AN ABSTRACT OF THE THESIS OF

Harold LeRoy Jensen III for the M. S. in Civil Engineering
(Name) (Degree) (Major)

Date thesis is presented August 25, 1966

Title ALUM COAGULATION IN CONJUNCTION WITH THE ACTIVATED SLUDGE TREATMENT OF CORN PROCESSING WASTE WATER

Abstract approved Redacted for privacy
(Major professor)

The treatment of waste water from a corn freezing process by activated sludge with the aid of alum coagulation was investigated. Both high and low energy level systems were observed with good flocculation occurring at the low energy level. Because poor flocculation occurs at high energy level conditions, alum was added to aid in floc formation. The effects of alum on the treatment system and the biological treatability of the waste were studied. The treatability of the waste, with respect to the reduction of Biochemical Oxygen Demand, Total Solids, and Volatile Solids, was related to alum dosage, detention time, and solids content in the aerator. Detention times of 24, 16, 10, and 6 hours with alum dosages of 0, 50, 100, and 200 milligrams per day per liter of aerator volume were used.

The following conclusions were reached.

1. The waste water investigated may be biologically treated to reduce the organic content by an activated sludge system.
2. The addition of alum to the aeration system produces an effluent low in organic content with a shorter detention time than that required without the use of alum.
3. The removal of total solids and volatile solids follow trends similar to the removal of BOD with the solids reduction being less efficient.
4. The reduction rates for the total solids and the volatile solids are essentially the same for similar aerator conditions.
5. Under the conditions of this investigation the maximum reduction rate for the BOD was approximately 1.7 mg BOD reduced/mg MLVS/day.

ALUM COAGULATION IN CONJUNCTION WITH THE ACTIVATED SLUDGE TREATMENT OF CORN PROCESSING WASTE WATER

by

HAROLD LEROY JENSEN III

A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1967

APPROVED:

Redacted for privacy

Professor of Civil Engineering
In Charge of Major

Redacted for privacy

Head of Department of Civil Engineering

Redacted for privacy

Dean of Graduate School

Date thesis is presented August 25, 1966

Typed by Opal Grossnicklaus

ACKNOWLEDGMENTS

The author wishes to express his appreciation to the following people and organizations for their part in the author's masters program:

To the United States Public Health Service for the financial assistance, without which the author's advanced studies could not have been undertaken.

To Dr. Donald C. Phillips for his much needed assistance, timely suggestions, and patience during the research and writing of this thesis.

To the faculty and staff of the Civil Engineering Department for the use of the facilities.

To Messrs W. R. MacClarence and V. K. Nicholson of the Birds Eye Division, General Foods Corporation who suggested the thesis topic and supplied the needed frozen corn to synthesize the feed.

To my fellow graduate students for their assistance.

And to my wife and my family for their patience and understanding support.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ALUM COAGULATION IN CONJUNCTION WITH THE ACTIVATED SLUDGE TREATMENT OF CORN PROCESSING WASTE WATER

INTRODUCTION

Since the beginning of the twentieth century the United States has evolved from an agricultural to an industrial society. In former times the processing and preserving of food was an individual matter or done commercially on a small scale. Because population densities were low throughout the nation and wastes were not concentrated at central processing plants, waste disposal was not a critical problem. This is no longer true. Today most of the food marketed and consumed in the United States has undergone some refining or preservation process. The modern-day food processing industry has developed large operations at single plants, essential in supporting and sustaining our present population at its high standard of living. But the improved diet, the convenience, the tastiness, the consolidation of plant operations, and the generally lower costs have been accomplished with increasing problems in waste management and disposal.

The food processing industry produces large amounts of organic wastes and has many problems that are peculiar to itself. Preservation processes are seasonal operations with a plant generally operating less than half of the year, coinciding with the time of the year that has low river flows and warm water. Quite often the personnel that handle the waste water treatment processes have limited knowledge in this field and also have other duties assigned. The waste fluctuates both in quality and quantity. Different products packed in the same plant may offer different treatment problems. One of the wastes that may be considered a major problem from the viewpoint of both quantity and difficulty of treatment is the waste water generated in the processing of corn.

During 1964, 1, 458, 700 tons of sweet corn were processed in the United States having a total value at the packing plant before shipment of $29, 918, 000 (22, p. 226). The population equivalent of the pack is 434, 000, 000 and required a total of 5, 840, 000, 000 gallons of water. In 1964 there were 37, 551, 000 cases of corn canned (22, p. 259), 159, 846, 000 pounds of cut corn frozen, and 27, 757, 000 pounds of corn-on-cob frozen (22, p. 260).

Waste water from the processing of corn is typified by a high concentration of organic matter. The five day, 20 degree centigrade, Biochemical Oxygen Demand (BOD_{20}^{5} or BOD) ranges from 500 mg/l to 4000 mg/l and the Total Solids (TS) range from 1500 mg/l to 9000 mg/l. The organic matter is mostly starch and other carbohydrates which readily decompose to acetic acids and after only a few hours of standing at room temperature the pH of the waste water may be as low as four. The waste water is low in both nitrogen and phosphate as compared to the BOD. Quantities of waste water from freezing and canning processes average about two gallons of water per pound of raw product.

Most of the waste water originates from washing of the product and the equipment. The origins of the organic load are blanchers and other cooking processes and water that has come in contact with the kernels or cob after the kernels are removed. Figure 1 is a schematic diagram of a corn freezing process.

The raw product is brought to the processing equipment by a dry conveying system. Husking of the ears is the first operation performed with all wastes being in the solid form. The kernels are then cut from the cob, washed, and inspected. Blanching is the next operation and provides a small volume of waste water that has a BOD greater than 20,000 mg/l. After a short time in the blanch water the kernels are cooled in water and are ready for packaging. The equipment is washed periodically and the resulting wash water has a BOD of 100 mg/l or less.

Not only is the flow unsteady, both organically and hydraulically, over a period of weeks but the flows change from hour to hour during the day. With a spill or when a blancher is drained a large organic shock load is produced. During lunch time or between shifts the equipment is cleaned, producing a small organic load but flow rates that may be twice normal. When the plant is not operating, such as

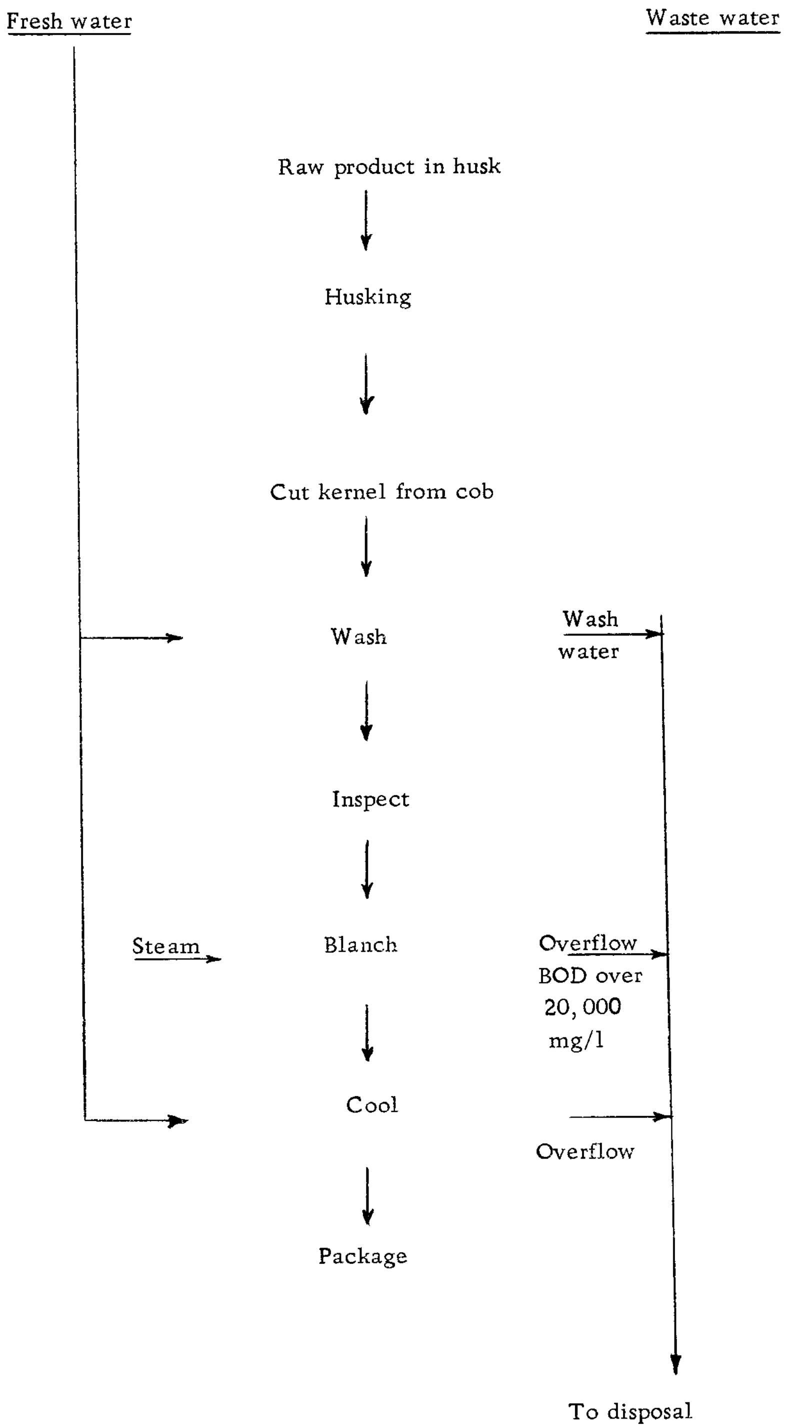

Figure 1. A corn freezing process.

when the night shift quits early, the flows may drop to near zero but on the start of the next shift the flow will be back to normal rates in a few minutes.

