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APPLICATION OF AERATED LAGOONS TO TERTIARY ORGANIC TREATMENT

BY

GEORGE B. VANIA

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degree Master of Science, Major in
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1969

APPLICATION OF AERATED LAGOONS TO TERTIARY ORGANIC TREATMENT

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser — Date

Head, Civil Engineering Department — Date

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INTRODUCTION

The desire to minimize the pollution of our water resources has led to the realization that sewage treatment processes are inadequate in many instances. The use and reuse of our surface waters is becoming more important. The water quality of these waters will have to be upgraded to satisfy the quality requirements for the beneficial uses. Population increases and industrial expansion will further accentuate the problem.

At the present time most wastewater treatment plants are capable of removing only 85-90 percent of the organic matter. For many municipal treatment plants, however, this degree of treatment is never achieved (1). To meet the increasing water quality requirements for users both the design and operating efficiencies of these plants will have to be improved.

Some receiving streams are able to assimulate wastewater without adverse effects. By their dilution and self-purification characteristics, the streams are able to contribute to the waste stabilization process. But in many areas of South Dakota where the stream flows are low or intermittent during a significant part of the year, improvements will have to be made upon inadequate waste treatment systems that discharge into these receiving streams. This appropriate upgrading will be necessary to protect the beneficial uses such as domestic water supplies, recreation, and fish-life propagation. The increased efficiency required by the above considerations will likely be met through some form of tertiary treatment.

In the literature today the term tertiary treatment is used to describe a great variety of processes from simple polishing ponds to complicated demineralization plants. In this study the following definitions will be used (2-238). Tertiary treatment connotes the removal of three or more forms of contamination, that is, suspended solids, dissolved organic solids, and dissolved inorganic solids. Secondary treatment is defined as the removal of two pollutional constituents, suspended solids and dissolved organic solids, and primary treatment denotes the removal of coarse solids and a portion of the suspended solids.

The term tertiary organic treatment refers to the optimum removal of total suspended solids and dissolved organic solids throughout the year. Its meaning includes a higher degree of organic removal than is normally achieved by secondary treatment, but it does not imply as high a degree of dissolved inorganic removal as is obtained by tertiary treatment. Tertiary organic treatment can be provided by stabilization ponds and aerated lagoons receiving effluents from secondary treatment systems.

Stabilization ponds are shallow basins with large surface areas. They provide wastewater treatment through the processes of sedimentation and the biological activity of bacteria and algae (3-199). Aerated lagoons consist of smaller basins of significant depths (6-12 feet) in which oxygenation is accomplished by mechanical or diffused aeration units and surface aeration (3-206).

Aerated lagoons are generally thought of in terms of two basic types, the aerobic basin and the anaerobic-aerobic basin (4). The aerobic basin is one in which all the solids are kept in suspension so that the character of the solids in the basin is the same as the character of the solids in the effluent from the basin. Basically a modification of the activated sludge process, this system generally requires an additional sedimentation basin which normally would be a facultative stabilization pond.

In the second type, the anaerobic-aerobic basin, the turbulence maintained is not enough to maintain solids in suspension. For this reason, most of the inert suspended solids and non-oxidized biological solids settle to the bottom of the basin and undergo anaerobic decomposition. The pilot plant used in this study was of the anaerobic-aerobic type.

Description of Project Location

The Brookings conventional high-rate, one stage trickling filter plant was chosen as the site for this study. It was in the process of being renovated and consisted of a new comminuted bar screen, a grit chamber, a primary sedimentation basin, two high-rate filters in parallel, a secondary sedimentation basin, a new anaerobic digestor, a sludge storage basin, a new sludge dewatering system, and a new lagoon. A flow-through diagram is shown in Figure 1. During the study, the plant treated about 1.15 MGD and removed 75-85 percent of the organic matter entering the system (5). It served a stable population of approximately 7,250 and a student population of about 5,250.[1] The

[1] Population estimate from Brookings City Auditor, May 1968.

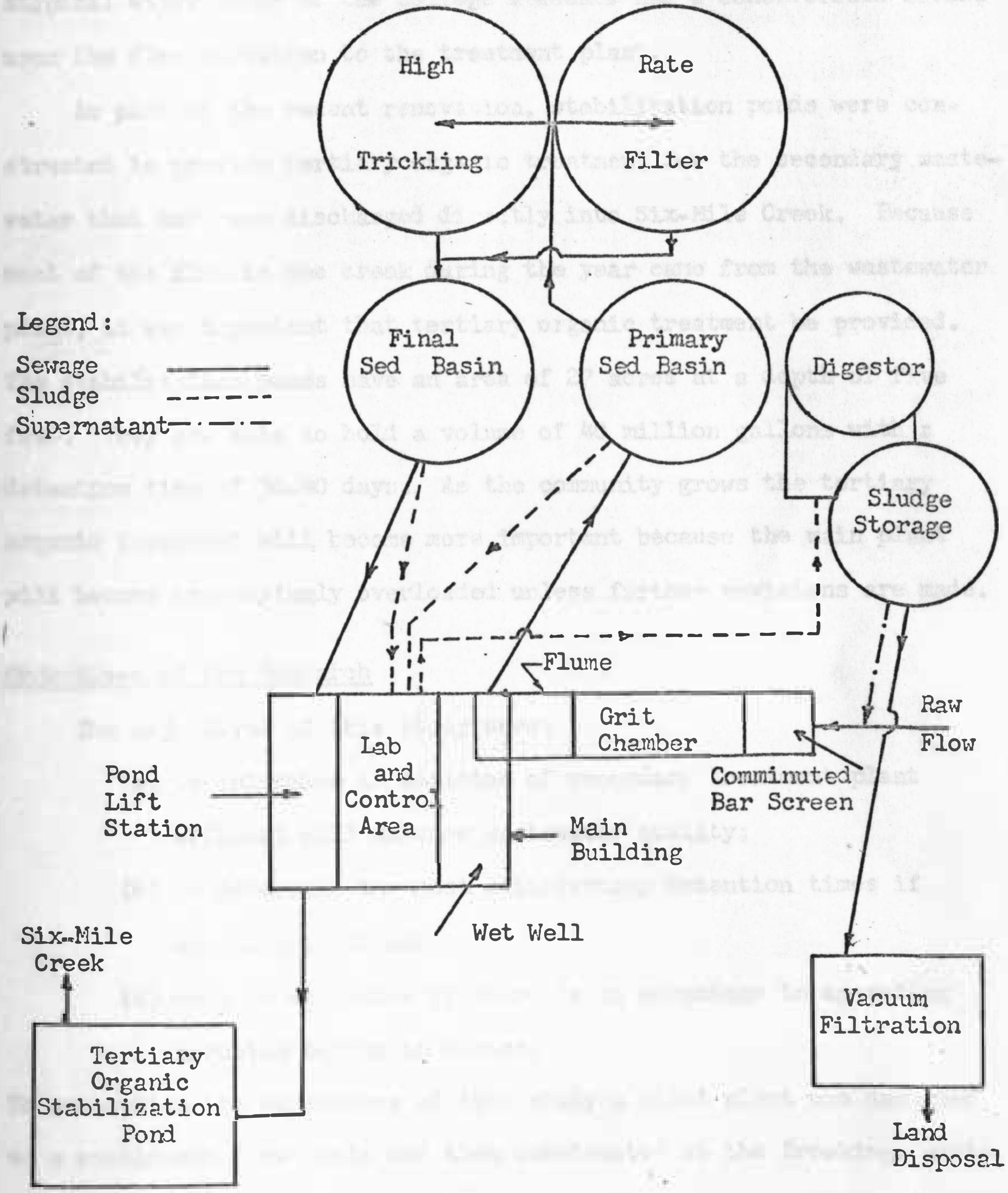


Figure 1. Simplified flow diagram of Brookings Wastewater Treatment Plant.

atypical water usage of the college students had a considerable effect upon the flow variation to the treatment plant.

As part of the recent renovation, stabilization ponds were constructed to provide tertiary organic treatment for the secondary wastewater that had been discharged directly into Six-Mile Creek. Because most of the flow in the creek during the year came from the wastewater plant, it was important that tertiary organic treatment be provided. The stabilization ponds have an area of 27 acres at a depth of five feet. They are able to hold a volume of 40 million gallons with a detention time of 30-40 days. As the community grows the tertiary organic treatment will become more important because the main plant will become increasingly overloaded unless further revisions are made.

Objectives of the Research

The objectives of this study were:

(a) to determine if aeration of secondary treatment plant effluent will enhance wastewater quality;

(b) to determine the most satisfactory detention times if aeration is feasible;

(c) and, to determine if there is an advantage to operating aeration basins in series.

To accomplish the objectives of this study a pilot plant was designed on a continuous flow basis and then constructed at the Brookings wastewater treatment plant.

Preliminary batch studies were made during the summer of 1967 to find the general ranges of the parameters used in the analyses. No definite values could be determined at that time because only one-fifth of the student body was living on campus and consequently the waste flows were at a minimum.

The main study utilizing the pilot plant with continuous flow was run in October and November and was divided into three testing periods. For each period the detention time and number of analyses varied. The analyses of the influent, reaction basins, and effluent samples consisted of chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and volatile suspended solids (VSS).

REVIEW OF LITERATURE

Principles of Biological Oxidation

The most efficient biological means available for reducing the organic content of dilute liquid wastes is by aerobic treatment (3-217). The objective of this process is to break down organic matter into simple and stable end products. The work force which accomplishes the task is the aerobic microorganisms such as protozoa and bacteria (6-46). In the design of treatment systems an environment is planned so that these microorganisms can do their work as completely and as efficiently as possible.

In most municipalities primary and secondary treatment is provided by wastewater treatment plants. With this degree of treatment 80-90 percent overall removal of organic matter can be expected (7-675). The performance of secondary systems has been studied extensively, but tertiary organic treatment has not been as well evaluated. It is believed that stabilization ponds and aerated lagoons used as tertiary organic treatment systems can be expected to assist in additional removal of COD, BOD, solids, and pathogenic bacteria. It is also believed, however, that nutrients such as nitrogen and phosphorous cannot be effectively removed through this form of treatment (8).

In an aerobic biological system the microorganisms responsible for treatment possess the ability to oxidize complex organic compounds. They use the energy derived from this reaction to synthesize new microorganisms and also to maintain enough energy for themselves (9). The organic matter used to produce energy is converted to the end products CO_2, H_2O and NH_3 as shown in Figure 2 (10). The main requirement for these two important reactions is oxygen. Oxygen is necessary because it acts as the final hydrogen acceptor for the oxidation of organic matter (9). It is during this hydrogen transfer that the energy used for synthesis and maintenance of cellular material is liberated. The amount of oxygen required depends upon the amount of organic material stabilized by treatment (9).

In the field of sanitary engineering, the biological growth mechanism is almost exclusively associated with the growth of heterogenous microorganisms. The growth curve for these microorganisms varies from the classical growth curve of pure cultures (6-119) and is shown in Figure 3.

Once a mass of heterogenous microorganisms comes in contact with an organic waste in a batch type system the initial or log growth phase begins. Here an excess of food is generally available and the rate of growth is controlled by the rate at which the given mass of organisms can consume the waste and synthesize new cellular material. The log growth phase continues until the food supply becomes a limiting factor. When this occurs the mass of microorganisms enters the declining growth phase and the number of microorganisms begins to decline. When the food supply is substantially reduced, the microorganisms enter the endogenous respiration phase where they are forced to consume their own protoplasm in order to obtain the energy required for living. As the process continues the microbial mass slowly decreases, the rate of metabolism decreases, and eventually a

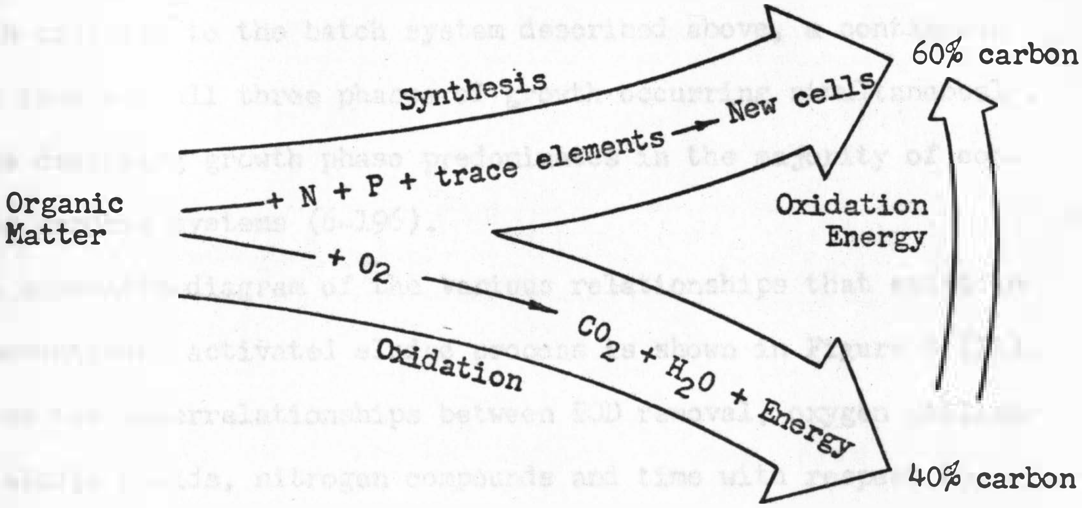


Figure 2. General metabolic reaction for aerobic bacterial systems (10).

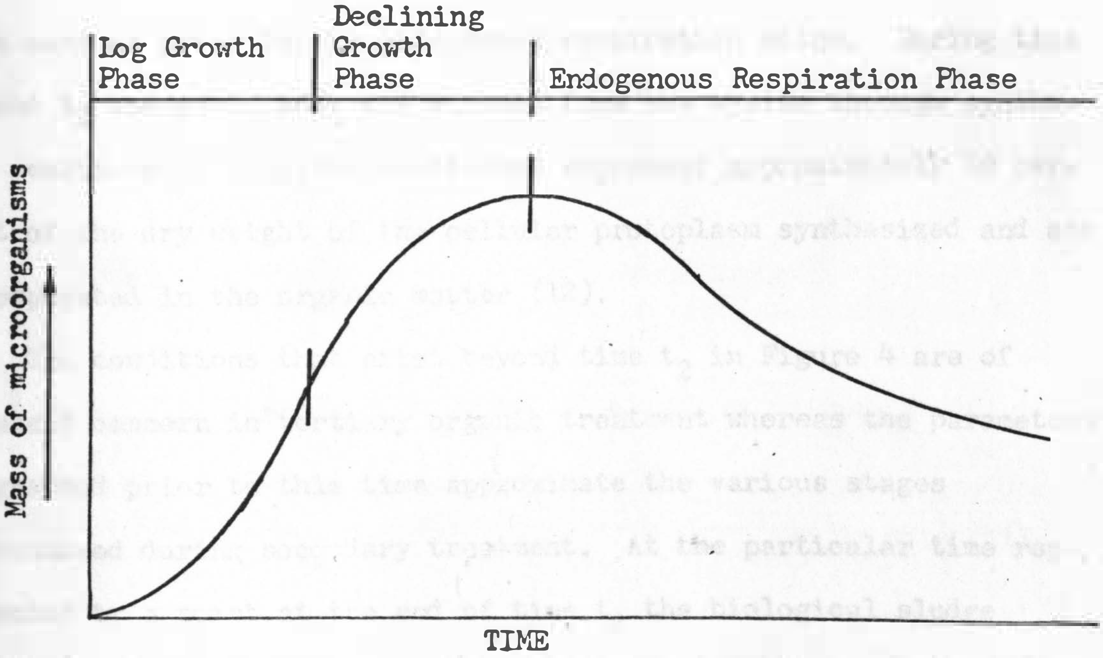


Figure 3. Growth pattern based on mass of microorganisms.

stable non-biodegradable organic residue is all that remains (6-120).

