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Disposal of wastes from a swine confinement unit in anaerobic lagoons

Lee Ellis Ashmore
Iowa State University

DISPOSAL OF WASTES FROM A SWINE CONFINEMENT UNIT IN ANAEROBIC LAGOONS

by

Lee Ellis Ashmore

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INTRODUCTION

General Background

Recent developments in methods of farm animal production have created new problems concerning farm animal waste disposal. The most significant development is the trend toward automation and large-scale animal production in confined areas, resulting in greater concentration of wastes in much smaller areas. Such waste accumulations represent a public health and stream pollution hazard comparable to that resulting from a human population far greater than that now in Iowa. A method of animal waste disposal is needed which can be applied effectively and economically by the individual animal producer. Use of anaerobic lagoons has been suggested as one possible solution. This thesis is concerned with the development and evaluation of design criteria which must be used in the successful application of anaerobic lagoons to the disposal of swine wastes from a confinement unit.

Confinement Production of Animals

There is a well established trend in agriculture today toward large-scale animal production. The poultry industry especially has already completed the adoption of automation in poultry production. In the swine industry, pen confinement units are rapidly becoming dominant in the production of hogs. Units capable of producing up to 10,000 hogs per year are now in operation. It is anticipated that future production units will produce up to 100,000 hogs per year. Hogs are placed in a confinement unit at an age of 6 to 8 weeks and remain there until reaching market weight of about 200 pounds. Generally, about 10 square feet of floor space are provided per hog with about 30 to 40 hogs per pen. Assuming approximately 100 days of confinement time per hog, a unit capable of producing 100,000 hogs per year would house about 28,000 hogs at any one time.

Clark (1964) collected and analyzed samples of hog manure from several confinement units in Illinois. He concluded that the waste from a hog of 150 pounds average weight was approximately three times greater in strength based on Chemical Oxygen Demand, than the wastes from a single human being. Envisioning a confinement unit of 100,000 hogs per year capacity, the waste disposal problem then approached that of adequately treating and disposing of the domestic wastes from a city of 84,000 population. Taiganides (1963) found that the population equivalent of swine wastes was 4 on a Biochemical Oxygen Demand basis when the swine wastes included only feed, manure, and urine. No bedding is generally used in a swine confinement unit. Using that value, he stated that in Iowa, swine wastes are equivalent to at least 12 times the waste from the human population. This amount of waste produces an immense potential pollutional hazard to lakes, streams, and underground water supplies. Wastes from other farm animals are all normally of much greater strength than human wastes. When all forms of farm animal wastes are considered, the potential hazards from pollution, both air and water, and from other sources, such as insect breeding, become enormous. To protect public health, these wastes must not be disposed of in a negligent manner.

Farm Waste Collection

Swine confinement units are generally designed to require a minimum of supervision. These units may or may not be divided into a series of smaller pens. Feed and water are conveyed to the individual pens or feeding floor automatically and in the correct amount. Wastes are collected and discharged by one or a variation of one of the methods described below.

One type of confinement unit consists of an enclosed building with the floor, except for the feeding floor, wholly or partially slotted. The slotted portion of the floor is underlain with concrete channels in which the manure is collected. The wastes are then either flushed periodically to a lagoon or disposed of in some other manner. The poultry industry in particular frequently makes use of an indoor lagoon, the lagoon occupying a position directly beneath the cages in which the fowl are confined.

In a second type of confinement unit, slotted floors are not used. The floor is made of concrete and sloped toward one or more dunging alleys, or troughs. Usually, a constant flow of water is maintained in the alleys, but at a rate low enough that the feeding areas will remain dry at all times. Most often, the hogs make direct use of the alleys. Manure collected on the feeding floor is periodically scraped, hosed, or flushed into the dunging alleys where it is hydraulically conducted from the building, either to a holding tank or to a lagoon.

Farm Waste Disposal

Several methods of treating and disposing of farm animal wastes are in use at the present time. The most general and widely practiced method, especially in the Midwest, is spreading on land. In several countries of the world, anaerobic digestion of livestock wastes has been practiced with some success, the methane gas given off by the process being used as a source of power for the farm. In recent years, lagooning has been advanced as a possible solution to the manure disposal problem. Up to now, however, none of these methods have been completely satisfactory.

Land spreading, the oldest and most widely practiced of the above methods, is most severely limited by land requirements. Taiganides (1963) states that 1,100 acres of land would be required every year for disposal by field spreading of the wastes from a pen confinement unit of 10,000 hogs per year capacity. The land, to be satisfactory for this use, would have to be available for spreading during the entire year. Also, spreading operations would have to be carried out in spite of the weather. Neither of these criteria are likely to be fulfilled in major hog-producing areas. The livestock producer, like any industrialist, prefers that his product be produced as near as possible to the available market, in his case, the city. In these locales, land can be expected to be quite expensive, if even available, and problems from odor or insect breeding might arise.

The process of anaerobic digestion of the swine wastes in heated, municipal-type digestion tanks presents a minimum land requirement. The organic content of the waste is reduced to relatively inoffensive end products. However, an operation of this kind is somewhat complex, and the initial cost is generally quite high. Part of the cost could be offset by recovery and use of the combustible gas produced by the process. The digested material, however still presents a problem of ultimate disposal. The process would probably be more applicable to units of very large capacity than to those of low or average capacity.

In recent years lagooning has frequently been treated by the popular agricultural press as a cure-all for the livestock industry. Few, if any, of these comments result from an evaluation of basic research in the field. Lagooning of farm animal wastes may result in reduced labor for the producer and may accomplish a significant reduction in nuisance and water pollution. Aerobic lagoons designed in accordance with set regulations for municipal sewage lagoons, however, are simply not practical for the individial producer. Recommended Standards for Sewage Works (1960) by the New York State Health Department, as an example, requires 1 acre of aerobic pond surface area for every 100 people served by the lagoon. Taking the population equivalent of a hog as four, this would mean providing 1 acre of aerobic pond surface area for every 25 hogs. With the anticipated future capacities of confinement units, the amount of land and water that would be required becomes prodigious.

Anaerobic lagoons are now under investigation in several parts of this country as a method of farm animal waste disposal. Having no dissolved oxygen requirements, a lagoon of this type could be designed on a volume basis rather than on a surface area basis. Research is now under way, particularly in the Midwest and on the West Coast, to determine allowable loading rates for anaerobic lagoons to obtain a satisfactory level of treatment.

OBJECTIVES

The objectives of this study were:

1) to develop preliminary design criteria for anaerobic lagoons for use in treatment of wastes from a hog confinement unit, and
2) to evaluate the effect of the loading rate and depth of lagoon on the treatment efficiency.

LITERATURE REVIEW

General Introduction

Lagoons, in the sanitary sense, may be defined simply as bodies of water into which are discharged some type of sewage waste for purposes of treatment or final disposal. The purpose of the lagoon is to stabilize the organic material in the waste by biological action and to render it innocuous. Lagoons may be classified as aerobic, anaerobic, or facultative, depending upon the type of micro-organisms accomplishing the stabilization. When the organisms require free dissolved oxygen to accomplish this, the lagoon is classified as aerobic. If the organisms do not require dissolved oxygen, the lagoon is classified as anaerobic. Both types of organisms operate in a facultative lagoon, aerobic in the upper layers, and anaerobic in the lower. For the purposes of this discussion only aerobic and anaerobic lagoons will be considered. The following descriptions of these processes are taken from Fair and Geyer (1954).

General Theory of Operation

Aerobic lagoons

Degradation of organic wastes in an aerobic lagoon is accomplished by the process of aerobic decomposition. In simple terms, the process results in a conversion of dead organic matter into plant life. The series of chemical and biological reactions which effect this conversion are highly complex. Nitrogenous, carbonaceous, and sulfurous organic matter are initially converted to ammonia, carbon dioxide, and hydrogen sulfide.

Ammonia and sulfides are then successively oxidized to nitrites and sulfur and then to nitrates and sulfates. The organisms responsible for this decomposition require gaseous oxygen for their respiration; they draw upon the dissolved oxygen supply in the water. Carbon dioxide is produced continuously during the process. Algae assimilate the carbon dioxide, nitrates, and sulfates with the aid of sunlight to build more living plant matter. This process of photosynthesis gives off oxygen which is in turn utilized by the organisms of decomposition.

From this general description of aerobic decomposition, it is understood that there are two important conditions which must be fulfilled in order to maintain a lagoon in aerobic operation. First, the depth of liquid must not be so great as to prohibit photosynthesis by retarding the penetration of sunlight. Most aerobic lagoons, therefore, are restricted to a depth of 3 feet or less. In one experimental lagoon designed for algae production the lagoon depth was maintained at 18 inches (Hart, 1963).

Secondly, the organic loading rate must be sufficiently low so that an adequate supply of dissolved oxygen is present in the lagoon liquid at all times. Too heavy loading rates, even at shallow depths, result in rapid oxygen depletion and anaerobic decomposition replaces aerobic decomposition.

In general, aerobic lagoons about 4 deep will operate successfully in Iowa with loading rates of 20-25 pounds of BOD per day per acre of lagoon surface when handling unsettled raw waste. If settled wastes are discharged to the lagoon, loading rates as high as 50-75 pounds of BOD per day per acre of lagoon may prove feasible.

Anaerobic lagoons

Anaerobic decomposition is accomplished by organisms which draw upon the oxygen contained in a chemically combined form in the organic matter itself. The initial products of this decomposition are ammonia nitrogen, humus, carbon dioxide, methane, and sulfides. This process is predominant in the sludge layer at the bottom of any lagoon. The gases produced escape to atmosphere as soon as the surrounding liquid becomes saturated.

Anaerobic Farm Waste Lagoons

Aerobic lagoons have been used successfully for the treatment and disposal of municipal and various industrial wastes. The much-used phrase, "a little waste in a lot of water", still generally applies to these types of wastes. Most farm animal wastes, specifically those from a swine confinement unit, consist of a large amount of solid material in just enough water to make it liquid. Farm lagoons must, therefore, be designed and operated differently than lagoons for other types of wastes.

The general requirements for maintaining a lagoon in aerobic operation have been briefly explained in a preceding section. An anaerobic lagoon, on the other hand, could theoretically be of any size or shape as long as the requirements of the organisms of decomposition are satisfied. The large surface area and shallow depth required for aerobic operation are not necessary for an anaerobic lagoon. The loading rate should, therefore, be determined on the basis of the amount of organic material entering the lagoon per unit of lagoon volume, not per unit of lagoon surface area as in an aerobic lagoon. Other types of anaerobic digestion processes, such as municipal sludge digesters, are designed on this basis.

How should the performance of a farm waste lagoon be evaluated? Municipal and industrial waste lagoons have as their ultimate goal the treatment and return to use of the used water supply. The swine producer is concerned not so much with treatment as with disposal. He is concerned with how often he will have to clean the lagoon and whether the lagoon will "stink". Effluent from municipal or industrial lagoons are usually discharged in some manner to a stream or other water course. Assuming a farm lagoon could produce an effluent of sufficiently high quality, it would still be difficult for the individual producer to provide enough water to maintain a flow of effluent. Most farm lagoons are, therefore, not even equipped with an outlet. What goes into the lagoon stays in the lagoon, except for what might be lost by evaporation or exfiltration.