The food packing industry has, in the past, used three methods of treatment; lagooning, land disposal by either spray or ridge and furrow irrigation, and public sewer systems. Quite often the latter is not available since the population equivalent of the packaging plant may be larger than the city itself. The other two systems have been attractive since they require little skill, are inexpensive when land is readily available, and can handle the variable loading conditions.

However, land may not be available at an economically justifiable price or the degree of treatment must be higher than that obtained by methods commonly in use now. Under these conditions the method of activated sludge treatment may be used.

An activated sludge treatment facility generally gives high organic removals and requires little land. Start up time at the beginning of a packing season would be a few days. Also, this system could be placed in conjunction with a lagoon system for expanding plants.

Due to the high concentration of organic matter in corn processing waste water, a biological treatment facility will be loaded very heavily. A microbiological system that has large quantities of food present will have very active organisms, resulting in a high energy level for the system. Activated sludge systems that operate at high energy conditions generally have poor flocculating characteristics.

In an activated sludge system, floc formation is of primary importance because the active organisms are removed from the effluent by flocculation and settling. In order to aid in the sludge removal from the effluent stream of a corn waste water treatment facility, a flocculation aid may be added. Alum is often used as a flocculation aid. This investigation, therefore, was the study of the treatment of corn processing waste water by activated sludge and the effects of alum on this treatment process.

REVIEW OF LITERATURE

A review of the literature revealed that waste waters from the processing of corn by canning, freezing, wet milling, and corn chip production, are quite similar.

Drake and Bieri (2) found the waste water from a freezing process had an average BOD of 1930 mg/l and an average Chemical Oxygen Demand (COD) of 2754 mg/l. Halvorson _et al._ (7), reporting on a canning process, observed a range of BOD from 1200 to 4000 mg/l with solids data also fluctuating greatly. They reported the pH to be usually neutral but would become acidic upon standing, with the pH going as low as 3.5 at times.

The wet milling process was studied by Foley _et al._ (3), Hatfield _et al._ (9), and Greenfield _et al._ (5). Foley reported an average BOD of 2200 mg/l, total solids of 8875 mg/l, and organic solids of 2390 mg/l. Both Hatfield and Greenfield reported adding some form of nitrogen to the waste during treatment. Porges (20) reported on wastes from processing corn chips, showing a BOD of 2700 mg/l. A summary of the six references is tabulated in Table 1.

Due to large amounts of corn steep being wasted by some corn processing operations in which the grain is given a preliminary soaking, studies have been made to find some economic use of this waste water. It has been found that the corn steep has some biological growth stimulants that are used by some bacteria.

Table 1. Summary of corn processing waste waters.

Reference	Process	BOD mg/l	Total Solids mg/l	Volatile Solids mg/l	During Treatment Added N	During Treatment Added PO_4
Drake	Freezing	1930			yes	no
Halvorson	Canning	1200 to 4000	1500 to 8000	1400 to 7000		
Foley	Wet Milling	2200	8900	2400	no	no
Hatfield	Wet Milling	500 to 2000			yes	yes
Greenfield	Wet Milling				yes	no
Porges	Corn Chips	2700				

Kennedy et al. (12) reported the effects of these stimulants on Lactobacillus casei in both aerobic and anaerobic conditions. They found that the logarithmic growth phase was shortened and carbon dioxide production increased by two and one-half times in two hours in the anaerobic condition. However, there was little change in growth in the aerobic condition.

Zuraw et al. (24) reported that three stimulants had been isolated and one identified as a phenylalanine. The other two were also thought to be some form of an amino acid.

Gundersen (6) studied the effects of these growth factors on the autotrophic nitrifying bacteria, Nitrosomonas europaea. It was found that cultures with corn steep in the media showed a nitrite production six to seven times greater than the control after six days, but the total production for each culture was about the same at 14 days. The growth rates were the same when the ash of corn steep was used in the media. Gundersen showed that doses of 0.1% corn steep gave the largest stimulant effect. Less concentrations had no effect and greater tended to inhibit growth.

Like all biological systems, an activated sludge system is dependent on its environment to dictate the type of balance reached. This type of system is especially dependent on the quality and quantity of the feed. The substrate need not be balanced but the extent of biological activity will be limited to an established level by the substrate component of least relative supply. This was shown by Komolrit and Gaudy (13) in their studies of qualitative shock loadings. They demonstrated that the carbon to nitrogen ratio must be within a certain range or either the carbon or nitrogen will be limiting. They also showed that as long as the rate of new cell production correspond to the feed rate (was not exceeded by the feed rate), all of the feed would be biologically acted upon.

Genetelli and Heukelekian (4) reported on the relationship between substrate chemical composition and new sludge production. They found that a carbohydrate feed produced the largest amount of new sludge when compared to protein or amino acid substrates. The value found for a glucose and ammonia nitrogen substrate was 67.8 to 69.8 g. per 100 g. BOD reduced. It was also found that the carbohydrate fed sludge bulked more readily then sludge fed the other types of feed.

Heukelekian _et al._ (11) found that the rate of accumulation of sludge in activated sludge aerators is a function of the feed BOD and the volatile solids in the aerator. They established that this accumulation rate is more dependent on the feed BOD than the mixed liquor volatile solids. However, Washington and Symons (23) related the sludge accumulation only to the feed BOD and Kountz and Forney (14) related it to the amount of activated sludge.

Flocculation is one of the more important reactions that take place in the activated sludge process. McKinney (18) states that the development of a floc in a biological system is dependent on agitation, energy in the system, intensity of charge on organisms, and van der Waals forces. When the energy of a system is high, the organisms are in the logarithmic growth phase, there is much movement of the individual cells and this movement will prevent large floc formations. McKinney also stated that high-rate activated sludge processes have higher energy levels and thus poorer flocculation than normal activated sludge processes.

Hartman (8) reported on floc formation and settling. He stated that the organic nitrogen content of the sludge is a good indication of the sludge settleability since this content is related to the sludge age.

The activated sludge treatment of corn processing waste water has been done with as much as 90% removal of BOD (3, 5). Folley _et al._ (3) reported aerator loading rates as high as 280 lb. BOD/1000 cu. ft. /day. High loading rates are not uncommon in the treatment of this waste water.

EXPERIMENTAL PROCEDURE

Experimental

Biological reduction of the concentration of organic matter from corn processing waste water by the activated sludge process was investigated using completely-mixed, continuously-fed activated sludge units. Alum was used in the aerators as a coagulant and its effect on the system was studied. A synthetic waste water was prepared from frozen corn to represent a waste water from a plant freezing corn. The removal of BOD, total solids, and volatile solids were recorded and related to detention times in aerator, solids content in aerator, and alum dosage rates.

Detention times of 6, 10, 16 and 24 hours were investigated. One of the aerators to which no alum was added was reserved as a control. To the other two aerators, different dosages of alum were added in accordance with the experimental plan shown in Table 2. The same feed was used throughout the testing period. Nitrogen and phosphate were added to the feed in proper amounts to allow unhindered biological reactions.

The aerators were made of acrylic tubes as shown in Figure 2. Air entered the aerator through a porous stone placed at the lower end of the central tube. The liquid circulated up through the tube

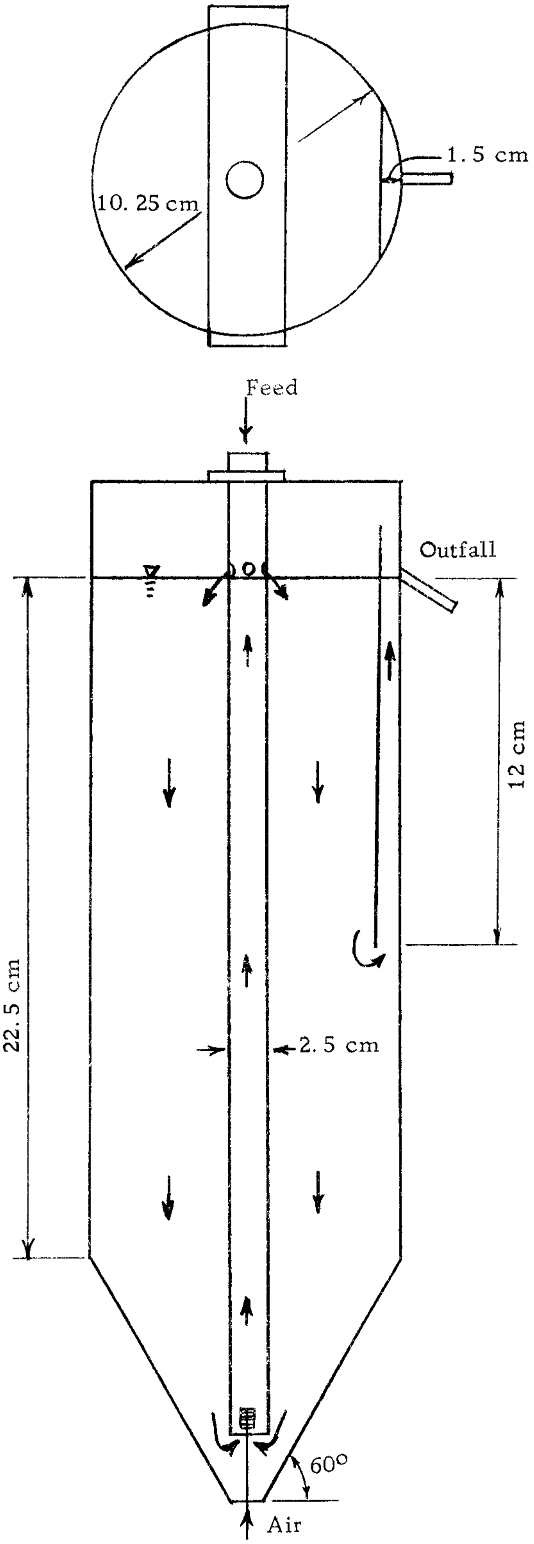

Figure 2. Experimental aerator.

and out four holes just above the water level, thus supplying the required mixing and oxygen to the system. The only control of the air supply was to maintain some dissolved oxygen in the aerator at all times and to supply adequate mixing. For most of the tests the dissolved oxygen concentration was greater than 2 mg/l.

