volatile content of the raw sewage is also above normal, is characterized by a decline in sludge density. A very rapid drop in the load factor as expressed by the percent volatile in the raw sewage apparently exerts more influence than a similar decline in the incoming load as indicated by the B.O.D. of the raw sewage.

5. The efficiency of the Wilmington Plant as indicated by the (5-day) B.O.D. of the effluent tends to be influenced by the density (or index) of the sludge.

6. At the Pasadena Plant, for a three-month period, selected at random, variations in characteristics of the raw sewage, as expressed by the (5-day) B.O.D. load factor, were paralleled (except for a lag) by equal but opposite changes in the sludge density (or sludge index).

Consideration of data from this same plant for a full year, however, disclosed the fact that sludge density did not follow the B.O.D. load characteristics of the raw sewage in every instance, indicating that, as at the Wilmington Plant, some factor other than that expressed by the B.O.D. of the raw sewage affected the nature of the sludge.

7. Plotting a curve derived by algebraic addition of the curves for (5-day) B.O.D. load of the raw sewage, and for suspended solids in the aeration units (expressed in parts per million) disclosed an inverse correlation with the curve for sludge density. It appears to be conclusive that for this plant sludge density is effected by a combination of strength factors indicated by the B.O.D. of the raw sewage expressed in pounds per day, and by the suspended solids content of the

aeration tanks (expressed as parts per million). An increase in suspended solids is counteracted if there is an equivalent decrease in B.O.D.. A decrease in suspended solids is nullified in its corresponding effect on the sludge density by a concurrent increase in the B.O.D. load factor.

REGARDING FACTORS WHICH RELATE TO SLUDGE BULKING

It has been shown previously that no general agreement exists as to the underlying cause or causes for sludge bulking. Bulking has been attributed to the following factors, among others: Over-aeration, under-aeration, oxygen demand due to carbohydrate wastes, filamentous growths, and to a "combination of factors not yet understood".

The research conducted in this field is valuable in that it has thrown light on fundamental characteristics of the activated sludge phenomena. Work by Grant, Hurwitz and Mohlman is particularly important in having made known the oxygen requirements of the actual sludge. The effect of under-aeration can thus be easily visualized. From the data presented in this study it appears that a corollary to the above is also true; when the circulating load is increased beyond a certain capacity for the plant, the quality of the sludge and final effluent deteriorate. The schedule followed in oxidation of the "pollute" as described by Harris, Cockburne, and Anderson, is of particular significance.

The effect on sludge density of the characteristics indicated by the volatile content of the activated sludge, as first concluded by Mr.

T. R. Haseltine, is a step toward solution of the practical control of sludge bulking. The further conclusions drawn by Mr. A. P. Banta are of even greater significance, since the characteristics of the sludge, as indicated by its volatile content, are thus shown to be due to inherent characteristics of the raw sewage and not to any process undergone during treatment.

Statistical study by the author, of information secured from both the Pasadena and Wilmington Plants, has shown that factors indicated by the B.O.D. and volatile content of the raw sewage, and suspended solids in the aerators, bear a direct relation to the quality of the sludge and effluent.

Morgan and Beck in their investigation of conditions at Chicago wherein bulking resulted concurrently with deposition of large quantities of carbohydrate distillery wastes in the sewage, have shown the association of sphaerotilus natons and carbohydrates with bulking. Dr. Jan Smit, in his studies at Amsterdam, proved that if carbohydrates were added in sufficient quantities to sewage that the sludge inevitably bulked, concurrently with the development of Sphaerotilus.

There are thus to be seen two distinct types of data regarding sludge bulking. One the one hand, oxygen requirements, and other characteristics of the raw sewage and activated sludge appear to have a direct relation to sludge bulking; on the other hand, a filamentous organism has been directly associated with the condition wherein the sludge had all the characteristics of true bulking.

There is disagreement among investigators as to which type of phenomena is the primary cause of bulking, and which is merely an incidental factor. Reasoning has been to the effect that since presence of carbohydrate wastes and development of filamentous organisms have been noted in many extreme cases of bulking, that therefore, the oxygen requirement of the carbohydrates is associated with the primary cause of the bulking, and Sphaerotilus or other filamentous growths is merely incidental.

This contention does not eliminate the effect of all types of Sphaerotilus-like filamentous organisms on the quality of the sludge, however, since at least at the Wilmington and Salinas Plants extraordinary bulking has occurred with filamentous organisms predominant in the sludge, but presence of carbohydrate wastes negative on test.

The obvious conclusion is that there exists not one, but two types of sludge bulking. The effect of each is the same; both cause the sludge to become less compact, are characterized by failure of the sludge to settle, and may or may not be associated with the development of Sphaerotilus-like organisms.

There is need for research to determine definitely whether or not these two causes for bulking are allied, and if they are not the same, to determine the mode of occurrance of each.

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