In evaluating the treatment potential of the process, the engineer is mainly interested in the degree of reduction of the organic material entering the lagoon. Once the lagoon is placed in operation at the farm site, however, the satisfaction or dissatisfaction of the owner will be based on factors which are not readily amenable to chemical analysis. Generally, esthetic factors such as odor production, scum accumulation, insect breeding, color, and need for lagoon cleaning will determine the acceptability of the process. The rate of sludge buildup on the lagoon floor, which will determine the effective life of the lagoon, is a very important consideration. Possibilities of pollution of underground water supplies should be reduced by proper lagoon location.

Design criteria for swine waste lagoons are numerous in the popular press. Most of these criteria have been transposed from municipal standards or are a result of observations of existing lagoons. Very few are based on the results of basic research. The variability of recommendations for loading criteria reflects the situation.

Most sources agree on details of construction. Briefly, the lagoon should be located at least one-quarter of a mile from the nearest habitation in the direction of the prevailing winds. The banks and bottom of the lagoon should be such as to prevent or reduce exfiltration with resulting pollution of underground water supplies. For convenience, the lagoon should be located downgrade from the confinement unit to allow for gravity flow of the waste material. For single-cell lagoons, a square or circular shape is generally recommended with the inlet submerged near the center. This would result in more effective dispersion of waste solids throughout the lagoon.

Table 1. Prediction of strength of waste from a swine confinement unit (Taiganides, 1963)

Manure weight	5.0 lbs/day/100 lbs live weight of pig
BOD	0.35 lb/day/100 lbs live weight of pig
Total solids	17 percent
Volatile solids	83 percent (dry basis) 14 percent (wet basis)

Recommended loading rates for anaerobic lagoons, loading rates in actual use, and methods of specifying loading rates are quite varied. In a survey conducted at the University of Missouri (Ricketts, 1964), 15 hog units were visited and observed. These lagoons were planned with a depth of 5 feet to provide 15 square feet of pond surface area per hog. As a result of the survey, it was found that the pond areas actually varied from 1 to 23 square feet per hog.

Jeffrey et al. (1964) suggested that 78 cubic feet per hog would be required to treat hog waste in an unheated digester. Most of the Missouri lagoons studied did not provide this volume. Dornbush and Andersen (1964) reported that in South Dakota, lagoons containing from 130 to 170 cubic feet per hog gave satisfactory performance from the odor standpoint. Using the waste strength predictions of Taiganides (Table 1), and assuming a 150 pound average pig and 150 cubic feet of lagoon volume per pig, this amounts to a loading of about 7 pounds of volatile solids per day per 1000 cubic feet of lagoon volume. Many of the lagoons they observed produced odors from sludge banks protruding above the surface of the lagoon. The liquid depth should, therefore, be at least sufficient to cover all solids to facilitate mixing. They recommend a depth of 5 to 8 feet and the previously mentioned solids loading rates.

Clark (1964) conducted tests on 7 hog lagoons in Illinois. Results of his study are shown in Table 2. Lagoons A and B were loaded at a much lower rate than were any of the others. These were the only two which were performing satisfactorily from the standpoint of odor. Notice that lagoon D, which received the heaviest COD loading, was producing the best effluent on the basis of COD. All lagoons except A and B were experiencing sludge buildup at a rate of 1 to 2 feet per year. All lagoons were operating anaerobically at the time of the study. It appears from the report that the lagoon depths were about 3 feet at the time of the study. Based on the study, Clark recommends designing the lagoon on the basis of 225 hogs per acre at 40° North latitude, with a 15 percent variation for each $2\frac{1}{2}^{\circ}$ variation in latitude. He recommends a depth of lagoon of $3\frac{1}{2}$ to 4 feet. Assuming the depth of 4 feet, his recommendations correspond to providing about 750 cubic feet of lagoon volume per hog. Although his recommendations are for an anaerobic lagoon, the recommendation for depth would seem to be more applicable to the design of an aerobic lagoon. However, Clark also included in his investigation a study of algae production in anaerobic lagoons. The relatively shallow depth was apparently recommended as a method of increasing the production of algae.

Table 2. Some results of Clark's investigation

Lagoon	COD loading lbs COD / acre/day	pH	COD of lagoon liquid mg/l
A	160	7.8	5,000
B	120	8.0	2,950
C	1600	7.6	7,500
D	6000	7.9	1,600
E	3400	7.8	1,850
F	1100	8.0	3,450
G	1300	7.3	9,600

In July, 1961, a hog lagoon was constructed at the Swine Research Farm of the University of Maryland. The lagoon was sized on the basis of 50 square feet of surface area and 250 cubic feet of lagoon volume per 200 pound average hog. Eby (1964) reports that after 3 years of operation the lagoon is adequately disposing of the wastes without producing excessive odors. He also presents a table giving surface loading rates for lagoons receiving wastes from various farm animals and for various geographical locations. For hogs, at 30° to 50° North latitude, the loading rate should be from 500 to 1000 pounds of BOD per acre per day, with a depth of from 5 to 10 feet. From Table 1, a 200 pound hog would produce 0.7 pounds of BOD per day. Assuming a loading rate of 1000 pounds of BOD per acre per day and a lagoon depth of 10 feet, this corresponds to providing approximately 300 cubic feet of lagoon volume per 200 pound average hog. For a 150 pound average hog, the recommended volume would be 0.75 of this value or 230 cubic feet per 150 pound average hog. This is higher than Dornbush and Andersen's recommendation of 130 to 170 cubic feet per hog, but lower than Clark's recommendation of 750 cubic feet per hog.

A two-celled lagoon has been in operation at the Iowa State University Swine Nutrition Farm since 1963. The first cell is 9 feet deep with a surface area of 0.16 acres. The second cell is 4 feet deep with a surface area of 0.48 acres. The two cells are not partitioned; they comprise one larger lagoon of two depths. The lagoon receives the wastes from a 600 hog capacity confinement unit located at the site. Various chemical tests and subjective appraisals were conducted on the lagoon during the summer of 1964. The average loading rate was approximately 470 pounds of COD per acre per day, or about 3 pounds of volatile solids per 1000 cubic feet per day. About 80 to 85 percent reduction in COD and BOD were accomplished in the first cell. Only a slight further reduction occurred in the second cell. Total and volatile solids reductions in the first cell averaged 81 and 90 percent respectively. The pH varied from 6.8 to 7.9 throughout the lagoon during the period of observation. Both cells operated anaerobically at all times.

Odor has been the only serious problem encountered in the operation of this lagoon. The odor is, however, only occasionally obnoxious, being greatest for a short time during the month of May.

Clark (1964) included algal counts in his investigation. Counts as high as 277 million per milliliter were observed in the more lightly loaded lagoons with an average for winter of about 60 million and for summer about 15 million. The larger counts occurred almost without exception near the raw waste inlet. It was calculated that a lagoon sufficient for the disposal of the wastes from 400 to 500 hogs could produce about 1750 pounds of recoverable dried algae per day. From analysis of the dried algae, it was concluded that it might be possible to provide the entire daily requirement of high protein supplement for the hogs as a by-product of the waste disposal system. Since no dissolved oxygen was observed in the lagoons at any time during the investigation, Clark concluded that the algae were assimilating the waste directly without the use of photosynthesis. Since odors were not observed from the lagoons under normal conditions, he also concluded that much of the odor-producing constituents were being used by the algae.

EXPERIMENTAL INVESTIGATION

General Introduction

The field investigation was designed to evaluate the effects of lagoon depth and loading rate on the efficiency of treatment in six small test lagoons. These lagoons were designated by the letters A through F. The dimensions and planned loading rates of each lagoon are shown in Table 3. There were three pairs of lagoons and each pair had a different depth. Two loading rates were selected so that a different loading rate could be applied to each of the two lagoons of the same depth. The results could then be analyzed and the effects of both loading rate and depth determined.

Table 3. Dimensions and planned loading rates the test lagoons

Lagoon	Depth (ft)	Surface area (sq ft)	Volume (cu ft)	Design loading rate lbs volatile solids / 1000 cu ft/day	lbs COD / acre/day
A	9.83	19.50	191.8	10	6000
B	9.83	19.50	191.8	5	3000
C	4.73	19.50	92.2	10	3000
D	4.73	19.50	92.2	5	1500
E	2.67	19.50	52.1	5	750
F	2.67	19.50	52.1	10	1500