In contrast to the batch system described above, a continuous system involves all three phases of growth occurring simultaneously. But the declining growth phase predominates in the majority of continuous aerobic systems (6-196).

A schematic diagram of the various relationships that exist in the conventional activated sludge process is shown in Figure 4 (11). It shows the interrelationships between BOD removal, oxygen utilization, sludge solids, nitrogen compounds and time with respect to synthesis and endogenous respiration. During time t_1 BOD removal is accomplished primarily by adsorption. Most activated sludge and trickling filter processes operate in time zone t_2. It may be observed from Figure 4 that the rate of oxygen usage is highest during the initial stages of treatment. Also, the sludge solids are at a maximum prior to the endogenous respiration stage. During time t_1 and t_2 inorganic ions are removed from the system through synthesis reactions. Inorganic substances represent approximately 10 percent of the dry weight of the cellular protoplasm synthesized and are incorporated in the organic matter (12).

The conditions that exist beyond time t_2 in Figure 4 are of greatest concern in tertiary organic treatment whereas the parameters as graphed prior to this time approximate the various stages encountered during secondary treatment. At the particular time represented by a point at the end of time t_2 the biological sludge solids are being destroyed by autooxidation at a rate greater than the corresponding synthesis because the organic loading is

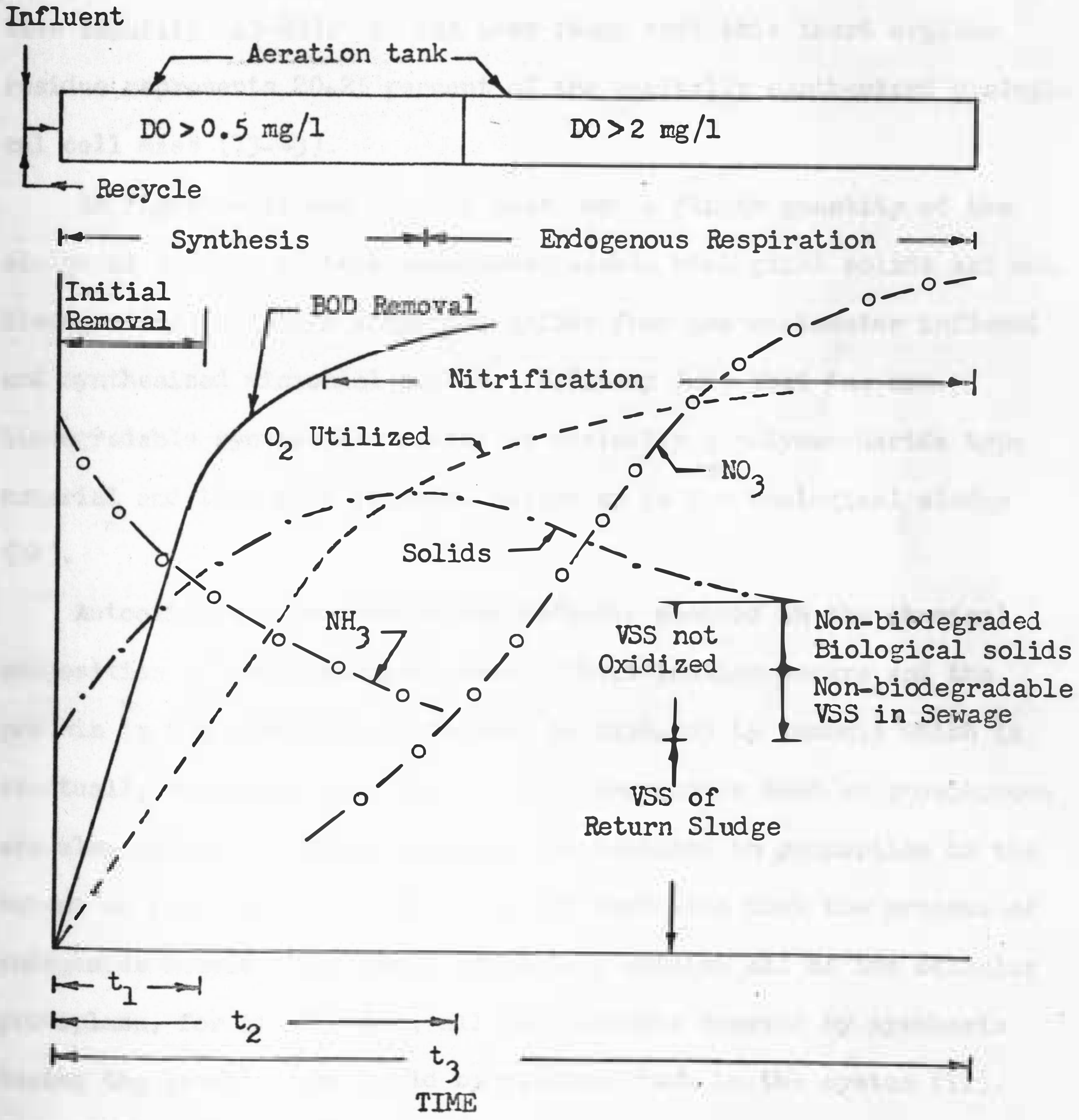


Figure 4. Conventional activated sludge schematic (11).

insufficient to support active growth. Initially, the process follows first-order kinetics; later it follows a decreasing oxidation rate as the microorganisms become less available for oxidation (13-42). Extensive autooxidation produces a sludge of low activity and reactive capacity (13-29). It has been found that this inert organic residue represents 20-25 percent of the initially synthesized biological cell mass (13-43).

In Figure 4 it can also be seen that a finite quantity of the sludge is made up of both non-biodegradable biological solids and non-biodegradable volatile suspended solids from the wastewater influent and synthesized microbial solids. McKinney felt that the non-biodegradable synthesized matter is basically a polysaccharide type material and that this fraction builds up in the biological sludge (12).

Autooxidation produces other definite changes in the chemical composition of the biological mass. Nitrification occurs and the protein in the microbial protoplasm is oxidized to ammonia which is eventually converted to nitrate (12). Inorganics such as phosphorous are also released. These elements are released in proportion to the extent of autooxidation. It is indeed fortunate that the process of endogenous respiration cannot completely oxidize all of the cellular protoplasm, for if it could, all the elements removed by synthesis during the growth phase would be released back to the system (12). Hence, it appears that in a continuous process an equilibrium could exist between synthesis and the release of cellular material back to the solution through autooxidation (3-206).

Factors Affecting an Aerobic Treatment Process

In addition to the basic principles discussed above there are other factors that influence the process of aerobic treatment. These include temperature, oxygen requirements, mixing, flow configuration and other miscellaneous parameters. All exert a significant influence on the process of biological oxidation (3-134). The effects of loading and of detention time were mentioned earlier, but it should be noted that all these factors are interrelated. A basic objective in treatment system design is to insure that none of the parameters reach limiting conditions and that an optimum environment is maintained in the reaction basins whenever possible (3-134).

Temperature. Generally, high temperatures are associated with high bacterial growth rates ranging up to limiting temperatures in which denaturization of protein takes place (6-121). Low temperatures are associated with low growth rates. The equation used for expressing the temperature dependence of a growth rate is as follows:

$$k_1 = k_{20}\,\theta^{t_1 - t_{20}} \quad \text{(van't Hoff-Arrhenius)} \quad (14\text{-}13)$$

k_1 = Growth rate constant at system temperature (t_1)

k_{20} = Growth rate constant at 20°C.

θ = Temperature coefficient

The temperature coefficient θ is generally taken to be 1.072, but values ranging between 1.07 and 1.09 have been reported (3-207).

A relationship also exists between temperature and solids concentration. Eckenfelder has stated that the temperature effect depends on the solids level in a basin and that effective flocculation does not occur at solids levels less than approximately 500 mg per liter. Since the solids level in aerobic-anaerobic lagoons rarely exceeds 50-100 mg per liter, the temperature effect will be at a maximum (15). In fact, low temperatures may actually govern the design of these treatment systems (16:30-7).

Temperature also has an effect on biological growth in the receiving stream and is especially important where the streams are used as part of the treatment system (13-123).

Oxygen Requirements. In an aerobic treatment system the oxygen requirements are a function of the COD or BOD removal rate and the quantity of bacterial solids under aeration (3-145). This relationship is expressed as shown in the following formula:

$$\text{Total lbs } O_2/\text{day} = a' L_r + b' S_a \quad (3\text{-}145)$$

a' = Synthesis coefficient
L_r = Pounds of COD or BOD removed per day
b' = Endogenous respiration constant
S_a = Pounds of sludge under aeration

The value of a' can be obtained from the slope and b' can be estimated from the intercept of a plot of lbs O_2/day/MLVSS versus lbs COD or BOD/day/MLVSS. A conservative estimate of b' can also be made by using the endogenous respiration rate of a batch system (16:30-37).

In an anaerobic-aerobic basin the active biological solids level is low; therefore, the oxygen requirements can be related to the COD or BOD removal alone for a given set of operating conditions (3-208).

$$\text{Total lbs } O_2/\text{day} = a' L_r$$

Results obtained for various wastes indicate that a' will vary from 0.9 to 1.4 on a BOD basis (3-208). When considering the anaerobic-aerobic basin, it should be noted that minimum power requirements are needed to maintain uniform oxygen dispersion. Surface aeration units require approximately eight horsepower per million gallons to maintain uniform oxygen dispersion in the basin (15). If a waste is aerated long enough to induce endogenous respiration, the oxygen demand rate will be low and a highly stabilized effluent will be produced (17).

Because the oxygen requirement is reduced as sludge age is increased, the oxygen utilization rate for endogenous respiration will generally vary from 5-10 percent of the rate for active metabolism during the sludge synthesis phase of the activated sludge process (18).

Mixing Characteristics. The mixing characteristics of continuous flow systems are important. Unfortunately, the nature of mixing in these systems is complex and very difficult to characterize. Nevertheless, the two extreme conditions, plug flow and complete mixing, can be defined and a given system can be compared against them.

Plug flow is that flow in which the individual particles of feed pass through the reaction basin and are discharged in the same sequence in which they entered. No intermixing or interaction between particles takes place (19-262). Reaction basins which are long and narrow, such as those in the conventional activated sludge process, approximate this system. Complete mixing is defined as a flow in which the feed completely intermixes with the contents of the reaction basin and the effluent and the contents of the reaction basin are the same and are uniform (19-262). This form of mixing is found in high-rate activated sludge processes today.

Series Operation of Reaction Basins. It had been proposed that a higher degree of treatment might be obtained if multiple reaction basins or cells were used for aerated lagoons (14-10). The optimum number of basins is a function of many factors including the variation in amount and strength of wastewater, desired removal by the system, consistency of the nutrient source, microbial population and other environmental factors. Milbury and Pipes believed that the effect of increasing the number of basins or of deviating from complete mixing toward plug flow was one of greater substrate removal and improved effluent quality at the expense of operational stability (20). Arranging a number of basins in series could be expected to reduce short circuiting and therefore improve the efficiency of the reactions.

To estimate what the additional removal might be, Thimsen (14-10) defined the removal as follows:

$$E = 100\,(1 - F^n)$$

where

E = % BOD removal from the sum total of the basins
F = fraction of BOD remaining in each basin based on the same value of K or $F = 1/1 + Kt$
n = number of basins
K = reaction rate coefficient
t = time in days

Thimsen stated that because the reaction coefficient appeared to decrease in each successive basin, there was some doubt that this order of efficiency could be obtained by the use of multiple basins in place of a single basin (14-10). The question was studied by Weston after he had assumed that the reaction rate was constant in each basin. His assumption was found to be incorrect when it was discovered that the times to equilibrium and the percent removals were not the same for the two basins studied (21).

McKinney agreed that it was possible to show that reaction basins in series are more efficient than a single basin. From his tracer studies the liquid detention time for eight basins in series was less than 10% greater than for a single basin of similar volume under complete mixing at a detention time of one unit. And in most situations the difference was not significant because adsorption and metabolism of organic matter was more critical than liquid detention time (22). A balance must be achieved, therefore, between the advantages of reducing short circuiting by using basins in series and the procurement of better biological treatment process characteristics through single basins with complete mixing.

Concepts Involved in Treating Secondary Effluent

Although the wastewater receiving tertiary organic treatment usually comes from the effluent of trickling filter or activated sludge plants, very little information is available concerning the variation and organic treatability of secondary effluents. Much information has been published concerning the chemical and biological characteristics of these effluents, but no one has suggested optimum methods for treating the organic material in them. The problem is one of not knowing the degree of treatment that a given secondary treatment system will provide, particularly during periods of cold weather or above average discharges.

The operation of the secondary treatment system plays an important part in determining the type and variation of the effluent received by a tertiary organic treatment system. For this study trickling filters provided the secondary treatment. Hence, it is important to discuss the nature of the effluent from this process.

Trickling Filters. Trickling filters operate on the basis of agglomeration, coagulation, adsorption, biooxidation, and simple dilution (13-227) (12). Soluble organics as well as colloidal and suspended solids are readily adsorbed to the microbial growths on stone surfaces, and the organic matter is converted to cellular protoplasm by aerobic metabolism. The concentration of inorganics must be reduced with dilution. Retention of the microorganisms on the stone surfaces and the increased detention time due to recirculation results in considerable endogenous respiration and the release of the nutrients. For this reason, the trickling filter is of limited value in stabilizing the organic matter in the raw waste (12).

The liquid waste temperature plays an important part in filter operation (23). A decrease in temperature results in a decrease in oxygen transfer, a decrease in respiration rate, and an increase in saturated oxygen. As a result of these combined effects a trickling filter has a lower operating efficiency during the colder winter temperatures (3-193).

It is difficult to determine the stage of biological growth and the percent of the solids that are active biologically in the secondary effluent from a trickling filter. With recirculation some organic material by-passes the filter without receiving adequate treatment, especially during cold weather conditions. It appears, however, that because the microorganisms in the filter adsorb, absorb, and metabolize the organic matter and thereby limit the food available, it can be said that the filter effluent is in the declining growth phase (6-120).

Nutrient Removal. The discharge of effluents from wastewater treatment plants into receiving streams is recognized as an undesirable source of biological nutrients (24). Unfortunately, as more dams and reservoirs are constructed along our rivers to improve navigation and flood control, the reservoirs will be subject to nutrient buildup if the discharges continue.

The nutrients, nitrogen and phosphorous, in wastewater discharges can stimulate the growth of algae and other aquatic plants (24). When aquatic microorganisms die, they may exert an oxygen demand on the receiving stream in excess of its oxygen capacity. An oxygen depletion may lead to nuisance conditions and may change the ecological characteristics of the stream. Conventional forms of primary and secondary wastewater treatment only remove a small amount of the nutrient material in raw wastewaters (24). In order to minimize the fertilization of receiving bodies of water by nitrogen and phosphorous, some form of tertiary treatment is necessary. To obtain a clearer picture of nutrient removal it is important to examine the aerobic process stoichiometrically.

The major elements in the composition of microorganisms are carbon, hydrogen, oxygen, nitrogen, phosphorous and sulfur (25). Mixed bacterial cultures found in biological waste treatment and mixed algal cultures common in surface waters are found to have on the average a stoichiometric relationship between carbon(C), nitrogen(N) and phosphorous(P) of about 106:16:1 atoms. If this proportion is used as a rough estimate and compared with the C:N:P composition of domestic wastewater of 70:17:1 it becomes apparent that domestic wastewaters are nutritionally unbalanced and, in a sense, are deficient in organic carbon. In addition, a percentage of the carbon is not available for synthesis into biological sludge (25).

