1969

A Pilot Plant Study to Determine the Treatability of Combined Domestic and Milk Wastes in an Aerated Lagoon

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A PILOT PLANT STUDY TO DETERMINE THE TREATABILITY OF COMBINED DOMESTIC AND MILK WASTES IN AN AERATED LAGOON

BY

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A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Civil Engineering, South
Dakota State University

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TREATABILITY OF COMBINED DOMESTIC

AND MILK WASTES IN AN AERATED LAGOON

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

ACKNOWLEDGMENTS

The author is deeply indebted to Dr. James N. Dornbush and Dr. John R. Andersen for their guidance and assistance throughout the investigation.

Appreciation is extended to T. Alvin Biggar, Civil Engineering Technical Assistant, for his assistance in construction of the pilot plant, and to Jerry L. Siegel for his aid in preparing the thesis.

The cooperation of the city of Volga, South Dakota, and the assistance of Ferman Feeney, as representative of the city, are gratefully acknowledged.

This study was supported in part by a Federal Water Pollution Control Administration Training Grant No. 5T1-WP-93.

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INTRODUCTION

The milk processing industry commonly produces large quantities of high-strength waste. Frequently, a milk processing plant is located in a small agricultural community in which it is the only sizable industry. Because of this, the wastewater from the milk plant may cause overloading of the wastewater treatment facilities of the community.

This situation exists in Volga, a small town in eastern South Dakota. The city of Volga, with an estimated 1967 population of 840, has been treating the domestic wastewater plus the industrial waste from the relatively large milk processing plant by utilizing a stabilization pond system. This type of treatment has been widely used in this area because it is an economical and reliable method of treating wastewater from small cities. However, for satisfactory operation, biological treatment in the stabilization pond must proceed aerobically. A high-strength industrial waste can overload a stabilization pond system and cause the pond to turn anaerobic. Noisome odors and high turbidity generally accompany anaerobic conditions.

Many residents of Volga were dissatisfied with their present wastewater treatment system because of the offensive odors coming from the lagoons. The lagoon location near an arterial highway gave travelers an unfavorable impression of the city. In addition to this problem, a pump failure had caused wastewater to back up into the basements of several of these homes. In response to these complaints, the city engaged the consulting firm of J. T. Banner and Associates to evaluate the existing system and to advise the city on needed improvements.

From their investigation the consultants concluded that the stabilization ponds were overloaded. Because of this, the quality of the effluent being discharged into the Big Sioux River did not comply with the water quality standards established by the State of South Dakota. The consultants recommended among other things that the city install an aerated lagoon which would precede the existing stabilization pond system.

However, because of their concern for treatment efficiency during the winter, the State Department of Health officials were hesitant to approve the installation of an aerated lagoon at Volga. The wintertime operation of an aerated lagoon had been investigated by John Lowthian (1), a graduate student in sanitary engineering at South Dakota State University. Because Lowthian reported favorably concerning operation and BOD removal, the consultant continued to seek approval for an aerated lagoon. After further discussions with the Federal Water Pollution Control Administration (FWPCA) and the

State Department of Health, approval was obtained for the aerated lagoon on condition that the efficiency of the aerated lagoons be evaluated for all seasonal conditions.

Preliminary investigations indicated that a large portion of the organic loading at the Volga waste treatment plant was contributed by the milk processing plant and that the domestic waste was mainly diluting the milk processing wastes. The purpose of this study was to determine the treatability of this combined milk waste in an aerated lagoon.

REVIEW OF LITERATURE

Characteristics of Milk Wastes

Milk is a complex mixture of proteins, fats, sugars, and salts containing calcium, phosphorus, iron, copper, and magnesium, all of which are essential to life processes. When milk is processed, the milk wastes which are discharged from the plant serve as an excellent food source for bacteria. Unfortunately, these bacteria require large amounts of oxygen to stabilize the milk waste. If sufficient atmospheric oxygen is not available, the stabilization will proceed anaerobically with the attendant problems of nuisance odors and high turbidity.

Although milk wastes are generally high in dissolved organic matter, they contain very little suspended material. Hence, the pollutional effect of a milk waste is due almost entirely to the oxygen demand which is imposed on a stream. The average composition of milk, milk by-products, and milk processing wastes is shown in Table 1. Because of the extremely high biochemical oxygen demand (BOD) of milk and its wastes, even relatively dilute solutions of milk exert a high BOD.

Table 1.

Average Composition of Milk, Milk By-Products, and Milk Processing Wastes (2-326)

Characteristics	Whole milk, ppm	Skim milk, ppm	Whey, ppm	Process Wastes, ppm
Total solids	125,000	82,300	72,000	4,516
Organic solids	117,000	74,500	64,000	2,698
Fat	36,000	1,000	4,000	--
Milk sugar	45,000	46,000	44,000	--
Protein (casein)	38,000	39,000	8,000	--
BOD, 5-day	102,500	73,000	32,000	1,890

Sources of Milk Wastes

The wastes from a milk processing plant consist primarily of the waterborne milk solids. Milk wastes may be classified according to their source as follows (3):

1. Washing and rinsings from cans, equipment, and floors.
2. Spillage, freeze-on, overflow, and leakage due to worn-out equipment and improper operation.
3. Entrainment from evaporators.
4. By-products such as buttermilk, separated milk, and whey which have not been utilized.

5. Spoiled or damaged raw or manufactured products or by-products.

Treatment of Milk Wastes

Milk wastes respond readily to treatment by biological methods. Although aerobic processes have been found to be most suitable, anaerobic methods have been used. Nemerow (2-326) described six conventional processes generally used for dairy wastes which are as follows: anaerobic digestion, irrigation, trickling filters, activated sludge, lagooning, and aeration. Many combinations of these processes are possible, such as anaerobic treatment followed by lagooning.

Anaerobic treatment. The septic tank method was used in the first deliberate effort to treat milk wastes anaerobically. Problems developed because the lactose in milk underwent acid fermentation under anaerobic conditions which rendered the waste resistant to further anaerobic treatment. The noxious odors produced further limited the use of this method.

An alternative possibility is anaerobic pretreatment followed by aerobic treatment. This method has been used successfully for treating meat packing wastes. Siegel (4) made a comparative study of anaerobic-aerobic treatment versus aerobic treatment on a skim-milk substrate. Results indicated that the milk which was pretreated anaerobically was more treatable in the subsequent aerobic system than was the non-pretreated milk.

Irrigation. The use of milk processing wastes for irrigation is an economical method of disposal where suitable land is available. Two methods of disposal by irrigation are used: spray irrigation and ridge-and-furrow irrigation (3). However, because domestic wastes contain pathogenic organisms, irrigation is probably not applicable for combined raw domestic and milk processing wastes.

Conventional biological treatment. The milk waste from a dairy processing plant can be efficiently treated by municipal treatment plants utilizing the trickling filter process or the activated sludge process. The cost of conventional waste treatment facilities is usually prohibitive for a small milk processing plant which cannot discharge its wastes to a municipal wastewater treatment plant (5).

Lagooning. Lagooning offers a relatively inexpensive means of treating a milk waste, both in terms of installation and maintenance. A disadvantage of lagooning is the problem of locating a large area which is well isolated. Also, during cold periods the waste treatment in stabilization ponds will be inhibited, and organics will be stored until spring. Objectionable odors may occur after the ice cover melts. Generally, lagoons receiving only milk wastes have not functioned satisfactorily (6).