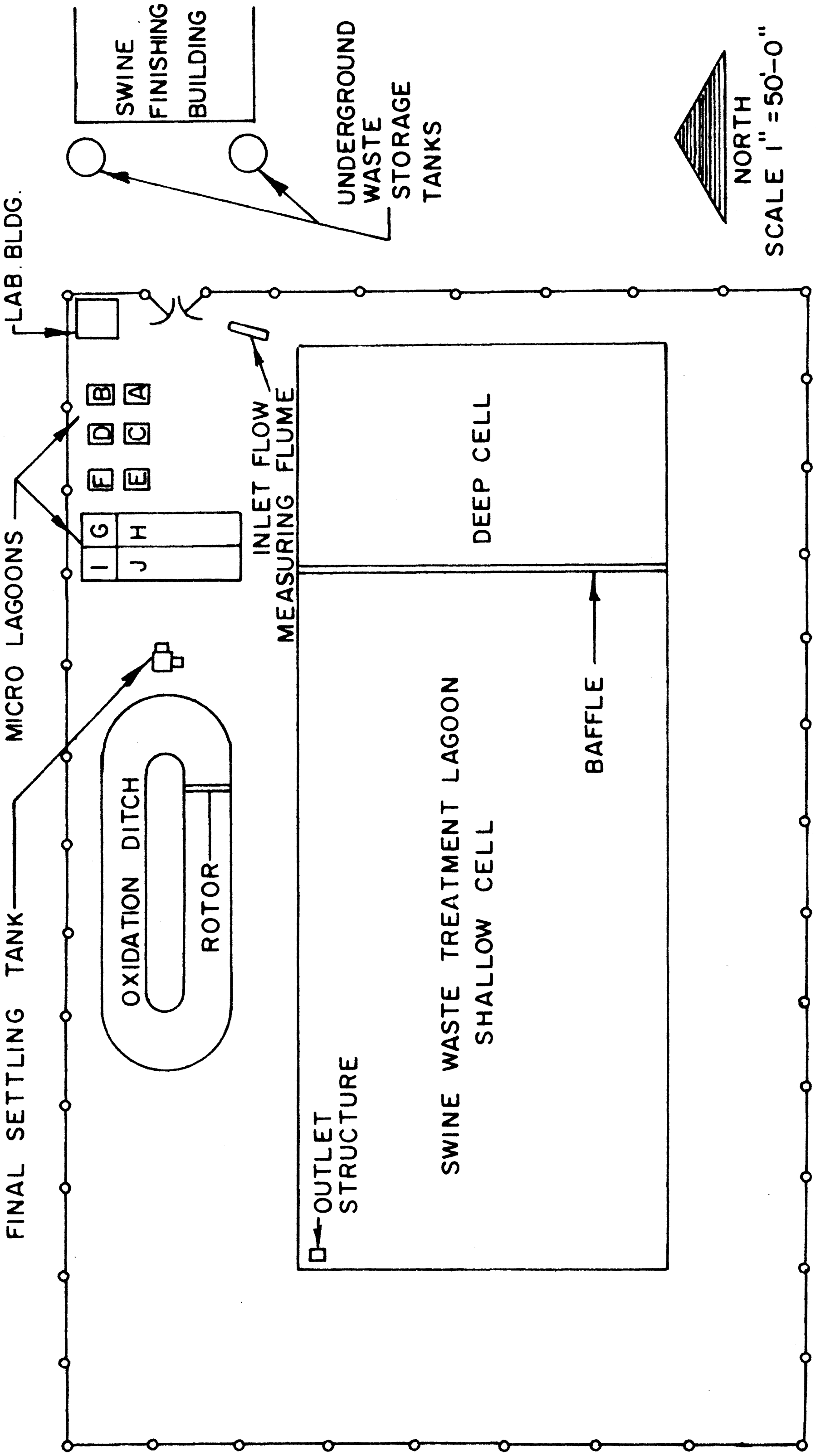
Equipment and Procedure

Equipment

The investigation was conducted at the Iowa State University Swine Nutrition Farm located 2 miles southwest of Ames, Iowa. A hog confinement unit has been in operation at the site for several years. A 0.64 acre lagoon is used to dispose of the wastes from the unit. Six single-cell test lagoons and 2 double-cell test lagoons were constructed at the plant-scale lagoon site for test purposes. A simplified flow diagram and the relative location of the components are shown in Figure 1. The confinement unit, designed for a hog population of 800 hogs, normally houses about 600 hogs. The building (Figure 2) is a clear-span prefabricated steel frame structure with a total floor area of about 6,000 square feet. The floor space is divided into smaller pen areas (Figure 3), one row of pens occupying the north half of the building and the other row the south half. The two rows are separated by a narrow passage which provided access to the automatic feeders and also functions as an observation gallery. Shallow 2 inch deep dunging alleys or gutters run along the north and south sides of the building. These gutters, like the rest of the floor, are of concrete. Water is allowed to flow continuously into the east or upstream end of each gutter at a rate of about 2 to 3 gallons per minute. Wastes which collect on the pen floors are periodically hosed into the gutters. Practically all the dung is dropped by the pig directly into the gutters.

A storage tank of approximately 2,500 gallons capacity is located at the west or downstream end of each gutter. Each tank can be sealed off and the flow diverted to a treatment lagoon through 6-inch clay tile sewer lines. The line from one tank leads directly to a manhole and a small Parshall flume preceding the lagoon. The diversion line from the other storage tank leads first to a sampling pit located beneath a small laboratory building, then through the manhole and Parshall flume and into the lagoon (Figure 1).

Figure 1. Relative location of components at lagoon site



SWINE FINISHING BUILDING
UNDERGROUND WASTE STORAGE TANKS
NORTH
SCALE 1" = 50'-0"
LAB. BLDG.
MICRO LAGOONS
A
B
C
D
E
F
G
H
I
J
INLET FLOW MEASURING FLUME
DEEP CELL
BAFFLE
FINAL SETTLING TANK
OXIDATION DITCH
ROTOR
SWINE WASTE TREATMENT LAGOON
SHALLOW CELL
OUTLET STRUCTURE

Figure 2. Outside view of confinement unit showing feed storage bins

Figure 3. Inside view of confinement unit showing observation gallery and automatic feeders

Data collected in this investigation were obtained from tests conducted with the 6 small test lagoons. Pertinent dimensions of the lagoons and the planned loading rates are shown in Table 3. Each lagoon was equipped with a 4-inch tile outlet (Figure 4) which emptied into a 6-inch sewer line running from the three sets of lagoons to the large treatment lagoon.

Figure 4. View of one of the test lagoons showing opening into sewer line

Procedure

A brief literature review was made to determine recommended loading rates for various types of biological treatment units. Rates were expressed in terms of pounds of volatile solids fed per 1000 cubic feet of the treatment unit per day. Loading rates in current use ranged from 0.2 for aerobic lagoons (Sewage Treatment Plant Design, 1963) to 350 for a household septic tank (Babbitt and Baumann, 1958). A loading rate of 100 was a common value used for Imhoff tanks without secondary treatment and for cold digesters with only primary treatment. It seemed logical that an acceptable value for anaerobic lagoons would lie somewhere between the value for an aerobic lagoon and that for a cold digester.

Three sets of 2 identical test lagoons were used. The two lagoons in each set were identical with respect to depth, surface area, and volume. Each set had a different depth. Three lagoons were selected randomly, one from each set, to be loaded at the same rate. The remaining three lagoons were to be loaded at a different rate. Lagoons A, C, and F received the heavier loading rate; lagoons B, D, and E, the lighter rate (Table 3). Thus, by comparing the test results from lagoons of like depth, the effect of loading rate could be observed. Likewise, by comparing the test results from lagoons loaded at the same rate, the effect of depth could be observed.

Preliminary analysis indicated that the volatile solids content of the raw waste was approximately 70 percent. It was arbitrarily decided to load three lagoons with approximately 10 pounds of volatile solids per 1000 cubic feet per day and to load the other three lagoons with 5 pounds of volatile solids per 1000 cubic feet per day. For Lagoon A, this required approximately 4.5 cubic feet of the raw waste per day.

It was decided to load the lagoons and take samples on alternate days. Therefore, at the time of loading the amount of raw waste introduced into each lagoon was twice the daily rate. The volume of raw waste fed to the lagoons at each loading remained constant throughout the investigation. Lagoon A received 9.00 cubic feet of raw waste per loading.

Lagoons B and C received 4.50 cubic feet, Lagoons D and F received 2.25 cubic feet, and lagoon E received 1.12 cubic feet. This procedure was selected for convenience; it allowed time between loadings to conduct laboratory analyses on the raw waste and on the lagoon liquid. Actual loadings were calculated based on the volume of waste fed and the volatile solids content of the raw waste.

At the beginning of the investigation, the lagoons were pumped dry, cleaned, and filled to the outlets with clear city water. Lagoons A and B were seeded with approximately 30 gallons of liquid from the first cell of the large disposal lagoon. Lagoons C and D were seeded with approximately 15 gallons, and lagoons E and F with approximately 8 gallons.

A standard operating procedure was used to collect a uniform sample of the raw waste and to transfer the required measured volume of the waste to the test lagoons. In its path from the dunging alley to the large treatment lagoon, the raw waste flowed through a Parshall flume and into a 10-inch drop pipe which carried the raw waste by gravity into the treatment lagoon. Raw waste was pumped from the drop pipe, which was normally full, into a large metal tank approximately 3 feet by 5 feet in plan and 3 feet deep. The tank was calibrated and marked at intervals of 9.00, 4.50, 2.25, and 1.12 cubic feet to indicate the correct amount of waste to be delivered to each lagoon. The waste required for dosing all lagoons was pumped into the calibrated tank and transferred to the lagoons by means of a gasoline-powered, 40 gallon per minute diaphragm pump with 3-inch suction and discharge. A 3-inch fire hose was used for suction and discharge lines. During waste transfers from the calibrated tank, waste was introduced first into lagoon E at approximately 2/3 the liquid depth. The contents of the tank were thoroughly stirred by hand, and the pump started at low speed. As soon as flow was established the pump was shut off, and the correct amount of waste was allowed to siphon into the lagoon. Overflow from the lagoon was conducted through the sewerline into the large treatment lagoon. The same procedure was followed in dosing each lagoon in turn, from the lightest loaded to the heaviest loaded. The contents of the tank were manually stirred during the entire lagoon dosing operation. At each loading, a sample of the raw waste was taken from the measuring tank for laboratory analysis.

When the investigation first began, samples of the lagoon liquid were taken on alternate days between loadings. After ten loadings, the procedure was changed so that these samples, along with certain objective and subjective observations, were obtained on the same days that loading actually occurred.

One-liter samples of the raw waste and of the surface liquid in each lagoon were collected. To obtain samples of the raw waste, the waste in the calibrated mixing tank was first mixed thoroughly using a 4-foot strip of stiff metal approximately 4 inches wide as a paddle. A 1-liter plastic bottle was then submerged in the waste until it was approximately 1/3 full. The operation was repeated twice more during the waste transferring operations. The composite sample was taken to the laboratory for analysis.

To obtain samples of the liquid in a lagoon, the scum layer, if present, was gently brushed aside. A 1-liter plastic bottle was then submerged in the top 1 foot of surface liquid until full. This sample was also taken to the laboratory for analysis.

Sludge samples were taken and the depth of sludge in each lagoon was determined using a small 6 gallon per minute rubber-impeller pump. A length of 3/4 inch garden hose was attached to the suction line of the pump. The hose was lowered into each lagoon, and the pump discharge observed until the discharge became thick and full of solids. The change in consistency was quite sharp and was taken as a measure of the upper layer of sludge. The depth of sludge was determined by measuring the length of hose submerged in the lagoon when sludge was encountered and subtracting this from the depth of liquid in the lagoon. The sludge depth was also checked by lowering a small weight attached to a cord into the lagoon until no tension could be felt in the cord. The loss in cord tension indicated that the weight was resting on the sludge layer. Sludge depth was then calculated by subtracting the length of submerged cord from the total liquid depth.

Preliminary investigation showed that BOD tests conducted on the raw waste and lagoon liquid were very inconsistent. No reproducible results could be obtained even on separate tests conducted on the same sample. The COD test, however, proved to be simpler to perform and produced much more consistent results. Therefore, COD and total and volatile solids analyses were selected as the major indications of the organic content of the raw waste and of the liquid in the lagoons.

Total solids, volatile solids, and COD of each sample of raw waste were determined. COD analyses were also conducted on each sample of lagoon liquid. The pH of the lagoon liquid was checked during the first 39 days of operation. On December 5, after freeze-up began, the depth of sludge accumulation was determined for each lagoon by the methods previously outlined. Total, volatile, and settleable solids tests were conducted on the sludge samples. Also on this date, the total and volatile solids content of the lagoon liquid was determined. All laboratory analyses were conducted according to Standard Methods (1960). The temperature of the waste in each lagoon was measured each time lagoon liquid samples were taken. Temperatures were observed in the top foot of liquid in the lagoon.

Subjective observations included estimation of color, scum formation, insect breeding, bubble formation, and odor in the test lagoons. All, (except odor), were determined at the lagoon site on each sampling day. The presence of odor from the large lagoon plus that from the nearby confinement unit precluded conducting a "sniff" test at the lagoon site. The samples of lagoon liquid were, therefore, taken to the Sanitary Engineering laboratory where each bottle was opened in turn and a subjective appraisal of the odor was made.

No samples were obtained of the gas produced by any lagoon. The only measure of gas production was provided by the observation of gas bubble formation in the surface liquid and the occasional occurrence of bottom sludge rising to the surface.

In addition, daily data on precipitation, wind velocity, and air temperature were obtained from the records of the Iowa State University Agronomy Department. These data were obtained from a U. S. Weather Bureau Station located approximately 3 miles from the lagoon site.

RESULTS

Laboratory Analyses

Analysis of raw waste

Some characteristics of the raw waste which was fed to the lagoons are shown in Table 4. The values shown are average values over the period of the investigation. Daily values are shown in Table 9 in the Appendix.

Table 4. Average characteristics of the raw waste from the hog confinement unit

Total solids	8,720 mg/l
Volatile solids	7,240 mg/l 83 percent (dry basis)
COD	8,870 mg/l
lbs COD/lb volatile solids	1.22

The average total solids content of the raw waste fed to the lagoons was approximately 5.1 percent of the solids content of raw swine manure collected in previous studies by using scrapers to move it to the collection point (Table 1). In this study, water used to carry the solids to the collection point resulted in the dilution of the waste. The average volatile solids content of the raw waste influent was 83 percent which is the same average found by Taiganides (1963). On the basis of solids content, therefore, the raw waste influent to the lagoons was composed of raw swine manure diluted to approximately 5.1 percent of its original strength. Assuming a figure of 159,000 mg/l (Taiganides, 1963) for the COD of raw swine manure, the lagoon influent was approximately 5.5 percent of the strength of raw swine manure based on COD.