Table 2. Experimental plan.

Detention Time Hours	Alum Dose--mg alum/l of aerator/day		
	Unit 1	Unit 2	Unit 3
6	0	100	200
10	0	100	200
16	0	100	200
24	0	100	50

The feed was pumped to the aerator from a central, refrigerated supply maintained at 2° C. Agitation was provided in the storage container to maintain a uniform feed supply. The feed was put into the mixed liquor at the top of the central tube so that the feed would be uniformly mixed throughout the aerator. Metering pumps (Brosites-Model R) were used to pump the feed from the supply container to each aerator. These pumps were controlled by a cyclic timer (Multi-Cam Timer Kit, Industrial Timer Corporation). The pumps were timed so that all would pump at the same time for the required number of seconds. The total cycle was from five to 20 minutes.

The feed supply was maintained near 1600 mg/l BOD and made to represent the waste water that might come from a freezing plant. About 175 pounds of unblanched waste corn kernels and some husks were frozen in 20 pound cans at the Woodburn, Oregon plant of the Birds Eye Division of General Foods Corporation during the 1965 packing season. Later the corn was thawed, blended in a Waring Blendor, and passed through a 20 mesh screen. This concentrated feed was put into quart size plastic bags and refrozen. When needed, the concentrated feed was thawed and diluted with tap water to the proper concentration. Since the feed was found to be low in both nitrogen and phosphate concentrations, urea and dibasic potassium phosphate were added when the feed solution was mixed. Amounts were added to make a BOD : N : PO_4 ratio of 100 : 5 : 1. Any nitrogen or phosphate originally in the corn was an extra supply.

Twice daily, alum was supplied to the aerators. A standard solution of ten grams aluminum sulfate per liter of water was used. From this the desired amount of alum was pipetted into the most turbulent section of the aerator.

For pH adjustment, a lime solution was pipetted into the aerator following the addition of the alum. The standard solution used was five grams lime per liter of water. The pH was maintained between seven and eight.

Analysis

For each detention time investigated, the aerators were operated for a period of time to bring the system to equilibrium. When conditions were determined to be at equilibrium, as evidenced by uniformity of total solids reduction, testing was started. A test was conducted in one day with all measurements made and samples taken within a few hours time. The following is a chronological outline of the sampling and testing period:

1. Effluent sampling period was started no sooner than 1.5 hours after an alum and lime application. The effluent was accumulated until the desired volume was obtained.
2. When the effluent sampling was completed each sample was swirled and allowed to settle for 1.5 hours in the refrigerator. During this time the feed samples and the aerator solids samples were taken and the temperature, pH, and dissolved oxygen readings were made.
3. After the effluent had settled the required time the supernatant was poured off to be used in the solids and BOD tests. The solids and BOD tests were then run on the feed and effluent.

The analyses performed are shown in Table 3. All testing was conducted in accordance with the procedures outlined in Standard Methods for the Examination of Water and Wastewater (1). The sampling procedures and methods of sample handling were as follows:

BOD-- Five day, 20° C. Two different dilutions made for each sample. Seed used was supernatant of a settled activated sludge that was fed the same feed used in the research.

Total Solids-- 50 ml samples dried for at least 12 hours at 103° C.

Volatile Solids-- The total solids samples were fired at 600° C.

Suspended Solids-- 25 ml Gooch crucibles were used with a filter media of one half centimeter of Celite placed on top of a glass fiber filter paper. The sample was dried for at least 12 hours at 103° C.

Temperature-- Taken with a mercury thermometer right after the sampling period.

pH-- Taken with a Beckman Model H2 pH meter right after the sampling period.

Dissolved Oxygen-- Beckman Oxygen Analyzer Model 777 with readings taken after the sample period.

Flow Rate-- The effluent samples were collected over a period of time. Rates were computed from the sample volume and sampling time.

Table 3. Research Analyses Performed.

Test or Data	Feed	Mixed Liquor	Effluent
BOD	X		X
Total Solids	X	X	X
Volatile Solids	X	X	X
Suspended Solids	X		X
Temperature		X	
pH		X	
Dissolved Oxygen		X	
Flow Rate			X

RESULTS

The results of this research indicate that waste water from corn freezing processes is readily amenable to biological treatment. This is shown in the data obtained from the 24 hour detention time tests with no alum. The average BOD reduction was 98.9%, the average total solids reduction was 93.4%, and the average volatile solids reduction was 98.0%.

The results also indicate that for ten and 16 hour detention times, the addition of alum is beneficial. By adding alum the detention time can be reduced from 24 hours to 16 or ten hours and yet maintain high removal efficiencies. With a detention time of ten hours and alum added at the rate of 200 mg per day per liter of aerator volume, the average BOD reduction was 92.5%, the average total solids reduction was 80.7%, and the average volatile solids reduction was 87.6%. Table 4 gives a summary of average results.

One of the conditions that changed throughout the testing period was the solids content in the aerator. When operating with a 24 hour detention time very little sludge was wasted. As a result the sludge built up at a rate between 10% and 15% of the BOD reduced. When the units ran with 16 and six hour detention times all sludge wasting was done through the effluent. For the ten hour detention time, sludge was wasted daily from the aerator.

Table 4. Average percentage removal of BOD, total solids and volatile solids for varying detention times and alum dosages.

Detention time hours	Alum Dosage - mg/l aerator/day											
	0			50			100			200		
	BOD %	Total solids %	Volatile solids %	BOD %	Total solids %	Volatile solids %	BOD %	Total solids %	Volatile solids %	BOD %	Total solids %	Volatile solids %
6	64.8	52.9	55.7				72.1	59.0	62.8	61.6	47.2	51.2
10	76.9	65.3	67.9				90.7	86.2	91.1	92.5	80.7	87.6
16	78.5	55.2	58.7				87.8	69.3	74.7	92.0	75.2	83.2
24	98.9	93.4	98.0	98.5	91.8	96.5	97.3	86.7	94.3			

When the aerators were run at the six hour detention time the maximum physical limitations of the aerators were reached. The oxygen transfer was the controlling limitation. Due to the high air flow rate the system was mixed vigorously and may have churned some of the solids out of the aerator and into the effluent.

The data are presented in graphical form in Figures 3 through 10 and are also tabulated in the appendix.

Figure 3 is a plot of the mixed liquor volatile solids (MLVS) multiplied by the detention time versus the percent reduction for the three indicators (BOD, total solids, and volatile solids (VS)). The units of the abscissa on this graph represent the amount of contact the feed has with the activated sludge. The MLVS is an indicator of the number of active organisms present in the aerator. By multiplying the MLVS by the detention time a relative contact of organisms with feed may be obtained.

Figure 4 is a plot of the MLVS multiplied by the detention time versus the milligrams of indicator reduced per milligram of MLVS per day. The units of milligrams of indicator reduced per milligram of MLVS per day is a measure of the amount of reduction per unit of organic sludge per day. The weight units used are irrelevant because the ratio is of like units and the expression is a rate value with a dimension of per time. This rate value will be termed the reduction rate.

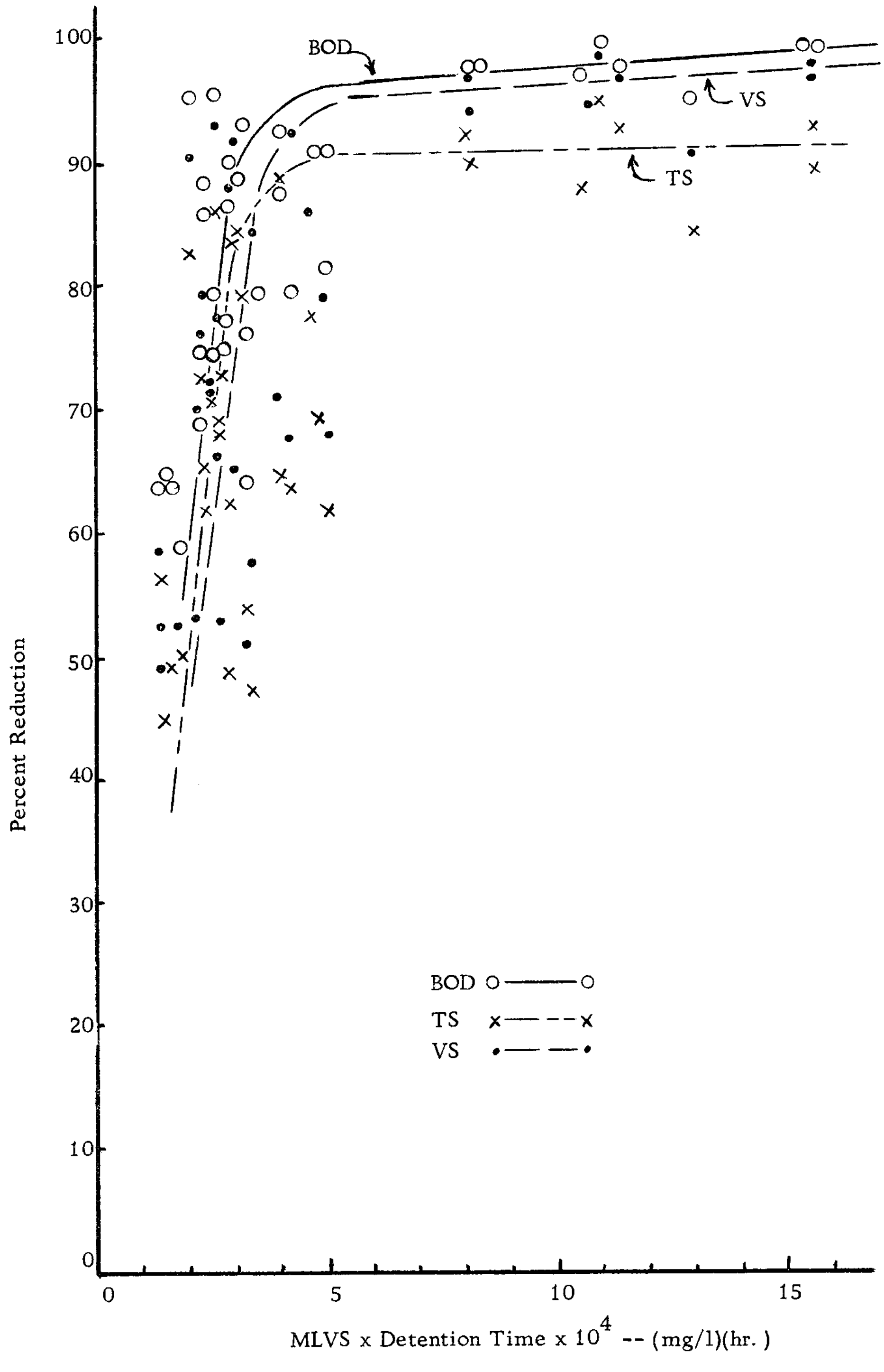

Figure 3. Relative contact of organisms with feed related to the efficiency.