Extended aeration. Extended aeration, which is a modification of the activated sludge process, employs high-rate aeration for the purpose of stabilizing the waste and aerobically digesting the majority of the biological sludge produced. A typical continuous flow treatment system consists of an equalization tank for equalizing the volume and strength of the waste, an aeration tank where the waste is vigorously agitated and oxidized by introducing air to convert the organic matter to cell material and energy, and a settling tank where the suspended solids are removed for return to the aeration tank (3).

The personnel at the Eastern Regional Research Laboratory of the U. S. Department of Agriculture studied the possibility of using extended aeration for the treatment of milk wastes. After extensive laboratory study, the process was field-tested at Pennsylvania State University. As a result of these studies, a number of dairy plants use extended aeration for treatment of their milk wastes (3).

The cell material or sludge which is produced in the process is aerated for an extended period until stabilized by endogenous respiration. An important factor in the operation of an aeration treatment system is the temperature. Optimum results occur at a temperature of about 30°C. Endogenous oxidation is retarded at lower temperatures and most activity ceases at 20°C. In colder climates, a shelter over the treatment facility is usually necessary (3).

Aerated lagoons. An aerated lagoon has been defined as a basin of significant depth (6-12 ft) in which oxygenation of wastewater is accomplished by mechanical or diffused aeration units and from induced surface aeration (7-206). The process was developed when aeration was applied to simple lagoons which had failed to accomplish the desired degree of purification and had probably created serious odor problems (8).

In an aerated lagoon the organic wastes are stabilized by dispersed growths of bacteria similar to the process that occurs in a conventional stabilization pond or even in a natural body of water. This process differs with the activated sludge process in which flocculent growths of bacteria oxidize the organic load (9).

There are generally considered to be two types of aerated lagoons. They may be classified as the completely-mixed aerated lagoon and the aerobic-anaerobic aerated lagoon. In the completely-mixed system, the mixing level is sufficient to maintain all solids in suspension. Therefore, the effluent suspended solids concentration will be the same as the suspended solids level of the basin. If the suspended solids level is high, some provision for sludge settling and disposal may be necessary. In the aerobic-anaerobic basin the mixing level is adequate to insure distribution of oxygen throughout the basin, but a large portion of the inert suspended solids and non-oxidized biological solids settles to the bottom where it decomposes anaerobically (10).

The aerated lagoon may provide an economical solution to the problem of wastewater treatment. The land requirement is only 1 to 10 percent of the area required for stabilization ponds and need not be much greater than the area required for a high-rate trickling filter (8). Also an aerated lagoon is generally more economical to construct than a conventional stabilization pond or the various activated sludge systems. In addition, an aerated lagoon can handle wastes of highly varying characteristics because of the equalization provided by dilution. This minimizes and may eliminate pre-treatment requirements. In order to provide the full potential capacity for overcoming waste load variations, toxic properties, and high and low pH conditions, the aerated lagoon should provide ample mixing (8).

The main disadvantages of the aerated lagoon are the cost of operating the aerators and the reduced removal efficiency which occurs at low temperatures and short detention periods. Operational changes have been suggested to reduce heat losses in the colder climates (8).

Aerated lagoons have been used successfully for treating milk processing wastes. Initially, milk processing wastes from the Grand View Dairy of Arkport, New York, were treated in a stabilization pond system. In order to eliminate the problems of odor and lack of dissolved oxygen in the effluent, two aerators were installed. Before installation of the aerators, the strength of the effluent was 235 mg/l BOD. After the installation of the aerators, the BOD discharged from the lagoons was reduced to 25 mg/l. Therefore, the aerators decreased the BOD being discharged by 89.5 percent (11).

EXPERIMENTAL METHODS AND TEST PROCEDURES

The purpose of this project was to determine the treatability of the combined domestic sewage and milk waste at Volga, South Dakota. Specifically, information was desired as to the degree of treatment that could be provided by an aerated lagoon. This information was obtained by designing and operating a small pilot unit which approximated the environment found in an aerated lagoon.

Review of Pilot Plant Designs

There are two basic pilot plant designs which can be used to study the treatability of a waste. Symons *et al.* (12) recommended that a batch-fed, fill-and-draw type aeration unit be used when evaluating treatability. This type of unit has the obvious advantage of simplicity of design and construction. Unfortunately, it does not provide design criteria in addition to evaluating whether the waste is biologically treatable (13).

The other method for studying treatability is the continuously fed pilot plant. The continuously fed system has the advantage of being operated similar to an actual wastewater treatment plant. Because of this, it is easier to evaluate the pilot plant data and apply it to actual plant operation. Eckenfelder and Barnhart (14) recommended that continuous studies be conducted on a waste. The pilot plant system used in this investigation followed the design for continuous studies as described by Eckenfelder and Barnhart.

Description of Pilot Plant System

The pilot plant was situated adjacent to the existing lift station which is located east of the city of Volga. The raw influent to the pilot plant was obtained by tapping into the discharge manifold of the lift pumps. The purpose of the lift station is to pump the wastewater to a series of stabilization ponds about a mile east of Volga.

The pilot unit which is shown in a schematic diagram in Figure 1 included a 5-gallon holding tank which was refilled at the frequent intervals when the pumps in the lift station operated. Excess flow coming into this holding tank was discharged to waste. The contents of the holding tank were aerated to maintain the solids in suspension. Wastewater was pumped from this holding tank by a positive displacement pump through two lines. The first line conveyed the waste to the 50-gallon capacity aeration tank of the pilot plant. The second line conveyed the waste to the proportional divider (tipping bucket) in order to obtain a representative sample.

Oxygen was supplied to the aeration tank and the holding tank from a portable air compressor through air diffuser stones. The overflow (effluent) from the aeration unit was discharged to a second