To understand why great uptakes of nitrogen and phosphorous are not possible in aerobic treatment, one must first consider Liebig's Law of the Minimum. It recognized that microorganisms depend upon the essential elements that are required for growth and reproduction and that the essential constituent that is present in smallest quantity relative to the nutritional requirements of organisms will become the limiting factor for growth (25).

Figure 5 illustrates the stoichiometric relations involved in the biological oxidation of organic material in wastewater into bacterial sludge (25). It can be shown that typical activated sludge and trickling filter systems are able to convert eight-ninths of the assimilable organic carbon into bacterial sludge. If the sludge can

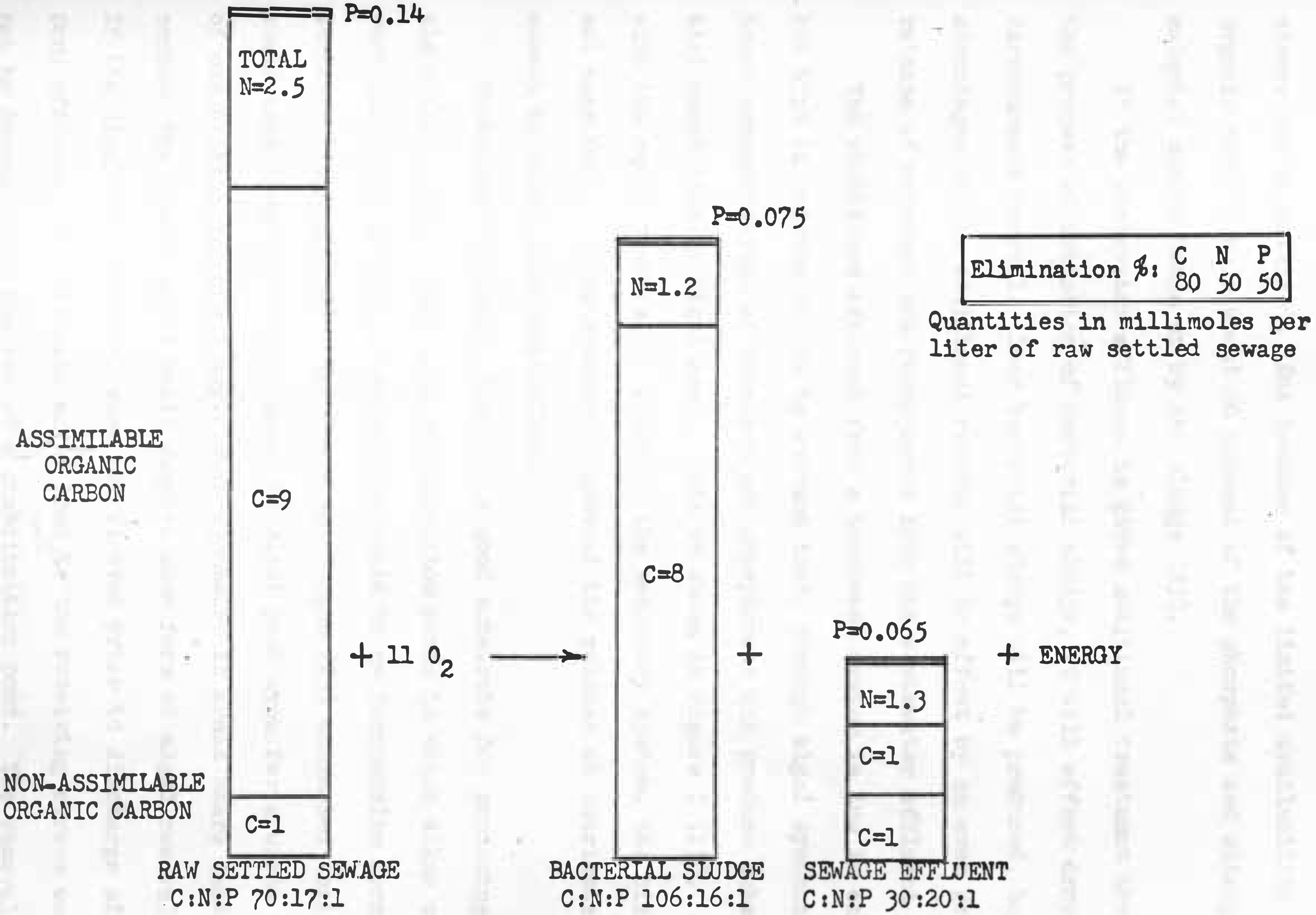


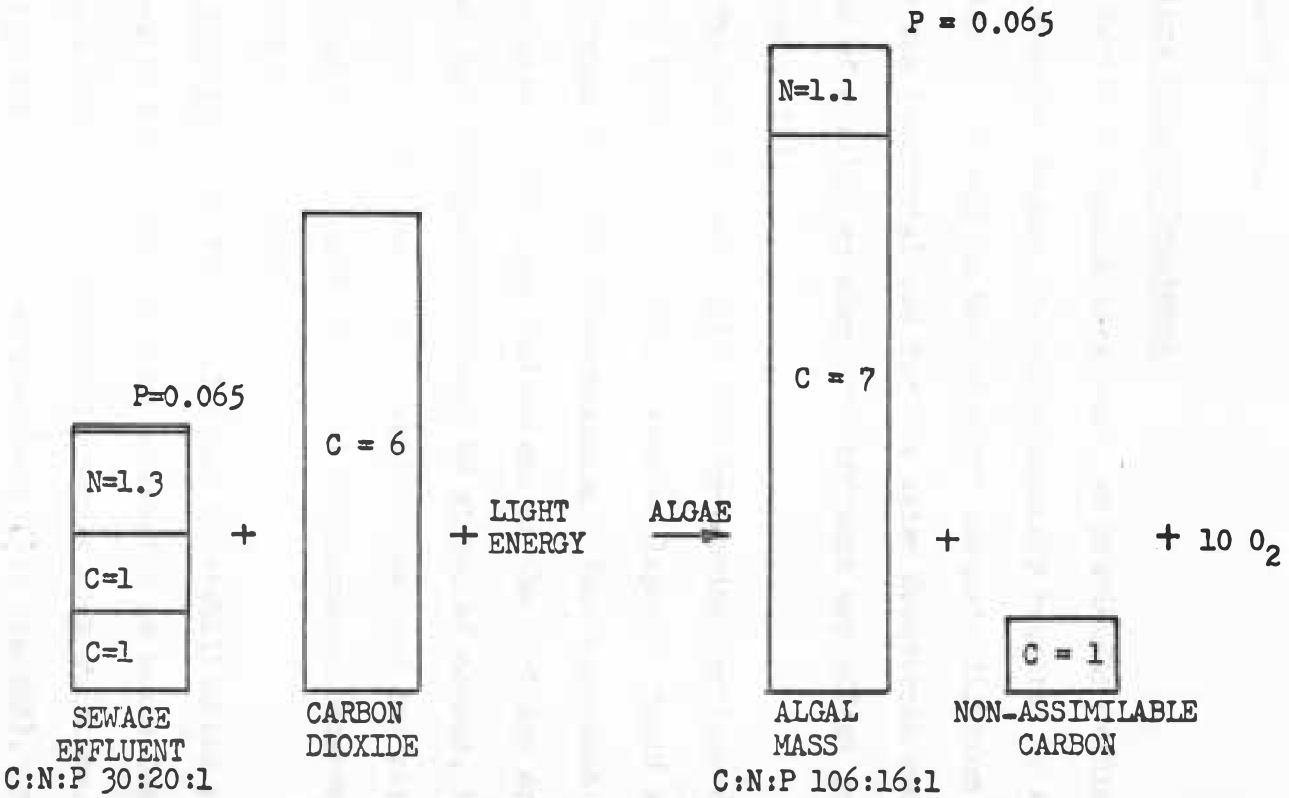
Figure 5. Stoichiometry of aerobic biological treatment (25).

be removed from the system, a high order of organic removal efficiency can be obtained. But because of the limited availability of organic carbon, only about 50 percent of the phosphate and nitrogenous material can be taken up by the sludge (25).

If the wastewater effluent is given additional treatment through the process of oxidation of bacterial sludge, it will effect increased carbonaceous removal. Less bacterial sludge will be produced, but the advantages of the additional removal will be offset by an even greater release of nitrogen and phosphorous into the wastewater effluent (12).

The stabilized effluent from a treatment system is low in carbon but high in nutrients. It is evident that, through algal synthesis, trace concentrations of nitrogen and phosphorous can produce substantial quantities of algal mass. This is shown in Figure 6 (25). As with the newly synthesized cells in the secondary system, the biological mass must also be removed to prevent the release of nutrients caused by endogenous respiration.

Wastewater effluent, then, is a good substrate for producing algae (26). Loehr said that stabilization ponds in which algae convert nutrients into algal protoplasm could be an inexpensive form of tertiary treatment (8). Yet Stumm and Morgan (25) estimated that it would take approximately 50 acres of algal pond area for a waste flow of one million gallons a day. Very expensive in areas where land is scarce, the system would still require some form of algal removal. If the algal cell material were not removed prior to discharge of the pond effluent, the ultimate waste load to the receiving stream would not be decreased by the use of a stabilization pond. The removal of



Quantities in millimoles per liter of sewage effluent

Figure 6. Stoichiometry of algal growth by biologically treated sewage (25).

algae prior to discharge has proved to be difficult and expensive (27). Thus it seems that stabilization ponds may not be effective enough in achieving a satisfactory or economically feasible form of nutrient removal.

Tertiary Organic Treatment

Tertiary organic treatment, as previously defined, is treatment of wastewater beyond the point commonly required by most water quality standards. It may be needed where adequate dilution is not available, where the beneficial use for the water downstream requires a high degree of purity, or where the effluent may affect private and public interests (28).

The methods presently used to provide tertiary organic treatment include stabilization ponds, aerated lagoons, rapid sand filters, land irrigation, and microstraining. Each treatment method must be tailor made to the type and extent of the tertiary organic treatment needed, and consideration must be given, of course, to the cost and availability of land. The stabilization pond and aerated lagoon are the forms of treatment that will be discussed because of their relationship to this study.

Stabilization Ponds. The use of stabilization ponds for raw wastewater treatment has been successful in South Dakota and especially where climatic conditions including much sunshine, low rainfall, and high air temperatures are usual (29) (19-422). These ponds are also used to stabilize and polish final effluents from aerobic treatment plants.

In a stabilization pond two biological processes take place at the same time. The primary controlling process is that of bacterial metabolism and the degradation of organic matter with the release of carbon dioxide and water. The secondary process is that of algal metabolism which produces sufficient oxygen to maintain aerobic conditions. The metabolism of algae is dependent upon the supply of sunlight, carbon dioxide, and the essential mineral nutrients (30).

In most cases tertiary stabilization ponds can be practical only where large areas of land--having suitable soil and terrain--are available (31). A problem exists with these ponds in that they are sensitive to changes in environmental conditions. Dissolved oxygen in the ponds is affected particularly by light required for photosynthesis and temperature (13-190). In a study by Weiss, Shamerand and Bruce in North Carolina an increase in BOD was observed through three tertiary stabilization ponds in series, following an initial BOD drop in passage through the first pond. The increase occurred during the months of July through October. In the months of January and February a drop in BOD was noticed through the ponds, but it was attributed to the low algal metabolism in the ponds during this period (30).

In another tertiary oxidation pond study, Loehr also found that the BOD removal efficiency that occurred in the colder months was equal to or better than that which occurred in the other months of the year.

Clearly, some form of algal cell removal would be necessary if optimum treatment would be desired. The advantage of stabilization ponds lies in their low maintenance costs, their esthetic value if planned properly, and their exceptional ability to reduce indicator organisms. In one study the most probable number coliform count from the effluent of a trickling filter was reduced from about 25,000 to 7 (31).

The use of stabilization ponds as tertiary treatment systems has been reported in Kansas and North Carolina (8, 30). All found that additional BOD, COD and SS removal was possible through the ponds. None of the data in these studies, however, was able to show substantial nutrient removals.

Aerated Lagoons. The aerated lagoon, the aerobic basin, and the anaerobic-aerobic basin were defined earlier. The organic removal for an aerobic treatment system can be taken to be a function of detention time, temperature, and nature of waste. From the activated sludge process the following equation applies:

$$\frac{L_e}{L_o} = \frac{1}{1 + KS_a t} \qquad (3\text{-}138)$$

where L_e = Effluent COD or BOD

L_o = Influent COD or BOD

K = Reaction rate coefficient

S_a = Mass of degradeable biological sludge

t = Mean retention time in days

When applying this equation to an anaerobic-aerobic basin, one can simplify it to:

$$\frac{L_e}{L_o} = \frac{1}{1+Kt}$$

It can be simplified because the solids concentration (S_a) is reduced to a small, relatively constant value by allowing settling to take place (3-206).

The value of the reaction rate coefficient for an anaerobic-aerobic basin must be determined experimentally for various conditions that might be encountered in the lagoon (14-29). If wastewater were of the same composition at all times, it would be expected that the BOD reaction rate coefficient (K) would be constant at a given temperature (23). Because the solids level maintained in the anaerobic-aerobic basin is low, temperature variations have a profound effect (3-208). According to the van't Hoff Arrhenius equation a decrease in 10° C will result in a decrease of K by one-half (13-67). The value of K may also be expected to increase as the BOD to unit volume in the lagoon increases since the microbial population will increase with the available food supply (3-11). Therefore, K will vary and such variations should be known and accounted for in the design and operation of biological systems.

Aeration allows aerated lagoons to receive a much higher loading. Thimsen stated that in northern climates supplemental aeration ponds and aerated lagoons can receive from 0.25 to 10 pounds 5-day BOD per 1000 cubic feet per day, while stabilization ponds are allowed only 0.15 pounds 5-day BOD per 1000 cubic feet per day (14-1). A higher loading rate, then, means that a shorter detention time can be used.

The greater depths associated with aerated lagoons result in a substantial reduction in land area requirements.

One aerated lagoon located in Mound, Minnesota, had been reported in use as a tertiary organic treatment device (31). It had a detention time of 7.5 days and was designed on a process loading of 0.08 pounds 5-day BOD/1000 cubic feet/day (14-89). No attempt had been made to remove the algal material from the effluent of the ponds. The engineer hoped that the algae and vegetation produced would remain in the pond.

When compared with stabilization ponds, aerated lagoons offer certain advantages. During winter operation in northern climates it can be expected that stabilization ponds as well as aerated lagoons will receive ice cover. Under these conditions many stabilization ponds develop anaerobic conditions and give off obnoxious odors during spring overturn (32). The mixing in aerated lagoons combines a portion of the anaerobic zone with the aerobic zone and allows for the more efficient aerobic process to predominate. During the summer months large quantities of algal growths occur in the ponds. Most of the algal activity occurs in the upper nine inches of water. Slight mixing may increase the contact between the algal mass and nutrients (33). Hence, the algal metabolism will increase and greater depths may be utilized in the design of aerated lagoons.

Conclusion

A great deal of information is available concerning biological oxidation and the use of aerated lagoons for treatment of raw wastewater. Data were not found in the literature, however, that evaluated the operation of aerated lagoons as a means of treating secondary effluents.

A disagreement was found between the publications of McKinney and Weston in contrast to those of Thimsen and Milbury concerning the operation of treatment basins in series (22) (21) (14) (20).