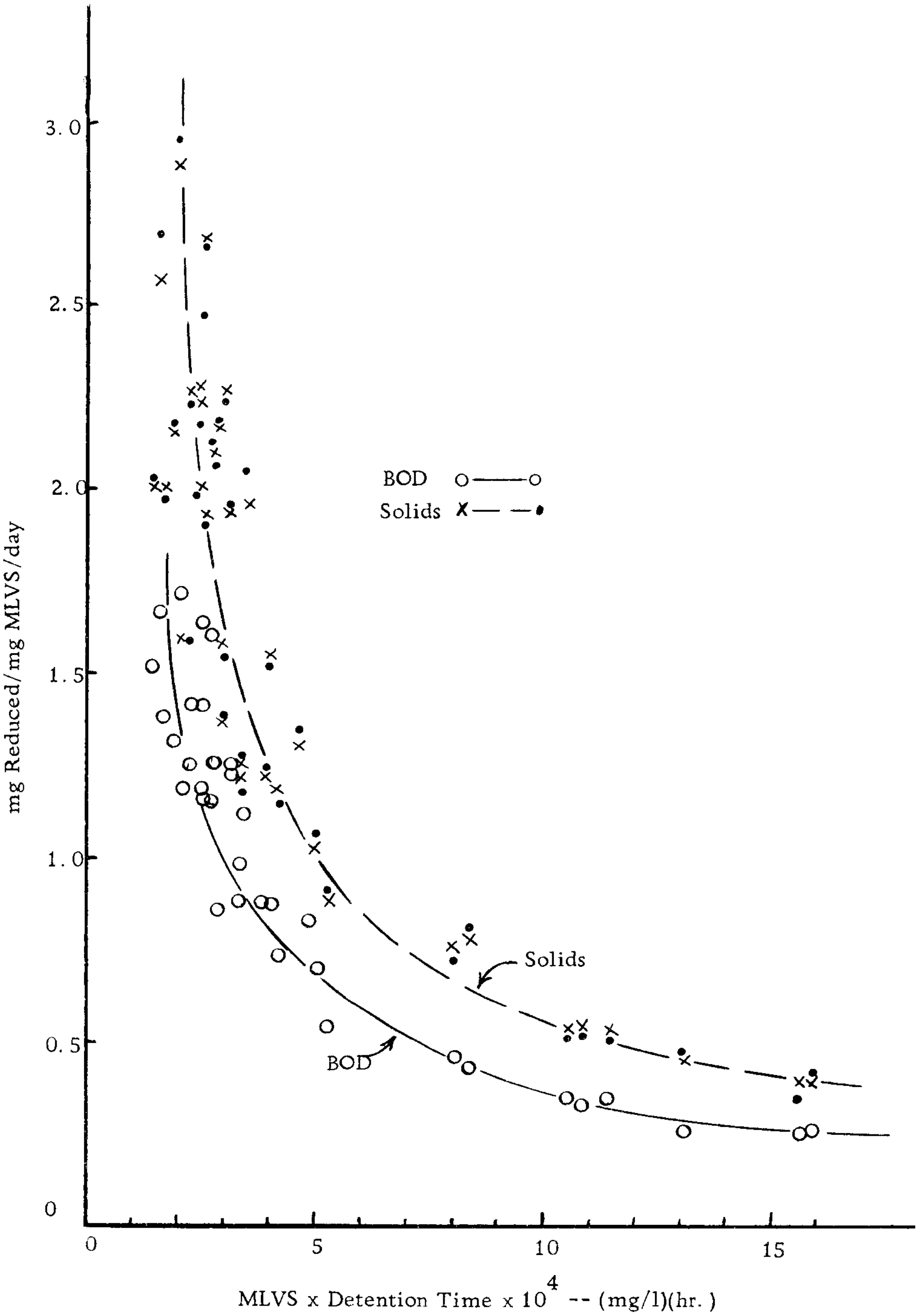

Figure 4. Relative contact of organisms with feed related to the reduction rate.

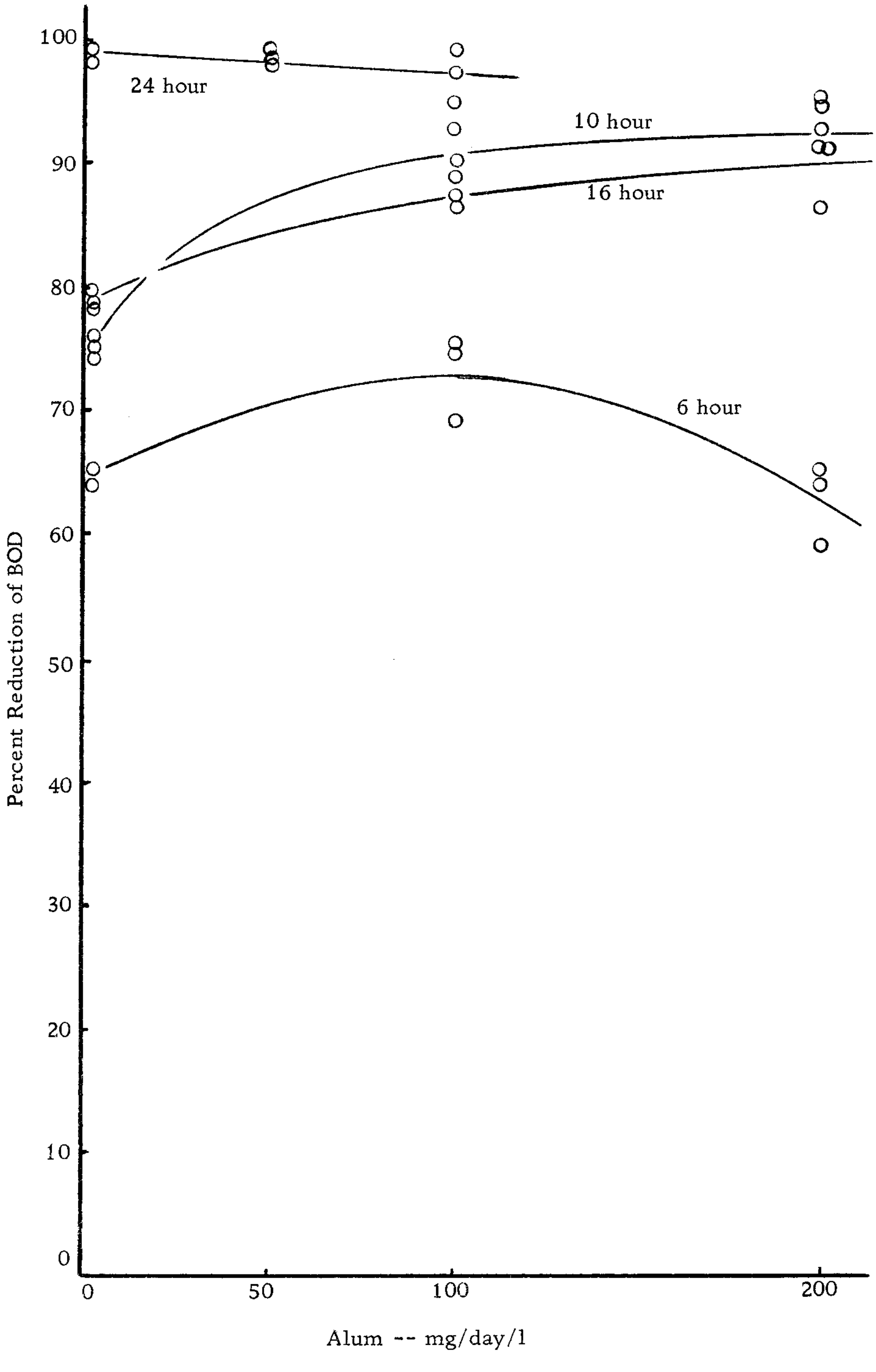

Figure 5. The effects of alum application on the efficiency of BOD reduction.