A strong municipal sewage may be assumed to have a 5-day BOD of about 300 mg/l and a volatile solids content of about 700 mg/l (Babbit and Baumann, 1958). Taiganides found that the COD/BOD ratio in undiluted swine wastes was about 2.34. On this basis, the COD in this study of 8,870 mg/l would be equivalent to a BOD of about 3,790 mg/l or about 12.5 times that of strong municipal sewage. On the basis of volatile solids content, the lagoon influent would be about 10 times greater.

From visual observation it was obvious that much of the raw waste was composed of feed particles which had passed through the hog's digestive tract relatively unaltered or had entered the flow of waste directly from the feeding floor. During the investigation, a COD determination was conducted on a sample of the raw waste which had been filtered through a coarse filter paper. The COD of the raw waste was 8,070 mg/l, whereas the COD of the filtrate was 2,810. In this sample, therefore, approximately 65 percent of the COD of the raw waste was removed by filtration. It is probable that a large amount of the COD of the unfiltered waste was due to the presence of feed particles. These particles are composed of lignaceous material and are difficult to decompose by any type of biological action. As a result, it was found that much of the sludge which accumulated in the test lagoons was made up of these feed particles which passed through the anaerobic lagoon process relatively unchanged during the short period of this investigation.

Loading rates

It is apparent from reference to the results shown in Figure 5 and Table 11 that the loading rates for each lagoon were extremely variable during the investigation. There were several reasons for this; the most important of which was the variability of the solids content of the raw waste influent. This was mostly due to increases or decreases in the amount of water flowing in the dunging gutters. It also depended on the volume of manure present in the gutter. If the flow of water in the gutters was increased after being maintained at a relatively low rate, the increased flushing action would result in a high solids content of the waste. This would be followed by a period of low solids concentration because the easily transportable material in the raw waste had been flushed out of the gutter.

During the first 58 days of operation in the investigation, daily lagoon loading rates were calculated on a 2-day basis. In other words, the amount of material added to each lagoon at each loading was treated as if it had been fed at a uniform rate to the lagoon over a period of 2 days. After 58 days of operation, it was decided to load the lagoons at a reduced rate until some later date. Accordingly, the lagoons were loaded on a once a week basis beginning on December 9 and ending on January 20. Between November 17 and December 9 lagoon A was loaded twice and the other lagoons were loaded once. Loading rates for these days were calculated by assuming that the loading was spread over the number of days from the previous loading up to the day on which the next loading occurred as noted in Table 11.

The average loading rates for the test lagoons for both loading periods are shown in Table 5. These loading rates were calculated by dividing the total volatile solids fed during the period by the total days in the period. Loading rates calculated for each day that the lagoons were loaded are shown in Table 11. The experiment was designed to evaluate the effect of the volatile solids loading rate on the operating efficiency of the lagoons. The loading rate is also expressed in terms of pounds of COD per day per acre of lagoon surface.

Table 5. Average loading rates for test lagoons

	lbs volatile solids / 1000 cu ft/day		lbs COD / acre/day	
Lagoon	Sept.21-Nov.18	Nov.19-Jan.28	Sept.21-Nov.18	Nov.19-Jan.28
A	9.20	2.63	4,680	1627
B	4.60	1.13	2,340	694
C	9.56	2.36	2,340	694
D	4.78	1.18	1,170	347
E	4.23	1.04	585	174
F	8.46	2.08	1,170	347

Analysis of lagoon supernatant

COD The data in Figure 5 and Table 11 demonstrate that the volatile solids loading rate and the COD loading rate were extremely variable for all lagoons except for the period between November 2 and November 20, the 42nd to the 60th day of the investigation. In spite of this, the COD of the lagoon supernatant tended to increase at a relatively uniform rate. The rise in COD was probably due to two factors: decreasing temperature

Figure 5 (a). Daily performance chart for lagoon A

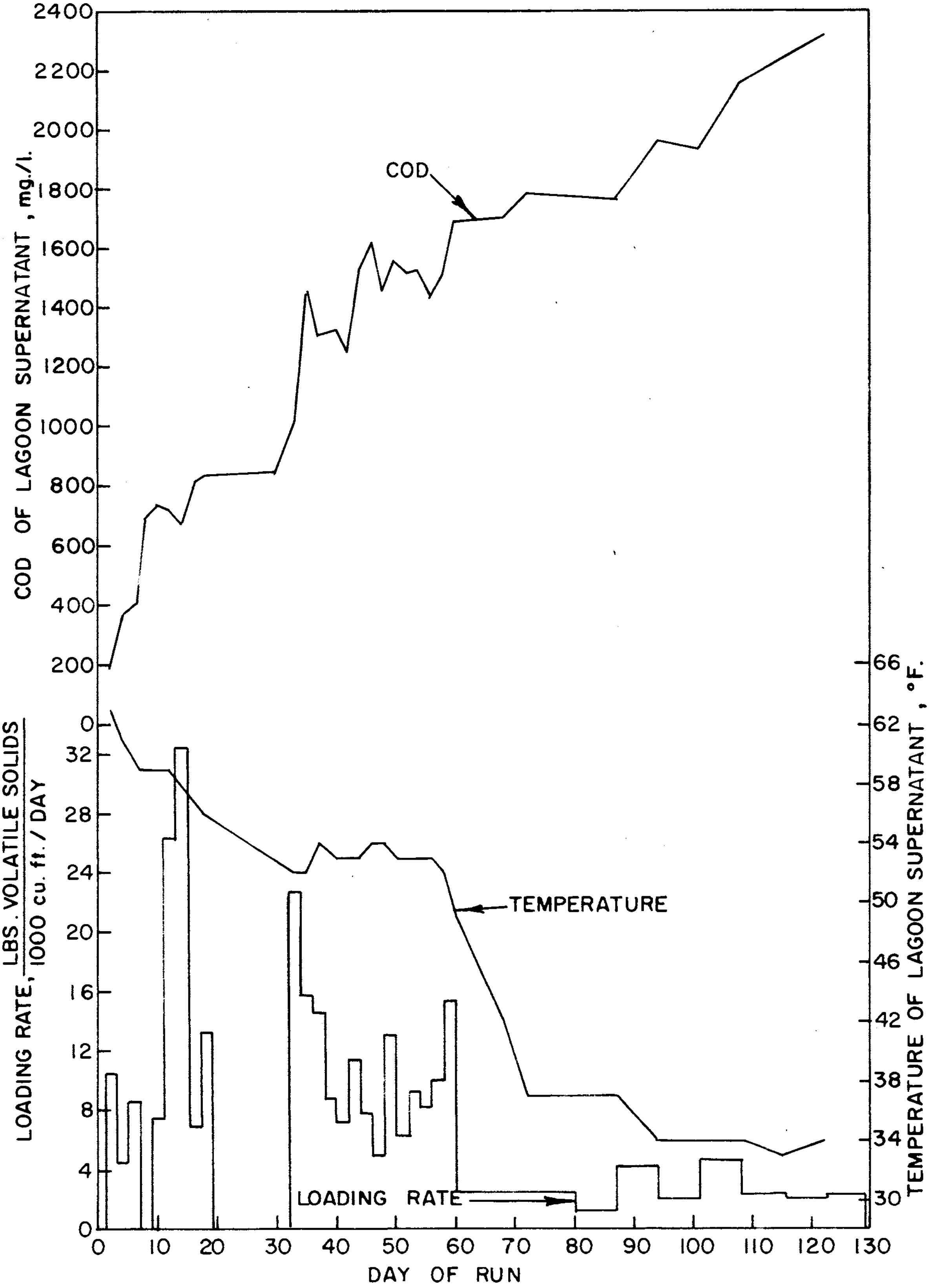

COD OF LAGOON SUPERNATANT , mg./l.
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
COD
LOADING RATE, LBS. VOLATILE SOLIDS / 1000 cu. ft. / DAY
0
32
28
24
20
16
12
8
4
0
TEMPERATURE
LOADING RATE
TEMPERATURE OF LAGOON SUPERNATANT , °F.
66
62
58
54
50
46
42
38
34
30
0 10 20 30 40 50 60 70 80 90 100 110 120 130
DAY OF RUN

Figure 5 (b). Daily performance chart for lagoon B

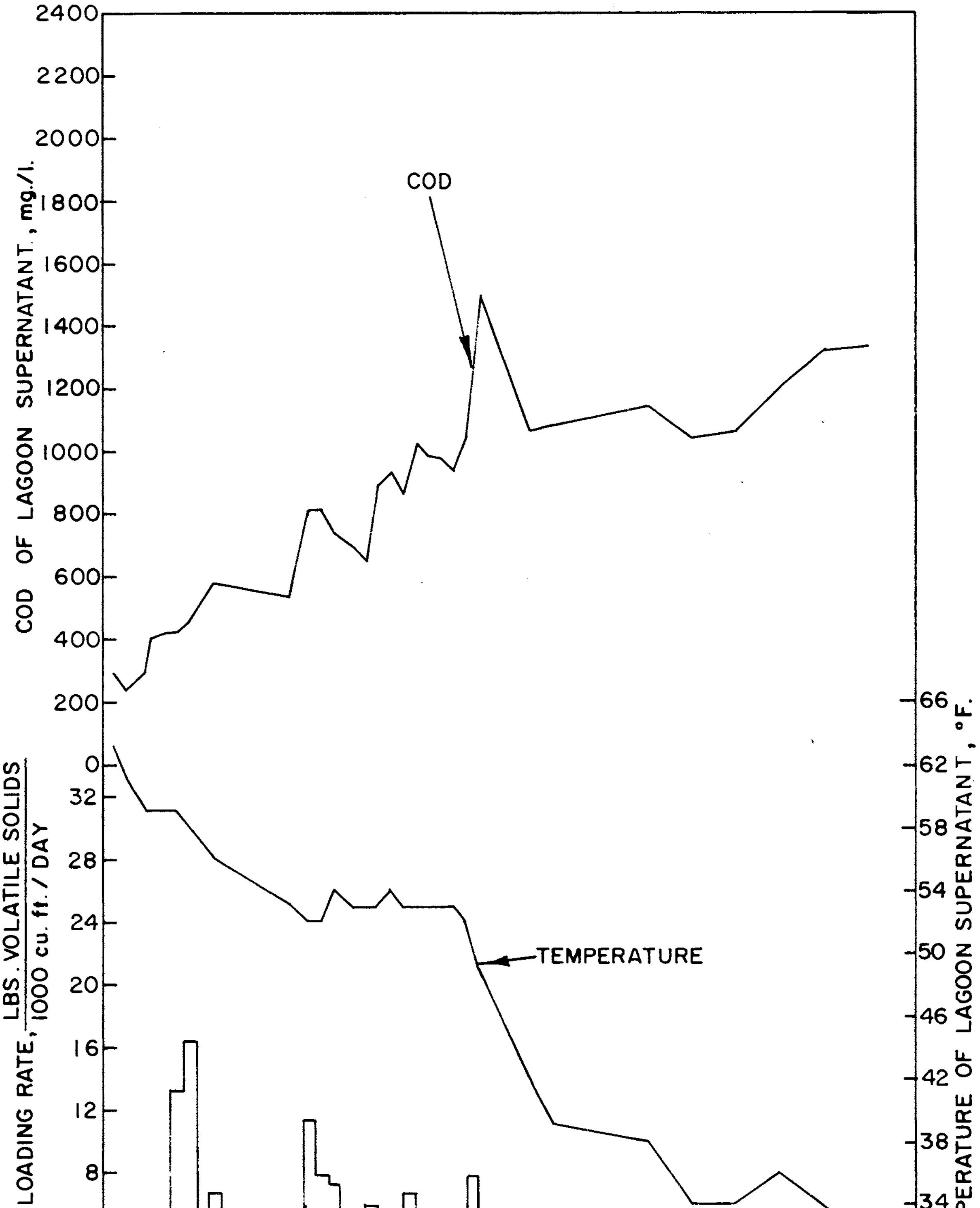

COD
TEMPERATURE
LOADING RATE
COD OF LAGOON SUPERNATANT, mg./l.
LOADING RATE, LBS. VOLATILE SOLIDS / 1000 cu. ft. / DAY
TEMPERATURE OF LAGOON SUPERNATANT, °F.
DAY OF RUN
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
32
28
24
20
16
12
8
4
0
66
62
58
54
50
46
42
38
34
30
0
10
20
30
40
50
60
70
80
90
100
110
120
130