It seems that aerated lagoons may have a beneficial use in the removal of additional carbonaceous matter from a given wastewater. But the literature has shown that the aerated lagoon will have little or no value as a means of nutrient removal unless some form of algal cell material removal is provided to treat the lagoon effluent (8) (25). For this reason, this study was limited to evaluating the carbonaceous removal aspects and no attempt was made to evaluate the nutrient picture with respect to tertiary organic treatment.

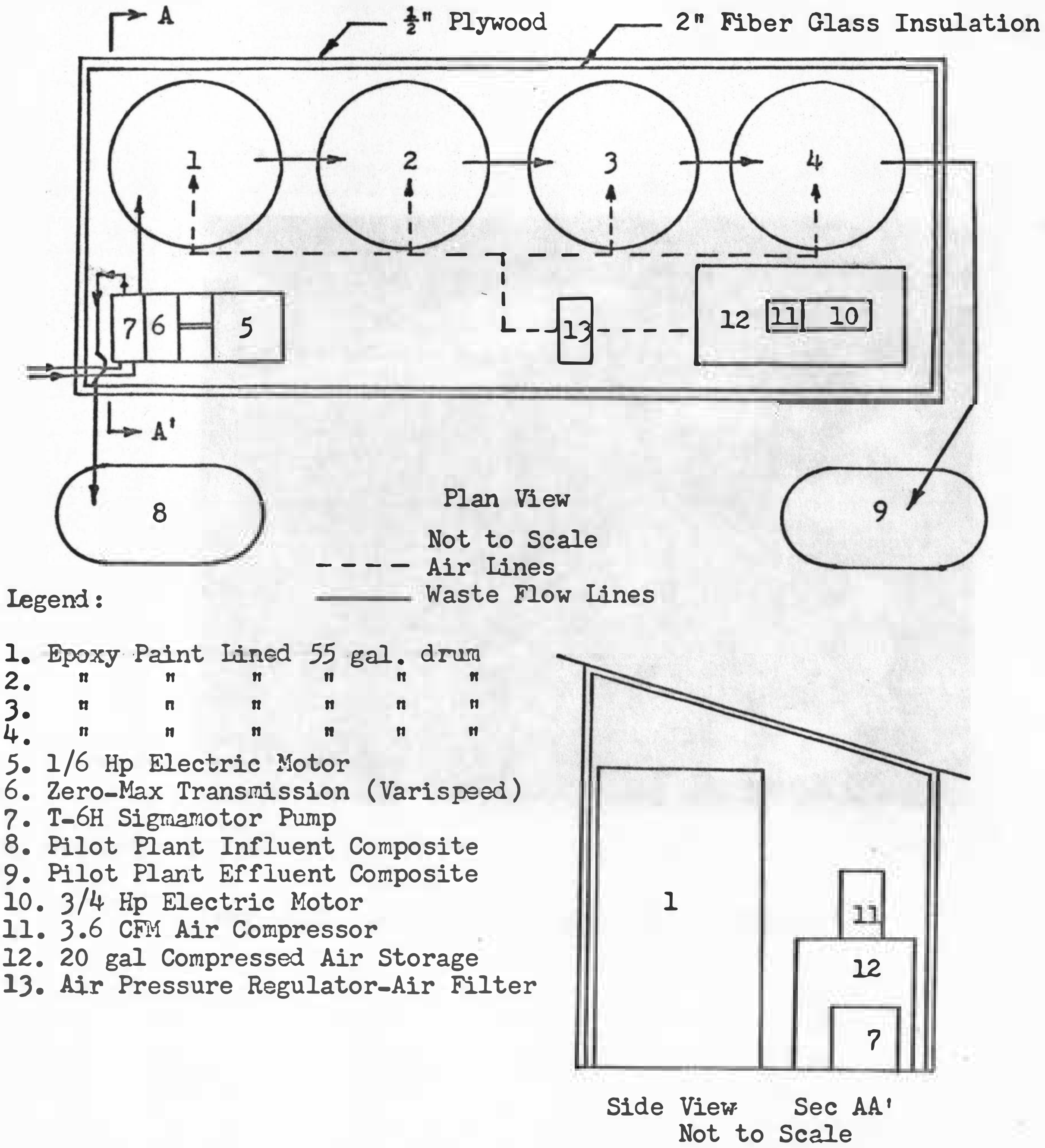
EQUIPMENT AND PROCEDURES

Pilot Plant Equipment

To obtain the information required for evaluating the major objectives, a continuous flow pilot plant was designed and constructed at the Brookings wastewater treatment plant. A continuous system was chosen in favor of a batch system because it most nearly parallels actual operating conditions. The pilot plant was located adjacent to the final sedimentation basin. This location provided access to a continuous source of effluent and furnished enough space for the pilot plant apparatus.

The pilot plant consisted of four epoxy-lined 55-gallon fuel drums, a Sigmamotor pump, an air compressor, an air pressure regulator and distribution system, and necessary plastic tubing and accessories. The layout can be seen in Figure 7. A side view of the barrels and equipment can be seen in Figure 8. Figure 9 shows a top view of the equipment assembled in the insulated enclosure.

The pilot plant apparatus was protected from the weather by an insulated enclosure constructed of $\frac{1}{2}$" plywood as shown in Figure 10. The enclosure and the equipment rested on a plywood floor that was supported by a 2"x4" wood framed foundation. The insulation was 2"x30" fiberglass and it was placed on the inside of the entire box. The heat from the electric motors on the Sigmamotor pump and air compressor protected the equipment from the adverse effects of cold weather. Continuous operation was maintained at air temperatures well below 0°F.



Legend:

1. Epoxy Paint Lined 55 gal. drum
2. " " " " " "
3. " " " " " "
4. " " " " " "
5. 1/6 Hp Electric Motor
6. Zero-Max Transmission (Varispeed)
7. T-6H Sigmamotor Pump
8. Pilot Plant Influent Composite
9. Pilot Plant Effluent Composite
10. 3/4 Hp Electric Motor
11. 3.6 CFM Air Compressor
12. 20 gal Compressed Air Storage
13. Air Pressure Regulator-Air Filter

Figure 7. Pilot plant layout.

Figure 8. Side view of pilot plant equipment.

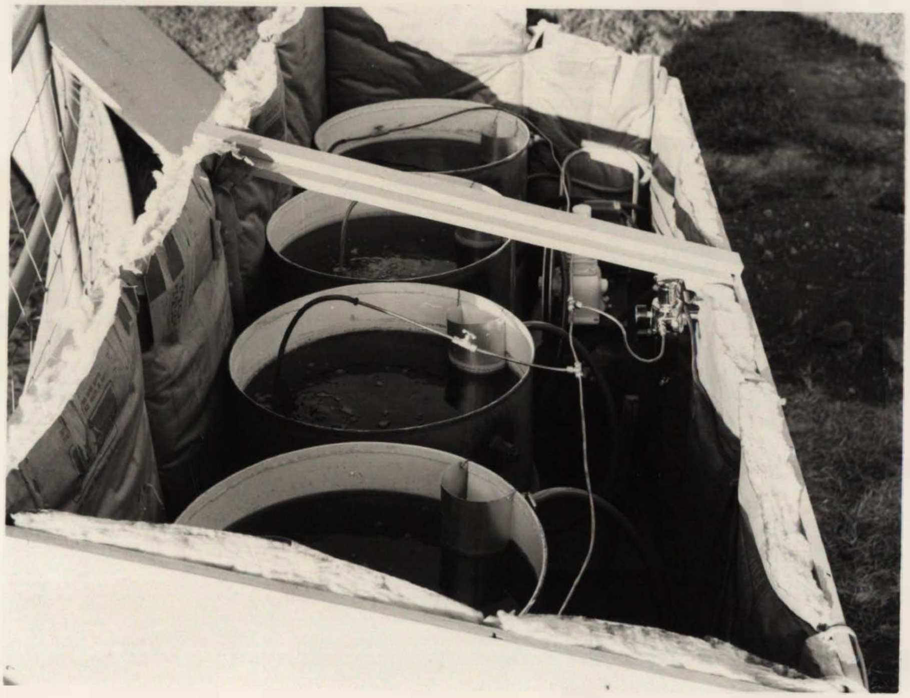


Figure 9. Top view of pilot plant equipment assembled in insulated enclosure.

Figure 10. Insulated enclosure for pilot plant equipment.

The 55-gallon drums were recommended for use in pilot plant studies for aerated lagoons by Eckenfelder (34). They provided a satisfactory volume to area ratio to minimize perimeter effects and they were convenient to handle. Each barrel was carefully sandblasted, cleaned and painted with two coats of epoxy enamel paint to prevent interference from iron rust. Each was calibrated to hold 50 gallons and connected in series with a plastic 5/8" garden hose. The use of four barrels in series was supported by Milbury, Pipes and Grieves who stated that three to five basins would produce a substantial improvement in performance over a single basin without a major loss of equalizing capacity in the system (20).

A continuous wastewater sample was pumped from the wet well of the final sedimentation basin into the pilot plant using a Sigmamotor pump operating at rates of 50 and 100 gallons per day. In this manner, the pilot plant received all the variation in effluent quality. The pump was calibrated in the operational ranges at the site with a 500 ml graduated flask and a stop watch. The required rates for the one-half and one day theoretical detention times were determined and set into the vernier adjustment mechanism as needed.

The source of oxygen for the system came from a 3.6 cubic feet per minute air compressor. The air was stored in a 20 gallon tank and released through a combination air pressure regulator and air filter. The air was then distributed to each 55-gallon drum through ¼" copper tubing. The copper tubing was terminated with a valve and tygon tubing was run from the valve to the fritted glass diffusers in each barrel.

Preliminary Studies

Preliminary batch studies run in June and July were used to determine the approximate aeration requirements (35) and detention times. In batch study No. 1 it was found that the aeration required was very slight and that in the range of 0.1 CFM gentle mixing was achieved. Heavier aeration did not cause a significant change in the dissolved oxygen. In batch study No. 2 it was found that the COD was reduced to an ultimate minimum of about 50 mg/l in a detention time of less than four days. For this reason, it was decided to initially operate the pilot plant at a hydraulic detention time of four days, one day detention in each 55-gallon drum.

An additional study was run to determine if complete mixing existed in the 55-gallon drums when the air was adjusted to the rate determined by the batch study. With the use of fluorescein dye and a Bausch and Lomb Spectronic-20 it was found that nearly complete mixing did exist in the reaction basin. It is realized that this study was run using a completely soluble material. If wastewater effluent had been used, a condition of complete mixing with sedimentation would have occurred. These are the characteristics, however, that one would expect with an anaerobic-aerobic basin.

In early September an analysis was made on a 24-hour composite of the effluent from the Brookings final sedimentation tank. The objective was to determine if there were typical hourly variations in BOD and COD as the flow increased and decreased. The results showed that the effluent from the plant could be considered typical; the waste strength increased as the flow through the plant increased.

Because there was little variation in waste strength, it was decided that a constant pumping rate could be used as input for the pilot plant system.

Start-Up and Operation

On September 23, 1967, each basin was filled with effluent from the final sedimentation tank. The aeration system was started and a gentle mixing rate was established. The wastewater effluent was pumped from the recirculation wet well into basin number one. Extra care was taken in sloping the plywood floor so that a slight positive slope existed from the first to the fourth basin.

The Sigmamotor pump was placed in operation using $\frac{1}{4}$" tygon tubing and set at a rate to provide one day detention time in each basin. Initially, the overflow from basin number four was allowed to run back into the Brookings final effluent. This was done for nine days until an equilibrium condition was thought to be established. During the start-up procedure, a problem arose with the tygon tubing and its position in the reciprocating fingers of the pump. Slippage and bulking of the tubing developed within the pumping chamber. To offset this a special restraining device was used to maintain tension on the tygon tubing within the pump. This device also had an additional advantage in that the tygon tubing within the pumping chamber could be replaced once it started failing due to the continuous flexing action caused by the reciprocating fingers of the pump. This replacement feature was of particular value when flexible black rubber hosing was used. Silicone stopcock grease was found to work best as a lubricant for the tubing.

On October 6, 1967, the sampling began and the displaced liquid was collected in a 64-gallon stock tank and stored until a 24-hour composite was taken. The influent composite sample was collected by taking advantage of the ability of the Sigmamotor pump to pump more than one line. Therefore, two lines of ¼" tygon tubing were placed in the pump. One line went to basin No. 1 and the other went into a second 64-gallon stock tank. In this way both the pilot plant and the composite sample tank received the same quantity and quality of the flow.

Between 11:00 and 12:00 a.m. each day, each stock tank was carefully mixed and a representative sample was taken. In addition, a grab sample was taken from each of the reaction basins. The air diffusers provided nearly complete mixing and hence good sampling was achieved. Six glass bottles with a volume of 250 ml each were used for sampling. Every sample was placed under refrigeration within one hour.

Methods of Analysis

There is sufficient information available indicating COD to be a sound basis for growth prediction for practical engineering design of aerobic systems (36). Loehr found that BOD removal occurred during periods of the summer when no COD removal took place (8). The COD data, however, indicated that the same quantity of chemically oxidizable material left the pond that entered it.

For these reasons the COD test was chosen to be the major parameter used in determining the organic removal characteristics of the system. The COD test measures 90-95 percent of the oxidizable matter which is made up of the biologically active as well as the inert biodegradable organic material. It gives consistent results and indicates oxidizable material that may become biochemically oxidizable later (37). The BOD test is the other alternative. It measures only the biologically active fraction. It is also more costly and takes five days instead of three hours to run. BOD tests, however, were made during Runs No. 2 and No. 3 to determine what percentage of each sample was biologically active organic material. Both tests were run in accordance with the procedures of Standard Methods for the Examination of Water and Wastewater (38).

Suspended solids (SS) determinations were not made on the first two pilot plant runs. They were made, however, during Run No. 3 using the glass fiber filter method as outlined by Wyckoff (39). Sawyer and McCarty (40-441) stated that this method is satisfactory for most application. The procedure was much faster than the standard Gooch Crucible Method and a uniform fiber filter pad was used for each test. Duplicate samples were run on typical samples and consistent results were obtained (25 mg/l ± 3 mg/l).

RESULTS AND DISCUSSION

Introduction

The investigation was divided into three separate pilot plant runs. The data collected during the period of investigation were evaluated to obtain the time variation, removal characteristics, and interrelationships of COD and BOD for the pilot plant system. The relationship between total suspended solids and volatile suspended solids for Run No. 3 were also obtained.

Variation of COD and BOD with Time

The operation of a continuous flow pilot plant can show many variations in waste strength when evaluated on a day to day basis or for a short time period. These variations can be due to daily changes in water usage, waste temperature, conditions of biological floc, and other effects. Plotting continuous data eliminates the effects of short term variation and affords a clearer picture of the actual trends. This is particularly true when a given system has to reach an equilibrium condition.

Figure 11 shows both the long and short term variation in COD that occurred during the three pilot plant runs made. The data used can be found in Appendixes A, B, and C. The daily COD results of the pilot plant influent, effluent, and basin No. 2 are plotted.