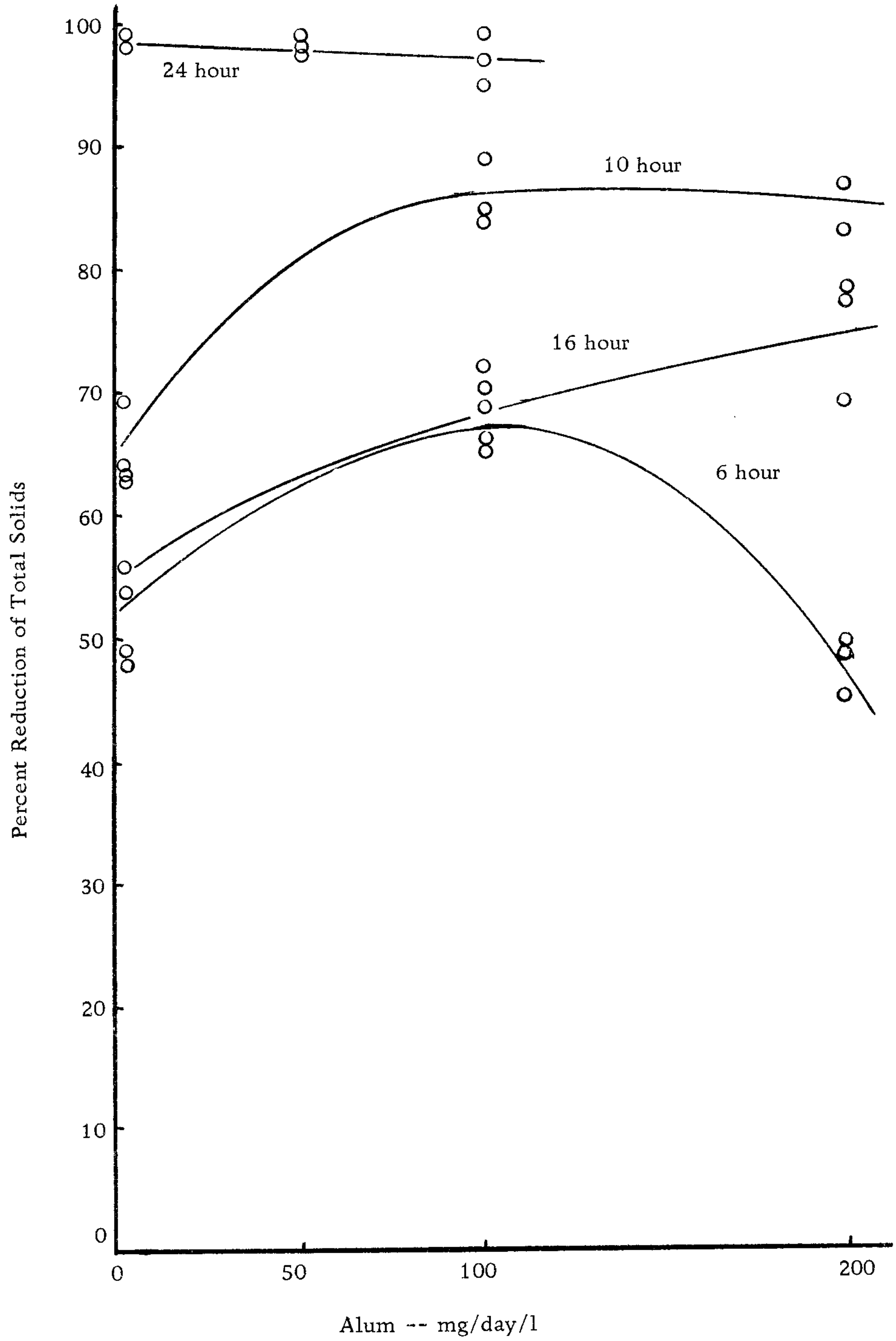

Figure 6. The effects of alum application on the efficiency of total solids reduction.

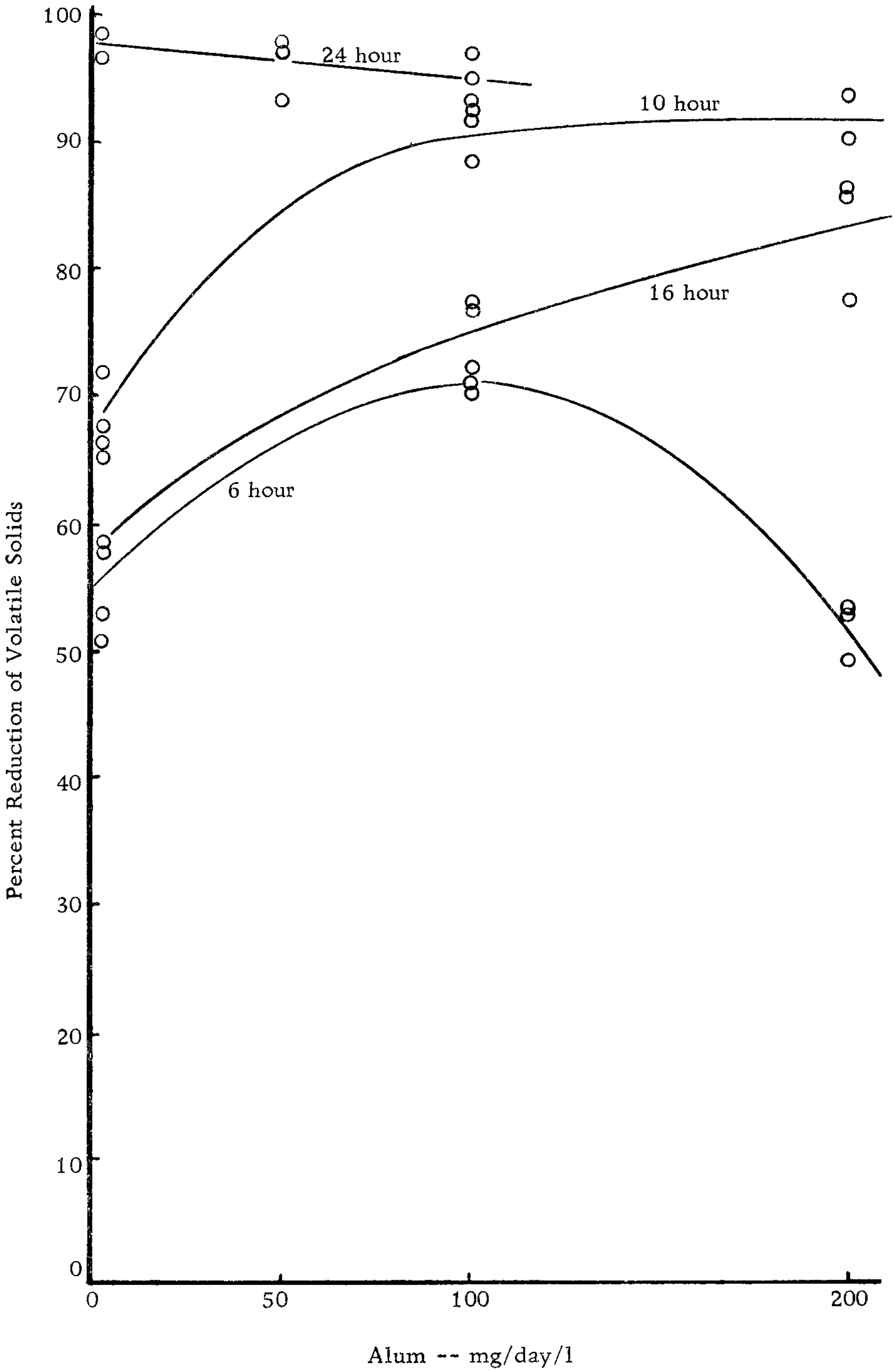

Figure 7. The effects of alum application on the efficiency of volatile solids reduction.

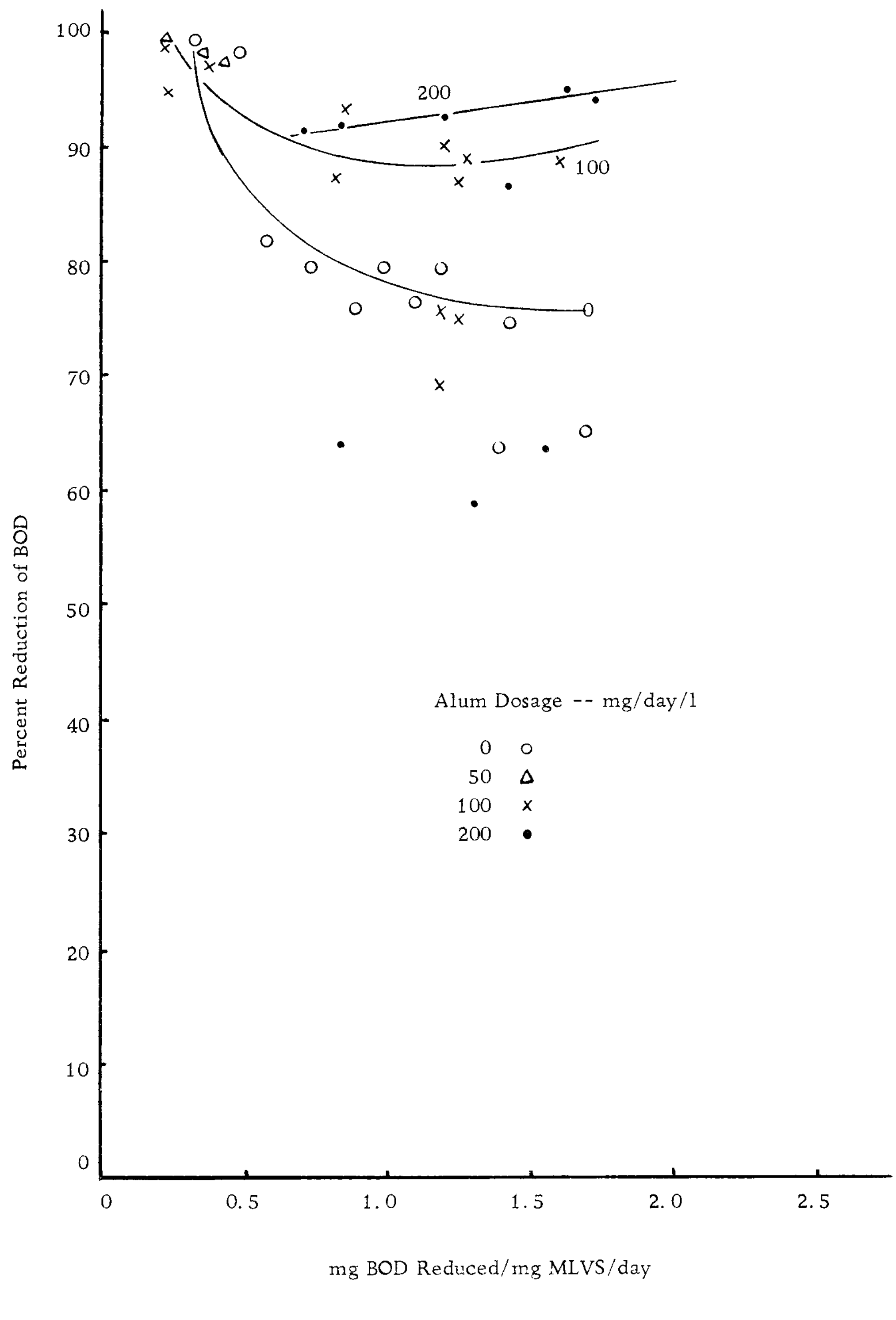

Figure 8. Relationship between reduction efficiency and reduction rate for BOD.

