1971

An Evaluation of an Aerated Lagoon System Treating Combined Dairy and Domestic Wastes During Summer Operation

Douglas M. Skie

AN EVALUATION OF AN AERATED LAGOON SYSTEM TREATING COMBINED DAIRY AND DOMESTIC WASTES DURING SUMMER OPERATION

BY

DOUGLAS M. SKIE

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

1971

AN EVALUATION OF AN AERATED LAGOON SYSTEM TREATING COMBINED DAIRY AND DOMESTIC WASTES DURING SUMMER OPERATION

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. Acceptance of this thesis does not imply 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 expresses appreciation to Dr. John R. Andersen, and Dr. James N. Dornbush for their advice and suggestions made during the course of this study.

Appreciation is also extended to T. Alvin Biggar, Civil Engineering Technical Assistant, for his aid in the construction and modifications of the equipment used throughout the testing period.

The City of Volga, South Dakota, and Kenneth Brotsky of J. T. Banner and Associates are extended a special thanks for their cooperation in providing information concerning the project and their aid in operation of the facilities.

This study was supported, in part, by a Federal Water Quality Administration Grant, No. 1T1 - WP - 272.

DMS

TABLE OF CONTENTS

Table of Contents (continued)

LIST OF TABLES

LIST OF FIGURES

List of Figures (continued) Page

INTRODUCTION

The Water Quality Act of 1965 and the adoption of the subsequent state water quality standards emphasized the general public's concern for the control of water pollution; for it has become the goal of our nation to maintain all American waters in a suitable condition for domestic and industrial supply, for recreation and for other beneficial uses. It is for these reasons that many communities have been faced with the problem of constructing new sewage treatment facilities or expanding present operations.

The use of stabilization ponds as a means of providing sewage treatment has been the practice of many small midwestern communities. However, with the upgrading of water quality standards and/or the addition of new industries, many of these communities have been required to improve the treatment of their liquid wastes. One economical method of improvement is the addition of an aerated lagoon located just ahead of the existing stabilization pond. Upon notification by the South Dakota Department of Health to upgrade their stabilization pond effluent, the City of Volga selected this method of improving their sewage treatment process.

The agricultural community of Volga, South Dakota, is located in the east-central portion of the state and had a population in 1970 of 1,030. Its principal industry is a milk drying plant owned by Land O' Lakes Creameries. During 1970 this plant processed from 275,000 to 350,000 pounds of raw milk per day to produce butter and non-fat dry milk.

The original sewage treatment facility at Volga was constructed in 1951 and consisted of an Imhoff tank, a trickling filter and a final settling tank. However in 1959, because of increased organic and hydraulic loadings, the State Department of Health recommended that the treatment provided by the old facilities be supplemented with the addition of a stabilization pond. Acting on this recommendation, a 3-celled, 21-acre stabilization pond was constructed approximately one mile east of Volga and in close proximity to the Big Sioux River.

This stabilization pond was also overloaded a short time after it was put into use, resulting in offensive odors for some distance around the treatment facility. These offensive odors and the additional problems created by the city's undersized pumping station and outfall line, indicated that additional improvements were needed. Therefore, in 1967 the City of Volga employed a consulting engineering firm to evaluate the existing system and to recommend these needed improvements.

A resulting study made by the firm on the effluent of the stabilization pond discharging into the Big Sioux River indicated an average BOD of 372 ppm. This value greatly exceeded the allowable effluent discharge of 30 ppm as required by the South Dakota Committee on Water Pollution. For this reason Volga was instructed by the State Department of Health to employ some method of treatment that would improve the effluent BOD being discharged from the stabilization pond to an acceptable value of 30 ppm or less. They were also instructed that before the State Department of Health would approve a request for a

grant to construct a new outfall line, Volga would have to arrive at some satisfactory solution for their inadequate waste treatment.

As a solution, the consultant proposed that the City of Volga construct an aerated lagoon to precede the present stabilization pond. It was felt that this method of treatment would provide Volga with an economical and practical answer to their treatment needs. However, the State Department of Health did not feel that the treatment provided by the aerated lagoons would be satisfactory in a Northern climate and therefore were reluctant to authorize approval of their use. Nevertheless, the Health Department did grant the City of Volga a conditional approval for the construction of the aerated lagoons. This approval was granted with the stipulation that the city would provide operational data for a period of one year to be used by the Department of Health in an evaluation of the treatment provided by the facilities.

The Civil Engineering Department at South Dakota State University became involved in the aerated lagoon project during the planning stage. This involvement was necessitated because of the lack of information regarding design and operational data for an aerated lagoon treating combined domestic and dairy wastes in South Dakota. In an attempt to provide these needed data, Vanden Hoek, a sanitary engineering graduate student at the University, conducted a pilot plant study concerning the aeration of Volga's untreated wastes. The data obtained during the pilot plant study provided much of the information required for the design of the full scale aerated lagoons. Construction of the aerated lagoons was then initiated and full time operation began in August of 1970.

The purposes of this study were:

1. To obtain operational data to be used by the South Dakota Department of Health for evaluating the effectiveness of an aerated lagoon treating combined dairy and domestic wastes in South Dakota.

2. To determine removal efficiencies and reaction rate coefficients for the aerated lagoon during full scale operation.

3. To evaluate the amount of mixing and the extent of oxygen distribution occurring in the aerated cell.

4. To compare full scale operational data with that obtained from the pilot plant study made at Volga in 1968.

REVIEW OF LITERATURE

Approximately 125 billion pounds of milk are processed per year in the 40 thousand dairy plants in the United States. This milk is produced by more than four million dairy farms and is processed to supply dairy products to the entire nation. Even though the present trend toward larger centralized plants exists, the milk industry consists of many small plants located near the milk supply. As these plants grow in size the waste loads created by them also grow. Therefore, because of the increased waste load and the additional emphasis being given to water pollution control, many of these plants are seeking economical and practical methods for the treatment of milk wastes. Aerated lagoons appear to be successful in providing this type of dairy waste treatment (1).

The first aerated lagoon was developed as a remedial step to enable a non-aerated lagoon which had become overloaded, to produce the desired treatment results (2). The aerated lagoons as known today are generally defined as a cell of significant depth, usually six to twelve feet, in which aerobic conditions are maintained by aeration with mechanical or diffused aeration devices (3). The basin is most often earthen with some type of bank protection to minimize erosion caused by wave action (2). The raw wastes are usually added at a point near the aeration device to facilitate mixing of the raw wastes with the lagoon contents. Following aeration the effluent is generally discharged at a single point over a weir type structure (4-2).

Considering the amount of organic loading which may be applied to a treatment facility, aerated lagoons appear to be midway between activated sludge and stabilization ponds as an effective method of aerobic waste treatment (5-1).

The cost of constructing an aerated lagoon is about one-half the cost of a conventional trickling filter system (6), and considerably less than that required for an activated sludge plant. Operating costs for an aerated lagoon are substantial because of the high rate of aeration, but the total annual cost, including amortization, is considerably less than the cost of equivalent conventional treatment facilities (1-56).

As compared with the stabilization pond, which is a common method of waste treatment in many small communities, McKinney and Benjes stated that the aerated lagoon has three advantages (4-1):

1. It requires less land area.
2. There is a relatively uniform dissolved oxygen content throughout the cell.
3. It is not dependent on sunlight for photosynthetic reactions to provide oxygen.

The disadvantages of an aerated lagoon as compared with the stabilization pond are (4-1):

1. Operation and maintenance costs are higher due to the power required for the aeration device.
2. Large surges in loading have more effect on the system due to the decreased volume.

Character of Milk Wastes

One of the most significant characteristics of milk and milk processing wastes is the extremely large amount of oxygen required to stabilize these wastes aerobically. Because dairy products are such a high strength waste, their discharge into a stream or lake in an untreated form, will cause severe degradation of that receiving body of water.

When milk processing wastes enter the sewer, they contribute essentially the same ingredients as are present in the natural product, i.e., proteins, fats, sugars and traces of other organic materials along with minerals and water. The characteristics of various milk, milk by-products, and milk processing wastes are presented in Table 1.

TABLE 1

Characteristics of Milk, Selected Milk By-Products, and Milk Processing Wastes (7-326).

Characteristic	Whole Milk (ppm)	Skim Milk (ppm)	Whey (ppm)	Process Wastes (ppm)
Total Solids	125,000	82,000	72,000	4,500
Organic Solids	117,000	74,000	64,000	2,700
Suspended Solids	---	---	---	3,900
Protein	38,000	39,000	8,000	---
BOD, 5-day	102,500	73,000	25,900	1,900

The amount of protein present in milk can create difficulties when the milk waste undergoes stabilization. The protein generally experiences two types of degradation depending on the amount of free oxygen available for the stabilization process. If the protein is broken down more or less incompletely under anaerobic conditions, a number of odoriferous compounds may be formed. Under aerobic conditions however, the proteins will break down to relatively odorless compounds (8).

The carbohydrates in milk, principally lactose, are generally converted to volatile acids when attacked by aerobic bacteria. These volatile acids will usually be further broken down to carbon dioxide and water if aerobic conditions are maintained. However, if anaerobic conditions exist, volatile acids will be produced much faster than the methane bacteria can consume them. If this situation is allowed to continue, the excess free acid will depress the p^H of the treatment system to a point at which the activity of the bacteria will be seriously inhibited or stopped completely (8).

Although dairy wastes are high in strength, Steffen concluded that there are three reasons why milk was especially suited for treatment by aeration (1). These reasons include:

1. Dairy wastes contain no appreciable amounts of suspended solids.
2. Dairy wastes are oxidized very rapidly and can be literally "burned up" aerobically with little floc formation.
3. Dairy wastes are generally discharged only during part of the 24-hour day, leaving many hours for equalization and extended treatment of the day's flow.

<u>The Theory of Oxygen Transfer in a Mechanically Aerated Lagoon</u>

The total amount of oxygen transferred by a mechanical aerator in an aerated lagoon is dependent upon (5-22):

1. The volume of the lagoon.
2. The oxygen deficit of the waste in the lagoon.
3. The overall transfer coefficient of the waste.

The volume of the lagoon affects oxygen transfer in that it will dictate the frequency that the waste being treated will be recirculated into the "spray zone" area. It is in this area that nearly 90 per cent of the total amount of oxygen supplied to an aerated lagoon is transferred. This type of transfer has been found to exist even when the surface velocities generated by the aerator are large (9). One reason for this highly localized oxygen transfer that exists in the "spray zone", is that the rate of diffusion of oxygen through a liquid-air interface is a maximum at the moment the interface is formed, with a rapidly decreasing rate of transfer occurring thereafter (10).

The oxygen deficit of the waste serves as the driving force for the oxygen transfer through the liquid-air interface. Therefore, an increase in the oxygen deficit and/or an increase in the area of the liquid-air interface will create a subsequent increase in the total amount of oxygen transferred for a given system.

The overall transfer coefficient of a waste is a function of the interfacial area of the droplets and bubbles produced by the aerator, the temperature of the lagoon, and the type of waste being treated. The interfacial area of a bubble provides the medium through which

oxygen can be transferred to the waste. The area of the liquid-air interface is dependent upon the diameter of the air bubbles formed in the waste. For example, a sphere with a volume of one cubic foot has only 4.8 square feet of liquid-air interface, whereas one cubic foot of air in the form of one-tenth to one-eighth inch diameter bubbles would contain almost 700 square feet of contact area. According to Thimsen (5-22), the temperature of a lagoon affects the overall transfer coefficient much in the same way as temperature affects the reaction rate coefficient. The relationship has been shown to be:

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

Where

K_T = overall transfer coefficient at temperature T, ^oC.

K_{20} = overall transfer coefficient at 20° C.

θ = temperature coefficient (1.02 for mechanical aeration in an aerated lagoon).

The type of wastes being treated affects what is known as the alpha factor. This factor is the ratio of the overall transfer coefficient of an aeration device operating in a particular waste to the transfer coefficient of the aerator when it is operating in pure water. The value of alpha may vary from 0.5 to 1.0 depending on the type of waste and the method of aeration being used (5-22).

Currently, there is a wide selection of aeration devices available for waste treatment use, however, for aerated lagoons oxygen is

usually supplied to the waste by one of three types of mechanical aerators. These types include the pitched blade surface aerator, the radial flow turbine or flat blade surface aerator, and the compressed air aeration system (4-14).

The pitched blade surface aerator generally has a draft tube which extends down from the aerator to near the floor of the lagoon. The turbine acts as a low lift pump carrying the liquid up the draft tube to be "thrown out" from the turbine. For this reason surface aeration due to the agitation of the wastes is the principal type of oxygen transfer in this system.

The radial flow turbine seems to offer the best combination of mixing and oxygen transfer characteristics. Generally, the mixing and oxygen transfer occur near the hydraulic jump which forms at the edge of the rotor. Because these aerators can be either fixed or floating, the unit is very applicable for use in aerated lagoons.

The compressed air system employs strings of pipe or tubing which are used to distribute air throughout the lagoon. Mixing and oxygen transfer is accomplished by the diffusion of air throughout the system. However, because of the nature of milk to form "milk stone", diffusers used as an aeration device require excessive maintenance to prevent clogging (11).

Of these aerator types, the surface aerating system appears to be the most popular and economical. As the most economical operation, the surface aerators eliminate the need for a blower and blower building as required for the diffused air system. In addition, surface aerators

require less power input to accomplish the same amount of oxygenation when compared with the submerged turbine or the compressed air aeration systems (10).

However, Busch has stated that there is little difference between the efficiencies of the various types of aerators during operation because of the limited range of reaction rates applied to most aerated systems. He drew this conclusion on the basis that "The efficiency of an aeration device or system depends on the rate of transfer per unit of energy input and is set, in a particular system, by the rate of biological reaction." He also remarked that all aeration systems now in use have the potential of transferring oxygen at a rate that exceeds most common biological reaction rates (12).

Factors Influencing the Efficiency of an Aerated Lagoon

Reaction Rate Coefficients

An important factor in determining the treatability of a waste in an aerated lagoon is the reaction rate coefficient. Thimsen stated (5-9) that, the BOD removal efficiency treatment for a system is dependent upon the reaction rate coefficient, detention time, and lagoon temperature according to the following formula:

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

Where

L_e = final effluent BOD, mg/l.

L_o = influent BOD, mg/l.

K_T = reaction rate coefficient at temperature T, °C.

t = aeration time, days.

The reaction rate coefficient or rate of biological oxidation is also affected by temperature in accordance with the following equation:

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

Where

K_T = reaction rate coefficient at temperature T, °C.

K_{20} = reaction rate coefficient at temperature 20° C.

θ = temperature coefficient.

This θ value for aerated lagoons was reported by Thimsen to have a value of 1.072 (5-5).

Knowing values of the reaction rate coefficient and the desired BOD removal efficiency at a given temperature, the detention time needed to accomplish this BOD removal efficiency can be calculated. These factors are all related as shown in the following formula:

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

Where

E = the desired BOD removal efficiency, per cent.

K_T = reaction rate coefficient.

t = aeration time, days.