Figure 5 (c). Daily performance chart for lagoon C

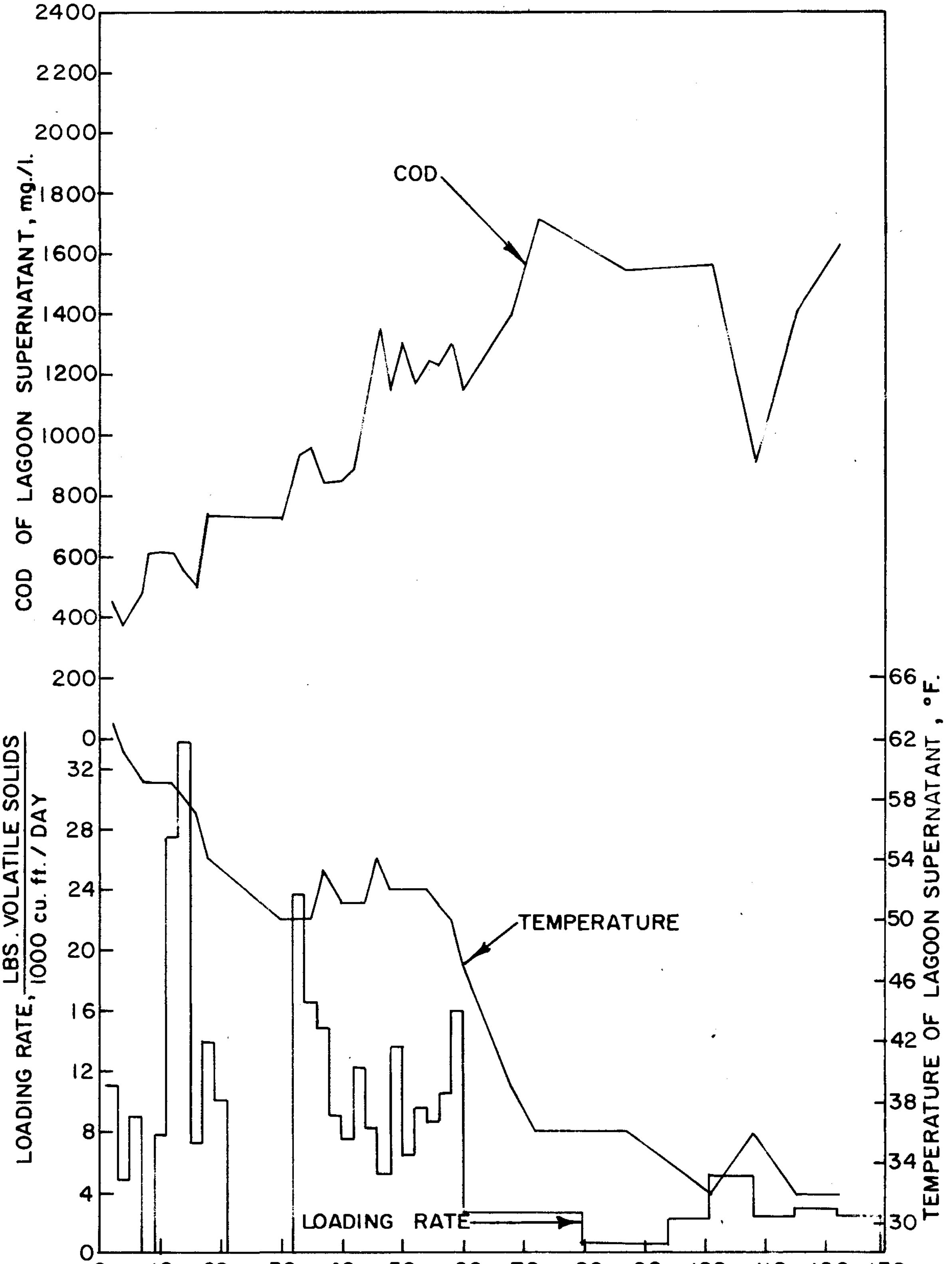

COD OF LAGOON SUPERNATANT, mg./l.
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
COD
LOADING RATE, LBS. VOLATILE SOLIDS / 1000 cu. ft. / DAY
32
28
24
20
16
12
8
4
0
TEMPERATURE OF LAGOON SUPERNATANT, °F.
66
62
58
54
50
46
42
38
34
30
TEMPERATURE
LOADING RATE
0 10 20 30 40 50 60 70 80 90 100 110 120 130
DAY OF RUN

Figure 5 (d). Daily performance chart for lagoon D

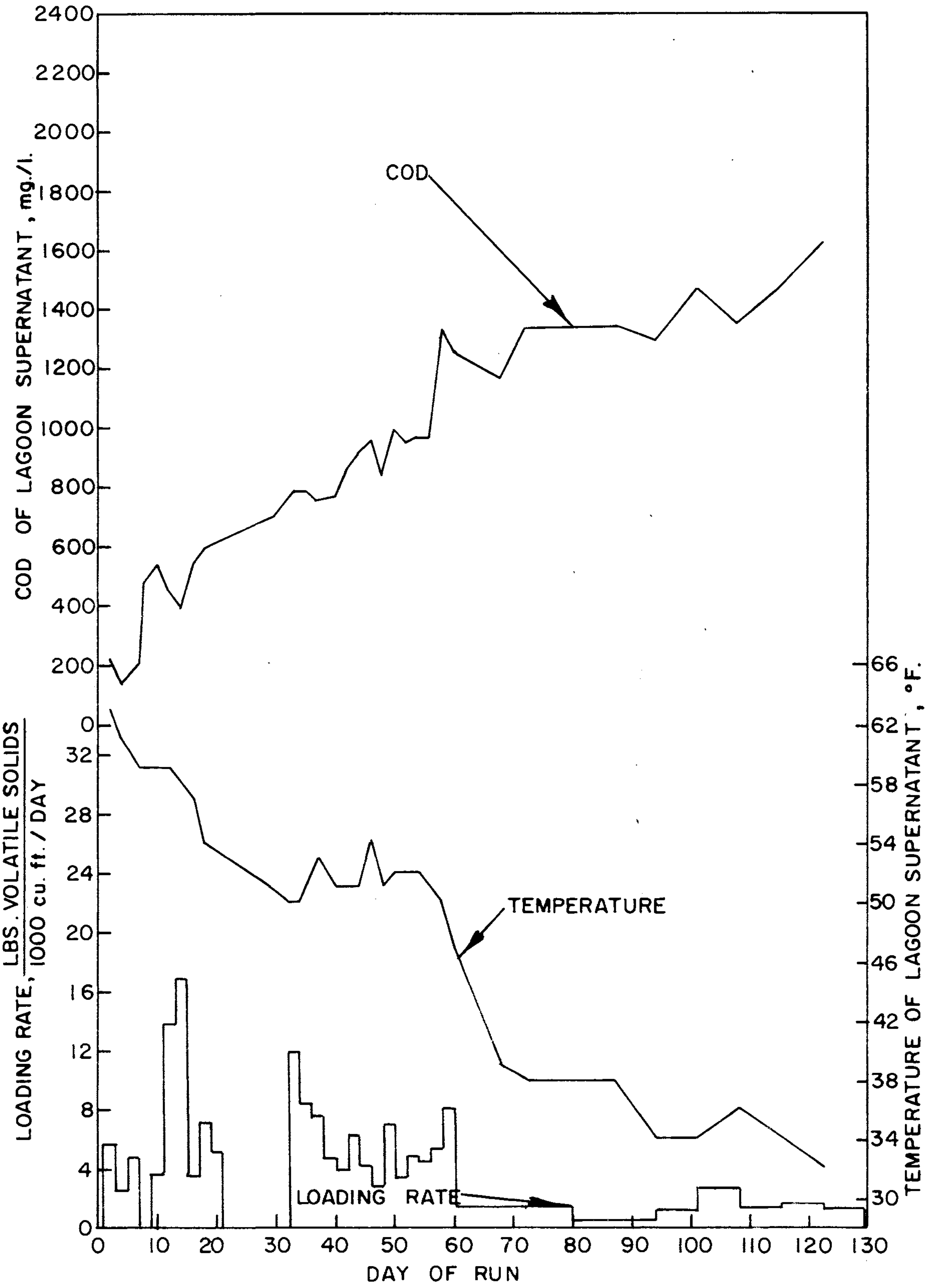

COD
TEMPERATURE
LOADING RATE
COD OF LAGOON SUPERNATANT, mg./l.
LOADING RATE, LBS. VOLATILE SOLIDS / 1000 cu. ft. / DAY
TEMPERATURE OF LAGOON SUPERNATANT, °F.
DAY OF RUN
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
32
28
24
20
16
12
8
4
0
66
62
58
54
50
46
42
38
34
30
0
10
20
30
40
50
60
70
80
90
100
110
120
130