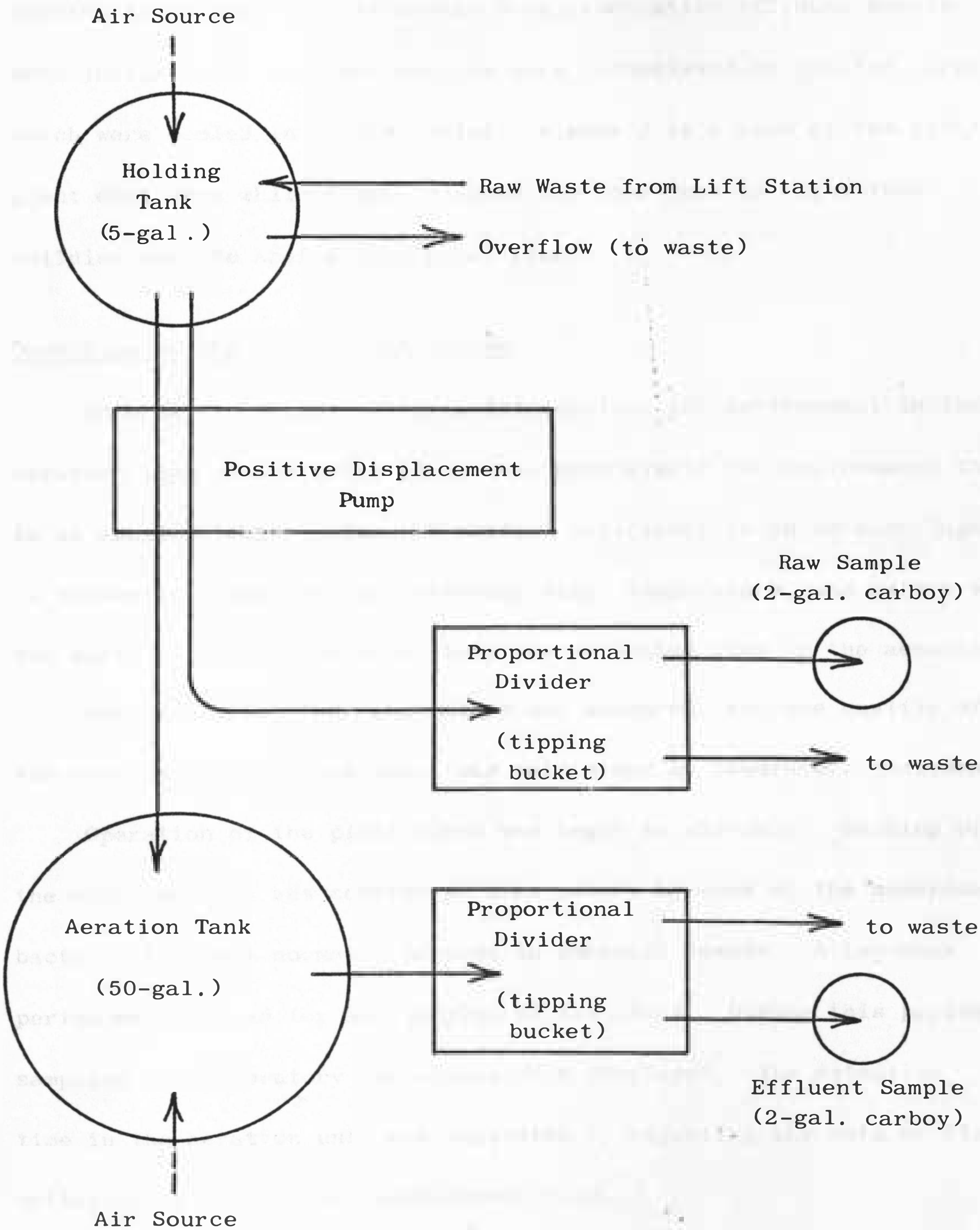

Figure 1. Schematic Diagram of Pilot Plant

tipping bucket in order to obtain a representative effluent sample. Both influent and effluent samples were accumulated in plastic carboys which were cooled in an ice cooler. Figure 2 is a view of the pilot plant equipment while Figure 3 shows the four-foot by eight-foot building used to shelter the pilot plant.

Operation of the Pilot Plant System

In order to obtain reliable information, the environment in the aeration tank of the pilot plant must approximate the environment found in an aerated lagoon. The BOD removal efficiency in an aerated lagoon is primarily a function of detention time, temperature, and nature of the waste (7-206). For this study the detention time in the aeration tank was regulated, the temperature was measured, and the quality of the raw waste and the effluent was determined by laboratory analyses.

Operation of the pilot plant was begun in mid-July. Seeding of the aeration unit was considered unnecessary because of the numerous bacteria that are normally present in domestic sewage. A two-week period was allowed for acclimation of the biota. During this period, sampling and laboratory techniques were developed. The detention time in the aeration unit was regulated by adjusting the rate of flow delivered by a positive displacement pump.

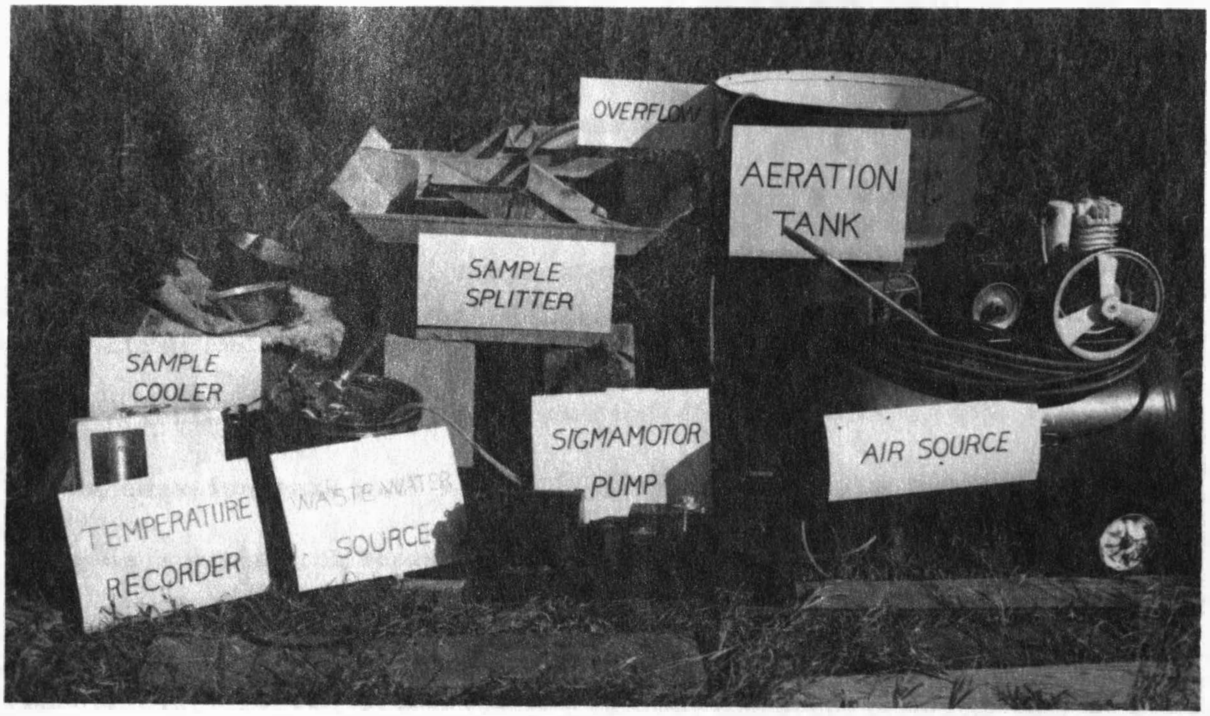

Figure 2. View of Pilot Plant Equipment

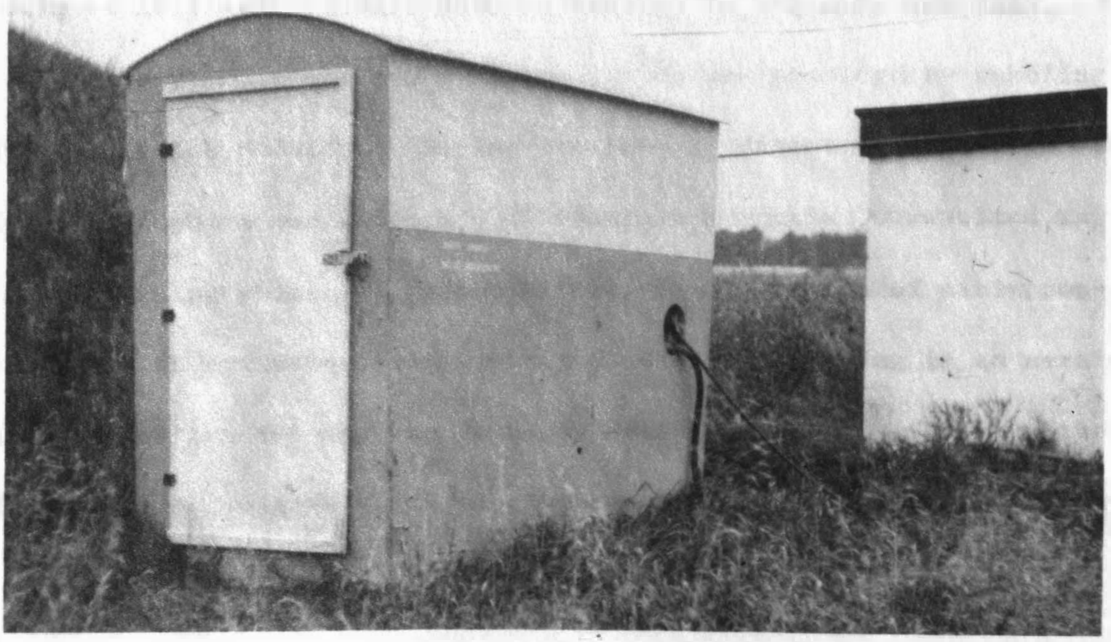

Figure 3. Enclosure over Pilot Plant
Located Adjacent to Volga Lift Station

The testing program was initiated on August 5 and was terminated on September 1. The pilot plant was operated at one-day, two-day and four-day detention periods during August 5 to 18, August 19 to 25, and August 26 to September 1, respectively. The process was monitored by collecting and analyzing daily representative samples.