Multiplying this calculated value for aeration time by the desired design flow rate, the volume of the aerated basin can be determined. Because of its temperature dependence, consideration should also be given to critical periods during the year such as mid-summer and mid-winter when determining values for the reaction rate coefficient.

Bennett reported that values for the reaction rate coefficient will vary with the type of waste being treated. For domestic sewage, values have been found to range from 0.3 to 1.0. However, for combined domestic and industrial wastes, reaction rates are generally somewhat larger with values as high as 3.0 having been reported (13). Vanden Hoek determined a reaction rate of 1.034 from his pilot plant study of the aeration of dairy and domestic wastes at Volga (14-29).

Organic Loading

The amount of organic material present in the raw waste has a great deal of influence on the BOD removal efficiency that will occur in an aerated lagoon. Lowthian concluded from his study of aerated lagoons that the relationship between BOD removal efficiency and the organic loading on the system (pounds of influent BOD per day) was more important than the relationship between BOD removal efficiency and detention time (15-55).

An organic loading rate of 1.0 to 10 pounds BOD per day per 1000 ft^3 was recommended by Thimsen for an aerated lagoon. This value may be contrasted with the maximum loading rate of 0.15 pounds BOD per day per 1000 ft^3 for northern area stabilization ponds and 25 to 40 pounds BOD per day per 1000 ft^3 for a conventional activated sludge plant (5-1).

The highly organic wastes produced by a dairy and discharged to an aerated lagoon may quickly overload the aerated system if adequate provisions are not made during the lagoon design. Porges indicated that one pound of milk solids (representing about 0.85 pounds of BOD) would produce one-half pound of bacterial cells when completely assimilated and would require 0.45 pounds of oxygen in the process. However total oxidation, including the endogenous respiration phase, would require 1.2 pounds of oxygen (16).

Concerning the rate at which these cells are oxidized, Kountz found in his pilot plant studies that the cells are "burned up" at the rate of one per cent of the total per hour, or 20 per cent per day (17).

Temperature

Temperature has an important effect on biological metabolism. Under normal operating conditions, as temperature increases the rate of biological metabolism increases and vice versa. Table 2 includes data concerning the effect of temperature on the aerated lagoon coefficient K_T according to the general formula:

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

Where

$$\theta = 1.072$$

TABLE 2

Values of a Reaction Rate Coefficient
K_T at Selected Temperatures (5-15)

Temperature (°C)	0°	10°	20°	30°
K_T Value	0.05	0.10	0.20	0.40
	0.10	0.20	0.40	0.80
	0.20	0.40	0.80	1.60

Table 2 indicates that for a waste temperature change of 10° C, the reaction rate coefficient changes by a factor of two. This would also mean that in order for a given BOD removal efficiency to remain constant, the detention time would have changed by a factor of two for each 10°C change in waste temperature. This large increase or decrease in required detention time for a given temperature change is due for the most part to the change in the rate of biological metabolism. Since the rate of metabolism is reduced in cold weather, it

follows that the oxygen uptake rate will decrease also. Conversely, the solubility of oxygen increases as the temperature of the liquid waste is decreased. This means that when the oxygen demand rate is at a maximum in warm weather, the oxygen saturation level is minimal (4-12). For this reason, the maximum lagoon temperature should control the oxygenation capacity of the aeration equipment, and the minimum lagoon temperature should control the total detention time required (5-30).

Freezing temperatures can also affect aeration in that these temperatures may possibly cause severe icing and mechanical difficulties on surface aerators. Lowthian however, reported no significant mechanical difficulties with the surface aerators he studied, even during severe winter conditions when the average effective air temperature was a minus 19° F (15-54).

Dissolved Oxygen

Eckenfelder and O'Connor reported that the rate of BOD removal in an aeration system will not be dependent upon the oxygen concentration in the aerated cell as long as the minimum dissolved oxygen concentration is greater than 0.2 to 0.5 mg/l (18-45). In order to sustain these minimum DO values during periods of peak organic loading, Thimsen recommended maintaining a minimum DO concentration of about 1.5 mg/l in the aerated cell (5-20). Therefore, if DO concentrations can be kept within these ranges, aerobic conditions will be provided. Under these conditions, by-products of oxidation will be negligible and acids should not accumulate (19).

Detention Time

An increase in detention time will generally bring about a subsequent increase in BOD removal efficiency in the treatment of dairy wastes if the detention time is two days or less. Beyond that time, organic loading appears to be more of a determining factor. As an example, a study made on a plant treating dairy wastes in New Holstein, Wisconsin, indicated that when using a surface turbine aerator, a 60 per cent BOD reduction was obtained for a 6 hour detention time, an 80 per cent reduction for an 8 hour detention time, a 90 per cent reduction for a 16 hour detention time, and a 98.6 per cent reduction for a 32 hour detention time (20). Concurring with this study, Hoover and Porges reported that 36 hours of aeration were necessary for complete oxidation of milk wastes. They concluded that when the waste is biologically oxidized, it is rapidly converted into cellular protoplasm. The majority of the aeration time is needed for the bacterial cells to undergo endogenous respiration so as to maintain a more or less constant sludge concentration. This equilibrium occurs when the amount of sludge built up by the formation of new protoplasm is equal to the amount of sludge destroyed by auto-oxidation.

Experience has shown that this equilibrium is not difficult to maintain. In fact, in almost all the aeration processes reported (extended aeration, 120 hour average aeration time), removal of excess sludge had not been necessary because the sludge was completely digested before leaving the system (21).

Miscellaneous Factors

Large amounts of suspended solids in an aerated lagoon influent may cause sludge accumulation problems and promote the discharge of suspended solids in the effluent. The suspended solids concentration of the effluent contributes to the organic load discharged from the aerated lagoon. Vanden Hoek reported from his study that approximately 67 per cent of the total effluent BOD discharged from the pilot plant was attributed to suspended solids. He also found from his study that the degree of mixing and the detention time influenced the concentration of suspended solids in the effluent (14-35).

The biological activity in an aerated lagoon is dependent upon p^H. Therefore, neutralization may be necessary if the biological system cannot buffer the waste or maintain the p^H of the lagoon between 6.5 and 9.5. Fortunately, the carbon dioxide formed as the end product of biological activity often serves as a neutralizing agent. This neutralization will generally provide an aerated cell with a natural buffering capacity of nearly one mg/l alkalinity for each mg/l of BOD removed (22).

There are two distinctly different types of aerated lagoons. The first type of lagoon is defined as an incompletely mixed system. In this system the turbulence level in the basin is great enough to distribute oxygen throughout the cell, but is not sufficient to maintain all solids in suspension. The second type of lagoon is defined as a completely mixed system in which the aerator provides a uniform distribution of DO and suspended solids throughout the aerated cell.

This type of system is much the same as an activated sludge plant operating without the recycling of return sludge (3).

The advantage of an incompletely mixed lagoon is that the selection of aerators is not dependent upon minimum scouring velocities. A disadvantage is that organic solids will settle out and therefore undergo anaerobic decomposition on the bottom of the aerated basin. This type of degradation of the settled solids may result in operational problems caused by rising sludge and unpleasant odors (4-40).

An advantage of the completely mixed aerated lagoon is that the organic strength of the effluent BOD is relatively uniform due to the absence of solids decomposition in the lagoon. Disadvantages include: a more temperature sensitive biota is created, selection of aerators must be on the basis of scouring ability, and the amount of effluent solids might be quite high (3).

One method of determining the adequacy of mixing occurring in an aerated cell is to compute the aerator HP to lagoon volume ratio. McKinney and Benjes found in their study of an aerated lagoon that 0.185 HP per 1000 cubic feet was not adequate power to provide complete mixing in the system. As a result, organic solids accumulated on the bottom of the lagoon and subsequently some operational problems did occur. For this reason, McKinney and Benjes recommended that the use of an incompletely mixed aerated lagoon should not be made unless pilot plant studies show that rising sludge can be controlled or does not exist. They also concluded from their study of aerated lagoons that 0.25 HP per 1000 cubic feet appeared to be a valid basis to obtain complete mixing with a turbine aerator (4-41).

Another method of determining the amount of mixing occurring in an aerated cell is to measure the liquid velocities generated by the aeration mechanism. Busch stated that a minimum velocity of 0.5 feet per second was needed to keep biological clumps in suspension. He felt however, that a single velocity figure is not adequate to specify the turbulence conditions in the lagoon, primarily because that at some point in the agitated waste, the horizontal and/or the vertical velocity must be zero. For this reason he indicated that a measurement of suspended solids concentrations is needed throughout the reactor to determine the true mixing ability of the aerated lagoon (12).

The size and shape of the cell affect the amount of oxygen transferred and the type of mixing accomplished in an aerated lagoon. Larger volumes have a dampening effect on the turbulence produced by the aerator, and increased liquid depth tends to decrease the oxygen transferred per unit volume of liquid. Cells of increased depth may cause some sludge accumulation problems whereas, usually sludge decomposition problems have not been encountered where relatively large shallow basins with sloping side walls have been used (4-16).

Thimsen stated that when an unusual quantity of industrial wastes which are low in nitrogen and phosphorous are included with domestic sewage in an aerated lagoon, some nutrient chemicals may have to be added. Optimum treatment should occur if 4 pounds of nitrogen and 0.6 pounds of phosphorous per 100 pounds of BOD removed are provided. In many cases it has been found that for those wastes having a nutrient deficiency, an addition of nutrients can increase the BOD removal

efficiency of an aerated lagoon. For this reason, the addition of nutrients is becoming more popular as an economical solution to increasing BOD removal without having to build a larger lagoon to provide a longer detention time (5-27).

Low BOD reductions are caused many times by a carryover of light and bulky particles. This type of bulky sludge may be produced by the overloading of an aerated cell because of under-aeration or lack of sufficient time to complete the oxidation process. A light sludge of this type can also be produced by an excessive carbohydrate to protein ratio (23).

Plant Efficiencies

A review of the literature produced little information concerning aerated lagoons being used as a method of dairy waste treatment. One example was a plant in New Holstein, Wisconsin, where milk and cheese wastes were aerated with surface turbine aerators to obtain BOD reductions of up to 98.6 per cent. The mean influent BOD of the waste was 1500 ppm, the p^H ranged from 5.5 to 8.25, the detention time was 32 hours, and the air supplied was approximately 400 to 1100 cubic feet per pound of BOD. It was also determined in this study that by adding one more aerated cell in series and by providing a sludge return to the first aerated cell, a 98 per cent BOD reduction was accomplished using 200 to 450 cubic feet of air per pound BOD with a detention time of only 7.7 hours per cell (20).

In New York, wastes being produced by a dairy processing from 600,000 to 800,000 pounds of whole milk daily were being discharged to

a series of lagoons containing a system of five sprays. However, in an attempt to reduce the organic strength of the lagoon effluent, the dairy replaced the five 15 HP spray units with two 5 HP surface aerators. It was found that once the mechanical aerators were put into operation, they eliminated the odors and lack of dissolved oxygen that had previously been associated with the lagoon effluent. In addition, the effluent BOD concentration was lowered from 235 ppm to 25 ppm, representing an 89.5 per cent reduction, and the need for spending about $2,000 per year for chemical nutrients was eliminated (24).

In Huntley, Illinois, wastes from a 200,000 pound per day dairy were aerated to give a BOD reduction as high as 97 per cent. However, the variation in BOD reduction seemed to be more dependent upon the condition of the floc in the aerated cell than upon the load applied. It was found that a heavy, dark tan-colored floc was associated with high BOD reduction, whereas the light fluffy floc was apparent when BOD reduction was low (25). Table 3 contains general information regarding the treatment of milk wastes provided at this plant and other dairies using aeration with return sludge and final sedimentation.

TABLE 3

General Information Regarding the Aeration of Dairy Wastes at Selected Plants (19)

Characteristic	Schell Dairy Germantown, Ohio	Blossom Hill Dayton, Ohio	Dean Milk Chemung, Illinois	Dean Milk Huntley, Illinois
24-hour flow, (gpd)	4,400	7,200	53,000	15,000
Aeration time, (hr)	39.4	41.2	14.7	21
Settling time, (hr)	2.5	3.2	—	3.3
BOD, raw, (ppm)	567	926	1,150	950
BOD removal, (%)	96.5	96.5	75 to 85	85 to 97
Air Supplied, (cfm per lb. BOD)	4.1	1.8	0.5	0.6

It has also been demonstrated that very high strength milk wastes may be treated effectively by aeration. Hoover found from laboratory experiments that wastes containing up to 10,000 ppm of skim milk solids could be aerated with a resulting 75 per cent BOD reduction (26). Hauer, however, concluded that much higher BOD removals could be accomplished with wastes having an average influent BOD of 1000 ppm. From his studies he reported that BOD reductions approaching 97 per cent were obtained (19).

DESCRIPTION OF TREATMENT FACILITIES AND TEST PROCEDURES

Description of the Sewage Treatment Facilities at Volga

The Volga sewage treatment facilities are located approximately one mile east of the Volga city limits and in close proximity to the Big Sioux River. The facilities, (Figure 1 and Figure 2), consist of two aerated lagoons with surface turbine aerators and a 3-celled, 21-acre circular stabilization pond. The sewage reaches the treatment site by means of an 18 inch diameter outfall line. This line feeds directly into a Parshall flume located in the control structure from which the sewage flow may be directed into either of the aerated lagoons, both of the aerated lagoons, or in case of emergency, directly into the stabilization pond. The Parshall flume allows for the measurement of the total flow coming into the treatment facility, however, the flume is not equipped with a continuous flow recording device.

The raw waste is conveyed from the control structure to the bottom of the aerated lagoon by means of a pipe which discharges to a point directly beneath the aerators. This means of adding raw sewage to the aerated cell helps to eliminate an excessive amount of short circuiting.