As the ambient air temperature dropped, the organic removal in the secondary treatment plant was reduced and the effluent strength from the plant increased. Operating records revealed that less water was used by the community and therefore the detention time in the

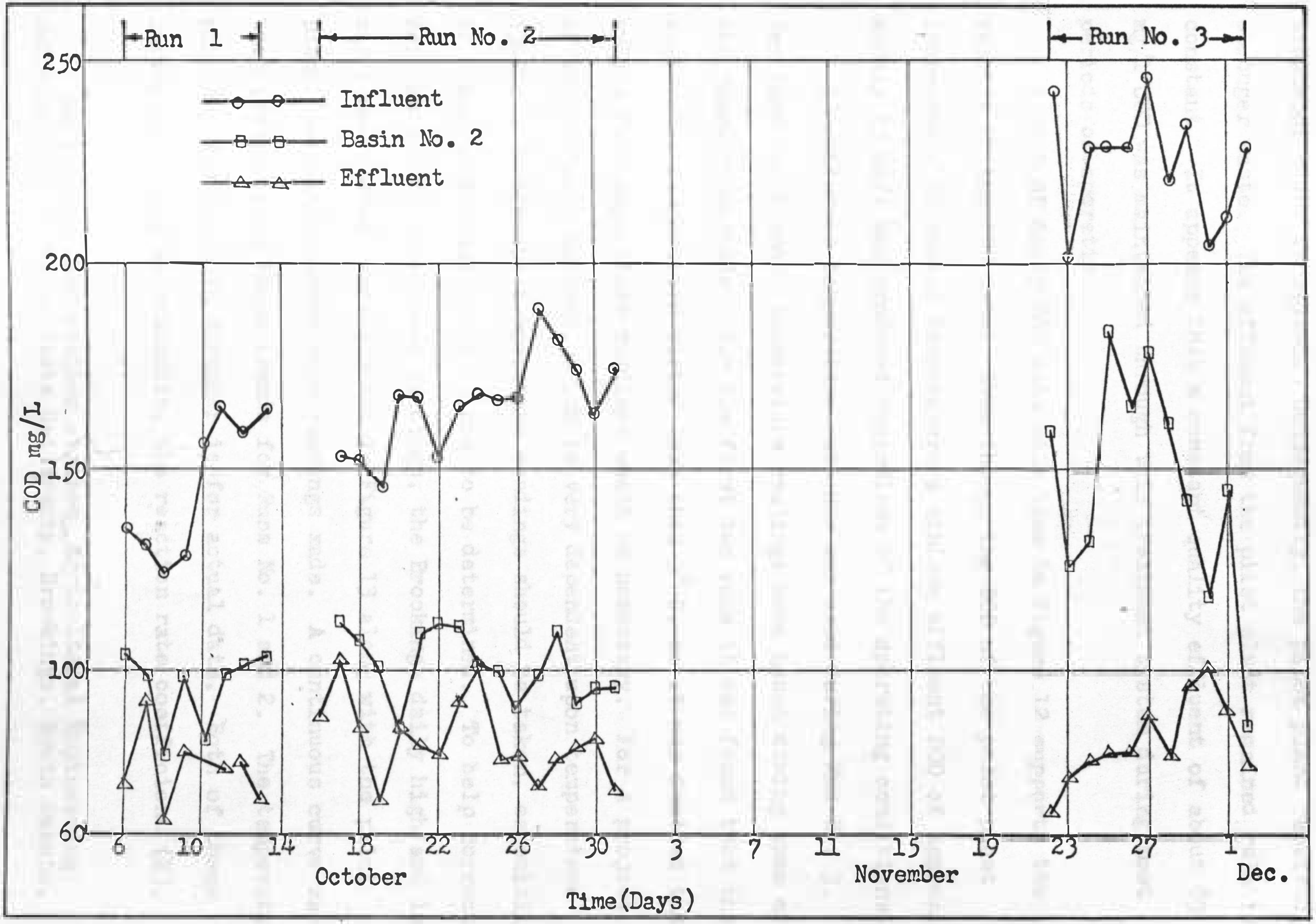


Figure 11. COD versus time in days for daily sampling.

treatment plant increased. Consequently, the pilot plant received a stronger waste. The effluent from the pilot plant remained relatively constant. It appears that a constant quality effluent of about 85 mg/l COD was maintained through this treatment system during most periods of operation.

A plot of daily BOD data with time in Figure 12 supports the results of the COD data. Even though the BOD of the pilot plant increased with colder temperature a minimum effluent BOD of approximately 15 mg/l was produced regardless of the operating conditions.

A continuous temperature recorder was used during Run No. 3. For Runs No. 1 and 2 temperature readings were taken during some of the sampling periods. For the first two runs it was found that the wastewater temperature varied less than 5° C, so it was decided that only a few temperature readings would be necessary. For a project of this nature, however, which is very dependent upon temperature (3-212), continuous temperature readings should be taken, especially if biological reaction rates are to be determined. To help correct for not taking continuous readings, the Brookings daily high and low air temperatures[2] were plotted in Figure 13 along with the pilot plant wastewater temperature readings made. A continuous curve was then traced using these trends for Runs No. 1 and 2. The temperature plot for Run No. 3 in November is for actual data. Both of these curves were used in evaluating the reaction rate coefficient (K).

[2] Data taken from weather station, Agricultural Engineering Building, South Dakota State University, Brookings, South Dakota.

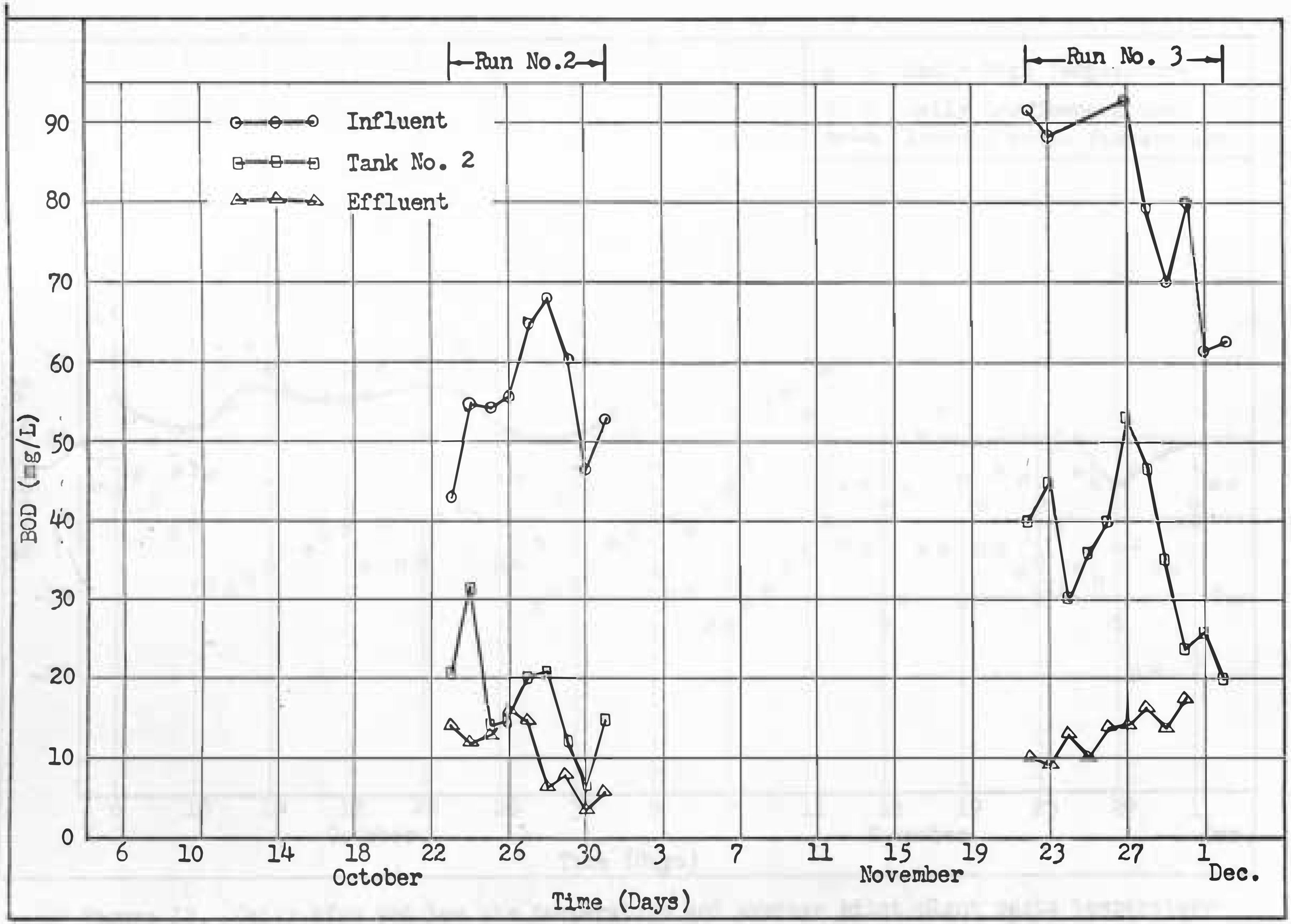


Figure 12. BOD versus time in days for daily sampling.

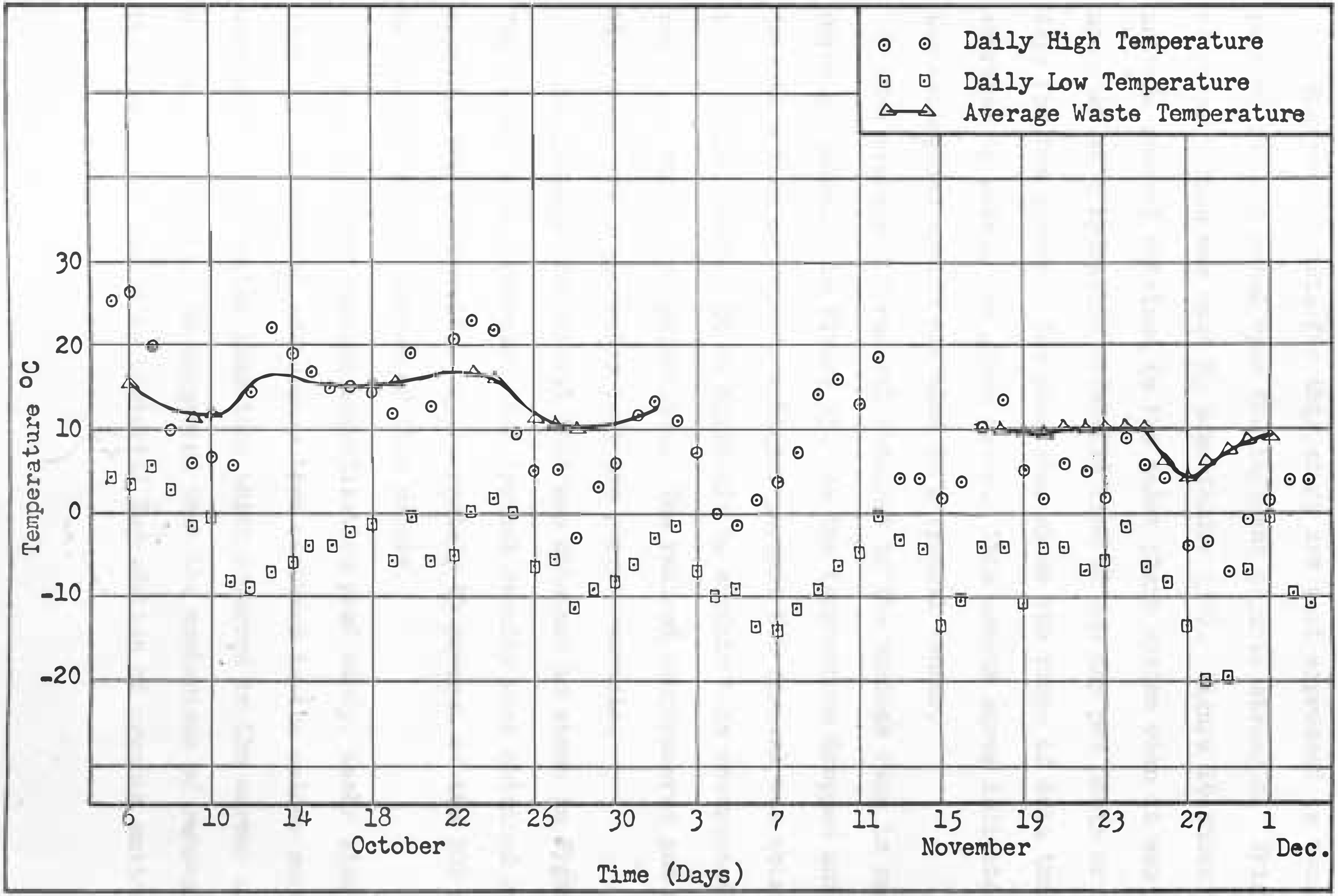


Figure 13. Daily high and low air temperature and average pilot plant waste temperature versus time in days.

Removal Characteristics

The removal data for this study are best expressed in terms of percent removal based upon the influent organic strength. This form of presentation was used by Eckenfelder (34). Figure 14 shows the uniform removal obtained in the pilot plant system when it was operated at a hydraulic detention time of one day per basin or four days for the system. The plot also shows the range of data that was averaged to obtain the given curve. This smooth curve indicates that the biological system operated in a typical manner.

The average COD removal obtained by the various runs is compared graphically in Figure 15. As the temperature dropped and the detention time decreased, a higher percent COD removal was obtained in the pilot plant. It is difficult to explain this unexpected result on biological principles. The reduced temperatures and detention times would generally indicate poorer removals.

The average BOD removal that was obtained is shown in Figure 16. The smooth curve indicates that typical results were obtained and supports the COD results. Approximately 80 percent of the BOD can be removed using a system of this nature.

In a tertiary organic stabilization pond study, Loehr also found that the BOD removal efficiency that occurred in the colder months was equal to or better than that which occurred in the warmer months of the year (8-36). He suggested that the mechanisms of removal in the summer was caused by bacterial degradation of organic matter and

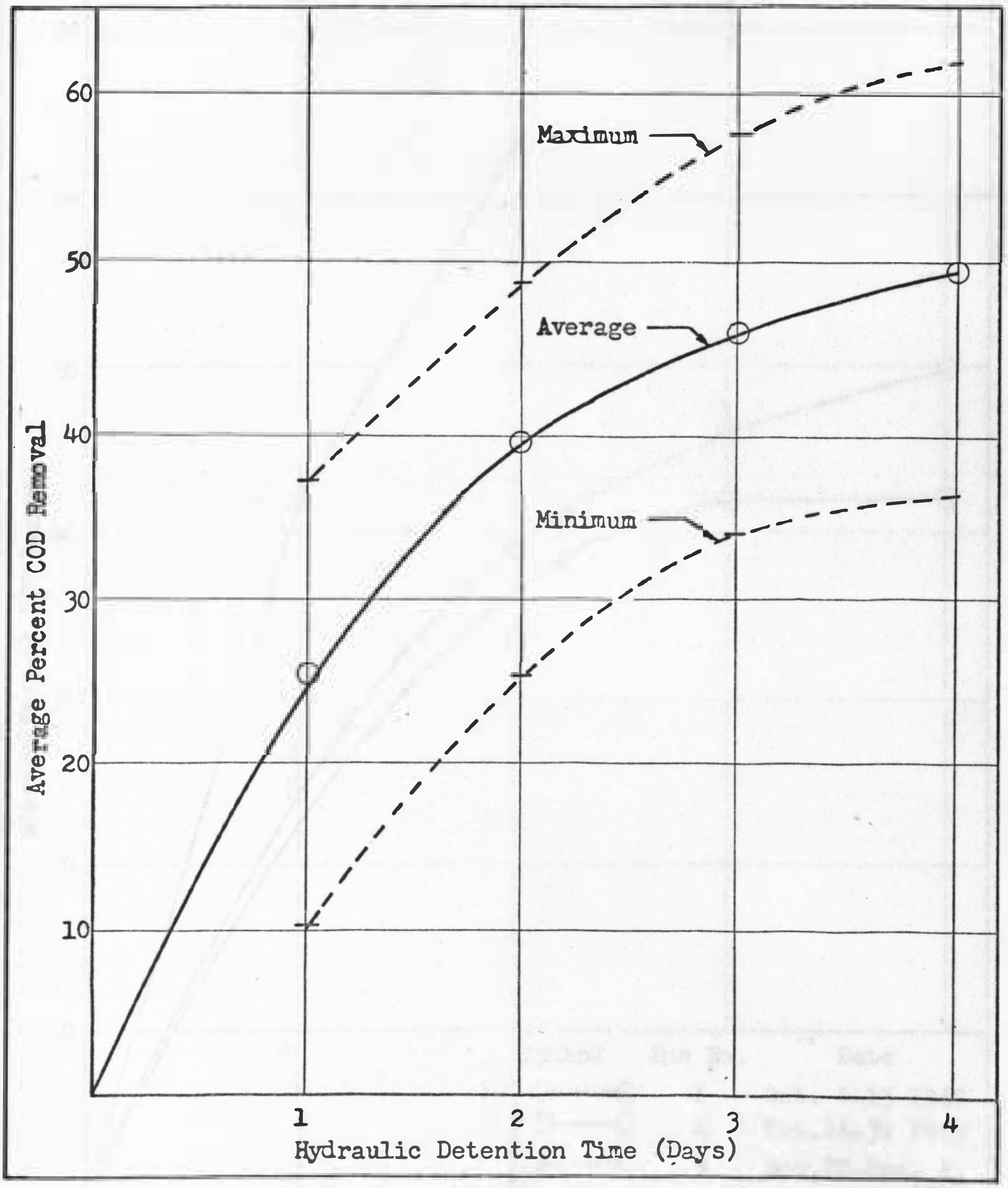


Figure 14. Maximum, minimum and average percent COD removal vs. hydraulic detention time for pilot plant Run No. 2 (Oct. 17-31, 1968).