Eckenfelder and O'Connor reported that the rate of BOD removal in an aeration tank will not be a function of oxygen concentration so long as a minimum dissolved oxygen concentration (DO) greater than 0.2 to 0.5 mg/l is maintained (15-45). However, good practice requires maintaining the DO level at about 1.5 mg/l (16,17) to sustain the high oxygen demand during peak loadings which would otherwise deplete the oxygen. Periodic tests made throughout this study indicated that DO levels of at least 1.5 mg/l were maintained in the aeration tank.

In the pilot plant study mixing action was provided by bubbling air through the solution. During the one-day detention, the high rate of aeration which was necessary to maintain adequate DO resulted in vigorous mixing which was probably more representative of mixing conditions in an activated sludge system than those existing in an aerated lagoon. For the two-day and four-day detention periods, however, the mixing was less vigorous and more representative of an aerated lagoon.

RESULTS AND DISCUSSION

Characterization of the Combined Raw Waste

A 24-hour sampling program using a Serco Automatic Sampler* was established in order to determine the characteristics of the combined raw wastewater. The most prominent physical characteristic noted in the samples which were collected hourly during the 24-hour period on July 15-16 was the variation in color. Some samples were deep yellow in color, which was later related to high pH values, other samples were white indicating large amounts of milk, while the remaining samples appeared much like typical domestic sewage.

The pH of these 24 hourly samples was determined because of its importance in biological waste treatment. The hourly pH values of the raw waste during the July 15-16 testing period are included on Figure 4. The large pH variation from pH 4.3 to pH 12.1 which occurred during the early morning hours may have been the result of clean-up operations at the milk processing plant. After 7 AM the pH values fluctuated within the range of 6.25 to 7.25. The pH value of the composite sample was 7.3.

After one week of pilot plant testing, a pH of 11.0 was measured on the daily representative sample of influent which represented the

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*Manufactured by Sonford Products Corp., 2355 Dain Tower, Minneapolis, Minnesota 55402.

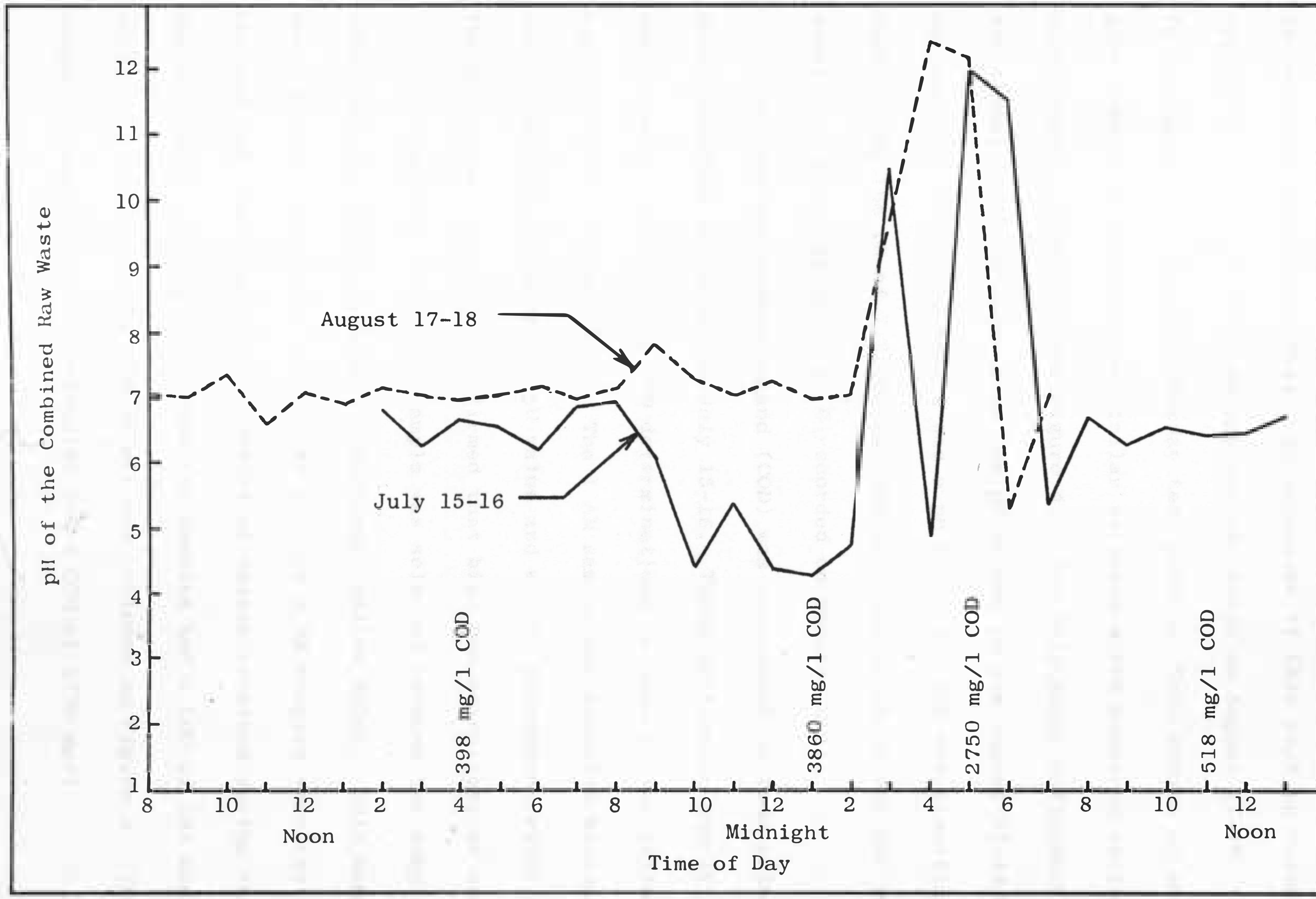

Figure 4. The Hourly pH Values of Volga Raw Wastewater Samples Collected on July 15-16 and August 17-18 and Selected COD Values from July 15-16

24-hour flow on August 10-11. To determine if this high pH value was representative, a 24-hour series was collected on August 17-18, the following similar Saturday-Sunday test period. This series of samples showed pH fluctuations similar to those which occurred during the July 15-16 test series (See Figure 4). The only major difference was the almost complete absence of low pH values in the August 17-18 test series. The composite sample had a pH of 10.3 which was significantly higher than the pH of 7.3 for the initial July 15-16 series but was similar to the high pH of 11.0 recorded on August 10-11.