Two aerated cells, whose physical characteristics are listed in Table 4 and shown in Figure 2, are provided so that detention times may be varied to compensate for the expected decrease in reaction rates during winter operations. To compensate for the effect that decreased reaction rates would have on the aerated lagoon's BOD removal efficiency, the raw sewage may be directed into both of the aerated

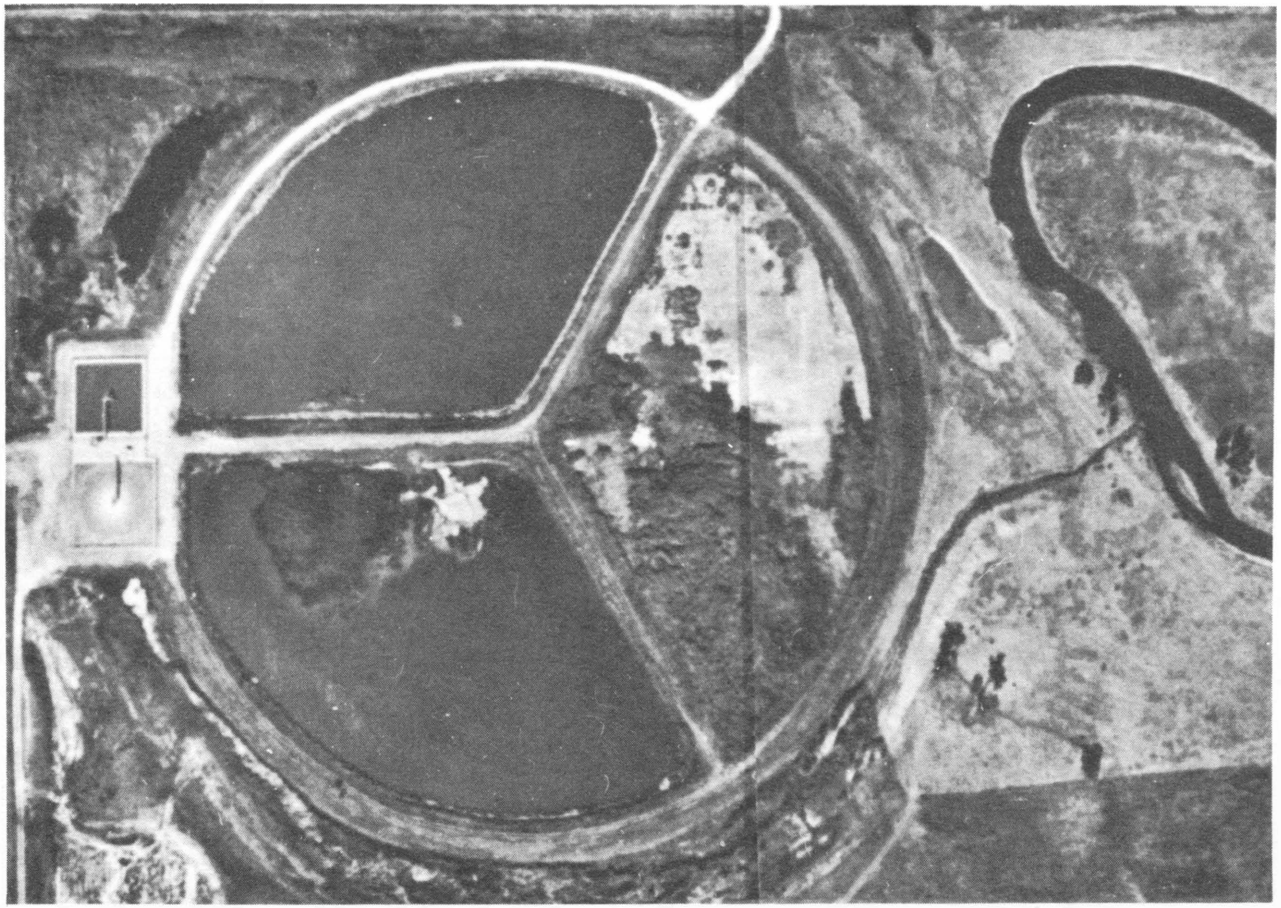

Figure 1. An Aerial Photograph Showing the Aerated Lagoons, the 3-Celled Stabilization Pond, and the Big Sioux River Near Volga, South Dakota.

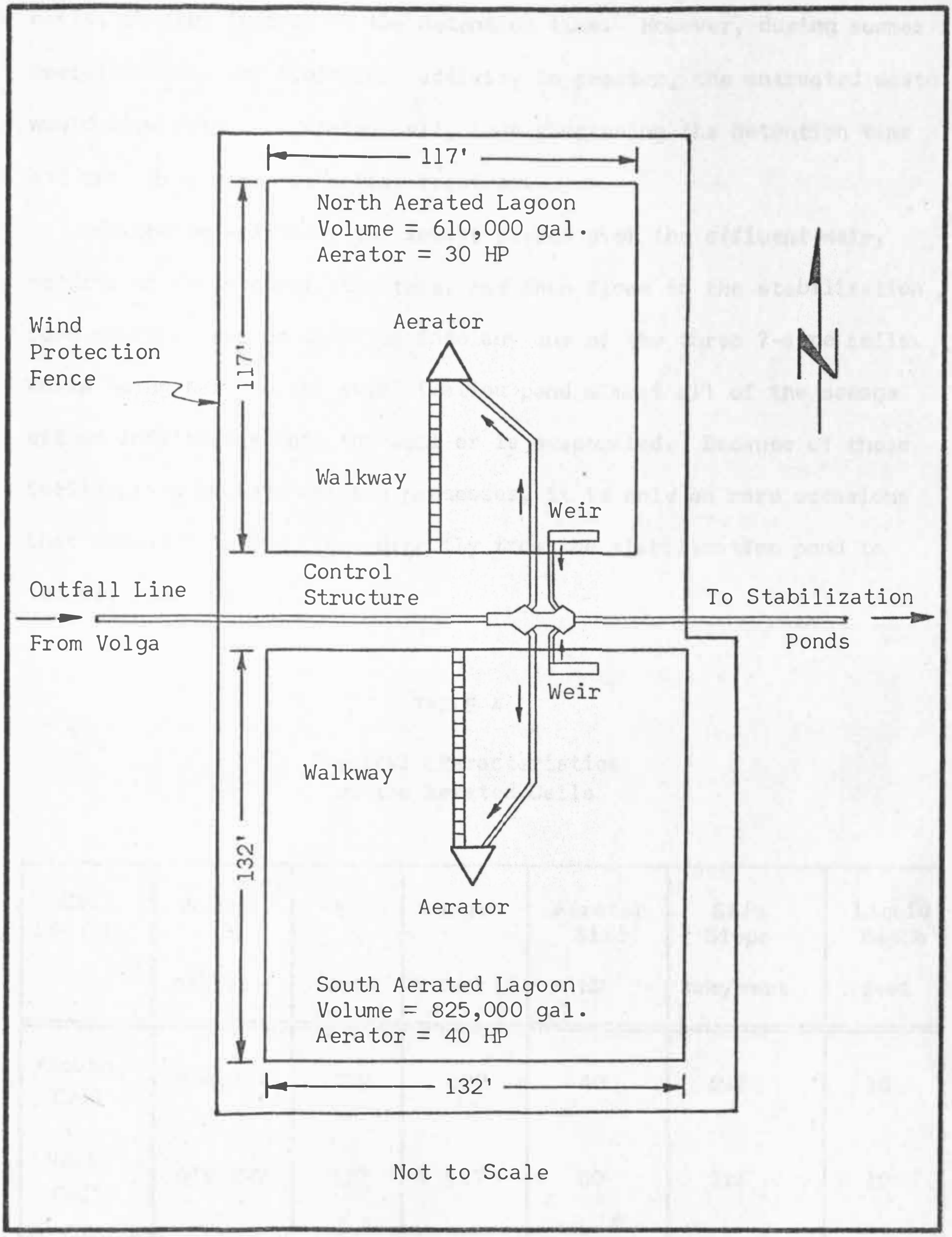

Figure 2. A Plan View of the North and South Aerated Lagoons at Volga, South Dakota.

cells, thereby increasing the detention time. However, during summer operation when the biological activity is greater, the untreated waste would flow into one aerated cell, thus shortening the detention time and providing more economical treatment.

Following aeration, the sewage passes over the effluent weir, returns to the control structure, and then flows to the stabilization pond where it may be directed into any one of the three 7-acre cells. While being held in the stabilization pond almost all of the sewage either infiltrates into the soil or is evaporated. Because of these infiltration and evaporation processes, it is only on rare occasions that sewage actually flows directly from the stabilization pond to the Big Sioux River.

TABLE 4

Physical Characteristics of the Aerated Cells

Cell Location	Volume gallons	Width feet	Length feet	Aerator Size HP	Side Slope hor/vert	Liquid Depth feet
*South Cell	824,727	132	132	40	2:1	10
North Cell	609,922	117	117	30	2:1	10

*All effluent samples were taken from this aerated cell. Photographs showing the south aerated lagoon in operation are shown in Figure 3 and Figure 4.

Figure 3 shows the agitation that is created in the spray zone of the 40 HP surface turbine aerator. Figure 4 points out the relative placement of the control structure, sampling station, bank protection apron, and wind protection fence located around the perimeter of the south aerated lagoon.

Influent and Effluent Sampling Procedure

Influent and effluent samples were collected at the control structure by means of two automatic samplers, (Serco Automatic Samplers, Sanford Products Corporation, Minneapolis, Minnesota). A schematic drawing showing the sampling station installation situated over the control structure is illustrated in Figure 5. Location of the influent and effluent sampling positions are represented in the figure by points (I) and (E) respectively. Each 24 hour sampling period began at 8 a.m. of one day and extended to 8 a.m. of the following day. The automatic samplers were started at the beginning of each day and drew a 200 to 300 ml sample every hour for the 24 hour interval. After the samples were removed at the end of each sampling period, the sampler tubes were drained and clean bottles were placed in the sampler to provide for the next 24-hour testing day. Following collection, the samples were transported to the Sanitary Engineering Laboratory in the Civil Engineering Department at South Dakota State University for compositing and analysis. The location of the sampling heads was selected in order to obtain samples that would be representative of the influent and effluent flows.

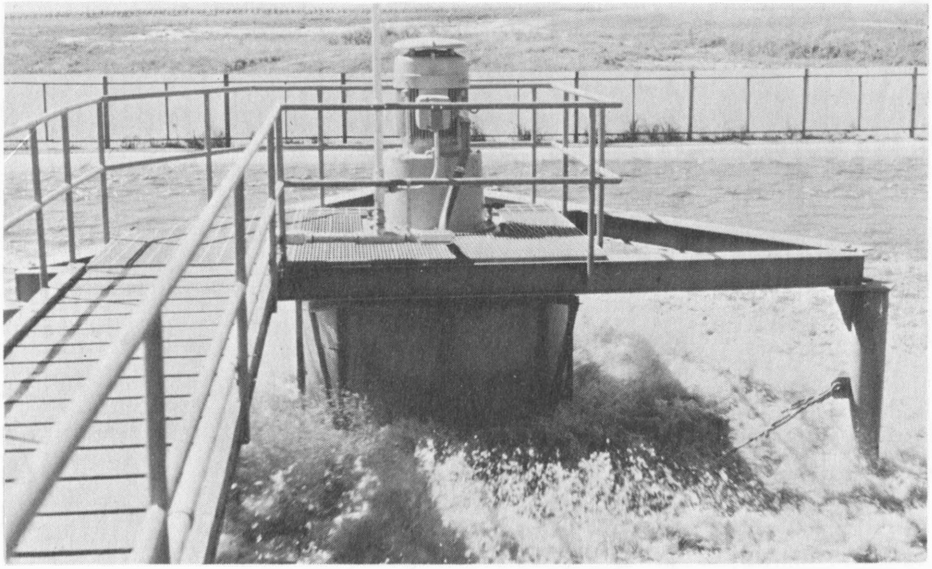

Figure 3. An Aerator in Operation at the South Aerated Lagoon Near Volga, South Dakota.

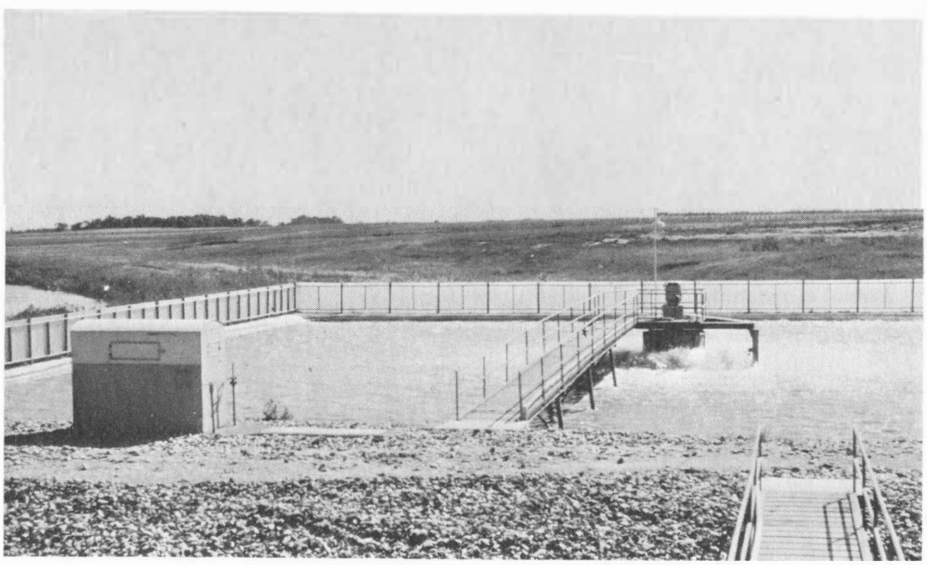

Figure 4. A View of the South Aerated Lagoon, Control Structure, and Sampling Station Near Volga, South Dakota.

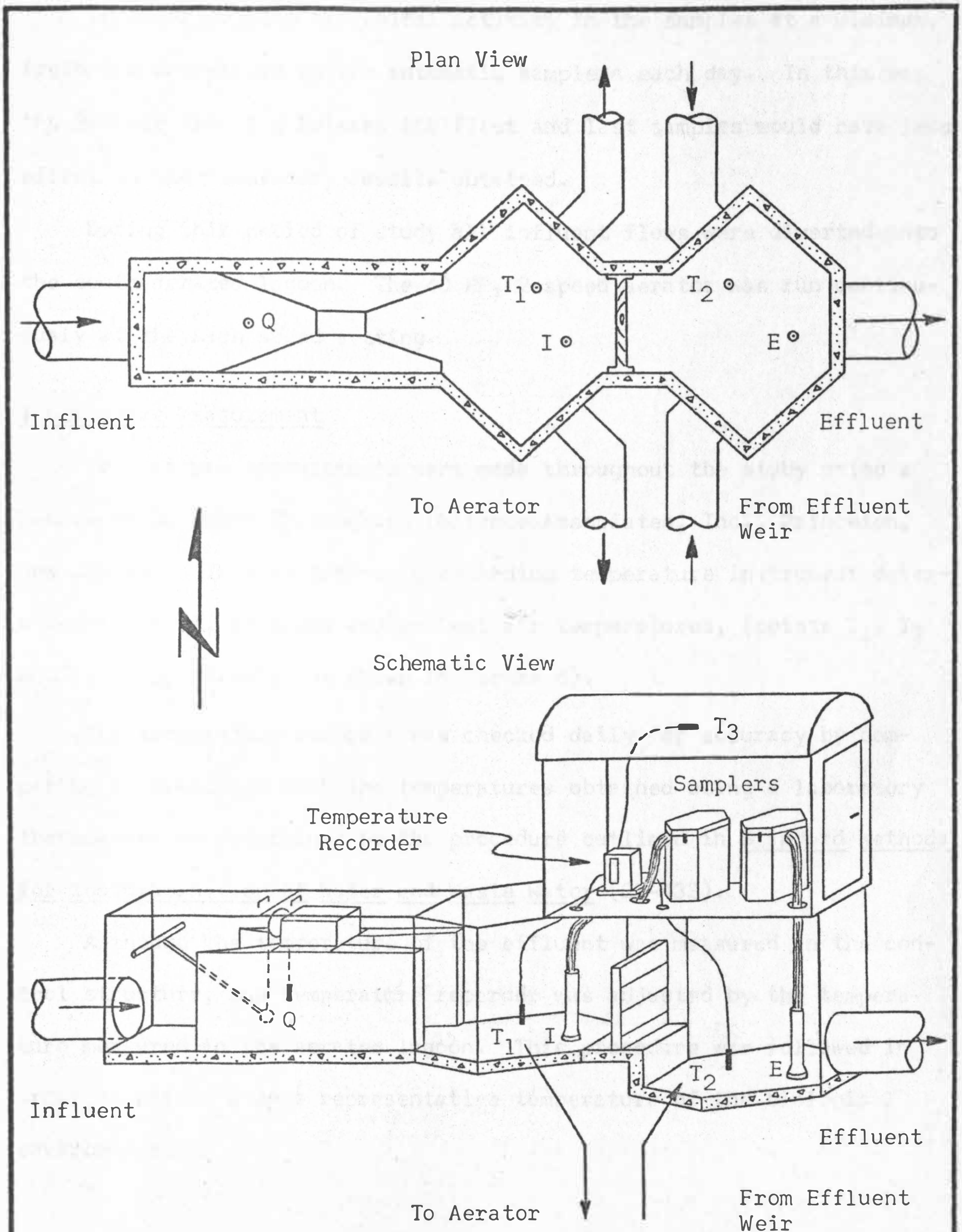

Figure 5. Plan and Schematic Views of the Aerated Lagoon Control Structure and Sampling Station at Volga, South Dakota.