Figure 5 (e). Daily performance chart for lagoon E

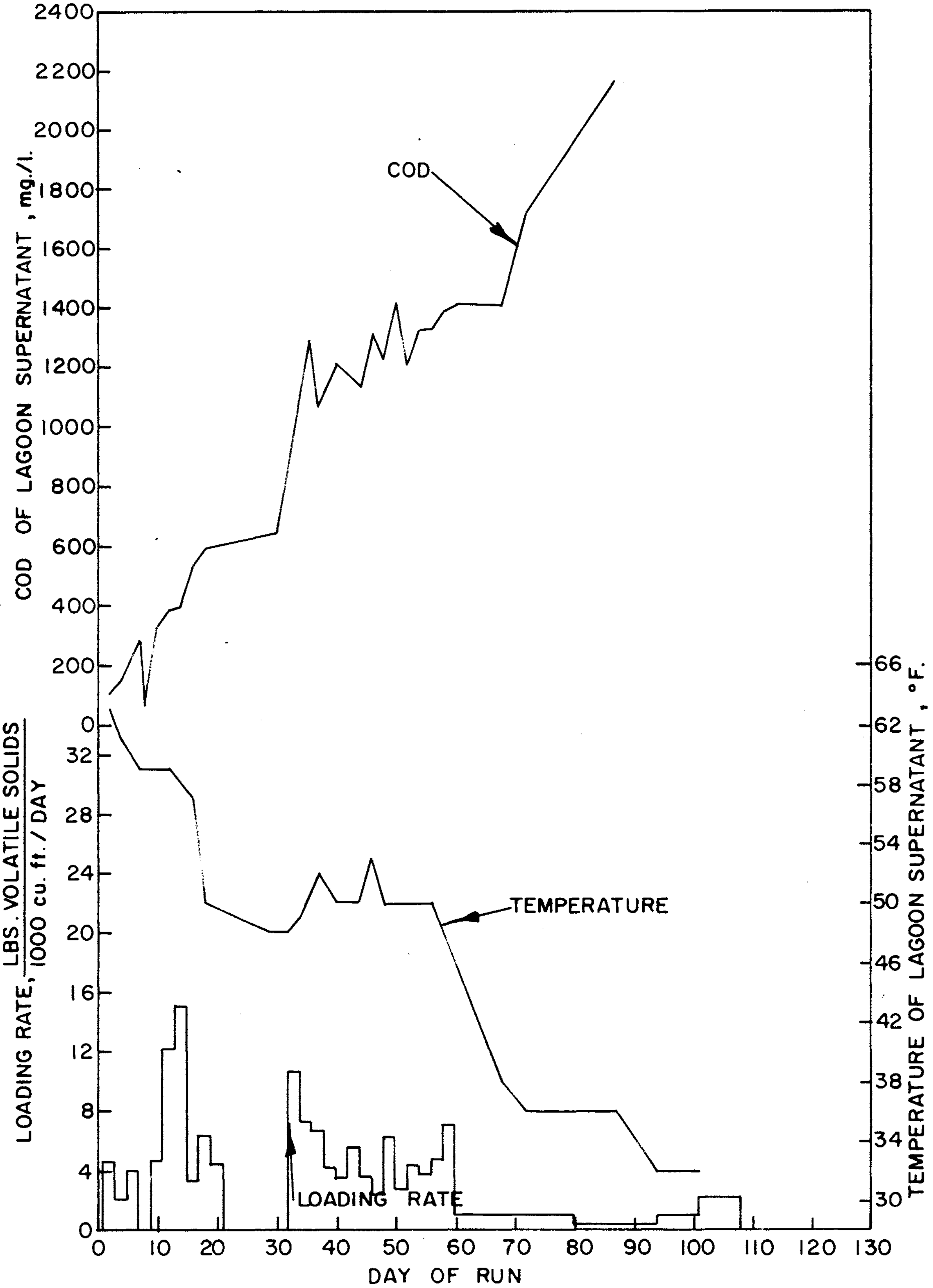
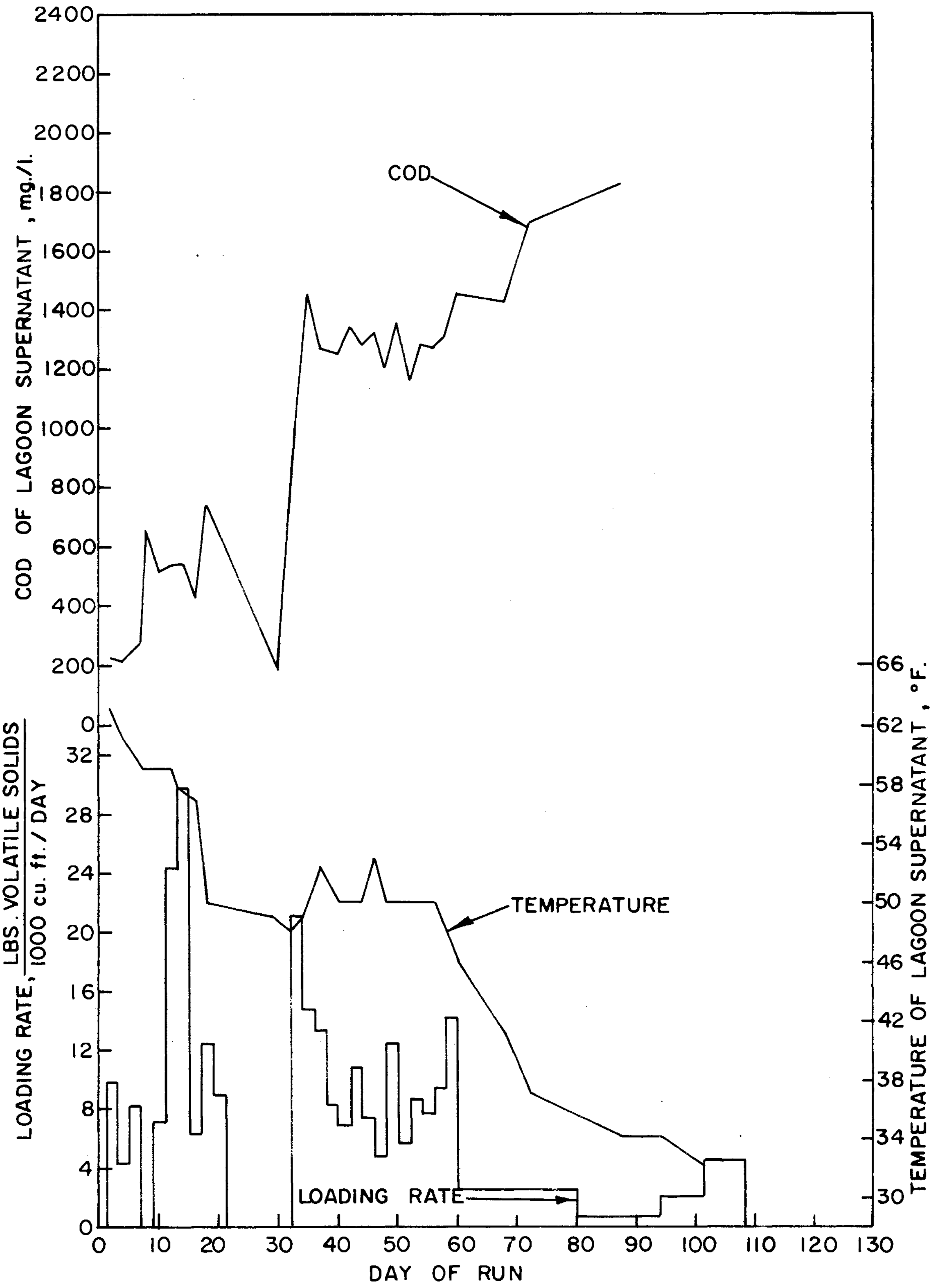

COD OF LAGOON SUPERNATANT , mg./l.
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
COD
TEMPERATURE
LOADING RATE
LOADING RATE, LBS. VOLATILE SOLIDS / 1000 cu. ft. / DAY
32
28
24
20
16
12
8
4
0
TEMPERATURE OF LAGOON SUPERNATANT , °F.
66
62
58
54
50
46
42
38
34
30
0 10 20 30 40 50 60 70 80 90 100 110 120 130
DAY OF RUN

Figure 5 (f). Daily performance chart for lagoon F



2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
COD OF LAGOON SUPERNATANT , mg./l.
COD
0
32
28
24
20
16
12
8
4
0
LOADING RATE, LBS. VOLATILE SOLIDS / 1000 cu. ft. / DAY
66
62
58
54
50
46
42
38
34
30
TEMPERATURE OF LAGOON SUPERNATANT , °F.
TEMPERATURE
LOADING RATE
0 10 20 30 40 50 60 70 80 90 100 110 120 130
DAY OF RUN

of the supernatant and loading rate.

Since the lagoons were initially filled with clear city water and a small amount of seed material, the initial COD of each lagoon was quite low. As waste material was added, the COD of the lagoons naturally began to rise. Once biological action was established in the lagoons, and assuming a constant temperature and loading rate, it was expected that the COD of the supernatant would approach a relatively constant value in each lagoon. Obviously, such conditions were not present during the investigation. However, between the 42nd and 60th day of the experiment, the variability of both temperature and loading rate appeared to be a minimum. The lagoon liquid COD observed during that interval also appeared to be relatively constant for each lagoon. The average lagoon liquid COD for each lagoon during this interval is shown in Table 6.

After the 60th day, the loading rates of the lagoons were reduced as shown in Figure 5. A rapid decrease in air and lagoon liquid temperature was also observed after the 60th day. In spite of the reduced loading rate, the decrease in temperature and the resultant decrease in biological activity apparently caused the COD to increase in all lagoons. The rate of increase of COD appeared to be much greater for lagoons E and F.

Figure 5 demonstrates that the anaerobic lagoon process has a large capacity for absorbing the variability in the loading rate. That is, even though the loading rate for each lagoon varied greatly from day to day, the COD of the supernatant did not reflect this variability in the same proportion. Even the period beginning on the 19th day when no loadings occurred did not greatly interrupt the increasing trend in COD. The effect of loading rate was probably most significant during the early stages of the investigation, before and during the time that biological action was established in the lagoons. After the 60th day, the temperature of the lagoon supernatant was probably the most important factor influencing the generally increasing trend in COD.

From Figure 5, it is apparent that the most stable period for each lagoon, in terms of supernatant COD, occurred between the 42nd and 60th day of the investigation. Preceding this period, the loading rate was extremely variable and the liquid temperature decreased approximately 10^{o}F. in each lagoon. After this period, the loading rate was greatly reduced. Also after the 60th day, the air and liquid temperatures dropped rapidly and ice formation occurred in all lagoons, which made it difficult to load the lagoons properly. The depth of ice formation is discussed in a later section. However, most of the lagoons froze to such a depth that proper loading was impossible. All except lagoons A and B began to lose liquid under the ice through exfiltration. Lagoons E and F were completely dry by the 87th day and were not loaded again. Losses through exfiltration and depth of ice were not included in the calculation of loading rates for the lagoons. For these reasons, data collected after the 60th day are not included in any comparisons of lagoon performance.

Data collected between the 42nd and 60th day of the investigation were selected for a comparison of performance among the lagoons based on the COD of the supernatant. During this period, it appeared that the COD had reached a relatively constant value in each lagoon. Therefore, comparing the averages of the COD values observed for each lagoon during this period should result in an indication of possible differences in treatment efficiency among the lagoons. The average COD values in each lagoon are shown in Table 6.

Table 6. Average COD of lagoon liquid observed from 42nd to 60th day of investigation

Lagoon	Depth (ft)	Av. loading rate during period (lbs vol. sol.) / (1000 cu ft/day)	COD mg/l
A	9.83	9.65	1537
B	9.83	4.88	1019
C	4.73	10.05	1216
D	4.73	5.03	1014
E	2.67	4.44	1296
F	2.67	8.89	1307

Comparing lagoons of like depths but of different loading rates, that is, lagoon A to lagoon B, lagoon C to lagoon D, and lagoon E to lagoon F, it is seen that the differences in level of COD decrease as the depth of lagoon decreases. At the greater depth of 9.83 feet the lower loading rate resulted in a 34 percent difference in COD. At the intermediate depth, the difference was 17 percent, and at the shallower depth the difference was less than 1 percent. Obviously, the reduction in COD for each pair of lagoons was not proportional to the reduction in loading rate.