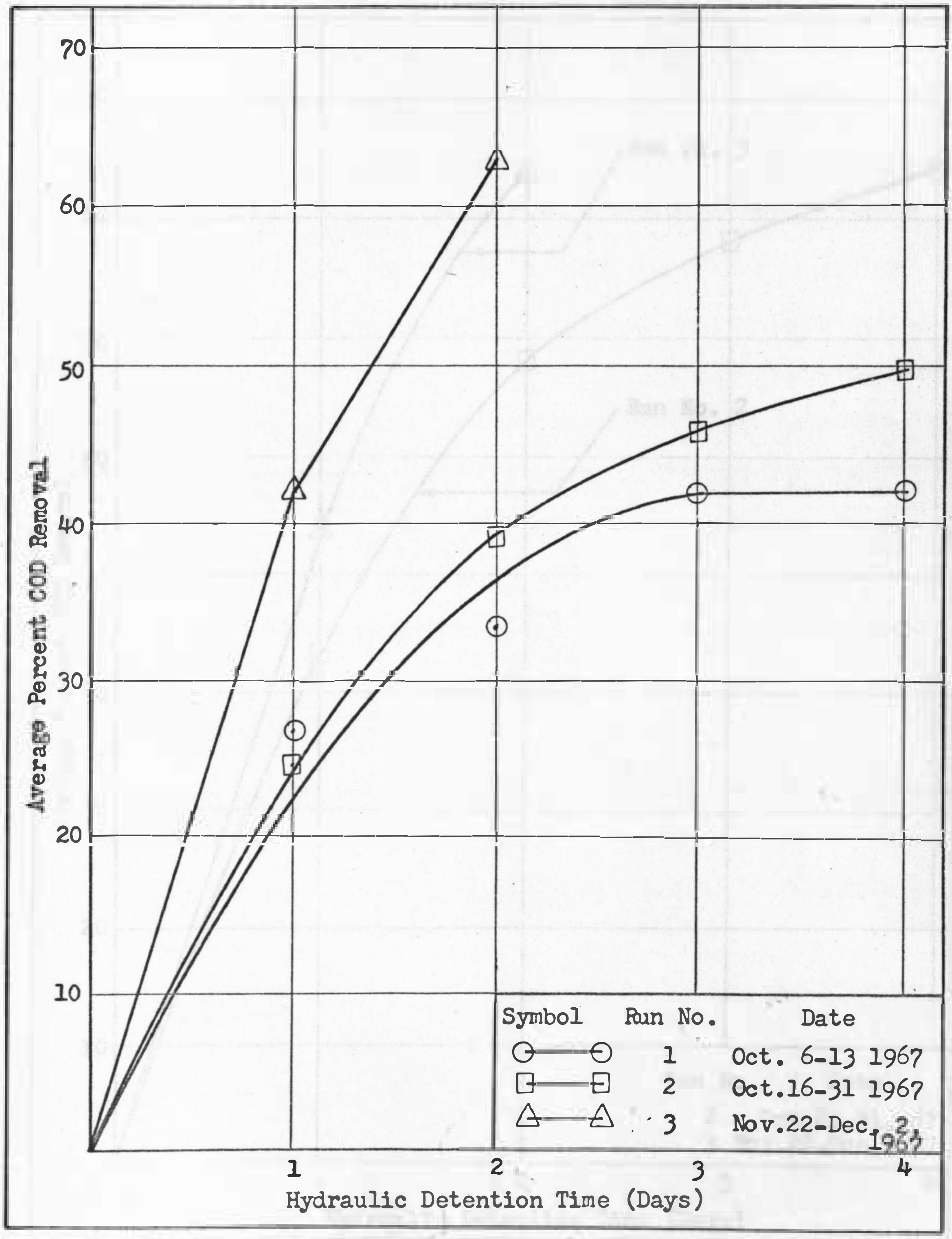


Figure 15. Average percent COD removal vs. hydraulic detention time for three pilot plant runs.

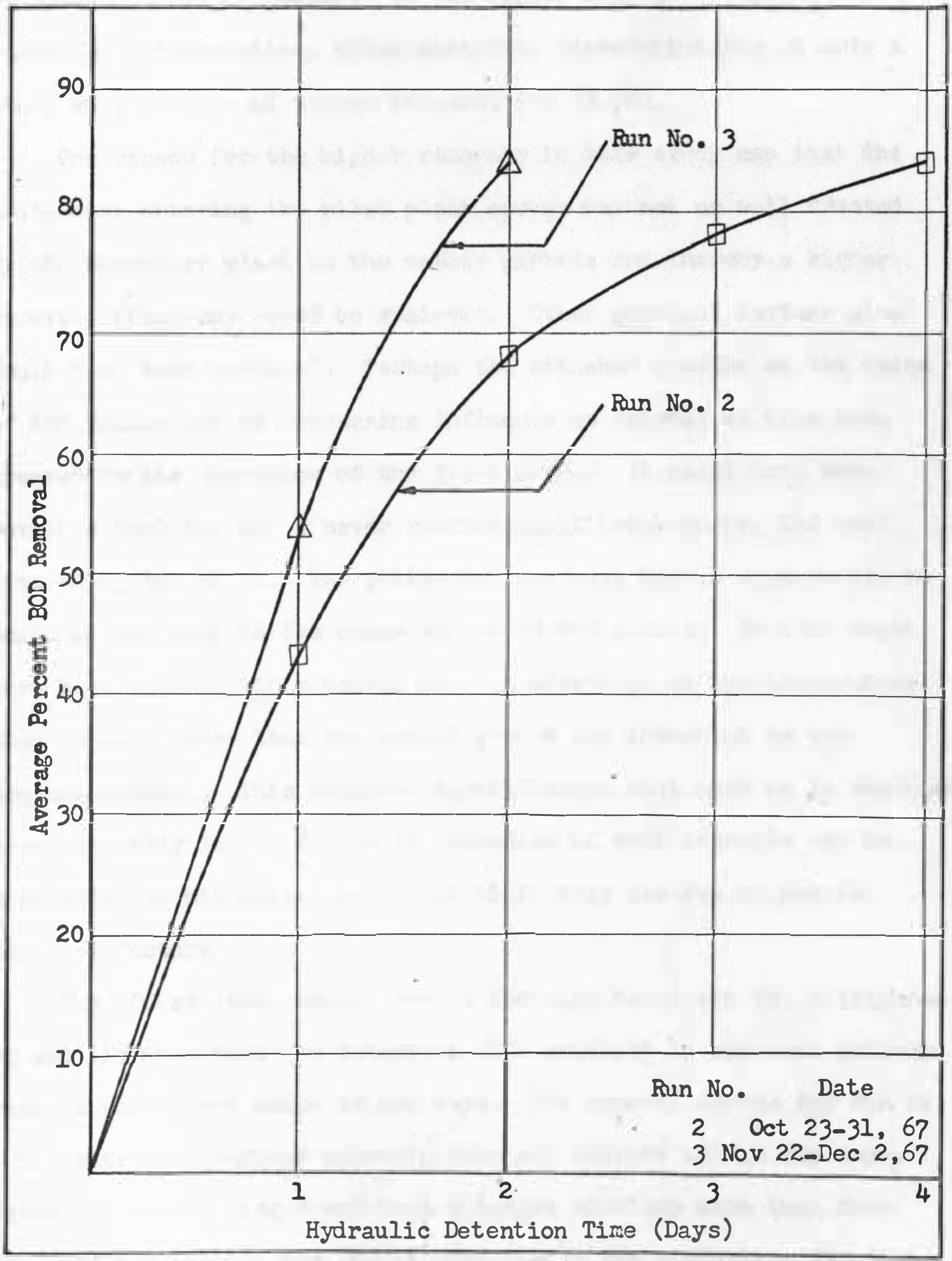


Figure 16. Average percent BOD removal vs. hydraulic detention time for two pilot plant runs.

by sedimentation of solids. In the winter removal was primarily caused by sedimentation, while bacterial degradation played only a minor role because of cooler temperatures (8-36).

One reason for the higher removals in this study was that the wastewater entering the pilot plant system was not as well treated by the secondary plant in the colder periods and thereby a higher removal efficiency could be achieved. Other physical factors also could have been involved. Perhaps the attached growths on the sides of the basins had an increasing influence on removal as time progressed in the operation of the pilot plant. It could have been possible that Run No. 3 never reached equilibrium during the week proceeding the trial. The solids may not have had an opportunity to build up and pass to the other basins in the system. It also might have been that multiple basins have an advantage at low temperature when factors other than biological growth are important to the organic removal. This apparent contradiction will have to be examined more carefully in the future to determine if such removals can be attributed to biological oxidation or if they are due mainly to physical factors.

The COD and BOD removal curves for Runs No. 1 and No. 2 (Figures 15 and 16) show that the detention time required to approach optimum removal was in the range of two days. The removal curves for Run No. 3 indicate that maximum removals were not reached within two day's detention time. Ling found that a longer aeration time than four days did not improve the BOD removal during the wintertime (37-965).

COD and BOD Relationships

It is generally well accepted that as the stabilization of wastewater is increased the ratio between COD and BOD increases. This trend is clearly shown in Figure 17 and illustrates that the wastewater was well stabilized by the pilot plant system. The COD/BOD ratios for Run No. 3 indicated that stabilization was approached in basin No. 4 whereas for Run No. 2 it was approached in basin No. 2. This may indicate that at least three basins are needed during cold weather operation while only two basins are adequate during warmer weather operation. The leveling off at basin No. 3 indicated that close to optimum stabilization was achieved at or prior to this point.

One objective of this study was to determine the variation of the reaction rate coefficients K_{COD} and K_{BOD}, as defined by Eckenfelder (3-138), from basin to basin in the pilot plant. In a series of basins one would expect that the reaction rate between basins would decrease as the organic concentrations decreased. This expected result was observed for K_{COD} in Runs No. 1 and No. 2 as shown in Figure 18. For Run No. 3, however, the reaction rate coefficient increased with time, indicating that a greater removal rate was achieved in the second and third basins rather than the first and second basins.

Similar results were found in Figure 19 when evaluating the K_{BOD}. A slight decline in the reaction rate coefficient was found between basins for Run No. 2, while on Run No. 3 an increase was found. This data supports the results of K_{COD}.

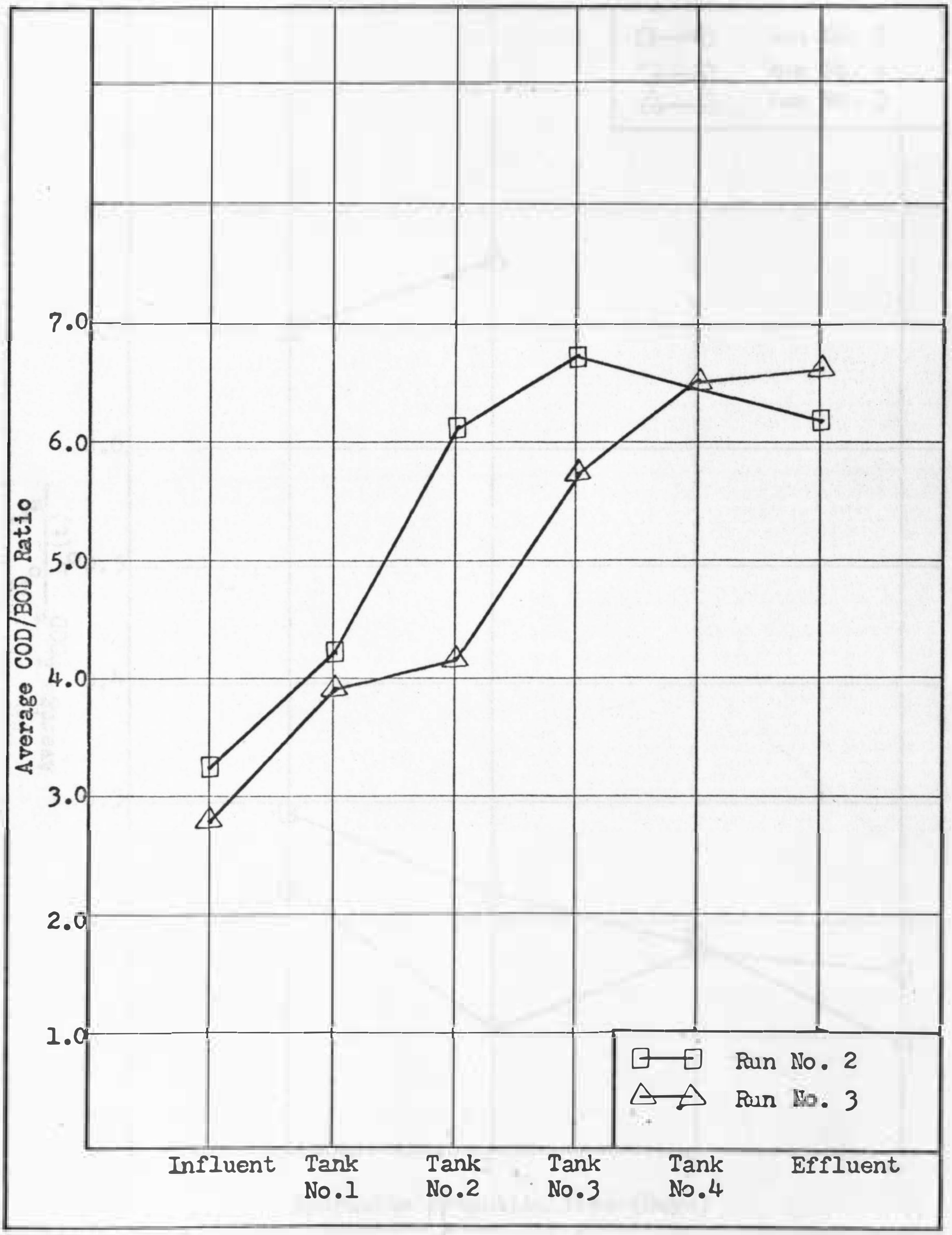


Figure 17. Average COD/BOD ratio in tanks for Run No. 2 and Run No. 3.