In order to keep biological activity in the samples at a minimum, fresh ice was placed in the automatic samplers each day. In this way the 24 hour time lag between the first and last samples would have less effect on the laboratory results obtained.

During this period of study all influent flows were diverted into the south aerated lagoon. The 40 HP, 2-speed aerator was run continuously at the high speed setting.

Temperature Measurement

Temperature measurements were made throughout the study using a Lambrecht Distance Thermograph (Science Associates, Inc., Princeton, New Jersey). This continuously recording temperature instrument determined influent, effluent and ambient air temperatures, (points T_1, T_2 and T_3, respectively, as shown in Figure 5).

The temperature recorder was checked daily for accuracy by comparing its readings with the temperatures obtained using a laboratory thermometer as determined by the procedure outlined in Standard Methods for the Examination of Water and Waste Water (27-433).

Although the temperature of the effluent was measured in the control structure, the temperature recorder was adjusted by the temperature measured in the aerated lagoon. This procedure was followed in order to obtain a more representative temperature of the biological environment.

Flow Measurement

Flow measurements were determined by measuring the head in the Parshall flume, (point Q, as shown in Figure 5). The head was recorded by connecting a float suspended in the flume to a continuous float recorder (Stevens Type F - Model 61, Leupold and Stevens Instruments, Inc., Portland, Oregon). The float recorder was checked daily for accuracy by comparing the head measured in the calibrated flume with the head being indicated on the float recorder. Care was also taken to observe that the flume remained clear of grit and debris, and that the flume was not operating under submerged conditions.

Flow measurements were made only on the influent side of the control structure as effluent flows were considered to be equal to the influent flows. This assumption was made because the aerated cell was lined with plastic thus eliminating for the most part infiltration losses, and evaporation losses were considered negligible as compared with the total volume of the cell.

Laboratory Test Procedures

At the conclusion of each sampling period, 24 hourly influent and 24 hourly effluent samples were collected and brought to the laboratory for analysis.

Initially, visual observations were recorded regarding the appearance of the wastes contained in the various sample bottles. Determination of hydrogen ion concentrations were made, using a Fisher Accumet p^H Meter, Model 210, on those samples that appeared to be of unusual color or consistency.

The flow chart was analyzed for the time period in which the influent and effluent samples were taken. The recorded heads were converted to flows, by use of the appropriate Parshall flume table, for each hour of the sampling period. In this way, influent and effluent samples could be composited according to flow, and the total flow and theoretical detention time for that sampling period could be calculated.

Once the influent and effluent samples were composited, p^H determinations were made on both of these composited samples. In addition, the influent composite sample was mixed in a blender in order to obtain more representative samples for the BOD, COD and suspended solids tests. This was necessary because of the substantial amount of large floating butterfat and/or grease particles contained in the influent sample.

In order to obtain some concept of the effect that sedimentation in the stabilization pond would have on the aerated sewage, BOD and COD determinations were made from centrifuged effluent samples.

The BOD and COD determinations were made according to _Standard Methods for the Examination of Water and Waste Water_ (27). The dilution water for the BOD determinations was seeded with the settled effluent from the primary clarifier at the Brookings Sewage Treatment Plant according to the method suggested by Sawyer and McCarty (28-401). This seeding was considered necessary because of the large range of p^H values found in the influent samples. For the COD determinations,

blanks were run in duplicate and influent and effluent composite samples were run in triplicate throughout the study.

Solids determinations were made according to the procedure outlined by Wyckoff (29). For this test, samples were filtered through a glass fiber filter (Reeve's Angel-Grade No. 934 AH), 4.25 centimeters in diameter. The sample size varied from 10 to 25 milliliters, depending on the amount of suspended matter contained in the sample. All solids determinations were run in duplicate or triplicate.

RESULTS AND DISCUSSION

Characteristics of the Raw Wastes

The characteristics of the raw wastes were of a highly variable nature as opposed to the relatively stable characteristics exhibited by the aerated lagoon effluent. The variations in the strength of the influent waste as measured by the characteristics of COD, BOD and suspended solids, are shown in Figure 6. It was noted that on those days when it appeared that the dairy was not operating at full production, such as Sunday, September 6 and Sunday, September 13 as shown in Figure 6, the strength of the influent waste was reduced substantially. This type of waste was characterized by the absence of floating grease, whitish color, and high flow rates as were common for samples collected when the dairy was operating at full production. On days when it appeared that the dairy was discharging much butterfat and milk waste, such as September 7, 8, 14, and 15, a subsequent increase in the strength of the influent waste was observed.

The values plotted in Figure 6 represent the strength of daily composited samples. However, individual hourly samples exhibited an even greater degree of variability than was shown by the composited samples. In one instance, a COD of 86 mg/l was obtained from an individual sample that was collected in the early morning when it appeared by observation of the influent flow chart that the dairy had shut down. In contrast to this case, another COD value of 14,300 mg/l was obtained from an individual sample that was very white in color and whose p^H

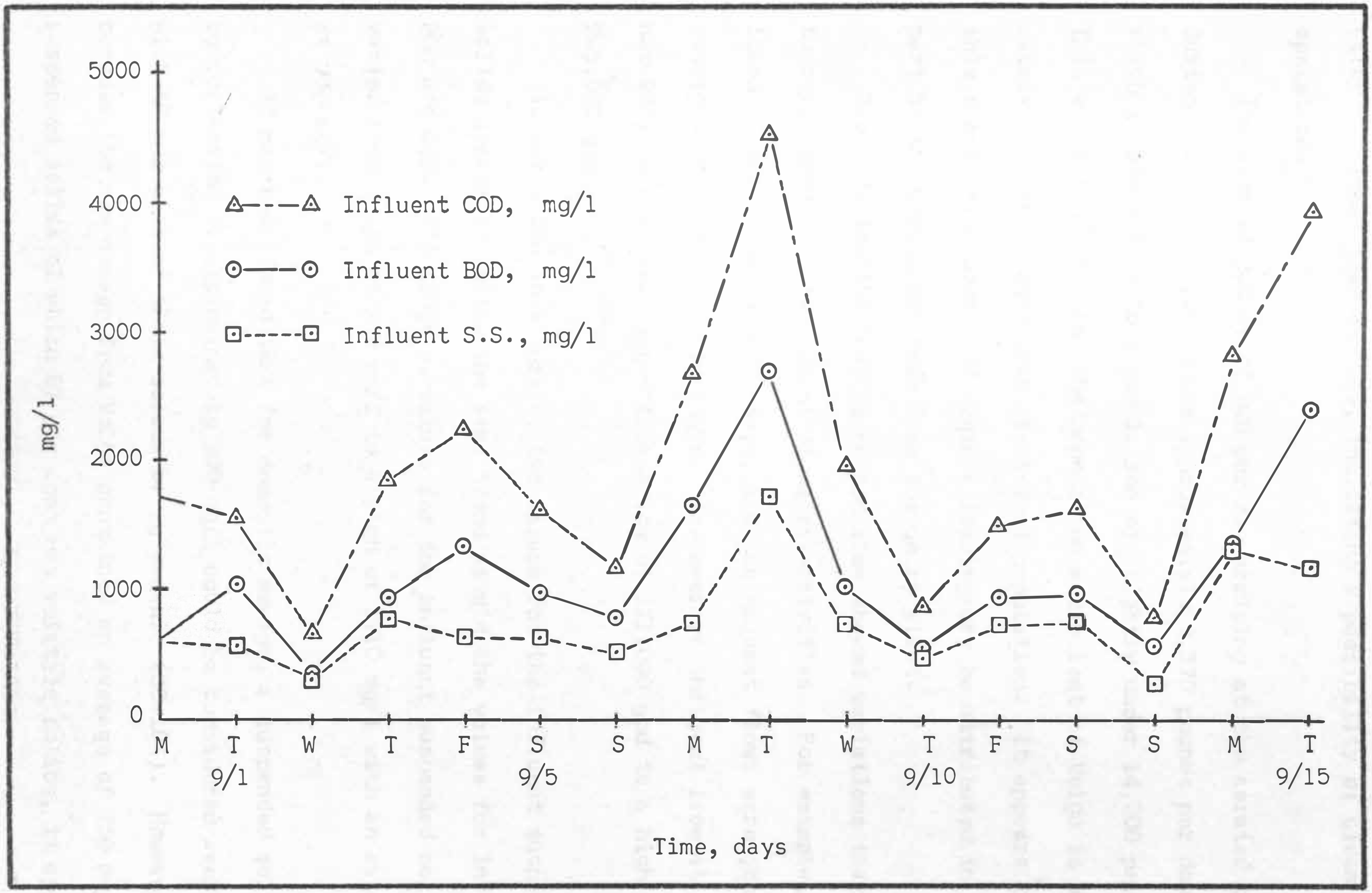

Figure 6. Daily Influent BOD, COD, and Suspended Solids Concentrations Measured During the Period of Study from August 31 to September 16, 1970, from the South Aerated Lagoon at Volga, South Dakota.

value was lower than average, indicating a possibility of clean-up operations.

The average pounds of BOD per day arriving at the aerated lagoon during the testing period was approximately 2,370 pounds per day, which is equivalent to a population of slightly under 14,000 people. This would indicate that the population equivalent of Volga is approximately 14 times larger than its actual population. It appears that this substantial amount of organic loading may be attributed in most part to the discharges made from the dairy plant.

Flows during the testing period also showed variations that seemed to correspond with the amount of dairy activities. For example, the lowest flows occurred on Sundays, and the highest flows were generally recorded on Mondays and Tuesdays. The average influent flow at Volga was 238,000 gpd, and ranged from a low of 171,000 gpd to a high of 285,000 gpd.

As was shown in Figure 6, the values for the influent suspended solids appear to follow the same trend as did the values for influent BOD and COD. The range of values for the influent suspended solids varied from a low of 282 mg/l to a high of 1710 mg/l with an average of 750 mg/l.

It has been found that for domestic sewage, a suspended solids concentration of approximately 300 mg/l could be considered average with 50 per cent of these solids being organic (30-104). However, because the raw sewage from Volga contained an average of 750 mg/l of suspended solids of which 87 per cent was volatile solids, it appeared

that the waste contained a large amount of organic suspended matter. This increase in suspended organic solids was generally attributed to the large amount of butterfat that floated on the surface of the raw sewage.

The pilot plant study made at Volga (14) determined that the p^H values of the raw waste ranged from approximately 4 to 12 during the course of that study. Because these values were well beyond the accepted p^H range of 6.0 to 9.5 considered necessary to maintain optimum biological conditions, it was felt that p^H values of hourly and composite samples should be determined for this study. From these determinations, a frequency distribution of p^H values for daily influent and effluent composite samples were tabulated as shown in Table 5.

TABLE 5

Frequency Distribution of p^H Values for Daily Influent and Effluent Composite Samples from Volga

p^H	Influent	Effluent
7.0 - 7.9	5	10
8.0 - 8.9	5	4
9.0 - 9.9	--	--
10.0 - 10.9	3	--
11.0 - 11.9	1	--

Hourly p^H values ranged from a low of 4.3 to a high of 12.4 during the study. In Figure 7 the p^H values are plotted for hourly samples collected at the influent of the aerated lagoon. Also included in this figure are values of BOD and COD concentrations for selected hourly samples.

On September 12, represented by the dashed line in Figure 7, the influent flow was reduced to almost half between the hours of 2 a.m. and 3 a.m. This reduced flow continued until the end of the sampling period, and the influent was also clear during this four hour interval. A COD determination made on one of these clear samples, as shown by point 3 in Figure 7, indicated a COD of 86 mg/l. It was also during this period that the influent p^H dropped from a value of 11.7 to a relatively uniform 7.5. It was concluded from these data that the dairy had engaged in cleanup operations during the early Sunday morning hours and had then shut down for the rest of the day.