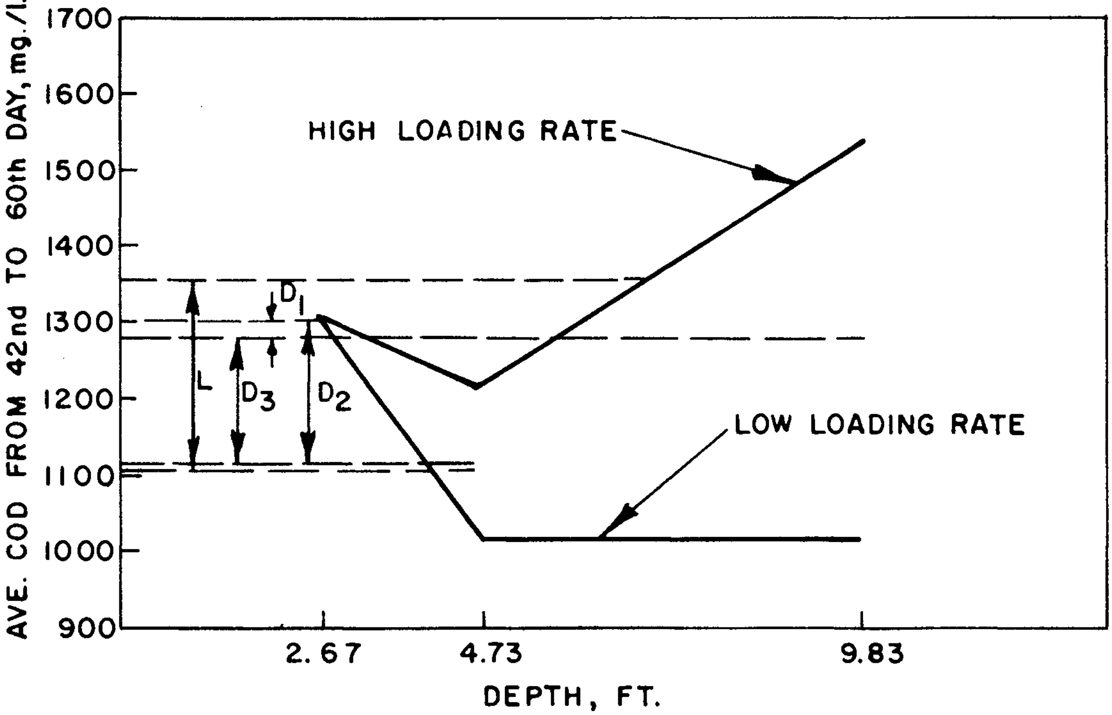
Comparison of results from lagoons with approximately the same loading rate but of different depths, that is, comparison of results obtained with lagoons A, C, and F and with lagoons B, D, and E, result in differences which are less than the differences between lagoons of like depth. These differences and the differences described in the preceding paragraph are shown graphically in Figure 6. In the figure, L represents the difference in the average COD levels obtained at the high and the low loading rate. D_1, D_2, and D_3 represent differences in the average COD level obtained at the three depths. The difference, L, is greater than either D_1, D_2, and D_3. It appears, therefore, that in general the effect of depth on the level of COD observed in the lagoons was less than the effect of a change in loading rate. There does, however, seem to be a significant interaction effect between loading rate and depth. In other words, the difference in COD level between the high and low loading rates does not remain constant over the range of depths studied, but increases with depth. This trend is clearly shown in Figure 6.

Another comparison which can be made among the lagoons is between lagoons of different loading rates and different depths which received equal amounts of raw waste. Two sets of lagoons were available for such a comparison. Lagoon B received the same total amount of waste as lagoon C,

Lagoon	Depth (ft)	Loading rate (Lbs. Vol. Sol.)/(1000 cu ft/day)	COD of supernatant (mg/l)
B	9.83	4.88	1019
C	4.73	10.05	1216
D	4.73	5.03	1014
F	2.67	8.89	1307

and lagoon D received the same total amount of waste as lagoon F. For both sets of lagoons, the greater depth resulted in a lower level of COD in the lag on supernatant. This comparison demonstrates the weakness of designing an anaerobic lagoon on the basis of a surface loading rate, such as pounds of BOD or COD per acre per day. It is apparent from the investi-

Figure 6. Graphical comparison of lagoon performance based on COD of lagoon supernatant


AVE. COD FROM 42nd TO 60th DAY, mg./l.
1700
1600
1500
1400
1300
1200
1100
1000
900
HIGH LOADING RATE
LOW LOADING RATE
D1
L
D3
D2
2.67
4.73
9.83
DEPTH, FT.

gation that the loading criteria for an anaerobic lagoon should be in terms of the amount of waste added to the lagoon per unit volume of liquid in the lagoon.

The data are insufficient to justify the estimation of levels of COD to be expected from anaerobic lagoons loaded at various loading rates. If one assumes that the data in Table 6 represent an approximate estimate of the optimum COD levels obtained in this experiment, then all test lagoons were operating in the range of approximately 82 to 89 percent reduction of COD in the raw waste.

If we assume that sedimentation takes out the same fraction of COD as was removed by filtration, then the lagoons should be expected to reduce the COD from 8,870 mg/l to about 2800-3000 mg/l, or about a 66 percent reduction. Thus, it is obvious that some biological degradation of the waste did occur in the lagoons.

Volatile solids No significant differences in the volatile solids content of the lagoon liquids were noticed. Values observed on the 76th day of the investigation are shown in Table 7. Assuming an average of about 1000 mg/l in the lagoon supernatant and a value of 7,240 mg/l in the raw waste, this represents a reduction of volatile solids in the lagoon supernatant of about 86 percent.

Table 7. pH and volatile solids content of lagoon supernatant

Lagoon	pH	Vol. sol. (mg/l)
A	7.2	1060
B	7.1	840
C	7.0	990
D	7.2	860
E	7.3	1050
F	7.2	970

pH The pH of the lagoon supernatant did not vary appreciably in any single lagoon or among lagoons during the first 39 days of observation. The pH of the various lagoons ranged generally from 6.8 to 7.2, with one low value of 6.5 observed in lagoons C and D, and a high value of 7.4 observed once in lagoon F. The pH of each lagoon on the 40th day of operation is shown in Table 7.

Temperature and ice formation As the investigation progressed into the fall, the surface temperatures of the lagoons decreased quite reasonably at a somewhat lower rate than the surrounding air (Tables 12 and 13). The temperatures of the shallower lagoons naturally decreased at a slightly greater rate than the deeper lagoons. Ice formation began on all lagoons except lagoons A and B, the deeper lagoons, about November 27, the 68th day of operation. By December 1, a thin film of ice had also formed on these lagoons. On that date, the ice cover was from 3 to 5 inches thick on the other lagoons. On December 23, the 94th day of operation, 3½ inches of ice covered lagoons A and B, 6½ inches of ice covered lagoons C and D, and lagoons E and F were frozen to a depth of approximately 9 inches. After this date, lagoons E and F began to lose liquid through exfiltration at a rate such that they would be almost completely empty by the time of the next loading. Those two lagoons were not used for data collection thereafter. However, they were filled with clear water and observed periodically for possible useful information. On January 20 the last date on which the lagoons were sampled, lagoons A and B were covered by 5 inches of ice, lagoon C by 15 inches of ice, and lagoon D by 12 inches of ice. The temperature of the lagoon liquid approximately 1 to 2 inches below the ice reached a low of 32°F. in lagoon C by December 23 and in lagoons B and D by January 20. By that date the liquid temperature in lagoon A had not fallen below 34°F.

Analysis of bottom sludge

Sludge samples from each lagoon were obtained on December 5, the 76th day of operation. The depth of accumulated sludge in each lagoon is given in Table 8, along with total and volatile solids, volatile acids, and settleable solids in the sludge. The depth of sludge in lagoon E could not be measured by either method used. The sludge layer was apparently too thin. For purposes of chemical analyses sludge samples from lagoon E were obtained by scraping a can along the bottom of the lagoon. Only about 8 inches of liquid was present in the lagoon at the time.

The method used to collect the sludge samples resulted in some lagoon liquid being pumped from the lagoons along with the sludge particles. Therefore, the values shown in Table 8 for volatile acids, total solids, and volatile solids do not represent the true characteristics of the sludge material in place at the bottoms of the lagoons.

The samples were obtained after lagoons E and F had lost most of their liquid volume through exfiltration. Therefore, in making comparisons among the lagoons, results from these two lagoons are not considered.

Volatile acids Due to the dilution of the sludge samples by an unknown amount of supernatant, the volatile acids determinations were conducted on a mixture of lagoon supernatant and bottom sludge. Except for lagoon E, all determinations resulted in volatile acids concentrations well below 2000 mg/l, which is a generally accepted upper limit for successful anaerobic digestion.

Total and volatile solids (Table 8) Total solids and volatile solids concentrations in the sludges are not significant in themselves due to the dilution of the samples. However, the percentage of volatile solids in the sludge appeared to be greater in lagoons A and B, the deeper lagoons, than in lagoons C and D.

Settleable solids (Table 8) An Imhoff cone was used to determine the amount of settleable solids in the sludge samples. In performing the test, it was noticed that the solids settled into two distinct layers, a lower layer of extremely coarse-grained material and an upper layer of fine black particles appearing to be about 1 millimeter in diameter. The relative amounts of each kind of particle to the total settleable solids in the Imhoff cone varied among the lagoons as shown in Table 7. The coarse material was composed of feed and waste material that had not been decomposed by the biological action in the lagoons.

Table 8. Results of analysis of sludge samples taken on December 5

Lagoon	Sludge depth (in.)	Volatile solids (mg/l)	(% of total)	Volatile acids (mg/l)	Settleable solids Total (ml/l)	Feed particles (%)
A	10.5	9,380	81.8	680	145	25
B	5.5	10,270	85.3	470	125	17
C	6.0	8,180	78.5	330	220	45
D	3.5	40,980	75.1	520	500	30
E	-	58,890	89.2	2,390	850	41
F	2.0	20,580	83.1	500	260	30

Sludge depth The total depth of sludge in each lagoon conformed to the generally accepted rule that the amount of sludge residue produced by anaerobic digestion is proportional to the total amount of feed or raw waste introduced to the process. Sludge depths measured in this study are shown in Table 8. Lagoons A and C, loaded at the heavier volatile solids loading rate, experienced sludge buildup of approximately 9-10 percent of their original depth during the first 76 days of operation. Lagoons B and D, the lighter loaded lagoons, experienced sludge buildup of approximately 4-6 percent of their original depth. The data show that neither the volatile solids loading rate nor the depth of the lagoon had any noticeable effect on the amount of sludge buildup in the lagoons. The sludge depth was apparently determined by the total amount of raw waste added to the lagoon regardless of the loading rate. For example, lagoon A had the same depth as lagoon B, but the loading rate was twice that of lagoon B. Therefore, twice as much raw waste was introduced into lagoon A. The resulting sludge depth in lagoon A was approximately twice the depth in lagoon B. Lagoon C was loaded at approximately the same rate as lagoon A, but since its depth was approximately one-half that of lagoon A, it received only one-half as much waste material, or the same total amount received by lagoon B. The results show that the depths of sludge in lagoons B and C were approximately equal and were both approximately 50 percent of the sludge depth measured in lagoon A.

In terms of yearly sludge buildup, the heavier loaded lagoons were accumulating sludge at the rate of about 48 percent of their original depth per year; lagoons B and D, at approximately 24 percent. Obviously, these values apply only to the test lagoons during the period of operation.