The chemical oxygen demand (COD) was determined on four selected hourly samples collected on July 15-16. These particular hourly samples were selected for COD determinations because of the following significant characteristics: The 1 AM sample was selected because the sample exhibited a very low pH value and a very pronounced milky color. The COD value (3860 mg/l) confirmed that high concentrations of organics were present. The 5 AM sample was selected because the sample exhibited a high pH value and a prominent yellow color. This sample had a COD of 2750 mg/l. The 11 AM and the 4 PM samples were tested because they appeared to be typical of wastes received during the period from 8 AM to 8 PM. These two samples had a COD of 398 and 518 mg/l, respectively. The COD values are included on Figure 4. The composite sample of raw wastewater had a COD of 1330 mg/l.

The pH Characteristics of the Raw Waste

The pH value of the aeration tank influent was measured daily. All data are shown in Appendix I. The pH values of the raw waste will have a large influence on the effectiveness of biological treatment. Neutralization is necessary if the biological system cannot buffer the waste. A frequency table of pH values for samples of both the raw and treated wastes is presented in Table 2. Although the pH value of the daily raw wastewater samples varied from a low of 6.8 to a high of 11.0, the pH values were grouped around the median pH value of 9.0.

The large fluctuation in pH values of the raw waste indicated the presence of substances other than domestic sewage and milk. It appears likely that the use of various cleaning compounds at the Volga milk processing plant was responsible for the large variations in pH values. Although the Volga plant was not contacted, it is known that the milk processing industry uses large quantities of alkalies, complex phosphates, and acid for cleaning purposes. Alkalies, which exhibit a high pH value, can readily hydrolyze fat to soap and are commonly used because of their rapid dissolving power. Acids are used to prevent, or remove, deposits of hard water salts and/or milk constituents (18-157). Thus, the use of these compounds in early morning clean-up operations at the Volga plant could have caused the pH fluctuations which were noted.

Table 2.

Frequency Table of pH Values for Daily Samples
of the Raw and Treated Wastewaters from Volga Pilot Plant

pH Range	Frequency of pH Values	
	Raw Waste	Treated Effluent
6.75 - 7.24	1	
7.25 - 7.74	1	
7.75 - 8.24	1	17
8.25 - 8.74	4	5
8.75 - 9.24	8	
9.25 - 9.74	3	
9.75 - 10.24	1	
10.25 - 10.74	2	
10.75 - 11.24	1	

Influence of Biological Treatment on pH

The hydrogen ion concentration of biological treatment processes should be maintained at a pH between 6.5 and 9.0 to insure optimum biological activity (19). The pH of the waste entering the biological system does not need to be within this pH range as long as the pH of the mixed liquor containing the biological growth remains within this optimum range. Sawyer et al. (20) reported that an aerobic biological system will yield an effluent with a pH of about 8.

Carbon dioxide will be produced as an end product by biological treatment thereby providing neutralization and buffering capacity. In an alkaline waste a pH reduction will result from the reaction of the carbon dioxide with hydroxyl and carbonate ion in solution to form bicarbonate. Ford (19) reported that a biological system can buffer one mg/l of alkalinity for each mg/l of BOD removed.

In wastes with pH values between 5.0 and 6.0 all mineral acidity will be absent and the low pH value will be primarily a result of weak organic acids or mixtures of such acids and their salts. These free acids will be oxidized by bacteria to form carbon dioxide which will be purged from solution by aeration; therefore, the pH value of the waste will rise as the concentration of free acids decreases. Oxidation of the salts of organic acids, such as sodium acetate, produces basic anhydrides which react with carbon dioxide to form sodium bicarbonates (20).

In the pilot plant study, biological action apparently buffered the pH of the system. The pH of the effluent samples varied between 7.7 and 8.7 which was within the reported optimal pH range of 6.5 and 9.0. The median pH value of the effluent was 8.1. Although the pH of the combined raw sewage was highly variable, the biological system was able to reduce the BOD of the waste without apparent difficulty and produced an effluent which exhibited a relatively narrow range of pH variation (see Table 2).

Relationship between BOD and COD

Biochemical oxygen demand (BOD) of a sewage or a polluted water has been defined as the amount of oxygen required for the biological decomposition of organic matter under aerobic conditions at a standardized time and temperature, usually five days at 20°C. The chemical oxygen demand (COD) test measures the total quantity of oxygen required for oxidation of organic material in the waste to carbon dioxide and water. The COD test measures virtually all organic compounds, including those which are either partially biodegradable or nonbiodegradable. Therefore, the COD will be larger than, but proportional to, the BOD for substrates such as sugar and milk which are readily assimilable. Porges et al. (21) found that the BOD of skim-milk was 67 percent of the COD. The ratio of BOD to COD will decrease as the waste undergoes biological treatment, because there will be a larger proportion of biologically resistant organic matter in the effluent.

The relationships between the BOD and COD concentrations for the combined raw waste and the treated wastewater are shown in Figures 5 and 6, respectively. The straight line of best fit and the correlation