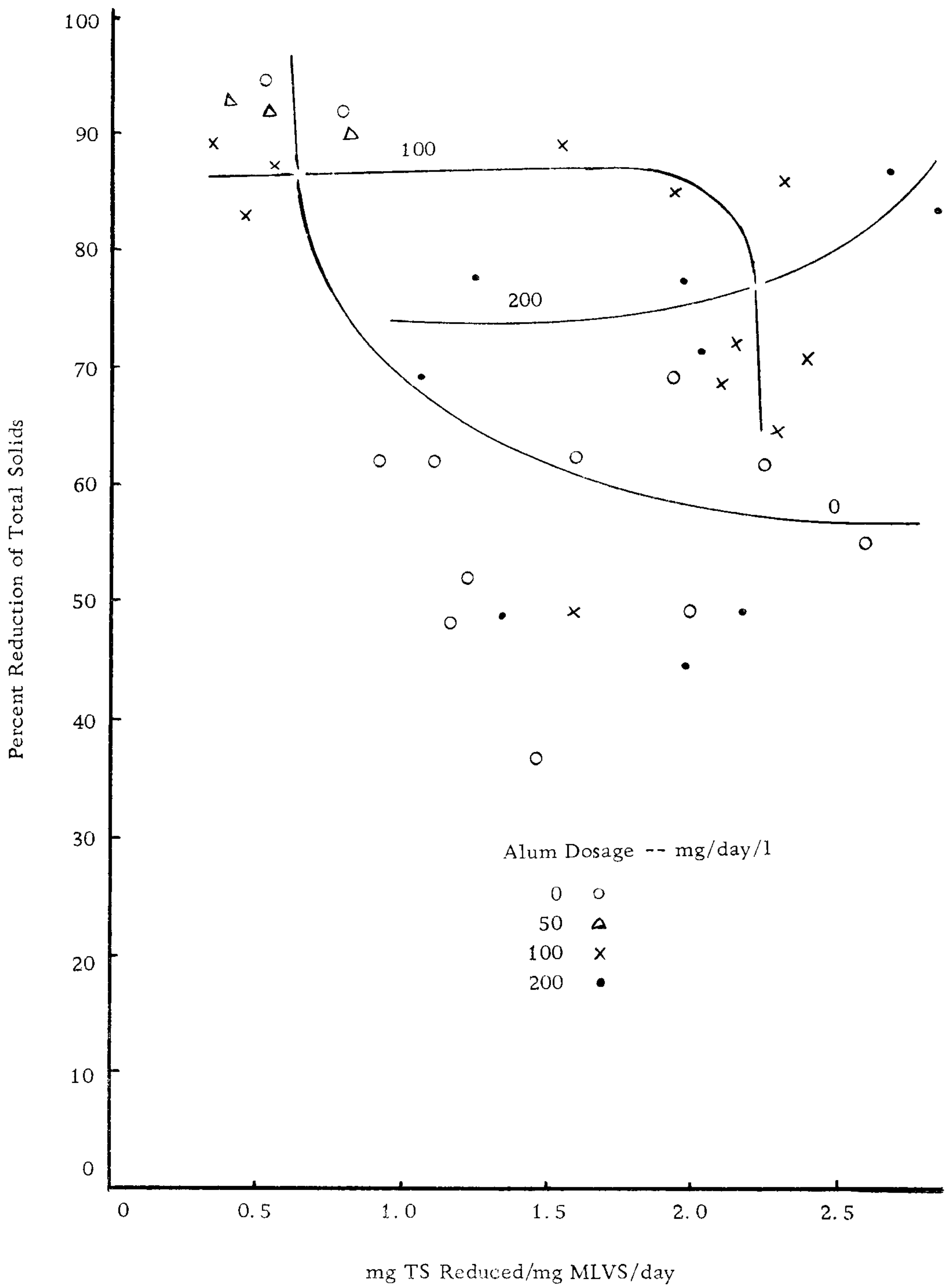

Figure 9. Relationship between reduction efficiency and reduction rate for total solids.

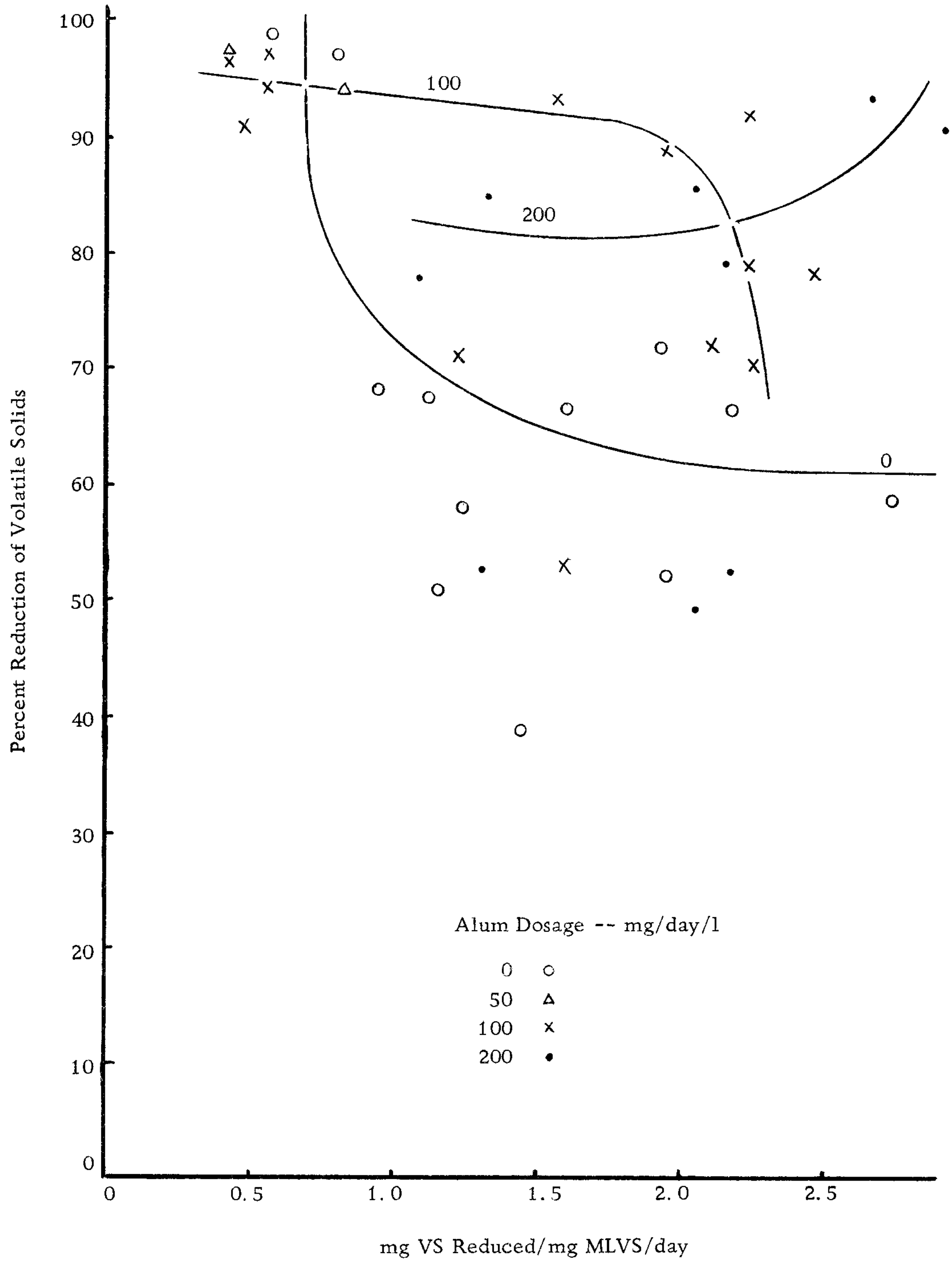

Figure 10. Relationship between reduction efficiency and reduction rate for volatile solids.

It may be seen from these two graphs that the BOD, TS, and VS data all follow the same trends. The reduction rates of the solids were higher than that of the BOD. Because the solids concentration in the feed was much higher than that of the BOD the solids reduction rate would be higher than that of the BOD.

To be noted also is the fact that the reduction rates for the two types of solids, under similar aerator conditions, are essentially the same. This may indicate that most of the solids removed from the waste were organic. An activated sludge system is designed to remove organic matter. Because very few inorganic salts are used in the biological process, the salts will pass through the treatment system unaltered and only the inorganic matter which is settleable will be removed.

Two inorganic salts were added to the aerator and recorded in the effluent and not in the feed. Therefore, the percent reduction of total solids was less than that of the volatile solids as may be seen in Figure 3. It may also be seen that the percent reduction of the BOD was the highest of the three indicators.