Generally throughout the course of this study, the p^H of the individual raw sewage samples appeared to be close to neutral for a large portion of the day. However, on most days, the p^H would raise substantially during the early morning hours when it appeared that the dairy was engaged in cleanup operations. During this period of time, p^H values would vary between 10 and 12 for a period of 2 to 4 hours. According to Ehlers and Steel, a typical operation for a dairy would be to use strongly alkaline cleaners to help break down fats and to remove milk film from surfaces. These cleaners, such as trisodium phosphate and sodium metasilicate, also would work as a good protein-dissolving agent when used at a p^H of 10.5 (30-197). It was for this

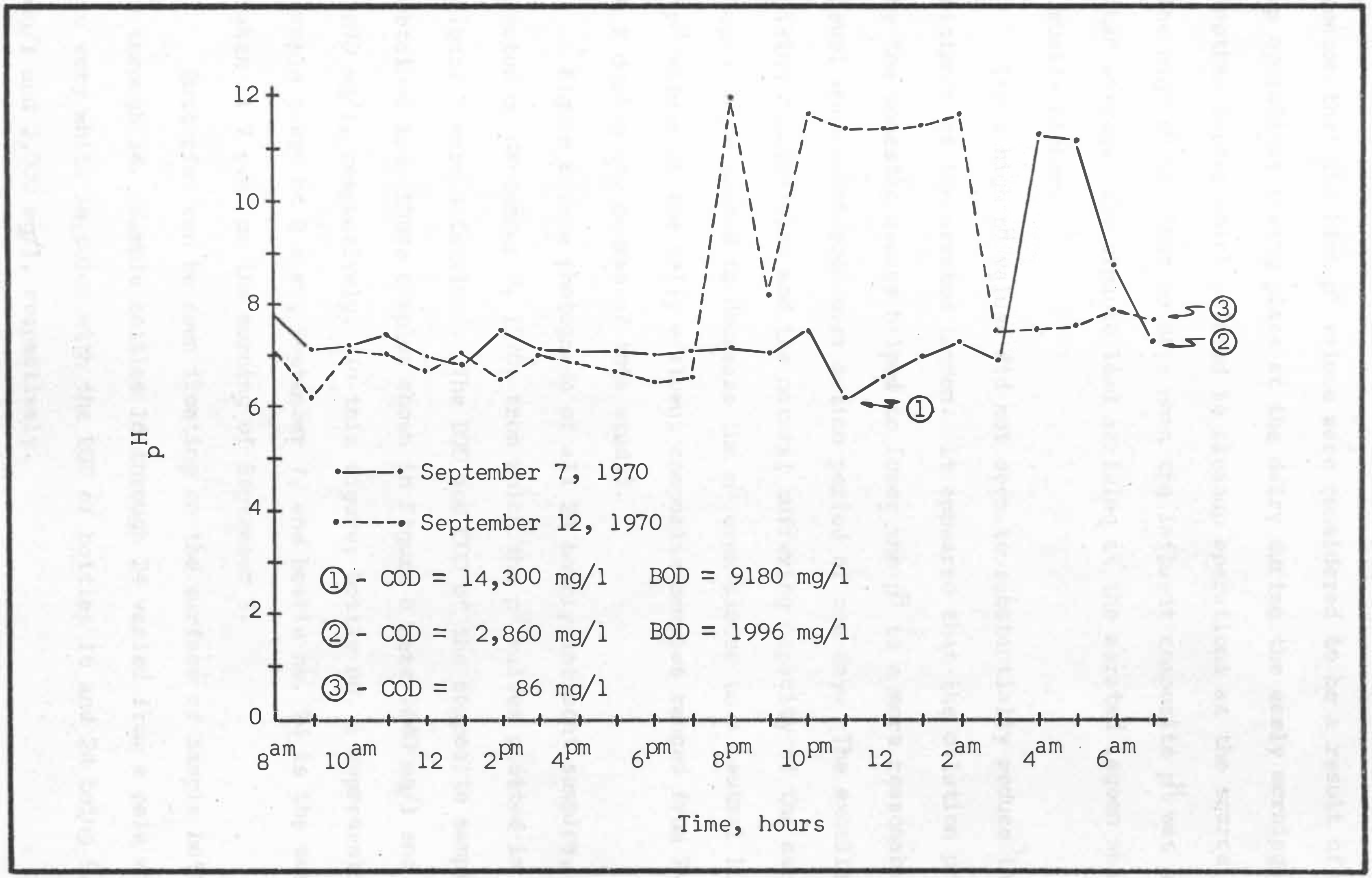

Figure 7. Hourly p^H Values and Selected Hourly BOD and COD Concentrations for Influent Samples Collected on September 7 and September 12, 1970, at Volga, South Dakota.

reason that the high p^H values were considered to be a result of clean-up operations taking place at the dairy during the early morning hours. Another factor which pointed to cleanup operations as the source of the high p^H was that on days when the influent composite p^H was higher than average, the organic load arriving at the aerated lagoon was also usually higher.

These high p^H values did not seem to substantially reduce the efficiency of the aerated lagoon. It appeared that the dilution provided by the domestic sewage helped to lower the p^H to a more reasonable level when considered over a time period of one day. The excellent mixing capabilities and the natural buffering capacity of the aerated lagoon also seemed to decrease the p^H even closer to a neutral level, (p^H values of the daily effluent composite samples ranged from 7.6 to 8.2 during the course of this study).

Figure 8 is a photograph of all 24 hourly influent samples, collected on September 7, 1970, from which the p^H values plotted in Figure 7 were determined. The BOD and COD of the composite sample, obtained from those samples shown in Figure 8 were 1640 mg/l and 2670 mg/l, respectively. In this figure, bottle no. 1 represents the sample taken at 8 a.m., September 7, and bottle no. 24 is the sample taken at 7 a.m. on the morning of September 8.

Butterfat can be seen floating on the surface of sample bottles 2 through 14. Sample bottles 16 through 24 varied from a pale white to very white in color with the BOD of bottles 16 and 24 being 9,180 mg/l and 2,000 mg/l, respectively.

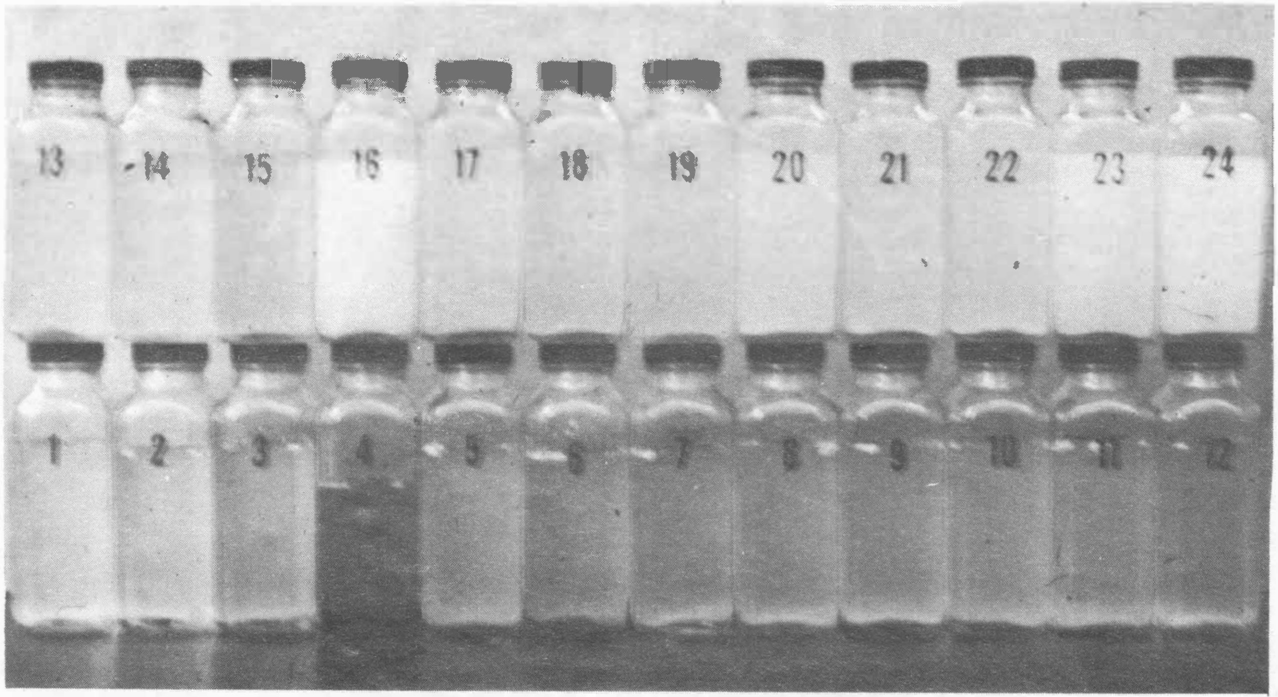

Figure 8. Individual Influent Samples Collected Over a 24-Hour Period on September 7, 1970, at the Volga Aerated Lagoon.

A summary of the characteristics of the influent composite samples analyzed during this study is shown in Table 6.

TABLE 6

A Summary of the Characteristics
of the Influent Composite
Samples Collected at Volga

Characteristics	Minimum	Average	Maximum
BOD, mg/l	375	1,135	2,700
COD, mg/l	660	1,970	4,550
S.S., mg/l	280	750	1,712
Flow, gpd	171,000	238,000	286,000
p^H	7.2	*8.7	11.7

*Arithmetic mean of p^H values.

Analysis of Removal Efficiencies

The BOD removal efficiency values resulting from the treatment provided by the aerated lagoon, averaged 76 per cent and ranged from a low value of 46 per cent to a high value of 92 per cent. For the computation of these removal efficiencies, BOD concentrations were converted to pounds per day, and the effluent discharges were calculated using a lag time in days equal to the theoretical detention time.

A summary of the characteristics of the influent composite samples analyzed during this study is shown in Table 6.

TABLE 6

A Summary of the Characteristics of the Influent Composite Samples Collected at Volga

Characteristics	Minimum	Average	Maximum
BOD, mg/l	375	1,135	2,700
COD, mg/l	660	1,970	4,550
S.S., mg/l	280	750	1,712
Flow, gpd	171,000	238,000	286,000
p^H	7.2	*8.7	11.7

*Arithmetic mean of p^H values.

Analysis of Removal Efficiencies

The BOD removal efficiency values resulting from the treatment provided by the aerated lagoon, averaged 76 per cent and ranged from a low value of 46 per cent to a high value of 92 per cent. For the computation of these removal efficiencies, BOD concentrations were converted to pounds per day, and the effluent discharges were calculated using a lag time in days equal to the theoretical detention time.

It appeared that the fluctuations in BOD removal efficiencies could be explained, in part, by the large daily change in the strength of the raw sewage as contrasted with the relatively stable character of the lagoon effluent. The daily strengths of composited influent and effluent samples as measured by pounds of BOD per day, are shown in Figure 9. It may be seen from this figure that in order for the effluent BOD discharge to remain relatively stable during periods of high organic loading, the BOD removal efficiency of the aerated cell would have to increase substantially. It was anticipated, as described by Sawyer and McCarty (28-396), that the efficiency of BOD removal would increase with an increase in organic loading. It was their opinion that an increase in organic loading would bring about an increase in biological activity due to the abundance of food in the system. Conversely, a decrease in organic loading would decrease the biological activity, thus creating a subsequent reduction in the BOD removal efficiency. Figure 10 which relates organic loading, expressed as pounds of influent BOD per day, to per cent of BOD removal efficiency appears to concur with their findings.

An attempt was made to establish some correlation between either detention time or lagoon temperature with the BOD removal efficiency of the aerated lagoon. However, during the course of this study neither the temperature nor the detention time appeared to have as noticeable an effect on BOD removal efficiencies as did organic loading. A tabulation of data concerning lagoon temperature, theoretical detention time and removal efficiencies is shown in the appendix.

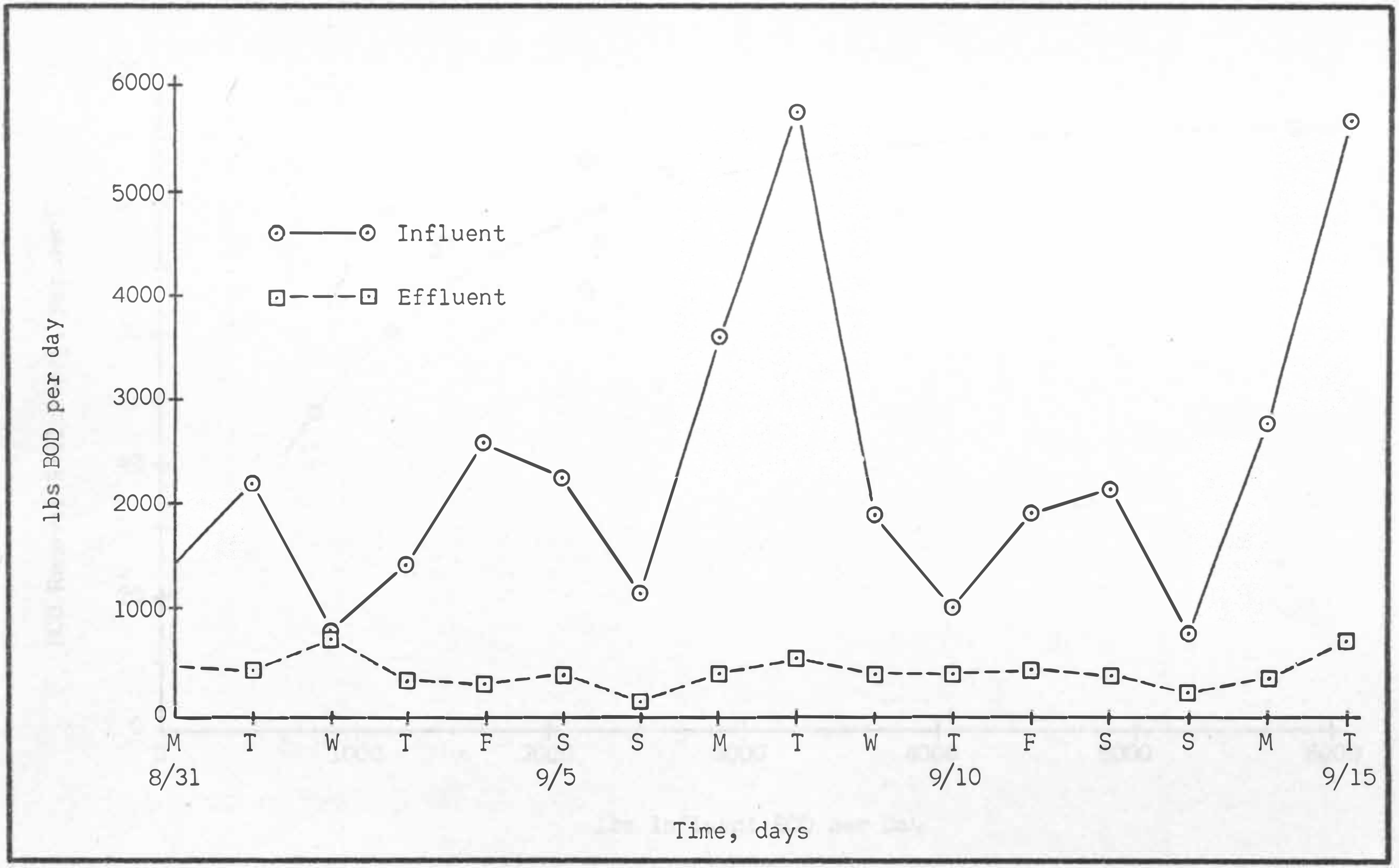

Figure 9. Daily Strength of Influent and Effluent Composited Samples Measured During the Period of Study from August 31 to September 16, 1970, from the South Aerated Lagoon at Volga, South Dakota.