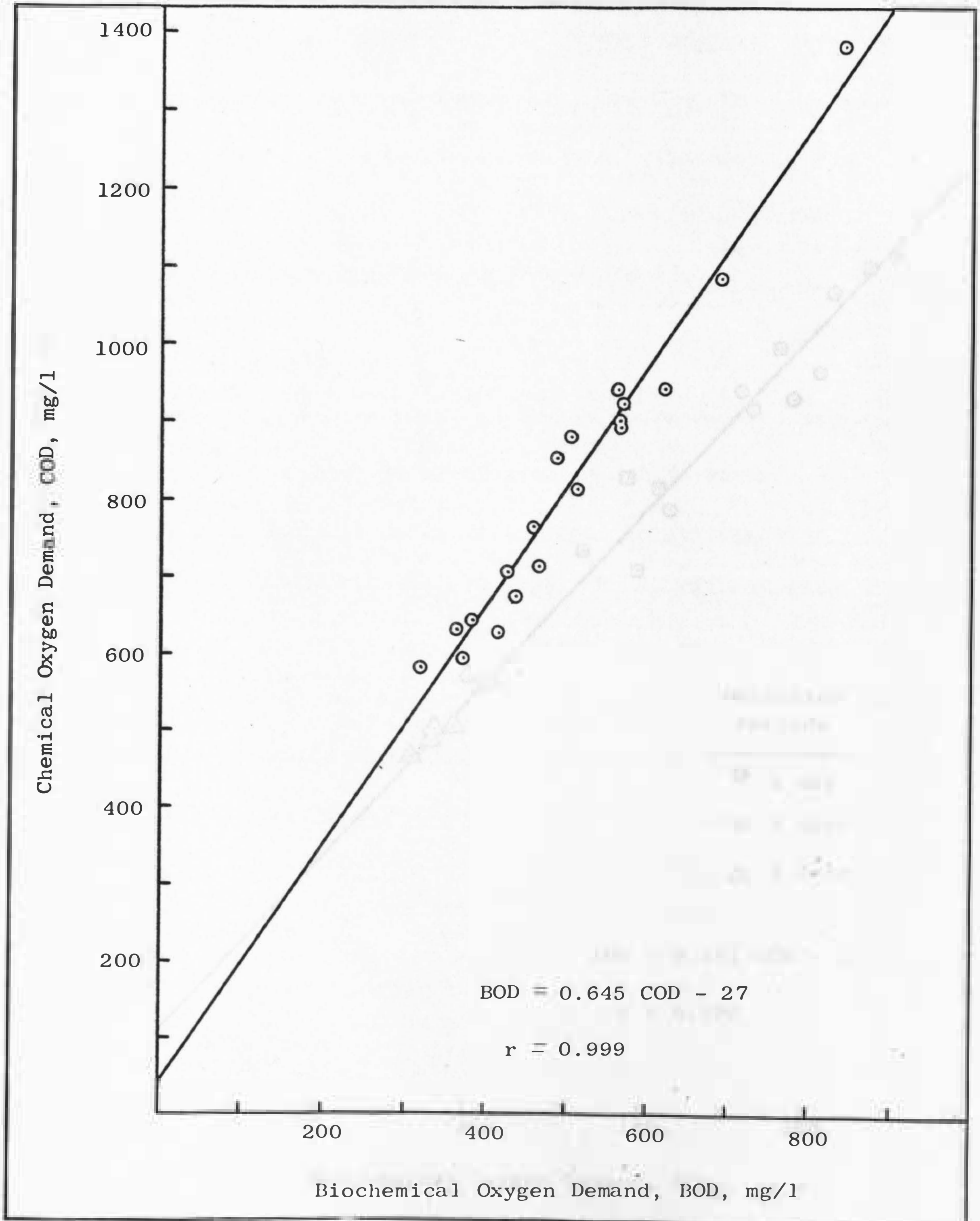

Figure 5. Relationship between BOD and COD for the Volga Combined Raw Waste

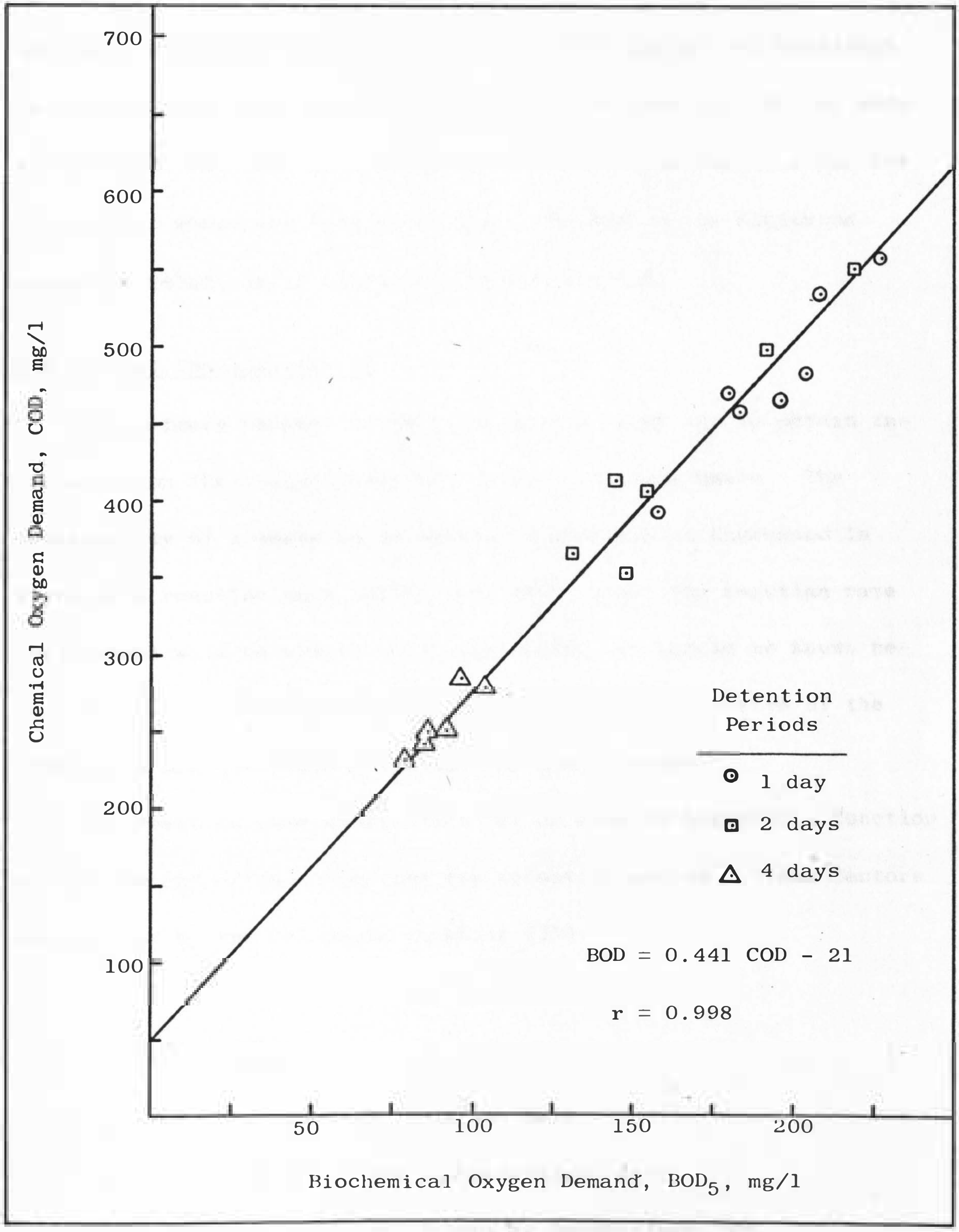

Figure 6. Relationship between BOD and COD for the Treated Wastewater from Volga Pilot Plant

coefficient were determined for both of these plots. An excellent correlation was found to exist between the BOD and the COD for both the combined raw and the treated wastewaters. Therefore, after the COD of this waste has been determined, the BOD can be estimated using the relationships shown in Figures 5 and 6.

BOD Removal Characteristics

The primary reason for performing this study was to obtain information on the treatability of the combined milk waste. The treatability of a waste in an aerated lagoon may be expressed in terms of a reaction rate coefficient (K). Since the reaction rate coefficient will be specific for each waste, it should be known before an aerated lagoon can be properly designed. A review of the literature did not yield a K value for a milk waste.

The reaction rate coefficient for an aerated lagoon is a function of the raw and effluent BOD and the detention period. These factors are related by the following equation (17):

$$\frac{L_e}{L_o} = \frac{1}{1 + K_T t} \qquad (1)$$

where L_o = initial BOD concentration, mg/l

L_e = final effluent BOD concentration, mg/l

K_T = reaction rate coefficient at temperature, T^oC

t = aeration detention period, days

The efficiency of a biological treatment process with a low solids level is also temperature dependent. Thus, the K_T values have to be corrected for the difference in temperature. The effect of temperature on values of the reaction rate coefficient is given by the formula (17):

$$K_T = K_{20}\ \theta^{T-20} \quad \ldots \quad 2$$

where K_T = reaction rate coefficient attemperature, T^oC

K_{20} = reaction rate coefficient at 20^oC

θ = temperature coefficient

The temperature coefficient, θ, for an aerated lagoon has been reported to have a value of 1.072 (17).

The reaction rate coefficient was determined for detention periods of one day, two days, and four days. The performance of the aeration unit was observed by analyses of daily samples. These samples of raw and effluent wastewater were continuously collected from the pilot plant. The temperature of the aeration tank was continuously monitored by a temperature recorder. An average temperature for each detention time was derived from this continuous temperature record.

The results of daily sampling have been averaged for each detention period and are shown in Appendix II. Average values of BOD and temperature are included in Table 3. The three reaction rate coefficients, K_T, which were calculated from these averaged values ranged from 0.935 to 1.223. However, the average temperature of the aeration tank was not constant for the three detention periods, and the K_T values were corrected for this temperature difference by using equation 2. The three resulting K_{20} values varied less than 1.4 percent. The average K_{20} value for the three detention periods, which were considered equally representative, was 1.034.