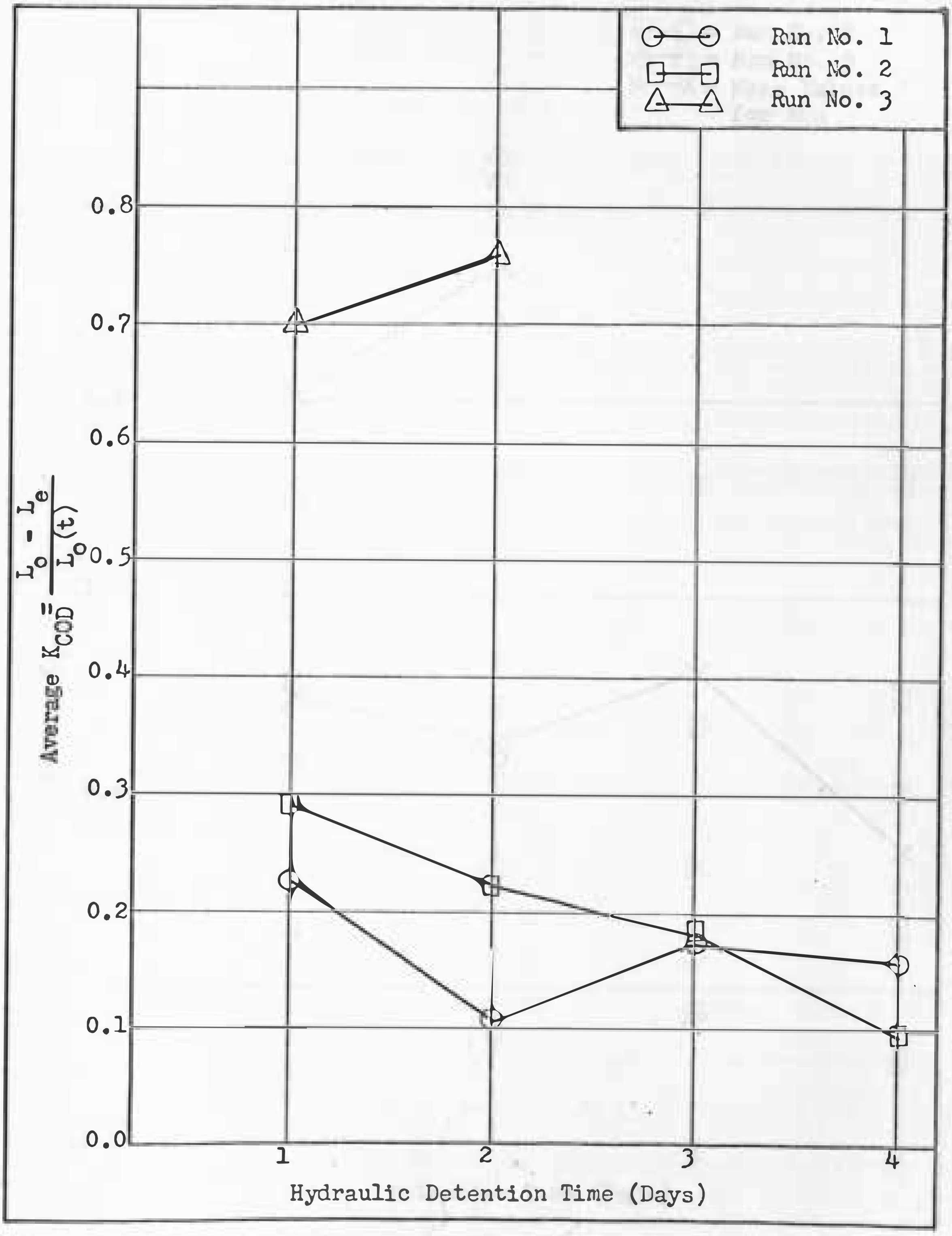


Figure 18. COD reaction rate coefficient versus detention time for three Runs.

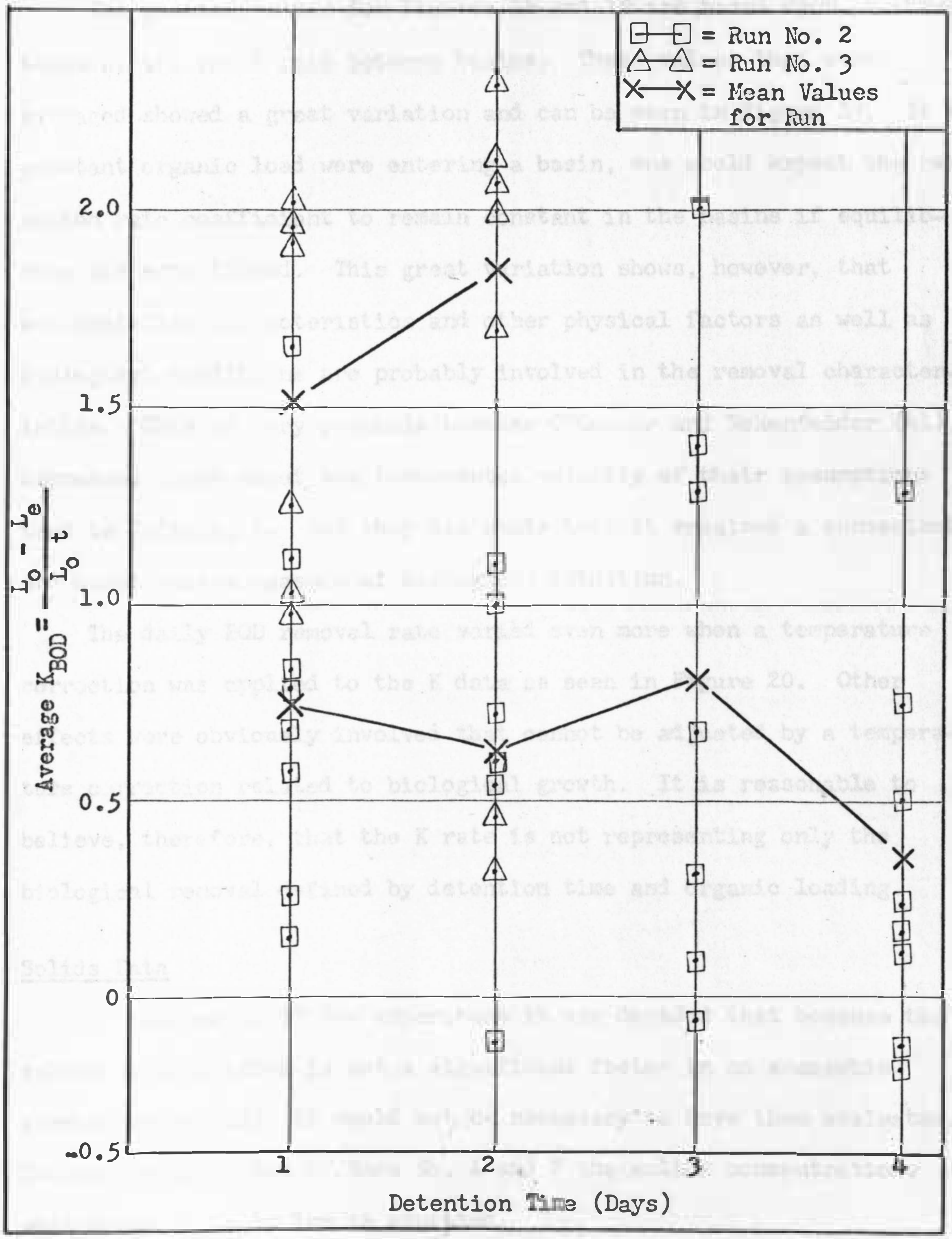


Figure 19. BOD reaction rate coefficient versus detention time for two Runs (no temperature correction).

The plotted values for Figures 18 and 19 are based upon averages taken of the raw K rate between basins. These values that were averaged showed a great variation and can be seen in Figure 19. If a constant organic load were entering a basin, one would expect the reaction rate coefficient to remain constant in the basins if equilibrium was established. This great variation shows, however, that sedimentation characteristics and other physical factors as well as biological conditions are probably involved in the removal characteristics. This is very possible because O'Connor and Eckenfelder (41) expressed doubt about the fundamental validity of their assumptions used in defining K. But they did state that it remained a convenient and quantitative measure of biological oxidation.

The daily BOD removal rate varied even more when a temperature correction was applied to the K data as seen in Figure 20. Other effects were obviously involved that cannot be adjusted by a temperature correction related to biological growth. It is reasonable to believe, therefore, that the K rate is not representing only the biological removal defined by detention time and organic loading.

Solids Data

In the design of the experiment it was decided that because the solids concentration is not a significant factor in an anaerobic-aerobic basin (15), it would not be necessary to have them evaluated. During the operation of Runs No. 1 and 2 the solids concentrations were observed to be low as expected.

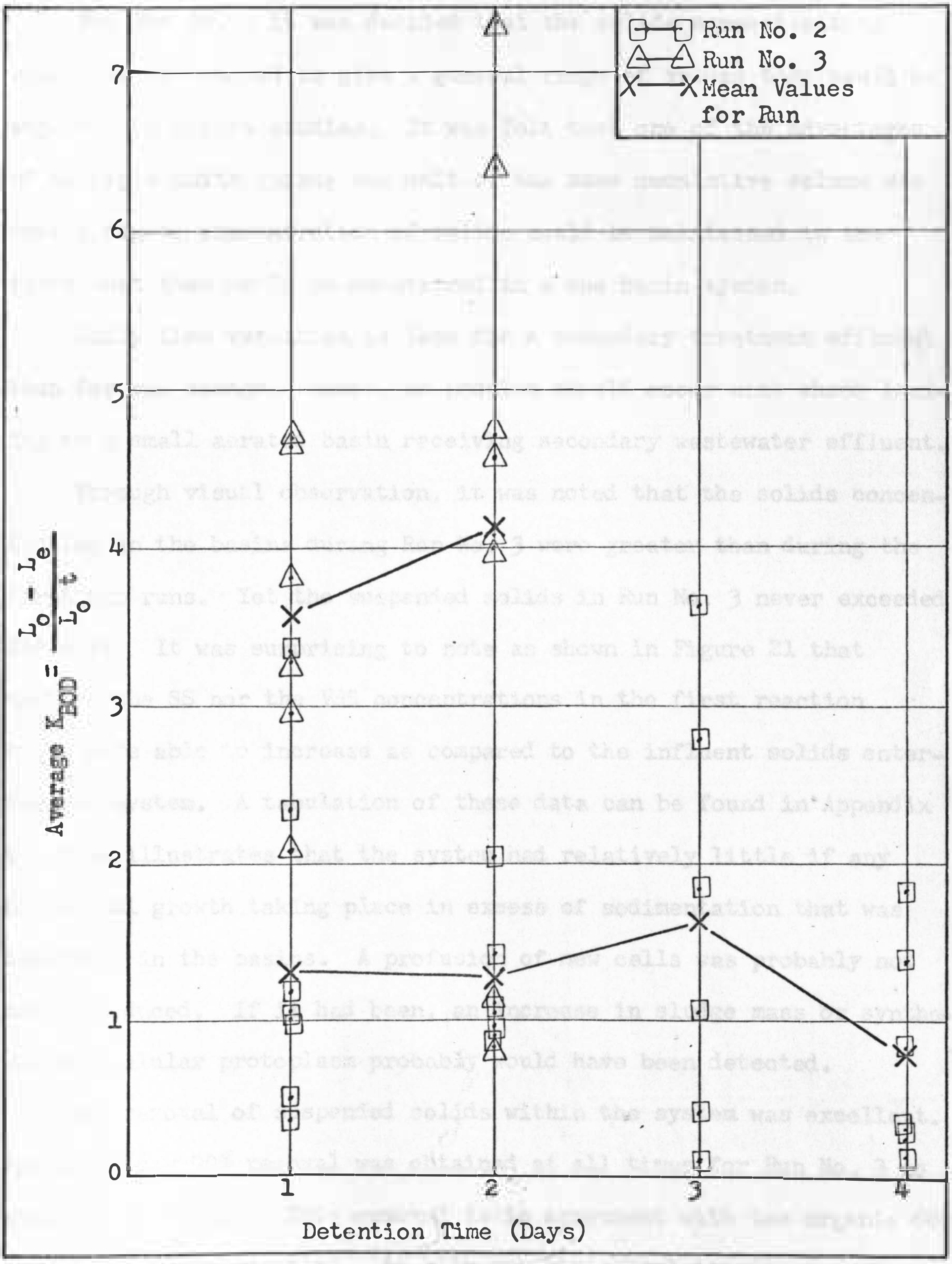


Figure 20. BOD reaction rate coefficient (K) versus detention time for two Runs (with temperature correction).

For Run No. 3 it was decided that the solids concentrations should be determined to give a general range of values that could be expected in future studies. It was felt that one of the advantages of multiple units versus one unit of the same cumulative volume was that a higher concentration of solids could be maintained in the first unit than could be maintained in a one basin system.

Daily flow variation is less for a secondary treatment effluent than for raw sewage. Hence, no problem should occur with shock loading in a small aerated basin receiving secondary wastewater effluent.

Through visual observation, it was noted that the solids concentration in the basins during Run No. 3 were greater than during the first two runs. Yet the suspended solids in Run No. 3 never exceeded 110 mg/l. It was surprising to note as shown in Figure 21 that neither the SS nor the VSS concentrations in the first reaction basin were able to increase as compared to the influent solids entering the system. A tabulation of these data can be found in Appendix D. This illustrates that the system had relatively little if any biological growth taking place in excess of sedimentation that was occurring in the basins. A profusion of new cells was probably not being produced. If it had been, an increase in sludge mass or synthesis of cellular protoplasm probably would have been detected.