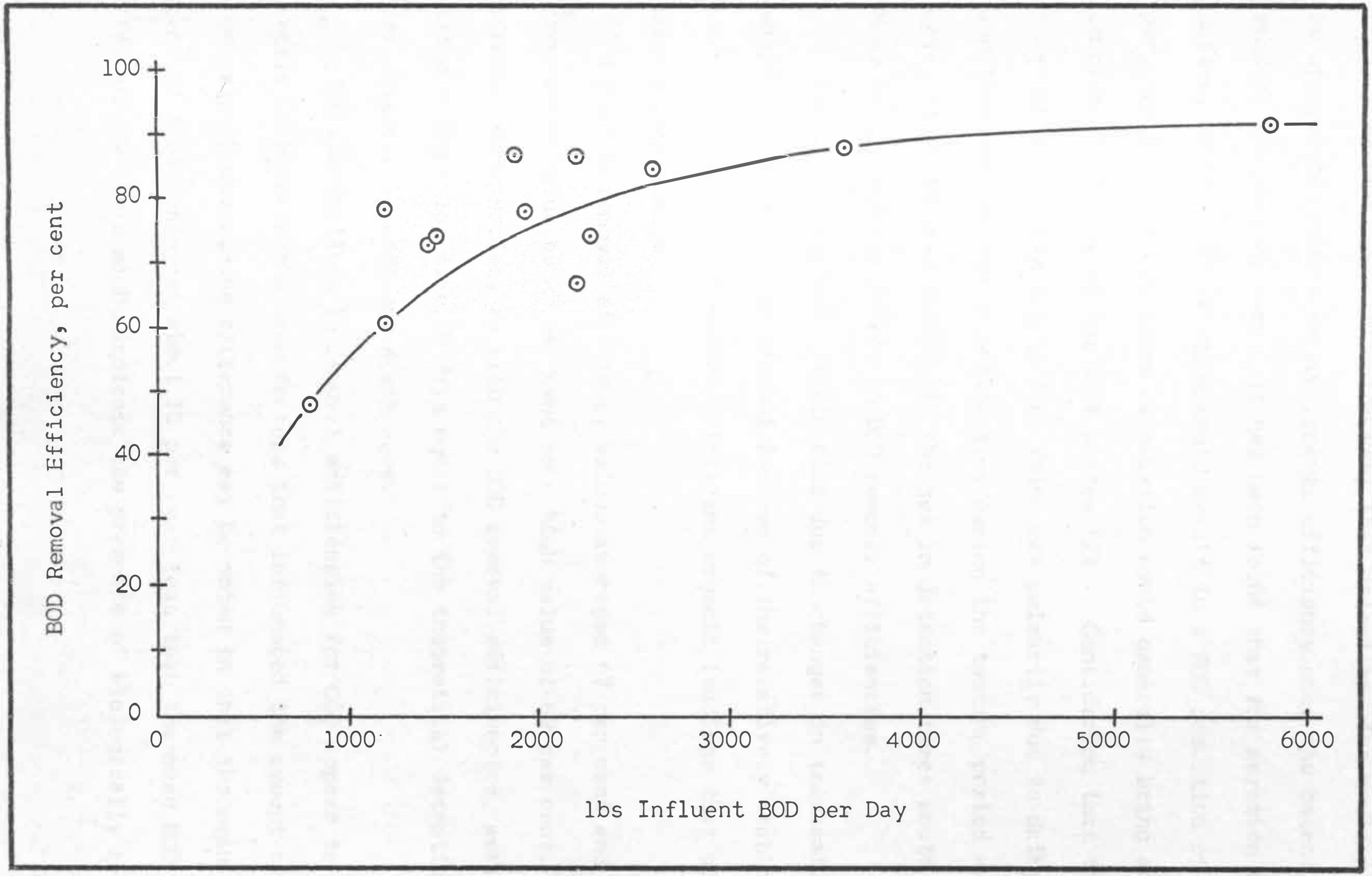

Figure 10. Relationship Between BOD Removal Efficiency and Influent Organic Loading Obtained During the Period of Study from August 31 to September 16, 1970, from the South Aerated Lagoon at Volga, South Dakota.

It seemed reasonable, however, that detention time would not have an appreciable effect on BOD removal efficiency once the detention time reaches two days or more. It has been found that for aeration of dairy wastes, 32 hours of aeration would result in a BOD reduction of 98.6 per cent (20), and 36 hours of aeration would generally bring about complete oxidation of the milk wastes (21). Considering that the strength of the raw sewage from Volga was primarily due to dairy wastes, and that the average detention time during the testing period was 3.46 days, it would seem that small changes in detention times would not have an appreciable effect on BOD removal efficiencies.

Effects on removal efficiencies due to changes in temperature would also appear to be minimal because of the relatively stable temperatures and the highly variable influent organic loadings that occurred during this study.

The COD removal efficiency values averaged 67 per cent and ranged from a low value of 25 per cent to a high value of 89 per cent. These removal efficiencies, as with the BOD removal efficiencies, were calculated using a lag time in days equal to the theoretical detention time for determining effluent discharges.

The fluctuations in removal efficiencies for COD appear to be directly related to the same factors that influenced the amount of BOD removal. However, one difference may be noted in that the mean COD removal efficiency was about 10 per cent less than the mean BOD removal efficiency. This might indicate the presence of biologically resistant

microbial masses in the effluent discharge which were not measured in the BOD test but were chemically oxidizable and were therefore measured by the COD test.

The suspended solids concentrations of the daily influent and effluent composite samples averaged approximately 750 mg/l and 480 mg/l, respectively. Removal efficiencies, considering detention time, averaged slightly over 24 per cent throughout the testing period with removal values ranging from a low of minus 26.6 per cent to a high of 75 per cent. However, because the lagoon seemed to be adequately mixed, thus maintaining most of the suspended solids in suspension during aeration, these low removal efficiencies did not seem unreasonable.

Because of the substantial amount of suspended solids contained in the effluent, an attempt was made to determine what portion of the oxygen demand contained in the effluent could be attributed to suspended solids. This was done by measuring the BOD and COD concentrations of the effluent and the centrifuged effluent samples. Analysis of these test results revealed that a decrease in BOD and COD concentrations of 91 per cent and 90 per cent, respectively, occurred. This information would seem to indicate that sedimentation occurring in the stabilization pond following the aerated lagoons at Volga would decrease the strength of the city's treated sewage to a large extent.

A summary of the BOD, COD and suspended solids removal efficiencies appears in Table 7.

TABLE 7

Summary of the Removal Efficiencies Obtained from the Analysis of the Aerated Lagoon at Volga, South Dakota, for the Period from August 31 to September 16, 1970

Characteristic	Per cent Removal		
	Minimum (%)	Mean (%)	Maximum (%)
BOD	48.0	76.4	92.0
COD	25.1	66.9	88.6
S.S.	-26.6	24.1	75.0

Analysis of the Reaction Rate Coefficients

The reaction rate coefficient (K_T) gives an indication as to the rate at which the biochemical oxygen demand of a waste will be satisfied by a treatment process. The reaction rate is useful, therefore, in determining the required detention time needed to stabilize the waste to a satisfactory BOD value. Unfortunately, very little information concerning this coefficient for an aerated lagoon treating combined domestic and dairy wastes was available prior to the design of the aerated lagoons at Volga. For this reason the pilot plant study made at Volga by Vanden Hoek was undertaken. Results from the pilot plant study reported a reaction rate (K_{20}) of 1.034 as compared to the (K_{20}) value of 1.495 obtained from this research conducted on the full scale operation.

Bennett reported that a large variation in reaction rates do occur. However, reaction rates of 0.3 to 1.0 for domestic sewage, and as high as 3.0 for some types of industrial wastes, appear to be representative values (13). Therefore, the reaction rates obtained from the pilot plant and full scale studies seem to be reasonable for the type waste being treated.

The reaction rate coefficients for this study were calculated by using Thimsen's equation (5-9). A wide range of reaction rate coefficients were found due to the highly variable organic loading, detention time and lagoon temperatures that occurred daily during the testing period. However, of these three variables, only the rate of organic loading seemed to have an influential effect on the reaction rate coefficient values. The relationship between organic loadings, expressed as pounds of BOD per day per 1000 cubic feet of lagoon volume, and the reaction rate coefficients are shown in Figure 11.

It appeared that the increase in reaction rates as associated with the higher rates of organic loading, could be attributed to the increase in biological activity as described previously by Sawyer and McCarty (28-396).

Comparison of Aerated Lagoon Performance With the Pilot Plant Study

From the data obtained during the Volga pilot plant study, Vanden Hoek developed a relationship among detention time, lagoon temperature and BOD removal efficiency. Applying the average values of detention time and lagoon temperature determined from the full scale operation to

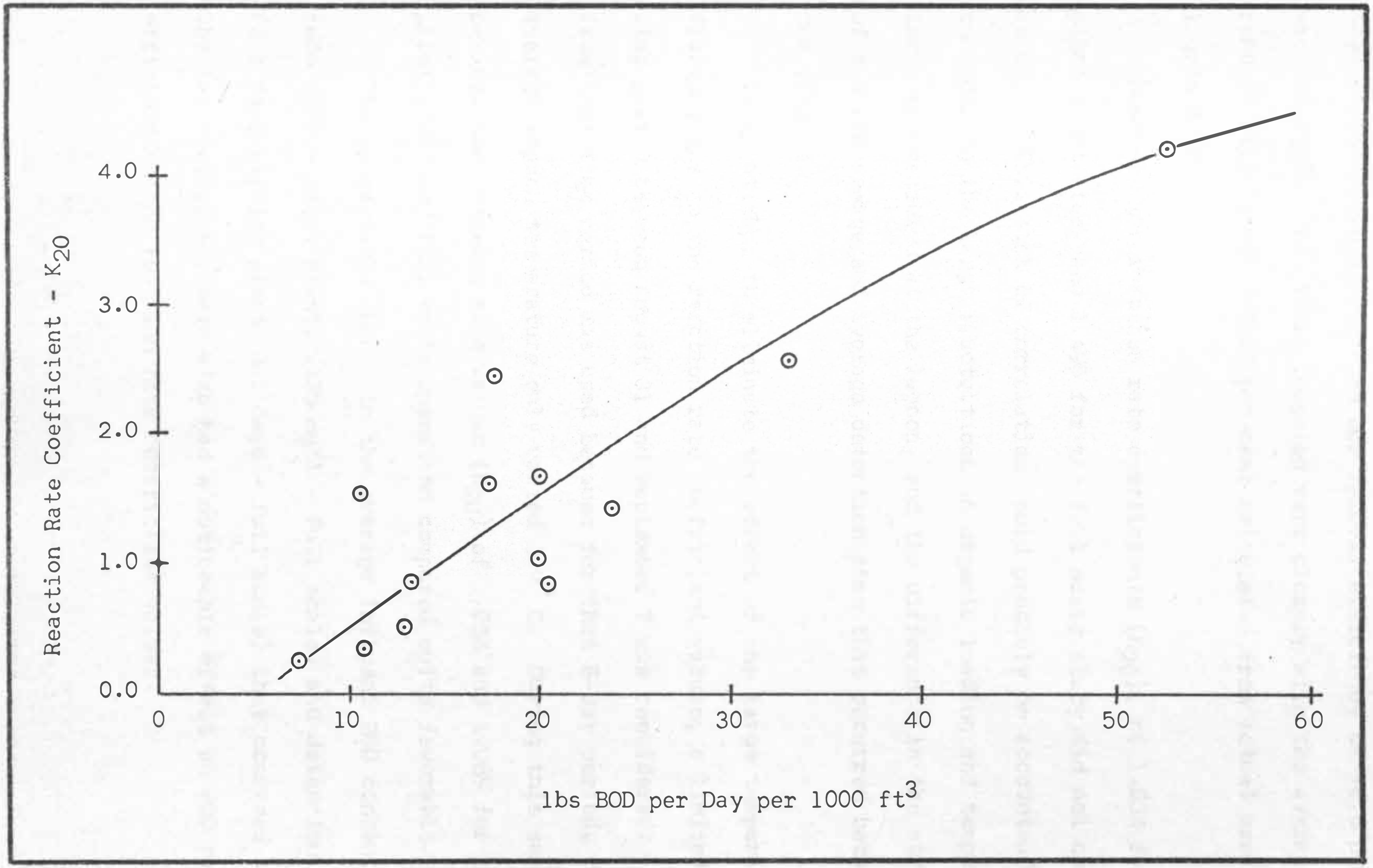

Figure 11. Relationship Between the Reaction Rate Coefficient (K_{20}) and Influent Organic Loading Obtained During the Period of Study from August 31 to September 16, 1970, from the South Aerated Lagoon at Volga, South Dakota.

this relationship a predicted BOD removal efficiency of 76.6 per cent was obtained. This value compared very closely with the average BOD removal efficiency of 76.3 per cent calculated from actual aerated lagoon data.

However, the reaction rate coefficients (K_{20}), of 1.034 for the pilot plant study and 1.495 for the full scale study did not compare as well. This lack of correlation could probably be accounted for by considering the large fluctuations in organic loading and temperatures that were measured at the lagoon, and the difference in the strength of the raw sewage and average detention time that occurred between the two studies.

In an attempt to eliminate the effect of the large temperature fluctuations on the reaction rate coefficient values, a limited sampling period between August 31 and September 7 was considered. Data from this time period was used because for that 8-day period, the average lagoon temperature only varied 2.9^{o} C. During this sampling period, the reaction rate values (K_{20}) of 1.034 and 1.069 for the pilot plant and full scale operation compared quite favorable.

The appreciable change in the average influent BOD concentrations (406 mg/l - pilot plant, 1135 mg/l - full scale) and detention times (2.1 days - pilot plant, 3.5 days - full scale) that occurred between the two studies may have also had a noticeable effect on BOD removal efficiencies and reaction rate coefficient values.

Relationship Between BOD and COD

It is often advantageous in making an industrial or municipal waste survey to establish a relationship between the characteristics of BOD and COD. If a close relationship can be established between these two characteristics, a three hour COD test may be used to estimate the 5-day BOD of a waste being analyzed. The COD test is also helpful in indicating toxic conditions and the presence of biologically resistant organic matter contained in a waste, when used in conjunction with the BOD test.

An excellent correlation (correlation coefficient = 0.974) was found to exist between the influent BOD and COD concentrations obtained at Volga. The relationships for the daily influent and effluent BOD-COD ratios are shown in Figures 12 and 13, respectively. The equation for the line of best fit, the mean, the correlation coefficient, and the standard deviation of the data presented are also included in these figures.

As is indicated in Figures 12 and 13, the average effluent BOD-COD ratio of 0.399 was smaller than that of the average influent BOD-COD ratio of 0.584. Since the aeration process primarily oxidizes biodegradable organics, the reduction in the BOD-COD ratio seemed reasonable.