Figure 5 is a plot of the percent reduction of BOD versus the amount of alum added for each detention time. The alum was measured as milligrams per day per liter of aerator volume. This graph demonstrates the effect of alum additions on the reduction of BOD. The data for the 24 hour detention time indicate a decrease in removal efficiency with alum additions. For the six hour detention time the removal efficiency increases for the first 100 mg alum/day/l added but decreases with alum added in larger dosages.

Figure 6 is a plot of the percent reduction of total solids versus alum additions for different detention times and Figure 7 is a plot of the percent reduction of volatile solids versus alum additions for the different detention times. The data presented in these two graphs also show a decrease in reduction efficiencies with alum addition for the 24-hour detention time. The ten and 16 hour detention times have an increase in reduction efficiencies with alum additions and the six hours detention time has a maximum removal efficiency at about 100 mg alum/day/l. It is noted that Figures 5, 6, and 7 indicate the same trends.

The data on these graphs for the ten and 16 hour detention times indicate that the addition of alum did aid in the treatment process by increasing the removal efficiency for each indicator. However, the relationship between alum additions and efficiencies was not a linear function. The data indicates that with each increment of alum the extra benefit gained, decreased. Because it was assumed that the addition of alum to an aerator would aid flocculation and thus aid removal of the solid matter from the effluent, it may be further assumed that the alum was not used to its fullest extent as a coagulant under all conditions. This is to be expected because with larger amounts of alum present, the concentration of free organisms (not flocculated) will decrease.

The phenomenon of decreasing efficiencies with increasing alum dosage rates noted in the 24 hour detention time data is a contradiction of the ten and 16 hour detention time data. The decrease in efficiencies is small but is noted for all three indicators.

Figure 8 is a plot of the reduction rate of BOD versus percent reduction for each alum dosage rate. The reduction rate is a measure of the activity level of the system. At a reduction rate of one, a mass of organisms uses its own weight of oxygen per day. Figure 8 is a relationship between the level of activity in the aerator and the efficiency of BOD removal for different alum additions.

To be noted in this graph is the fact that when no coagulant was added to the system the efficiency decreased with increasing reduction rates. The more active the organisms, and thus the higher their energy level, the less efficient the system became. When alum was added greater BOD removals were obtained. When 200 mg/day/l of aerator volume of alum was added to the systems with high reduction rates, the efficiency increased with increasing reduction rates. This is of special interest because it is a reversal of the results noted in systems with low reduction rates and systems with no alum added.

A number of points in Figure 8 are below an efficiency of 75%

and are not in agreement with other data of similar alum dosages. These points represent the data gathered from the six hour detention time. It is also noted that no condition exceeded the BOD reduction rate of 1.8 mg BOD reduced/mg MLVS/day. The largest reduction rates were reached during the ten and 16 hour detention times.

Figure 9 relates the total solids reduction rate to the percent reduction of total solids for each alum dosage rate and Figure 10 relates the same conditions with respect to the volatile solids. The same trends are noted in the solids data as in the BOD data.

In the solids data, the reduction efficiency obtained is less for 200 mg alum/day/l added than 100 mg alum/day/l added. However, aerators with alum added had higher efficiencies than the aerators without alum. The six hour detention time data is in the lower efficiency portion of the graph and does not fit with the other data.

For all three indicators, the largest reduction rate obtained was at the ten and 16 hour detention time conditions. The phenomenon of lower efficiencies and reduction rates for the six hour detention time could have been caused by activated sludge leaving the aerator in the effluent or by some of the organic matter in the feed not being biologically acted upon. It is felt that the latter condition was the case and that a maximum reduction rate for the investigated feed may exist.

A maximum reduction rate would be the maximum amount of feed that a unit of activated sludge could biologically reduce. The bacteria and other organisms reach their ultimate sustained activity rate during their logarithmic growth phase. At feed concentrations greater than that required to maintain the organisms in the logarithmic growth phase the excess feed will not be utilized.

The following is a discussion of conditions that could have existed within the aerators and is offered as a possible explanation of the observed data. The following assumptions are made and will be discussed.

1. Activated sludge is removed from the effluent by settling.
2. The activated sludge must form a floc before settling will occur.
3. The microorganisms of the activated sludge have a negative charge with an intensity related to the energy level of the system.

Bacteria may be considered colloidal matter with a negative electrical charge of variable intensity. As shown in the work by McKinney (18), the intensity of the charge is related to the activity of the organisms, the more active the bacteria the greater the intensity of charge.

When the system is at a low energy level, van der Waals forces hold the bacteria together to form floc particles. As the energy level increases, and thus the electrical charge on each cell increases, the repelling force between cells increases. When the energy level of the system is large enough to render the van der Waals forces ineffective, poor floc formation results.

The activated sludge is removed from the effluent by settling. In order for a sludge to settle a floc must form. As the floc forms and becomes larger the center cells are unable to get food and/or oxygen. This results in either an anaerobic condition or cell death. Also, inorganic products of biological decomposition accumulate in the floc center. Each of these resulting conditions in the floc core increases the density of the unit and increases settleability. Therefore, a floc must form and stay formed for a length of time before the sludge will show good settling characteristics.

The purpose of the alum addition was to supply the system with plus three electrically charged aluminum ions to aid in floc development. There were other negatively charged units in the aerator besides the bacteria. Sulfate ions were added to the system as part of the alum. Hydroxide ions were present as well as phosphate ions added as a growth requirement. The only ions present with a negative three charge were the phosphate ions, all others had a negative one or two charge. Ions with the larger negative charges had the strongest attraction to the aluminum ion (largest charge differential). It is felt that as the charge on the bacteria increased the bacteria became more competitive with the negative ions for the aluminum ions. Since the intensities of the charge on the bacteria were not measured during this investigation the extent of competitiveness of the bacteria is not known.

This would account for results recorded in Figures 8, 9, and 10 showing the reduced efficiencies where no alum was added and the increasing efficiencies with increasing reduction rates at high alum applications. It would also account for the increase in efficiencies of the systems when alum was added.

An explanation for the reduction in efficiency at the 24 hour detention time when alum was added may be made. It is felt that the system was operating at a low energy level during the 24 hour detention time. Thus, the phosphate ions may have been combining with the aluminum ions quite readily, removing the phosphate from biological activities. If sufficient amounts of phosphate were removed, growth would be inhibited and thus the system's efficiency would be reduced.

The investigator feels that when the aerators were operated at the six hour detention time the system was biologically overloaded. For this reason, it is felt, the data was inconsistent and no explanation is attempted for the relationship between alum dosage and reduction efficiencies.

Also, no explanation is offered for the solids data indicating greater reduction efficiencies for an alum addition of 100 mg/day/l than for 200 mg/day/l.

CONCLUSIONS

As a result of this study the following conclusions are made.

1. The waste water investigated may be biologically treated to reduce the organic content by an activated sludge system.

2. The addition of alum to the aeration system produces an effluent low in organic content with a shorter detention time than that required without the use of alum.

3. The removal of total solids and volatile solids follow trends similar to the removal of BOD with the solids reduction being less efficient.

4. The reduction rates for the total solids and the volatile solids are essentially the same for similar aerator conditions.

5. Under the conditions of this investigation the maximum reduction rate for the BOD was approximately 1.7 mg BOD reduced/mg MLVS/day.

SUGGESTIONS FOR FURTHER STUDY

The entire concept of high energy activated sludge systems could be studied further. Some of the phases that could be investigated are:

1. Define a high energy level system in terms of sludge settling characteristics, intensity of bacteria charge, or organic reduction rates.
2. Measure the charge intensity of the bacteria at different system energy levels. Two methods of altering the energy of a system are changing the reduction rate of organic matter and changing the temperature levels.
3. Study sludge buildup in high energy systems.
4. Investigate different flocculation aids in high energy systems.
5. Study effects of shock loadings on high energy systems.
6. Investigate a two or more stage aeration system (aerators in series) for wastes that are high in organic loadings.

A further study that is suggested for the waste water and feed used in this investigation is:

1. Development of an economic model that industries could apply to their own case in sizing an activated sludge plant that uses alum as a flocculation aid.

BIBLIOGRAPHY

1. American Public Health Association. Standard methods for the examination of water and wastewater. 12th ed. New York, 1965. 769 p.

2. Drake, James A. and Fred K. Bieri. Strength of wastes from frozen food processing. In: Proceedings of the Fifth Industrial Waste Conference, Lafayette, Indiana, 1949. p. 79-109. (Purdue University. Extension Series no. 72)

3. Foley, Marion B., Roger J. Mauterer and G. James Dustin. Aerobic oxidation of corn wet milling wastes. In: Proceedings of the Tenth Industrial Waste Conference, Lafayette, Indiana, 1955. p. 173-185. (Purdue University. Extension Series no. 89)

4. Genetelli, E. J. and H. Heukelekian. The influence of loading and chemical composition of substrate on the performance of activated sludge. Journal of the Water Pollution Control Federation 36:643-649. 1964.

5. Greenfield, R. E., G. N. Cornell and W. D. Hatfield. Cornstarch processes. In: Proceedings of the Third Industrial Waste Conference, Lafayette, Indiana, 1947. p. 360-368. (Purdue University. Extension Series no. 64)

6. Gundersen, K. Influence of corn steep liquor on the oxidation of ammonia to nitrite by _Nitrosomonas europaea_. Journal of General Microbiology 19:190-197. 1958.

7. Halvorson, H. O., Dale W. Johnson and Henry Tsuchiya. The treatment of corn canning wastes. The Canner 90:12. January 20, 1940.

8. Hartmann, L. Activated sludge floc composition. Water and Sewage Works 110:262-266. 1963.

9. Hatfield, R. _et al._ Treatment of wastes from a corn industry by pilot-plant trickling filters. Sewage and Industrial Wastes 28: 1240-1246. 1956.

10. Heimbuch, A. H., L. W. Aurand and M. L. Speck. Some characteristics of a growth stimulant in corn steep liquor for _Lactobacillus casei_. Journal of Bacteriology 72:543-547. 1956.