The removal of suspended solids within the system was excellent. Approximately 90% removal was obtained at all times for Run No. 3 as shown in Figure 22. This removal is in agreement with the organic COD and BOD removals reported. As with any biological treatment system, one cannot expect this high degree of solids removal for an infinite

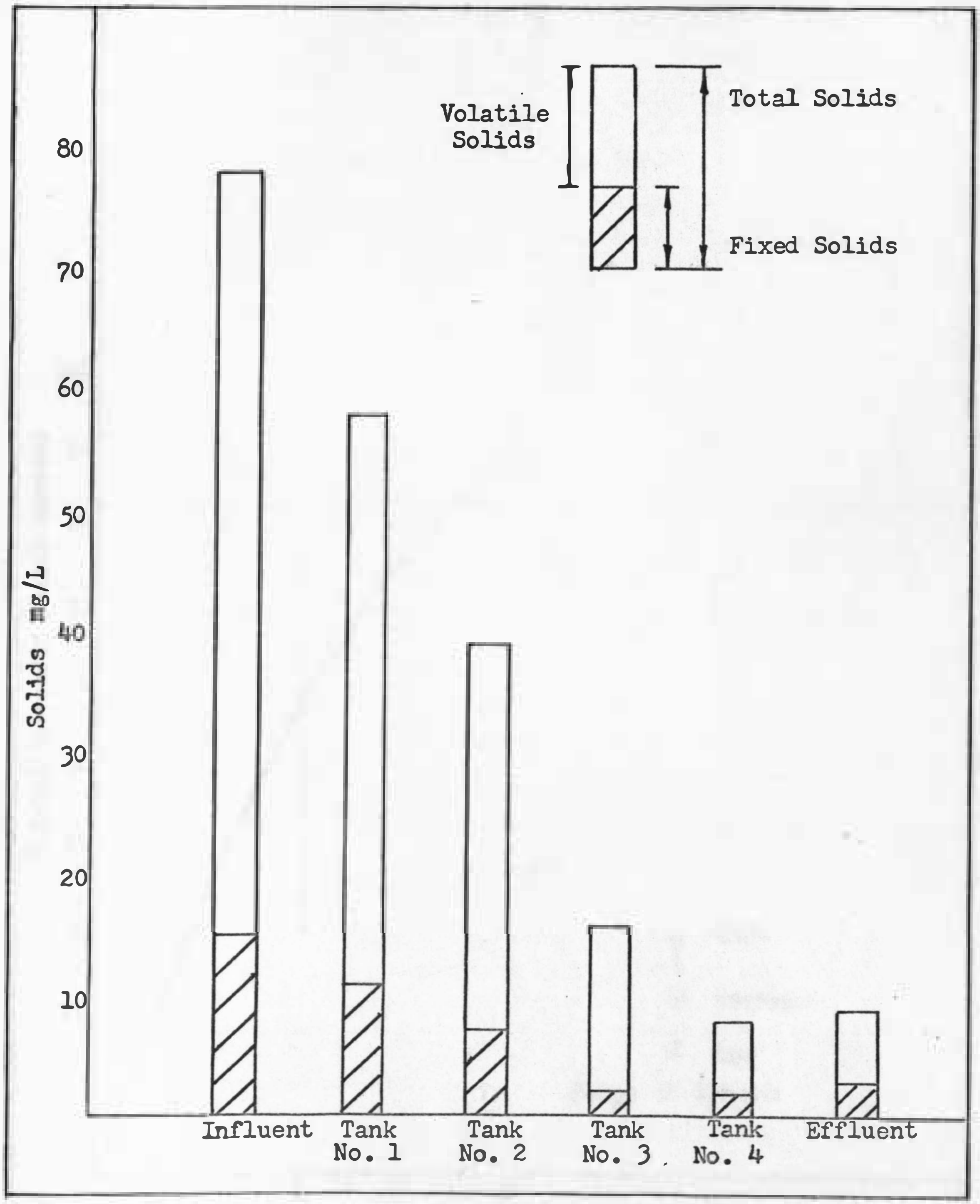


Figure 21. Comparison of average total and volatile suspended solids in four basins for Run No. 3.

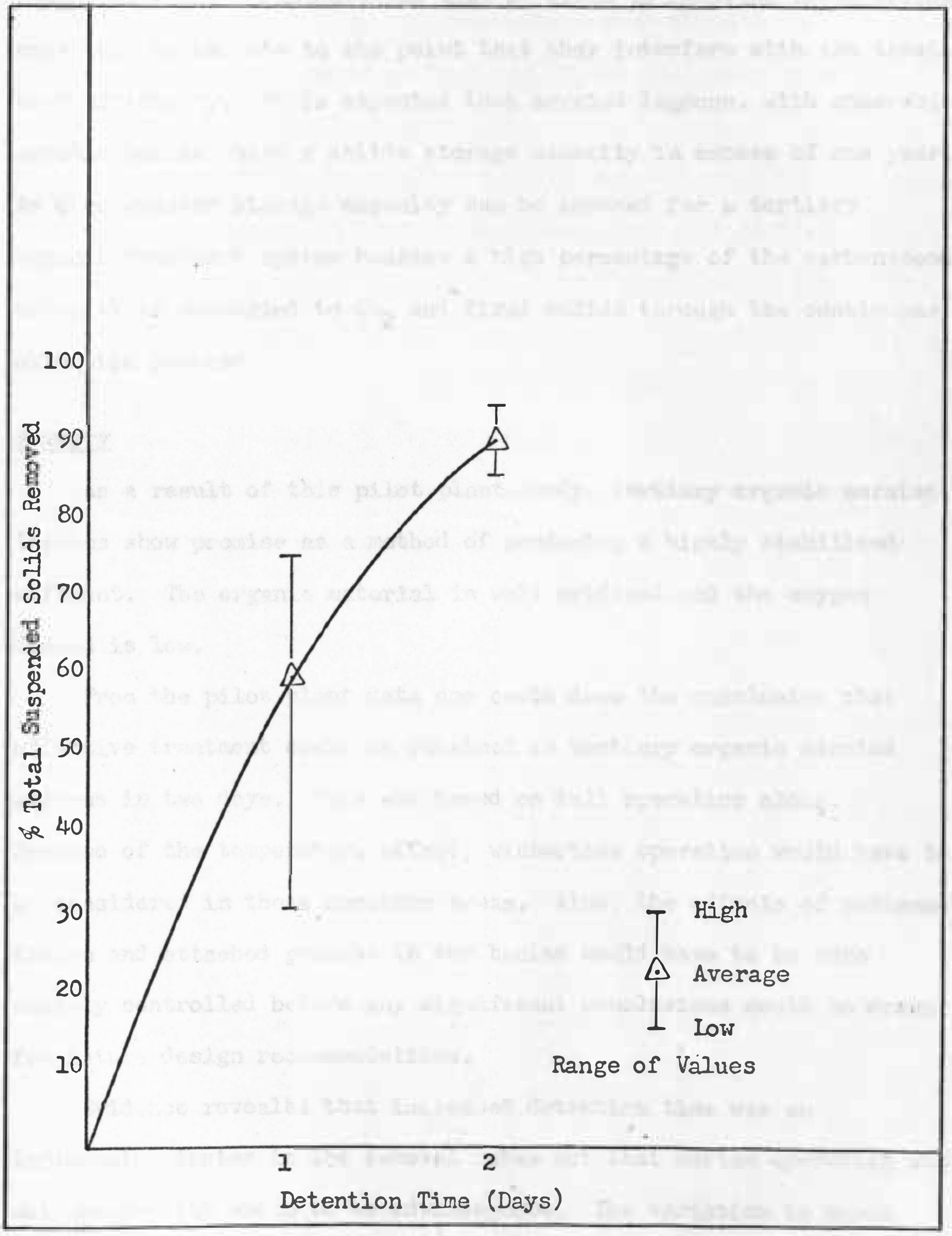


Figure 22. Percent total suspended solids removed versus detention time for Run No. 3.

amount of time. Consideration must be given to removing these solids once they accumulate to the point that they interfere with the treatment efficiency. It is expected that aerated lagoons, with anaerobic-aerobic basins, have a solids storage capacity in excess of one year. An even greater storage capacity can be assumed for a tertiary organic treatment system because a high percentage of the carbonaceous material is converted to CO_2 and fixed solids through the continuous oxidation process.

Summary

As a result of this pilot plant study, tertiary organic aerated lagoons show promise as a method of producing a highly stabilized effluent. The organic material is well oxidized and the oxygen demand is low.

From the pilot plant data one could draw the conclusion that effective treatment could be obtained in tertiary organic aerated lagoons in two days. This was based on fall operation alone. Because of the temperature effect, wintertime operation would have to be considered in these northern areas. Also, the effects of sedimentation and attached growths in the basins would have to be more closely controlled before any significant conclusions could be drawn for future design recommendations.

Evidence revealed that increased detention time was an influencing factor in the removal rates but that series operation was not necessarily shown to be advantageous. The variation in waste strength from the Brookings Wastewater Treatment Plant prevented accurate evaluation of the importance of series operation of aerated lagoons. A constant waste strength influent might make this type of evaluation possible.

The nutrient removal problem was not considered in this testing program. It must be considered, though, in any tertiary treatment design when the ultimate disposal of the effluent is a lake or slow moving stream. As a result of the discharge from a tertiary organic treatment system, lakes will approach eutrophication faster and streams will become choked due to excess growths of algae and aquatic weeds. Although the pilot plant data showed that aerated lagoons would be useful as tertiary organic treatment systems, this treatment system should not be considered as a means for tertiary treatment.

CONCLUSIONS

The following conclusions were drawn from the investigation involving a pilot plant study on the effluent of the Brookings Wastewater Treatment Plant:

1. The pilot plant as used in this study can be used during all periods of the year, and with daily maintenance it can be depended upon for continuous operation.

2. Aeration of secondary treatment plant effluent enhances wastewater quality. During the fall it was shown that COD could be reduced to 85 mg/l and BOD could be reduced to 15 mg/l. A system of this type should make an excellent buffer against the poor operation of wastewater treatment plants discharging to receiving streams with little or no dilution capacity.

3. The pilot plant data indicated that aerated lagoons with a detention time of two days would probably give close to optimum removal of organic material during fall operation.

4. The organic removal rate coefficient K as defined by Eckenfelder proved inadequate for describing the treatment characteristics when applied to an aerated lagoon pilot plant where removal may have been due to factors other than biological removal.

5. Based upon the literature review, it is believed that aerated lagoons would not obtain adequate nutrient removal in tertiary treatment systems unless they were followed by an oxidation pond with facilities for sludge and algal cell removal.

SUGGESTIONS FOR FUTURE STUDY

In the course of this pilot plant study additional alternatives and problems arose. The following should be considered in future research programs of this nature:

1. The pilot plant should be applied to a raw waste in another problem area where lagooning may appear feasible.

2. The volumes of air required should be measured with a rotometer so that the air requirements could be established.

3. An attempt should be made to differentiate between physical removal and biological removal occurring during winter time operation.

4. A study of the economics of tertiary organic aerated lagoons should be made considering such factors as land requirements, air requirements, quantity of sludge produced, and methods of removal of excess sludge.

5. The effect of nitrification should be checked to see if this process interfered with the BOD test results. One would not want the oxygen requirements of nitrification to be interpreted as oxidizable carbonaceous matter.

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APPENDIX A

COD Data for Pilot Plant Run No. 1
Oct. 6-13, 1967
Data Expressed in mg/l

Date	Influent Composite	Basin Number 1	Basin Number 2	Basin Number 3	Effluent Composite
10/6/67 (Fri.)	135(1)	121	104	85	73
10/7/67 (Sat.)	131	122(1)	99	95	95
10/8/67 (Sun.)	124	93	79(1)	70	62
10/9/67 (Mon.)	128	93	97	73(1)	81
10/10/67 (Tues.)	156	97	82	80	--(1)
10/11/67 (Wed.)	165	112	99	72	76
10/12/67 (Thur.)	158	118	101	76	78
10/13/67 (Fri.)	164	118	104	87	68

(1) Percent Removal and Reaction Rate values were found using these diagonal values for COD. A one day theoretical detention time was thus assumed.

APPENDIX B
Part 1

COD Data for Pilot Plant Run No. 2
Oct. 16-31, 1967
Data Expressed in mg/l

Date	Influent Composite	Basin Number 1	Basin Number 2	Basin Number 3	Effluent Composite
10/16/67 (Mon.)		118	136	107	89
10/17/67 (Tues.)	153(1)	121	112	103	103
10/18/67 (Wed.)	153	121(1)	108	94	86
10/19/67 (Thur.)	146	116	101(1)	93	68
10/20/67 (Fri.)	168	131	86	86(1)	86
10/21/67 (Sat.)	168	133	109	88	82(1)
10/22/67 (Sun.)	153	112	112	92	80

APPENDIX B
Part 2

COD and BOD Data for Pilot Plant Run No. 2
Oct. 16-31, 1967
Data Expressed in mg/l

Date	Test	Influent Composite	Basin Number			Effluent Composite
			1	2	3	
10/23/67 (Mon.)	COD	165(1)	128	111	101	93
	BOD	43	28	21	14	14
10/24/67 (Tues.)	COD	169	123(1)	102	89	102
	BOD	55	24	32	16	12
10/25/67 (Wed.)	COD	167	120	100(1)	88	78
	BOD	54	30	14	14	13
10/26/67 (Thur.)	COD	168	114	91	81(1)	79
	BOD	56	32	15	13	16
10/27/67 (Fri.)	COD	188	139	99	83	73(1)
	BOD	65	44	20	16	15
10/28/67 (Sat.)	COD	182	226(2)	109	83	79
	BOD	68	56(2)	21	12	7(3)
10/29/67 (Sun.)	COD	175	125	93	111	82
	BOD	61	32	12	7(3)	8(3)
10/30/67 (Mon.)	COD	163	110	96	83	83
	BOD	47	23	7	5(3)	4(3)
10/31/67 (Tues.)	COD	175	122	96	81	71
	BOD	53	30	15	10	6

(1) Diagonal values were used to determine percent removal and reaction rate (K) values. A one day detention time was assumed.

(2) High values due to excessive aeration. Bottom sediment was stirred up and entered the aerobic mixing area.

(3) D. O. drop for these values was less than 1 mg/l.

APPENDIX C

COD and BOD Data for Pilot Plant Run No. 3
Nov. 22--Dec. 2, 1967
Data Expressed in mg/l

Date	Test	Influent Composite	Test 1	Test 2	Test 3	Test 4	Effluent Composite
11/22/67 (Wed.)	COD	260	219	159	100	80	66
	BOD	92(1)	59	40	17	11	10
11/23/67 (Thur.)	COD	202	182	126			76
	BOD	88	45	45(1)	19	11	9
11/24/67 (Fri.)	COD	170	104	132	86	76	78
	BOD	65	29	30	14	9(1)	13
11/25/67 (Sat.)	COD	150	224	184	88	78	80
	BOD	64	50	36	16	10	10
11/26/67 (Sun.)	COD	182	244	166	98	86	80
	BOD	57	61	40	16	39(2)	14
11/27/67 (Mon.)	COD	264	212	178	102	94	90
	BOD	93	67	53	16	13	14
11/28/67 (Tues.)	COD	220	145	161	89	81	79
	BOD	79	47	47	22	16	17
11/29/67 (Wed.)	COD	234	132	142	95	109	97
	BOD	70		35	19	15	14
11/30/67 (Thur.)	COD	204	129	117	109	91	102
	BOD	79	31	24	11	13	18
12/ 1/67 (Fri.)	COD	212	153	145	97	87	90
	BOD	62	37	26	13	18	23(2)
12/ 2/67 (Sat.)	COD		112	87	75	73	77
	BOD	63	25	20	22	18	41.5(2)

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(1) Diagonal values were used to determine percent removal and reaction rate (K) values. A one day detention time was assumed.

APPENDIX D

TSS and VSS Data for Pilot Plant Run No. 3
Nov. 22--Dec. 2, 1967
Data Expressed in mg/l

Date	Test	Influent Composite	Test				Effluent Composite
			1	2	3	4	
11/22/67 (Wed.)	TSS	124	98	45	11	8	8
	VSS	94(1)	79	38	10	6	4
11/23/67 (Thur.)	TSS	73	70	38	12	7	9
	VSS	57	53	28(1)	9	5	4
11/24/67 (Fri.)	TSS	53	62	28	10	8	9
	VSS	38	47	25	7	6(1)	6
11/25/67 (Sat.)	TSS	65	79	45	9	7	8
	VSS	53	63	35	7	5	5
11/26/67 (Sun.)	TSS	55	110	59	10	8	8
	VSS	44	89	45	9	5	6
11/27/67 (Mon.)	TSS	86	84	75	16	10	11
	VSS	71	67	61	13	9	8
11/28/67 (Tues.)	TSS	68	38	59	15	9	8
	VSS	55	33	50	13	8	7
11/29/67 (Wed.)	TSS	64	31	30	10	7	6
	VSS	-	-	-	-	-	-
11/30/67 (Thur.)	TSS	78	18	20	6	4	7
	VSS	-	-	-	-	-	-
12/ 1/67 (Fri.)	TSS	74	39	19	10	9	9
	VSS	58	24	13	8	7	6
12/ 2/67 (Sat.)	TSS	58	19	14	7	7	10
	VSS	46	17	12	7	5	6

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(1) Diagonal values were used to determine percent solids removal.