The amount of organic material oxidized in a treatment system depends on such factors as temperature, detention time, and organic loading. Because these characteristics all varied throughout the

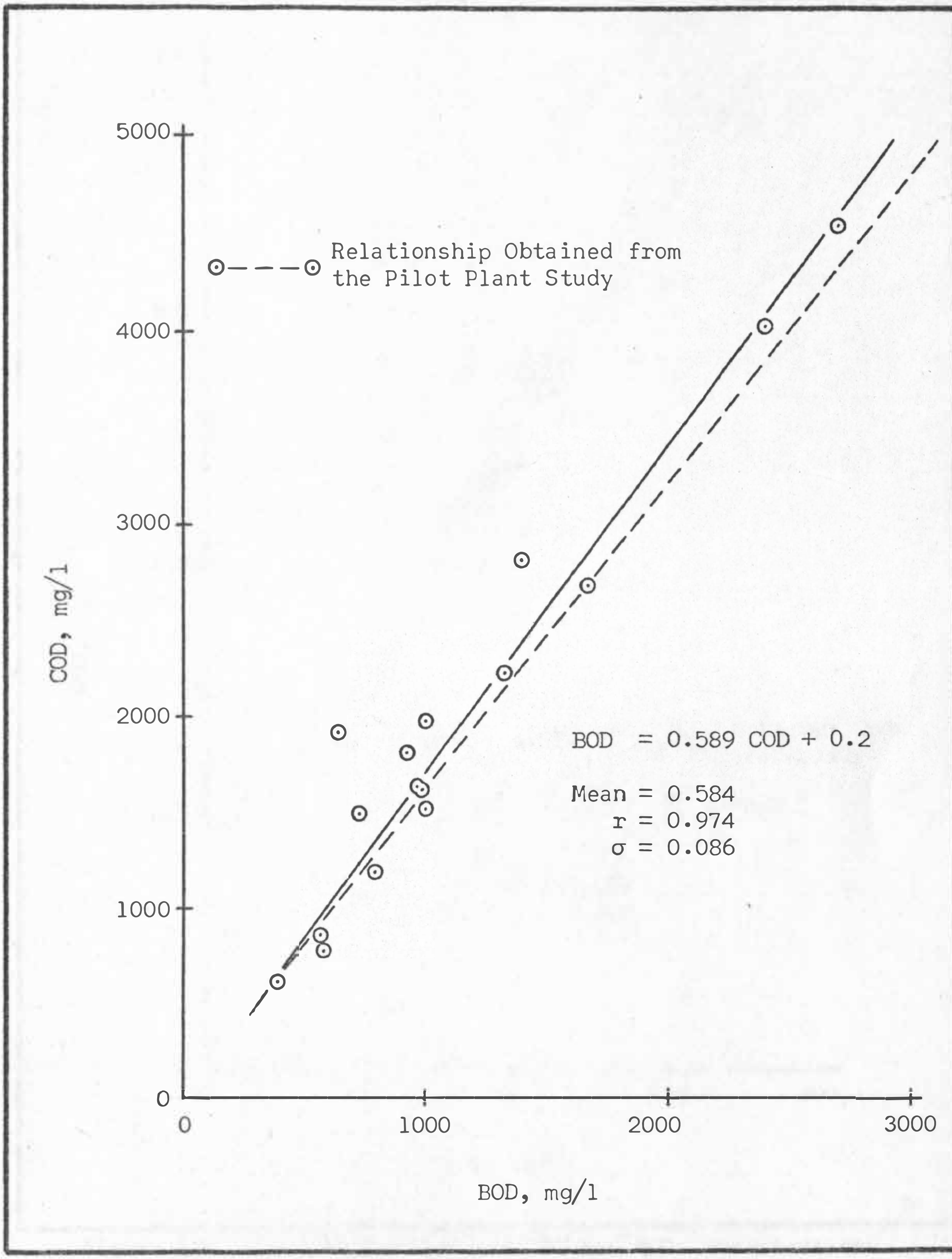

Figure 12. Relationship Between COD and BOD Concentrations of Influent Composite Samples Obtained During the Period of Study from August 31 to September 16, 1970, at Volga, South Dakota.

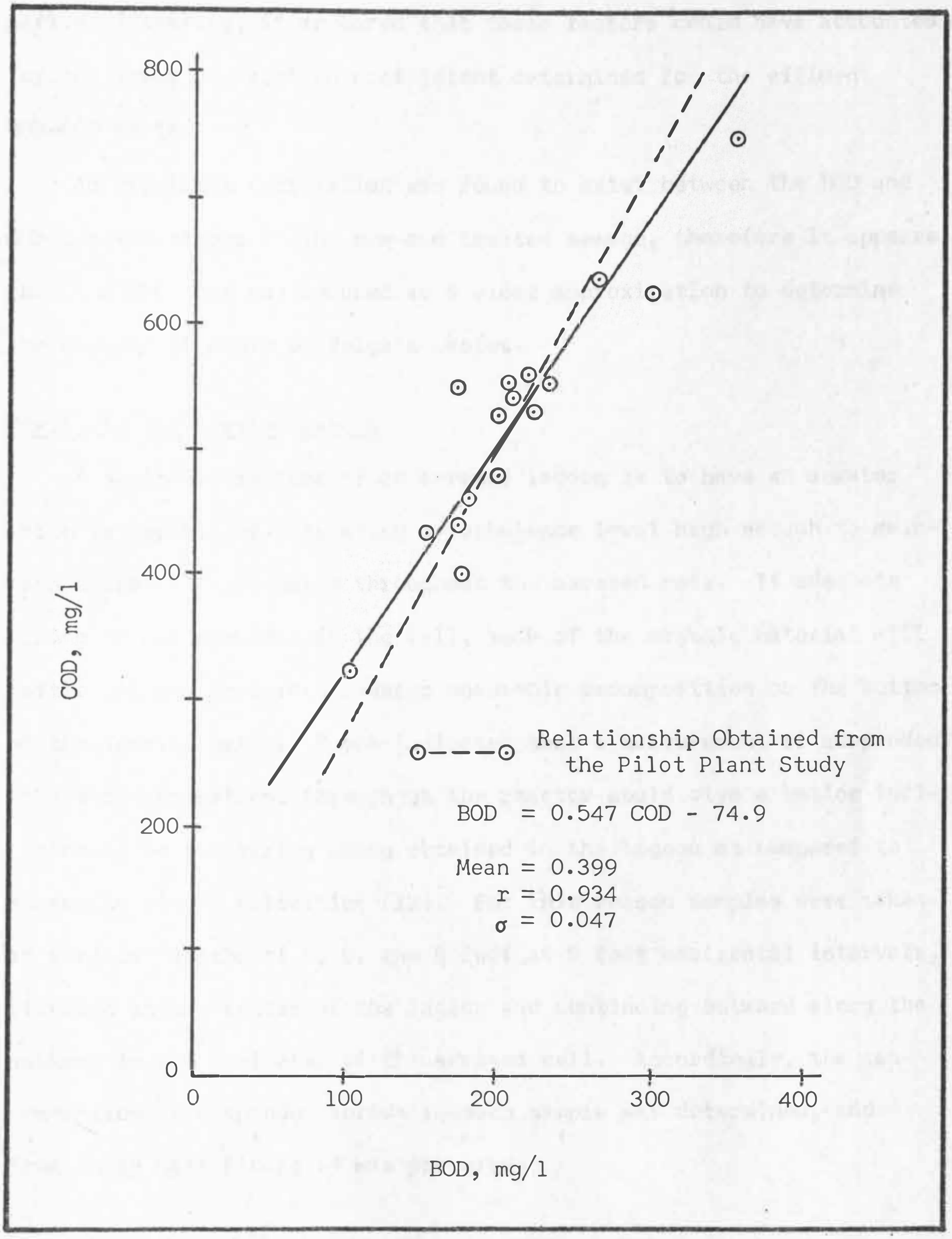

Figure 13. Relationship Between COD and BOD Concentrations of Effluent Composite Samples Obtained During the Period of Study from August 31 to September 16, 1970, at Volga, South Dakota.

period of testing, it appeared that these factors could have accounted for the lower correlation coefficient determined for the effluent BOD-COD ratio.

An excellent correlation was found to exist between the BOD and COD concentrations of the raw and treated sewage, therefore it appears that the COD test can be used as a close approximation to determine the organic strength of Volga's wastes.

Mixing in the Aerated Lagoon

A desirable feature of an aerated lagoon is to have an aerator which is capable of generating a turbulence level high enough to maintain solids in suspension throughout the aerated cell. If adequate mixing is not provided in the cell, much of the organic material will settle out and therefore undergo anaerobic decomposition on the bottom of the aerated basin. Busch indicated that a measurement of suspended solids concentrations throughout the reactor would give a better indication as to the mixing being obtained in the lagoon as compared to measuring liquid velocities (12). For this reason samples were taken at vertical depths of 2, 5, and 8 feet at 5 foot horizontal intervals, starting at the center of the lagoon and continuing outward along the walkway to the perimeter of the aerated cell. Accordingly, the concentration of suspended solids in each sample was determined, and from these data Figure 14 was prepared.

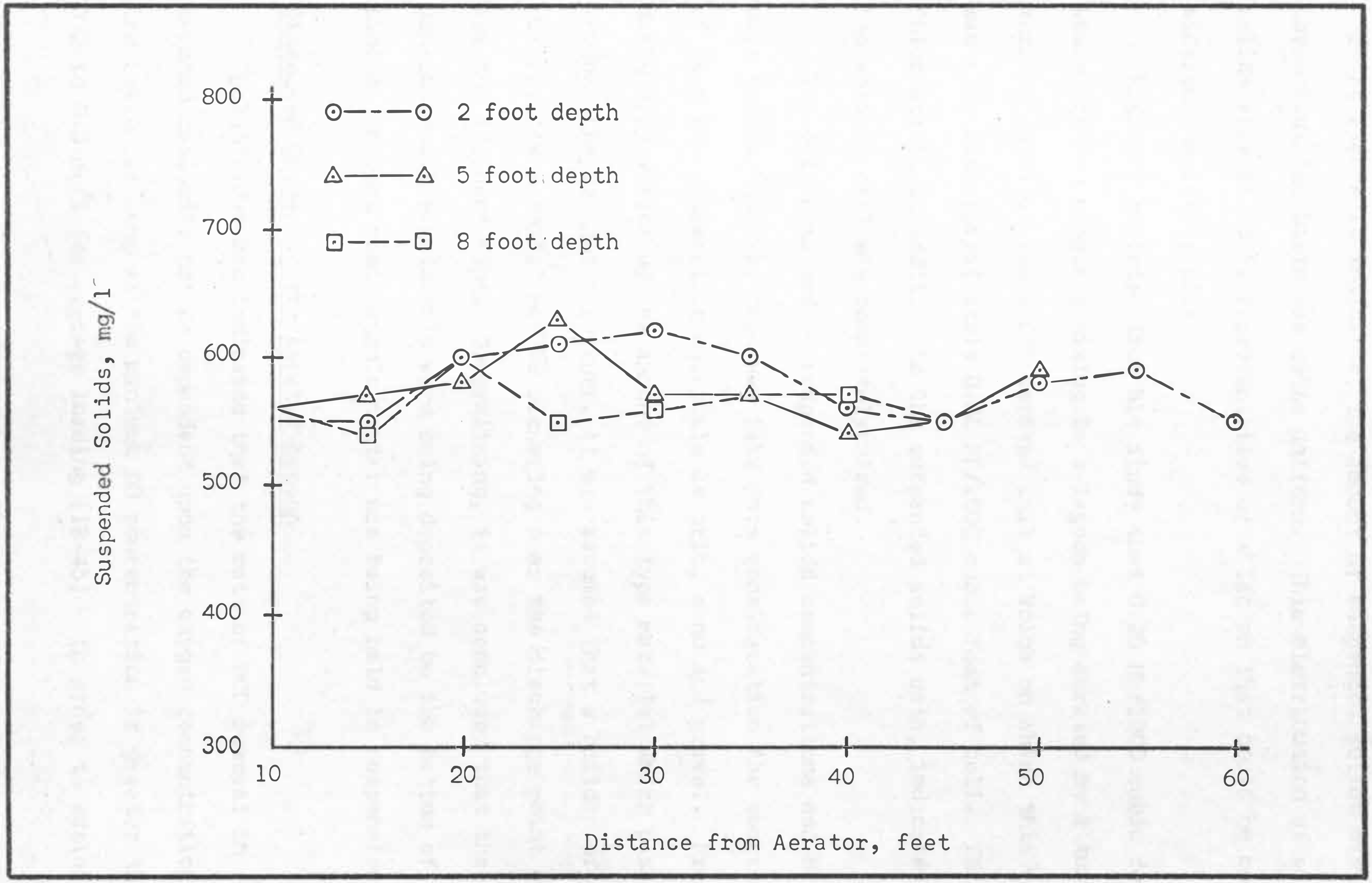

Figure 14. Suspended Solids Concentrations Measured at Selected Depths and Radii from the Aerator Operating in the South Aerated Lagoon at Volga, South Dakota.

As Figure 14 indicates, the amount of suspended solids distributed throughout the basin was quite uniform. This distribution of suspended solids appears to be representative of a lagoon that could be considered completely mixed.

McKinney reported from his study that 0.25 HP/1000 cubic feet would provide complete mixing in a lagoon being aerated by a turbine aerator (4-41). The south aerated cell at Volga on which this study was made had approximately 0.36 HP/1000 cubic feet of cell. This information, in addition to the suspended solids data, indicated that the aerated cell was completely mixed.

The data obtained on suspended solids concentrations and HP per unit volume however, does not take into consideration the suspension of such non-putrescible materials as grit, sand and gravel. From daily observation of the amount of this type material which passed through the control structure, it was assumed that a buildup of non-putrescible material may be occurring near the discharge point of the aerator influent pipe. Generalizing, it was concluded that the heavier non-putrescible materials were being deposited on the bottom of the lagoon, whereas most organic matter was being held in suspension.

Dissolved Oxygen in the Aerated Lagoon

Eckenfelder has indicated that the rate of BOD removal in an aerated cell will not be dependent upon the oxygen concentration in the system as long as the minimum DO concentration is greater than 0.2 to 0.5 mg/l for average loading (18-45). In order to sustain

these minimum DO values during periods of peak organic loading, Thimsen recommended maintaining a minimum DO concentration of 1.5 mg/l throughout the aerated cell (5-20).

In order to determine the distribution of dissolved oxygen throughout the aerated lagoon, DO concentrations were measured on four different days. On each of these sampling days, a large number of DO determination were made in an attempt to obtain a representative cross-section of the DO distribution. Table 8 summarizes the data obtained from these studies.

TABLE 8

Summary of DO Concentrations in the South Aerated Lagoon at Volga, South Dakota

Date	Lagoon Temperature (°C)	Minimum DO (mg/l)	Maximum DO (mg/l)
9/23/70	18	4.0	5.0
9/25/70	14	6.1	6.3
9/28/70	16	3.7	4.4
9/30/70	17	3.6	3.9

As Table 8 indicates, the difference between the maximum and minimum DO concentrations found in the aerated cell on any one day was never greater than 1 mg/l. The minimum DO concentration found to exist in the lagoon during all four sampling periods was 3.6 mg/l, which occurred when the lagoon temperature was 17^{o} C. This value is well above the minimum DO concentration of 0.2 mg/l considered necessary to maintain adequate biological activity in a liquid waste. The maximum value measured for DO concentrations was 6.3 mg/l and was determined when the lagoon temperature was 14^{o} C. From these data it seemed likely that during this study the aerator was providing sufficient amounts of oxygen to supply the biochemical oxygen demands of the system.

Estimated Industrial Production Loss

In order to establish an economic justification for an industry to reclaim more of its raw products and to reduce the amount of waste discharged to the city sewer, an estimated industrial production loss due to excess wasting of materials during processing should be calculated.