11. Heukelekian, H., H. E. Orford and R. Manganelli. Factors affecting the quantity of sludge production in the activated sludge process. Sewage and Industrial Wastes 23:945-958. 1951.

12. Kennedy, H. E., M. L. Speck and L. W. Aurand. Studies on a growth stimulant from corn steep using Lactobacillus casei. Journal of Bacteriology 70:70-77. 1955.

13. Komolrit, K. and A. F. Gaudy, Jr. Biochemical response of continuous-flow activated sludge processes to qualitative shock loadings. Journal of the Water Pollution Control Federation 38: 85-101. 1966.

14. Kountz, R. Rupert and Charles Forney, Jr. Metabolic energy balances in total oxidation activated sludge system. Sewage and Industrial Wastes 31:819-826. 1959.

15. Ludzack, F. J., H. L. Krieger and M. B. Ettinger. Interactions of waste feed, activated sludge, and oxygen as traced by radioactive carbon. Journal of the Water Pollution Control Federation 36:782-788. 1964.

16. McCarty, Perry L. and C. F. Brodersen. Theory of extended aeration activated sludge. Journal of the Water Pollution Control Federation 34:1095-1103. 1962.

17. McKinney, Ross E. A fundamental approach to the activated sludge process. II A proposed theory of floc formation. Sewage and Industrial Wastes 24:280-287. 1952.

18. McKinney, Ross E. Biological flocculation. In: Aerobic oxidation, ed. by Brother Joseph McCabe, F. S. C. and W. W. Eckenfelder, Jr. New York, Reinhold, 1956. p. 88-100. (Conference on Biological Waste Treatment. Biological treatment of sewage and industrial wastes. Vol. 1)

19. McKinney, Ross E. Microbiology for sanitary engineers. New York, McGraw-Hill, 1962. 293 p.

20. Proges, Ralph. Wastes from the processing of corn chips. Journal of the Water Pollution Control Federation 32:182-185. 1960.

21. Sawyer, Clair N. Chemistry for sanitary engineers. New York, McGraw-Hill, 1960. 367 p.

22. U. S. Department of Agriculture. Agricultural statistics 1965. Washington, 1965. 635 p.

23. Washington, Donald R. and James M. Symons. Volatile sludge accumulation in activated sludge systems. Journal of the Water Pollution Control Federation 34:767-789. 1962.

24. Zuraw, E. A. et al. Purification of stimulants from condensed corn-fermentation solubles active for Lactobacillus casei in milk. Journal of Bacteriology 80:457-463. 1960.

APPENDIX

Table A1. Twenty-four hour detention time data.

Item	Alum	Influent and Effluent				MLTS	MLVS	Detention	Lime	pH
		BOD	TS	TVS	SS			Time		
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	hours	mg/l	
Feed		1395	2570	2420	992					
Aerator - 1	0	5	138	24	--	4514	4216	26.0	0	7.8
% Reduced		99.6	94.6	99.0						
Red. Rate		0.30	0.53	0.52						
Aerator - 2	50	8	180	50	8	6714	6054	25.9	0	7.7
% Reduced		99.4	93.0	97.9						
Red. Rate		0.21	0.37	0.36						
Aerator - 3	100	10	278	74	20	6636	5888	26.7	50	7.5
% Reduced		99.3	89.2	96.9						
Red. Rate		0.21	0.35	0.36						
Feed		1530	2754	2600	770					
Aerator - 1	0	29	216	72	80	3402	3126	25.9	0	7.6
% Reduced		98.1	92.2	97.2						
Red. Rate		0.44	0.75	0.75						
Aerator - 2	50	24	212	64	90	5462	4940	23.2	0	7.5
% Reduced		98.4	92.3	97.5						
Red. Rate		0.32	0.54	0.53						
Aerator - 3	100	40	352	128	140	5342	4762	22.4	25	7.1
% Reduced		97.4	87.2	95.1						
Red. Rate		0.33	0.54	0.56						
Feed		1438	2972	2858	760					
Aerator - 1	0	257	1100	912	970	2590	2432	21.0	0	7.2
% Reduced		82.1	63.0	68.1						
Red. Rate		0.55	0.88	0.91						
Aerator - 2	50	32	298	170	115	4312	3962	20.8	0	7.1
% Reduced		97.8	83.7	94.0						
Red. Rate		0.41	0.78	0.78						
Aerator - 3	100	70	484	258	110	6200	5584	23.3	25	7.3
% Reduced		95.1	90.0	91.0						
Red. Rate		0.25	0.46	0.48						

Table A2. Sixteen hour detention time data.

Item	Alum mg/l	Influent and Effluent: BOD mg/l	TS mg/l	TVS mg/l	SS mg/l	MLTS mg/l	MLVS mg/l	Detention Time hours	Lime mg/l	pH
Feed		1590	3050	2886	1214					
Aerator - 1	0	322	1092	938	730	2714	2554	16.2	0	7.3
% Reduced		79.8	63.6	67.5						
Red. Rate		0.74	1.14	1.13						
Aerator - 2	100	193	1068	836	640	2678	2458	16.1	25	7.0
% Reduced		87.7	65.0	71.0						
Red. Rate		0.85	1.20	1.24						
Aerator - 3	200	133	922	628	590	3706	3248	15.2	75	6.8
% Reduced		91.6	69.8	78.2						
Red. Rate		0.71	1.03	1.10						
Feed		1630	3396	3228	1567					
Aerator - 1	0	389	1754	1588	1710	2252	1846	18.0	0	7.2
% Reduced		76.2	48.3	50.8						
Red. Rate		0.89	1.19	1.18						
Aerator - 2	100	208	936	748	670	1904	1682	16.2	25	7.0
% Reduced		87.2	72.4	76.8						
Red. Rate		1.25	2.16	2.18						
Aerator - 3	200	118	736	460	380	3554	2046	15.8	75	6.9
% Reduced		92.8	78.3	85.8						
Red. Rate		1.12	1.98	2.05						
Feed		1730	3202	3054	1440					
Aerator - 1	0	356	1480	1288	1270	2080	1900	17.6	0	7.1
% Reduced		79.4	53.6	57.8						
Red. Rate		0.98	1.23	1.26						
Aerator - 2	100	200	948	726	260	1632	1402	16.2	25	6.9
% Reduced		88.4	70.4	76.2						
Red. Rate		1.62	2.38	2.47						
Aerator - 3	200	145	718	438	270	3490	3008	15.5	75	7.1
% Reduced		91.6	77.6	85.7						
Red. Rate		0.82	1.28	1.35						

Table A3. Ten hour detention time data.

Item	Alum mg/l	Influent and Effluent BOD mg/l	TS mg/l	TVS mg/l	SS mg/l	MLTS mg/l	MLVS mg/l	Detention Time hours	Lime mg/l	pH
Feed		1630	2760	2662	725					
Aerator - 1	0	382	1010	922	920	2870	2726	9.75	0	7.2
% Reduced		76.6	63.4	65.4						
Red. Rate		1.12	1.58	1.57						
Aerator - 2	100	162	428	310	70	2910	2708	10.71	50	7.0
% Reduced		90.1	84.5	88.4						
Red. Rate		1.21	1.93	1.94						
Aerator - 3		216	760	552	335	2510	2278	10.50	150	7.1
% Reduced	200	86.8	72.4	79.3						
Red. Rate		1.42	2.01	2.12						
Feed		1540	2930	2776						
Aerator - 1	0	320	895	780		2495	2316	10.90	0	7.2
% Reduced		79.2	69.4	71.9						
Red. Rate		1.15	1.93	1.90						
Aerator - 2	100	107	330	194		4225	3876	10.42	50	7.0
% Reduced		93.0	88.7	93.0						
Red. Rate		0.85	1.54	1.53						
Aerator - 3	200	78	490	272		2450	2160	9.46	150	7.1
% Reduced		94.9	83.3	90.2						
Red. Rate		1.72	2.87	2.94						
Feed		1780	3334	3062	1540					
Aerator - 1	0	450	1230	1020	927	2586	2328	9.68	0	7.1
% Reduced		74.8	63.0	66.6						
Red. Rate		1.41	2.24	2.18						
Aerator - 2	100	195	482	246	107	5522	3118	9.63	50	7.2
% Reduced		89.1	85.5	92.0						
Red. Rate		1.26	2.28	2.24						
Aerator - 3	200	77	450	204	133	3096	2684	9.53	150	6.8
% Reduced		95.7	86.5	93.3						
Red. Rate		1.61	2.70	2.68						

Table A4. Six hour detention time data.

Item	Alum mg/l	Influent and Effluent BOD mg/l	TS mg/l	TVS mg/l	SS mg/l	MLTS mg/l	MLVS mg/l	Detention Time hours	Lime mg/l	pH
Feed		1504	2832	2622	920					
Aerator - 1	0	542	1426	1238	860	2832	2596	6.50	0	7.1
% Reduced		63.9	49.7	52.8						
Red. Rate		1.38	2.00	1.97						
Aerator - 2	100	463	1430	1216	370	3650	3356	5.76	50	7.5
% Reduced		69.2	49.5	53.6						
Red. Rate		1.29	1.74	1.74						
Aerator - 3	200	542	1572	1328	580	3070	2786	5.45	75	7.6
% Reduced		63.9	44.5	49.4						
Red. Rate		1.52	1.99	2.04						
Feed		1654	3214	3040	1325					
Aerator - 1	0	570	1410	1256	860	2846	2660	5.94	0	6.9
% Reduced		65.6	56.1	58.6						
Red. Rate		1.65	2.58	2.71						
Aerator - 2	100	414	1010	848	366	4096	3836	6.57	50	7.0
% Reduced		75.0	68.6	72.1						
Red. Rate		1.18	2.10	2.08						
Aerator - 3	200	675	1612	1426	626	3328	3064	5.85	75	7.4
% Reduced		59.2	49.8	53.1						
Red. Rate		1.31	2.14	2.16						