Table 3.

Average Raw and Effluent BOD Concentration and the Reaction Rate Coefficient for the Three Detention Periods

	Detention Period, t, days		
	0.95	1.90	4.0
Biochemical Oxygen Demand			
Raw, L_o, mg/l	454	579	431
Effluent, L_e, mg/l	210	165	91
Removal, %	53.7	71.5	78.9
Average Temperature, T^oC	22.5	23.4	18.6
Reaction Rate Coefficient			
K_T	1.223	1.321	0.935
K_{20}	1.029	1.043	1.031

Considerable variation in the reaction rate coefficient will exist for different types of wastes. For domestic sewage, reaction rate coefficients of 0.3 to 1.0 have been reported (22). For mixtures of domestic and industrial waste, the rate of removal of the organic material is often greater than for domestic sewage alone. Reaction rate coefficients as high as 3.0 have been reported for certain types of industrial wastes (22). The K_{20} value of 1.034 for the combined milk waste in this study appears to be reasonable.

Before an aerated lagoon can be designed, the engineer should know the required BOD reduction and the treatability of the waste. If the expected operating temperature is not equal to 20°C, a temperature correction should be applied to the reaction rate coefficient. The desired BOD reduction and reaction rate coefficient of the waste are related to the detention time within the aerated lagoon according to the following expression (17):

$$E = \frac{100\ K_T t}{1 + K_T t} \quad \ldots \quad 3$$

where E = the desired percentage of BOD removal

K_T = reaction rate coefficient at temperature, T°C

t = aeration detention period, days

The relationship may also be expressed in terms of the detention period, t, as follows:

$$t = \frac{E}{K_T(100-E)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 4$$

Therefore, by knowing the flowrate and calculating the detention time from the above equation, the design engineer can size the basin.

The interrelationship between the BOD removal, the detention period, and the temperature based on the results of the pilot plant studies can be readily seen in Figure 7. The line representing the relationship of BOD removal and the detention period at 20^{o}C must be considered the most reliable because it is derived from data represented by the three points shown in Figure 7. The results may be further extended to 15^{o}C and 25^{o}C with reasonable accuracy. However, further extension of the data should be supported by additional pilot plant information.

The BOD loading of an aerated lagoon which is often expressed in terms of lb BOD/day/1000 cu ft will depend on the detention period and the concentration of BOD in the raw waste. The average BOD loadings for the pilot unit were 29.8, 19.0, and 6.72 lb BOD/day/1000 cu ft for the one-day, two-day, and four-day detention periods, respectively.

Thimsen (17) tabulated the range of BOD loadings for the various treatment processes. These ranges are included in Table 4. From the above information, when the pilot plant was operated at detention times of one day and two days, the loading was comparable to that

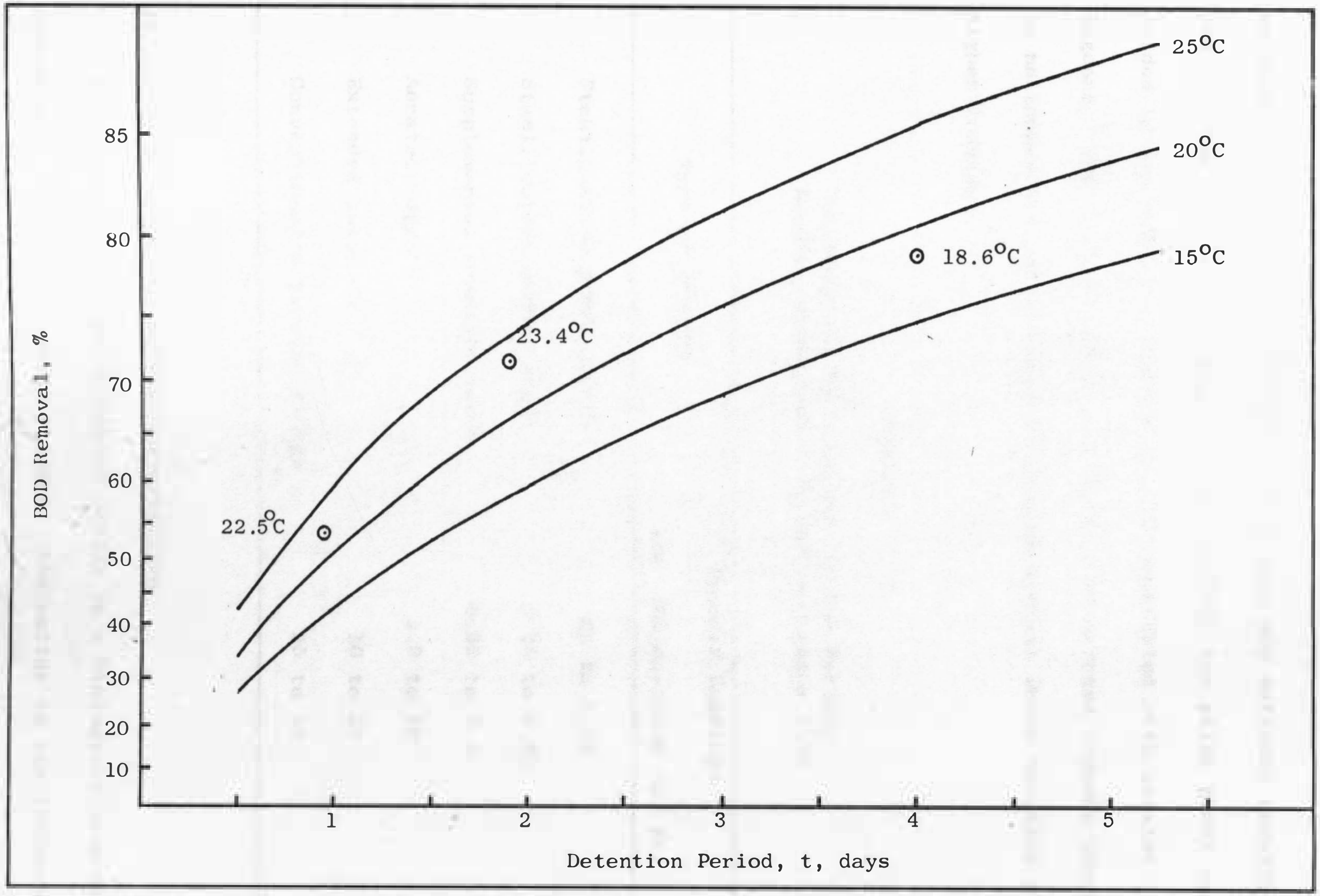

Figure 7. Relationship between BOD Removal Efficiency and Detention Period at Warm Weather Temperatures, Volga Pilot Plant Study, 1968

encountered in conventional activated sludge and extended aeration plants. During the four-day detention period, the pilot plant was loaded in the range of loadings usually associated with aerated lagoons. The trend in design and loading of aerated lagoons appears to be toward the use of completely mixed systems which function at higher loadings.

Table 4.

The Range of BOD Loadings for the Various Aerobic Biological Treatment Processes (17)

Type of Process	Process Loadings lbs. BOD/day/1000 cu. ft.
Stabilization ponds, north	up to 0.15
Stabilization ponds, south	0.15 to 0.50
Supplemental aeration ponds	0.25 to 1.0
Aerated lagoons	1.0 to 10
Extended aeration	10 to 25
Conventional activated sludge	25 to 40

Influence of Suspended Solids Concentration

The concentration of suspended solids in a biological treatment system is a function of three factors: the solids in the influent waste, the synthesis of biological sludge during waste stabilization, and the auto-oxidation of biological solids (10). In an aerated lagoon, the degree of mixing would also influence the solids level. In an aerobic-anaerobic aerated lagoon a portion of the solids settles to the bottom and decomposes anaerobically, but in a completely mixed aerated lagoon a high degree of mixing maintains most of the solids in suspension.