The City of Volga, according to preliminary 1970 census figures, had a population of 1030 people. Steel has stated that for a strictly domestic sewage collected during dry weather flow, the 5-day per capita oxygen demand would probably be between 0.12 and 0.17 pounds per day (31-459). Because Volga has a consolidated public grade and high school and a parochial school, the higher value of 0.17 pounds BOD

per capita per day was used. Multiplying this value by the 1970 population of Volga resulted in a theoretical oxygen demand for the city of 175 pounds of BOD per day. However, during the 16 days of continuous testing made for this study, the average loading rate of the Volga aerated lagoon was 2,366 pounds of BOD per day. Because the Land O' Lakes Creamery is the only major industry in Volga contributing substantial amounts of organic wastes to the sewer system, the difference in organic loading (2,191 pounds BOD per day) between average domestic sewage and Volga's combined domestic and industrial sewage, was considered to be contributed by the creamery. If the 0.17 pounds BOD per capita per day conversion is applied to 2,191 pounds BOD load, the creamery would have an estimated population equivalent of approximately 12,900 people.

It has also been computed that 100 pounds of raw milk will exert a 5-day BOD of approximately 10.2 pounds (7-326). This would indicate that the average BOD load of 2,190 pounds per day would be equivalent to approximately 21,400 pounds of whole milk. This loss may represent on the average, nearly 7 per cent of the total raw milk being processed daily at the plant. Considering that the dairy must purchase on the average day almost $14,000 of raw milk (300,000 pounds raw milk per day at $4.75 per 100 pounds), a 7 per cent waste of raw product might represent a monetary loss of about $980 per day.

However, it should be recognized that all milk plant losses cannot be eliminated. Nevertheless, measures to prevent such losses due to residual waste, willful waste, spillage and leakage can be expected to substantially reduce product losses.

SUMMARY AND CONCLUSIONS

During the period of study from August 31 to September 16, 1970, of the south aerated lagoon located at Volga, South Dakota, the average operating conditions included: temperature - 70^{o} F, organic loading - 21.5 lbs BOD per day per 1000 ft^3, and detention time - 3.46 days. Operating under these conditions, the following results were obtained:

1. BOD removal of 76 per cent.
2. COD removal of 67 per cent.
3. Suspended solids removal of 24 per cent.
4. Reaction rate coefficient (K_{20}) of 1.495.

The following conclusions were drawn from the study of the aerated lagoon treating combined dairy and domestic wastes at Volga, South Dakota:

1. The aerated lagoon-stabilization pond treatment process at Volga appeared to be adequate to satisfy the South Dakota Committee on Water Pollution sewage effluent standards during summer operation.
2. Organic loading seemed to have a greater effect on BOD removal efficiency than did detention time or lagoon temperature.
3. The aerated lagoon studied showed an excellent capability of being able to handle highly variable organic loading rates and p^H changes without a serious adverse effect on the quality of the aerated lagoon effluent.

4. With a power to liquid volume ratio of 0.36 HP/1000 ft^3, the aerated lagoon appeared to be of the completely mixed type, providing a uniform distribution of DO and suspended solids throughout the cell.

5. An excellent correlation was found to exist between BOD and COD concentrations for both the raw and treated wastes.

6. Data obtained from the pilot plant study did correlate well with operational data obtained from the full scale operation.

7. It appeared that an unusually large amount of organic wastes were being discharged by the dairy to the treatment facilities at Volga.

LITERATURE CITED

1. Steffen, A. J., "Aeration of Milk Wastes," Land Disposal of Liquid Wastes, A collection of papers presented at the University of Wisconsin Engineering Institute on Industrial Wastes, Extension Division, University of Wisconsin, Madison, Wisconsin, (1958).

2. Sawyer, C. N., "New Concepts in Aerated Lagoon Design and Operation," In "Advances in Water Quality Improvement," University of Texas Press, Austin, Texas, 325, (1968).

3. "Aeration in Wastewater Treatment - MOP 5," Journal of the Water Pollution Control Federation, 41, No. 12, 2058-2061, (December, 1969).

4. McKinney, Ross E., and Benjes, Henry H., Jr., "Design and Operation of Aerated Lagoons," Paper No. 3P2-1, National Symposium of Sanitary Engineering Research, Development and Design, 1-42, (July, 1965).

5. Thimsen, Donald J., "Biological Treatment in Aerated Lagoons," Paper presented at the 12th Annual Waste Engineering Conference, University of Minnesota, Minneapolis, Minnesota, 1-47, (December, 1965).

6. McKee, F. J., "Milk Waste Treatment by Aeration," Sewage and Industrial Wastes, 22, No. 8, 1041-1046, (August, 1950).

7. Nemerow, Nelson Leonard, Theories and Practices of Industrial Waste Treatment, Addison-Wesly Publishing Company, Incorporated, Reading, Massachusetts, (1963).

8. White, J. C., "Disposing of Dairy Wastes," American Milk Review, 22, 38-40, December, (1960).

9. "Hydraulics of Mechanical Surface Aerators," Water and Wastes Engineering, 5, 65-68, (April, 1968).

10. Tharp, Charles E., "Modern Aeration Techniques," Water and Wastes Engineering, 6, 31-33, (June, 1969).

11. Siebert, C. L., "Pennsylvania Milk Waste Treatment Methods," Sewage and Industrial Wastes, 29, No. 9, 1038-1041, (September, 1957).

12. Busch, A. W., "Biological Factors in Aerator Performance," Paper presented at the 25th Annual Industrial Waste Conference, Purdue University, Lafayette, Indiana, (May, 1970).

13. Bennett, G. E., "Basic Design Considerations for Aerated Lagoons," Welles Products Corporation Publication No. WP 1204-1, Roscoe, Illinois.

14. Vanden Hoek, Allen M., "A Pilot Plant Study to Determine the Treatability of Combined Domestic and Milk Wastes in an Aerated Lagoon," Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1969).

15. Lowthian, J. T., "Evaluation of an Aerated Lagoon System Treating Domestic and Industrial Wastewaters," Master of Science Thesis, South Dakota State University, Brookings, South Dakota, (1968).

16. Porges, N., "Practical Application of Laboratory Data to Dairy Waste Treatment," Food Technology, 12, No. 2, 78-79, (February, 1958).

17. Kountz, R. R., "Dairy Waste Treatment," Milk and Food Technology, 18, No. 10, 243, (October, 1955).

18. Eckenfelder, W. W., Jr., and O'Connor, D. J., Biological Waste Treatment, Pergamon Press, New York, New York, (1961).

19. Hauer, G. E., "Successful Treatment of Dairy Wastes by Aeration," Sewage and Industrial Wastes, 24, No. 10, 1271-1277, (October, 1952).

20. Schulze, K. L., "Non-Clogging Foam-Safe Aerators Lick Cheese Waste Problem," Food Engineering, 26, No. 9, 51-53, (September, 1954).

21. Horton, J. P., and Trebler, H. A., "Recent Developments in Design of Small Milk Waste Disposal Plants," Sewage and Industrial Wastes, 25, No. 8, 941-949, (August, 1953).

22. Ford, D. L., "Laboratory Methodology for Developing Biological Treatment Information," In "Manual of Treatment Processes," 1, Environmental Science Service Corporation, Stamford, Connecticut, (1968).

23. Eldridge, E. F., "Dairy Waste Disposal," Sewage Works Journal, 21, No. 4, 668-673, (July, 1949).

24. "Aerators Solve Waste Treatment Problem," American Dairy Review, 29, No. 4, 40, (April, 1967).

25. Hasfurther, W. A., "Aeration Gives Low-Cost Waste Disposal," Food Industries, 23, No. 2, 90-93, (February, 1951).

26. Hoover, S. R., "Aeration as Partial Treatment," Sewage and Industrial Wastes, 24, No. 6, 812, (June, 1952).

27. Standard Methods for the Examination of Water and Wastewater, 12th Edition, American Public Health Association, Incorporated, New York, New York, (1965).

28. Sawyer, C. N., and McCarty, P. L., Chemistry for Sanitary Engineers, 2nd Edition, McGraw-Hill Book Company, Incorporated, New York, New York, (1967).

29. Wyckoff, Bruce M., "Rapid Solids Determination Using Glass Fiber Filters," Water and Sewage Works, 111, 277-280, (June, 1964).

30. Ehlers, V. M., and Steel, E. W., Municipal and Rural Sanitation, 6th Edition, McGraw-Hill Book Company, Incorporated, New York, New York, (1965).

31. Steel, E. W., Water Supply and Sewerage, 4th Edition, McGraw-Hill Book Company, Incorporated, New York, New York, (1960).

APPENDIX I

Test Results on Influent and Effluent Composited Samples Obtained During the Period of Study from August 31 to September 16, 1970, From the South Aerated Lagoon at Volga, South Dakota

Date	BOD		COD		Inf.		Eff.		p^H	
	Inf. mg/l	Eff. mg/l	Inf. mg/l	Eff. mg/l	S.S. mg/l	V.S.S. %	S.S. mg/l	V.S.S. %	Inf.	Eff.
8/31	622	213	1723	546	605	82	470	71	---	---
9/1	1018	209	1561	558	562	94	492	65	---	---
9/2	375	355	656	750	355	94	455	87	7.3	7.7
9/3	910	235	1829	554	788	95	429	74	7.9	7.7
9/4	1320	155	2240	435	610	95	398	82	7.2	7.8
9/5	995	183	1605	461	631	83	414	71	8.7	7.7
9/6	795	101	1177	326	515	94	276	66	7.2	7.8
9/7	1640	176	2673	442	735	89	413	66	7.5	7.7
9/8	2696	268	4550	638	1712	92	612	73	8.4	7.6
9/9	1004	220	1950	563	737	85	510	70	8.2	8.0
9/10	552	202	882	480	480	83	862	84	8.7	7.8
9/11	915	222	1500	532	733	68	440	68	10.4	7.8
9/12	975	173	1612	550	742	75	435	62	10.7	8.0
9/13	577	178	793	402	282	84	420	63	8.0	8.2
9/14	1375	203	2814	530	1333	87	440	65	10.2	8.1
9/15	2400	303	3940	629	1173	94	555	77	11.7	7.9

APPENDIX II

A Tabulation of the Characteristics Related to the South Aerated Lagoon for the Period of Study From August 31 to September 16, 1970, at Volga, South Dakota

Date	Detention Time Days	Flow GPD	Temperature Air °C	Temperature Lagoon °C	Organic Loading lbs BOD per day	Organic Loading lbs BOD per 1000 ft³ per day
8/31	2.96	278,300	23.5	20.8	1444	13.1
9/1	3.18	259,200	24.0	21.7	2200	20.0
9/2	3.25	253,750	25.0	23.1	794	7.2
9/3	4.39	187,900	18.0	22.3	1426	12.9
9/4	3.49	236,400	12.0	20.9	2603	23.6
9/5	3.05	270,400	22.0	21.9	2244	20.4
9/6	4.57	180,300	26.0	23.7	1196	10.8
9/7	3.11	265,000	14.0	21.0	3624	32.9
9/8	3.20	257,000	17.0	19.8	5778	52.4
9/9	3.58	230,400	13.0	18.6	1930	17.5
9/10	3.23	255,000	11.0	16.2	1174	10.7
9/11	3.30	249,600	13.0	16.1	1905	17.3
9/12	3.06	269,200	8.0	15.5	2189	19.9
9/13	4.81	171,250	7.0	13.3	824	7.5
9/14	3.37	245,000	5.5	12.3	2809	25.5
9/15	2.88	285,800	5.0	12.7	5722	51.9

APPENDIX III

Minimum, Maximum, and Average Values for Selected Characteristics Obtained During the Period of Study from August 31 to September 16, 1970, from the South Aerated Lagoon at Volga, South Dakota

Characteristic	Minimum	Maximum	Mean	Standard Deviation
Influent BOD, mg/l	375	2696	1135	641
Effluent BOD, mg/l	101	355	212	59
[a]BOD Removal, %	48	92.0	76.4	12.3
BOD Removal, %	0.1	90.1	74.8	21.6
Influent COD, mg/l	656	4550	1969	1079
Effluent COD, mg/l	326	750	525	101
[a]COD Removal, %	25.1	88.6	67.0	18.4
COD Removal, %	-1.4	86.0	66.0	21.0
Influent S.S., mg/l	282	1712	749	369
Effluent S.S., mg/l	276	862	476	126
[a]S.S. Removal, %	-26.6	75.0	24.1	31.0
S.S. Removal, %	-79.6	67.0	23.7	41.1
[b]Reaction Rate, K_{20}	0.25	4.22	1.50	1.09
Reaction Rate, K_{20}	0.01	3.99	1.55	1.08
lbs Influent BOD per day	794	5778	2366	1519
lbs Effluent BOD per day	254	751	437	152
[c]Influent p^H	7.2	11.7	8.7	1.45
[c]Effluent p^H	7.6	8.2	7.8	0.17
Detention Time, days	2.88	4.81	3.46	0.59
Lagoon Temperature, ^oC	12.3	23.7	18.7	3.8

[a]Lag time was taken into consideration when calculating these removal efficiencies. Mean values are the arithmetic average of the daily removal efficiencies shown in Appendix IV.

[b]Lagoon temperatures were averaged over the detention time period, and lag time was taken into consideration.

[c]The means and standard deviations for the p^H values were calculated arithmetically.

APPENDIX IV

A Summary of Daily Removal Efficiencies and Reaction Rate Coefficients Obtained During the Period of Study from August 31 to September 16, 1970, from the South Aerated Lagoon at Volga, South Dakota

Date	Reaction Rate Coefficient		BOD Removal Efficiency		COD Removal Efficiency		S.S. Removal Efficiency	
	*K	K	*%	%	*%	%	*%	%
8/31	0.860	0.614	74.5	65.7	78.3	68.3	47.9	22.3
9/1	1.694	1.081	86.1	79.5	74.6	64.2	35.4	12.5
9/2	0.245	0.014	48.0	00.1	25.1	-1.4	-24.3	-28.2
9/3	0.528	0.557	72.7	74.2	65.9	69.7	26.0	45.5
9/4	1.429	2.022	85.1	88.3	77.9	80.6	24.2	34.7
9/5	0.853	1.274	74.4	81.6	62.2	71.3	7.8	34.4
9/6	0.367	1.162	61.4	87.3	37.4	72.3	-26.6	46.4
9/7	2.578	2.496	88.1	89.3	82.7	83.5	-12.9	43.8
9/8	4.219	2.870	92.0	90.1	88.6	86.0	75.0	64.2
9/9	2.451	1.097	86.8	78.1	84.7	71.1	57.6	30.8
9/10	1.555	0.699	78.4	63.4	69.4	45.6	41.2	-79.6
9/11	1.617	1.240	78.2	75.7	65.3	64.5	41.0	40.0
9/12	1.043	2.070	67.0	82.3	58.6	65.9	20.6	41.4
9/13		0.743		69.2		49.3		-48.9
9/14		2.926		85.2		81.2		67.0
9/15		3.993		87.4		84.0		52.7

*For these columns, the effluent discharges were calculated using a lag time in days equal to the theoretical detention time.