The suspended solids concentration of all daily samples was determined. The concentration of solids in the pilot plant effluent varied from 140 to 530 mg/l. The higher concentrations of effluent solids were generally associated with the lower detention periods. Average values of the suspended solids concentrations of the raw waste and the effluent for the three detention periods are contained in Table 5.

Table 5.

Average Concentration of Solids in the Combined Raw Waste and the Treated Wastewater from Volga Pilot Plant

	Detention Period, days		
	0.95	1.9	4.0
Suspended Solids, raw, mg/l	408	464	344
Suspended Solids, effluent, mg/l	414	365	174
Solids removal, %	-1.4	21.3	49.4

The concentration of suspended solids present in the effluent appeared to be influenced by the detention time in the pilot aeration unit, although the degree of mixing may have been the main contributing factor. When the pilot plant was operated at a one-day detention period, the oxygen demand was high and the mixing level was necessarily vigorous in order to maintain a DO level of 1.5 mg/l. Therefore, the suspended solids concentration of the effluent was probably the same as the solids level in the aeration tank. The one-day detention period did not exhibit a reduction in suspended solids. During the two-day and four-day detention periods, less vigorous aeration was required to maintain adequate DO, and the mixing level that was used may not have been able to maintain all solids in suspension. For detention periods of two days and four days, the solids concentration was reduced by 21.3 and 49.4 percent, respectively.

The presence of suspended solids in the effluent would contribute to the organic load discharged from an aerated lagoon. In order to determine the portion of the organic strength contributed by the suspended solids, the BOD and COD of centrifuged samples of effluent were measured. The average values of effluent BOD both before and after centrifugation are shown in Table 6.

Approximately 67 percent of the total effluent BOD was attributed to suspended solids. Therefore, removal of suspended solids from the lagoon effluent would improve the quality of the effluent being discharged to a watercourse. In the case of the aerated lagoon proposed for Volga, South Dakota, the present stabilization ponds would receive these solids.

Table 6.

Average Effluent BOD Concentration before and after Centrifugation--Volga Pilot Plant

	Detention Period, days		
	0.95	1.9	4.0
Effluent BOD, before centrifugation, mg/l	199	165	91
Effluent BOD, after centrifugation, mg/l	63	57	29
BOD of Solids, mg/l (difference)	136	108	62
Ratio of Solids BOD to Effluent BOD before centrifugation	0.68	0.65	0.68

CONCLUSIONS

The following conclusions were drawn from the pilot plant studies conducted on the combined milk waste from the city of Volga, South Dakota:

1. The combined milk waste received by the aeration unit exhibited widely fluctuating pH values. This variation was attributed to the intermittent discharges of alkalies and acids from the milk processing plant. The biochemical system provided adequate equalization and buffering of the pH which may have prevented a biological upset.
2. The COD determination may be used as the primary measure of organic strength of the combined raw and treated waste-waters because an excellent correlation was found to exist between BOD and COD concentrations.
3. The combined milk waste from the city of Volga was found to be treatable in an aerated lagoon. The reaction rate coefficient, K_{20}, which represented the rate of BOD removal, was 1.034. Therefore, at a temperature of $20^{o}C$ the process may be expected to remove 67 and 80 percent of the BOD at two-day and four-day detention periods, respectively.

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Appendix I. Tabulation of Test Results on Daily Samples - Pilot Plant Study at Volga, South Dakota, August 1968

Date of Sample*	pH		Suspended Solids mg/l		Biochemical Oxygen Demand 5-day, mg/l			Chemical Oxygen Demand mg/l			Temperature °C		
	Raw	Eff	Raw	Eff	Raw	Eff	Cent	Raw	Eff	Cent	Min	Max	Ave
1-day detention period													
Aug 5	6.8	7.9	240	490	414	208	-	627	534	-	25.0	28.0	26.5
Aug 6	9.2	8.0	545	530	484	227	-	856	558	-	24.5	27.0	25.8
Aug 7	8.5	8.05	415	515	436	196	-	673	465	-	23.6	28.0	26.5
Aug 8	8.75	7.9	445	440	620	204	-	944	483	-	23.6	27.0	25.5
Aug 9	7.50	8.0	168	388	334	180	-	546	470	-	17.0	24.0	21.0
Aug 10	11.0	8.45	-	-	-	-	-	-	-	-	17.0	21.0	19.5
Aug 14	8.8	7.75	500	290	566	276	-	892	526	227			
Aug 15	9.1	7.95	420	375	385	257	83	643	527	193	17.0	22.0	19.5
Aug 16	8.75	8.2	390	295	287	158	64	533	394	162			
Aug 17	10.35	8.4	550	405	561	183	42	942	459	142	16.5	19.5	18.5
2-day detention period													
Aug 19	10.5	8.7	400	355	502	148	56	881	352	141	18.0	22.0	20.5
Aug 20	9.2	8.1	515	358	690	155	30	1087	407	131	19.5	24.0	23.0
Aug 21	8.9	8.05	480	355	566	145	47	897	413	120	24.0	27.0	25.5
Aug 22	9.3	8.00	538	418	835	218	79	1386	550	221	25.0	28.0	26.5
Aug 23	9.05	7.95	450	408	455	192	81	767	498	224	26.5	21.5	25.0
Aug 24	9.9	8.1	403	293	423	132	53	704	365	175	21.5	17.0	20.0
Aug 25	7.9	8.4	-	-	-	-	-	228	-	-	-	-	-
4-day detention period													
Aug 26	8.3	8.3	305	143	510	80	26	817	231	118	16.5	18.5	17.5
Aug 27	8.25	8.05	305	143	462	93	38	713	251	126	17.0	20.0	19.0
Aug 28	8.1	8.1	273	140	368	86	32	593	243	121	19.0	20.0	19.5
Aug 29	9.3	8.3	410	165	319	86	27	583	250	120	16.5	19.0	18.0
Aug 30	8.6	8.2	485	220	568	105	26	926	279	127	16.5	20.0	18.5
Aug 31	9.3	8.2	283	230	361	97	27	631	285	125	18.0	20.0	19.0

* Samples collected continuously during 24 hours following 8 AM of date shown

Note: Raw-Combined Raw Waste, Eff-Effluent Wastewater, Cent-Centrifuged Effluent Wastewater

Appendix II. Average Values of Test Results for the Three Detention Periods - Volga Pilot Plant

	Detention Period, days		
	0.95	1.90	4.0
Biochemical Oxygen Demand			
Raw, L_o, mg/l	454	579	431
Effluent, L_e, mg/l	210	165	90.9
Removal, %	53.7	71.5	78.9
Chemical Oxygen Demand			
Raw, mg/l	740	954	711
Effluent, mg/l	491	431	257
Removal, %	33.6	54.8	63.9
Suspended Solids			
Raw, mg/l	408	464	344
Effluent, mg/l	414	365	174
Removal, %	-1.5	21.3	49.4
Temperature, ^oC			
Average	22.5	23.4	18.6
Minimum	16.5	18.0	16.5
Maximum	28.0	28.0	20.0
BOD Loading			
lbs. BOD/day/1000 cu.ft.	29.8	19.0	6.72
lbs. BOD/day/acre-ft	1300	829	293