Since the investigation was relatively short and was conducted during a colder period of the year, these values are undoubtedly far higher than they should be. The results indicate, however, that the higher loading rates studied would probably be too high due to excessive sludge accumulation. Since a lagoon would probably fill with sludge at less than the above rates, it appears that the lower loading rates might be acceptable under certain conditions, such as if the lagoon was to be in operation for only a few years.

Sludge composition The composition of the sludge was apparently influenced by both loading rate and depth of lagoon. The percentage of feed particles observed in the sludge samples are shown in Table 8. These particles apparently passed through the lagoon processes relatively unaltered in color, size, or shape. The results indicate that some lagoons were more efficient than others in the decomposition of such particles.

Effect of loading rate To obtain an indication of the effect of loading rate on sludge composition, lagoons can be compared which had the same depth but which were loaded at different volatile solids loading rates. Lagoon A can be compared to lagoon B, and lagoon C to lagoon D. Lagoon A received twice as much raw waste as lagoon B, and lagoon C received twice as much as lagoon D. The percentage of feed hulls in the sludge samples from the lighter loaded lagoons, as measured by volume in the Imhoff cone, was approximately 32-33 percent less than the percentage for the heavier loaded lagoons. Apparently, the lighter loading rate resulted in a higher efficiency of degradation of the hard to digest feed particles.

Effect of depth To obtain an indication of the effect of depth on sludge composition, lagoons of approximately the same loading rate but of different depths can be compared. Lagoon A can be compared to lagoon C, and lagoon B to lagoon D. The results show that at the deeper depths the percentage of feed particles was about 55-56 percent of that at the shallower depths. Since lagoon A received twice as much raw waste as lagoon C, and lagoon B received twice as much waste as lagoon D, the depth of sludge in lagoons A and B was approximately twice as great as in the shallower lagoons. However, the portion of the sludge depth which was composed of feed particles remained approximately the same between lagoons of the same loading rate. For example, even though the total depth of sludge in lagoon A was twice the total amount in lagoon C, both lagoons contained relatively the same amount of feed particles. Since lagoon A received twice as many feed particles as lagoon C during the period of operation, but at the time the sludge was sampled contained the same amount of feed particles, it is apparent that the deeper lagoons were accomplishing the degradation of the lignacious particles at approximately twice the rate of the shallower lagoons. The percentage of feed particles in the sludge samples from lagoon B, which was approximately twice the depth of lagoon C and was loaded at the lower loading rate, was about 62 percent less than lagoon C. Apparently, increasing the depth and decreasing the loading rate both act in the same direction to increase the operating efficiency of the lagoon in the destruction of feed particles. This is also shown by comparing the results of lagoons A and D, where the decreased lagoon depth and lower loading rate resulted in only a minor difference in the percentage of feed particles present in the sludge.

Apparently, the shallower depths also resulted in a slightly lower percentage of volatile solids in the sludge residue.

Subjective Observations

Odor

Odor is a difficult item to evaluate. For example, on one day lagoon A might smell worse than lagoon C, whereas the next day the situation might be reversed. An odor analysis must, therefore, be an extremely subjective picture of lagoon performance over the entire period of operation.

The lagoons were first loaded on September 21. No odor was detected from any lagoon for three days, when a slight H_2S odor was noticed from lagoon A. After one week, this odor had become quite noticeable, but not too objectionable. After one week, lagoon B had developed a very slight odor. After two weeks, the odor from lagoon A had become quite objectionable, due to a strong odor of H_2S. As yet only a very slight odor had been noticed from the other five lagoons. During the period from October 9 to October 20, when the lagoons were allowed to stand idle, no noticeable change in odor was detected. After about one month, the odor from lagoon A had become definitely putrid. Lagoon B was the only other lagoon that had as yet developed an easily detectable odor. The other lagoons all developed noticeable odors before the end of the investigation, but none of the odors seemed too obnoxious. The odor from lagoon A remained extremely bad throughout the rest of the investigation.

Differences in odor among lagoons B, C, and D, could not be detected. The odor was noticeable, but not obnoxious. It was reminiscent of the odor of raw municipal sewage. Occasionally harsh odors were noticed from lagoons E and F, but for the most part no disagreeable odors occurred. Their usual odor could be compared to that of stagnant water in a shallow pond or river slough.

Considering the entire period of the investigation up to November 27, when ice began to form on the lagoons, the odor production may be stated as follows. The worst odors were produced by lagoon A followed by lagoon B. The least disagreeable odors were produced by lagoons E and F. Again, the odor from lagoon A was by far the most objectionable. It would then appear that the odor became more objectionable as the depth increased. However, odors would probably have been much more noticeable had the lagoons been larger, which might have resulted in a different conclusion concerning odor production.

Gas production

Bubbles of gas were observed first in lagoon A after about one week of operation. By October 8, the 13th day of operation, gas bubbles were observed in all lagoons except lagoon F. The first bubbles were observed in this lagoon on October 30. There was no noticeable difference among the lagoons in the quantity of bubbles produced. Apparently, the gas was being produced by anaerobic digestion which was taking place in all of the lagoons.

Rising sludge occurred frequently in all lagoons except lagoons A and B. Sludge in large quantities was observed rising to the surfaces of lagoons E and F on October 27. This date corresponds quite well with the sudden rise in liquid COD in these lagoons. Solids tests on the samples of the lagoon liquid taken at that time showed the total solids content of the supernatant in lagoon A to be 0.19 percent, that of lagoon C to be 0.17 percent, of lagoons B and D to be 0.15 percent, and of lagoons E and F to be 0.18 percent. Differences among these values do not appear to be significant.

Appearance

Scum cover   After only 1 day of loading, scum had formed on all lagoons. The cover was very light and disappeared after a few days. After 16 days of operation lagoons A and B were completely covered by a thick grey scum layer. After 33 days, a light covering of grey scum was noticed on lagoons C and D, and a light red scum over lagoons E and F. Traces of red were also noticed in the grey scum which covered lagoon B. After 37 days of operation lagoons B, E, and F, were completely covered by red scum. Lagoon A was still completely covered by grey scum. Lagoons C and D were partially covered by a grey scum layer, but a trace of red was noticed in each lagoon. By the 46th day of operation, (November 5), all lagoons except lagoon A were 50-100 percent covered by a thin layer of red scum. Lagoon A was still covered by grey scum.

Incomplete laboratory tests indicated that the red scum was probably composed of a Euglena type of algae, while the grey scum was probably formed by a type of yeast. The red scum and the grey scum to a lesser extent were easily broken up by gentle agitation with a pole. On windy days, the degree of coverage of the lagoon surfaces was greatly diminished.

The test lagoons had very small surface areas, and the water surfaces were approximately 1 foot below ground level. These conditions undoubtedly reduced the effectiveness of wind and wave action in breaking up the layers of scum on the lagoons.

Color Some mention should be made of color, even though it might not be considered a measure of lagoon performance. Where a lagoon must of necessity be located within the occasional view of the public, however, color may contribute to the overall acceptance of the operation. All lagoons were initially filled with clear city water. As time progressed, the liquid in all lagoons changed to a dark grey color. The liquid in lagoon A was at times definitely black. After only one loading, the liquid in lagoon A had begun to turn color. The liquid in lagoon B first changed to a light green, then to a very dark green, and, by September 27, to a grey-black color. These lagoons remained grey to black in color throughout the remainder of the investigation.

Lagoons C and D progressed from clear water to a greenish liquid. By September 24, the liquid in lagoon C had turned to a very dark green and by September 27 had changed to greyish-black. Lagoon D retained a greenish color until October 2, when it also turned to a very dark grey.

Lagoons E and F turned quickly to a dark green. Lagoon F was always slightly darker in color than lagoon E. By November 5, the liquid in both lagoons was a very opaque black, that of lagoon E being somewhat the blacker. All lagoons remained grey to black in color for the remainder of the investigation.

Insect breeding After the lagoons were initially filled, what appeared to be a type of insect larvae appeared in the surface layer of each lagoon. Large numbers of small flying insects were also noticed hovering around and clinging to the inside walls of the lagoons above the water surface. After the second loading, no trace of insects was again noticed near any lagoon. It is probable that most larvae or insects present in the surface layers were washed out the overflow with the lagoon effluent. No further evidence of the presence of insects was noticed.

SUMMARY

Effect of Depth

The depth of lagoon appeared to exert a major effect on the composition of the accumulated sludge in the lagoons. Increasing the depth resulted in a higher percentage of digestion of the raw waste, especially of the hard to digest solids such as feed particles. Due to insufficient data, the actual cause can not be determined. There are several factors related to depth which might affect lagoon performance such as temperature variation at different depths, stratification in the lagoon liquid layers, and gas formation in the sludge layer. Possibly one or more of these or other unknown factors resulted in the lighter digested sludge particles occupying a larger space in the deeper lagoons, which would account somewhat for the lower percentage of feed particles in the sludge in these lagoons. The depth of lagoon exerted no noticeable effect on the total depth of sludge buildup in the lagoons.

Effects due to possible interactions of depth with loading rate or other factors may also be important, but can not be isolated based on data from this investigation. It is obvious however, that the depth of the lagoon, or some factor or factors related to depth, does exert a noticeable effect on the digestion process which takes place in an anaerobic lagoon used for the disposal of swine wastes.

It is not obvious from the results of this investigation what effect, if any, the depth of lagoon had on the COD of the lagoon supernatant. The average COD in the lagoons having the greater depth and in the lagoons having the lesser depth were both greater than the COD in the lagoons of intermediate depth. This indicates that the COD of the supernatant was probably most affected by various combinations of depth and loading rate, not by depth alone.

Effect of Loading Rate

In this investigation, the loading rate was determined in three ways. Table 12 in the Appendix includes loading data for each time the lagoons were loaded in terms of: 1) total pounds of COD and volatile solids added to the lagoons at each loading, 2) pounds of volatile solids added per 1000 cubic feet per day, and 3) pounds of COD added per acre of lagoon surface area per day.

Evaluation of the analytical data indicates that the loading rate in terms of pounds of volatile solids per 1000 cubic feet per day exerted a slightly greater effect on the COD of the lagoon supernatant than either depth of lagoon or the various combinations of depth and loading rate. The higher loading rates resulted in a higher supernatant COD than did the lower loading rates. This effect appeared to be greater as the depth of lagoon was increased.

When lagoons loaded at the same surface loading rate, i.e., pounds of COD per acre per day, but having different depths were compared, the COD of the supernatant in the shallower lagoons appeared to be significantly greater. Where varying depths are in use, surface loading rate should not be used as the loading criteria.

The total amount of raw waste added to the lagoon, regardless of the depth of lagoon or the rate at which the waste is added, appears to be the controlling factor in determining the depth of sludge which will accumulate in the lagoon.

The subjective observations obtained during the investigation point to no obvious conclusions concerning significant effects of either depth or loading rate. Only lagoon A stands out from the rest according to these observations. Lagoon A, which received the greatest total amount of raw waste during the investigation, consistently produced odors which were more obnoxious than those produced by any other lagoon. Lagoon A received at least twice the total amount of raw waste received by any other lagoon and, therefore, experienced at least twice as much sludge accumulation as any other lagoon. Possibly the odor problem was due to increased gas production caused by the large amount of bottom sludge present in the lagoon.

CONCLUSIONS AND RECOMMENDATIONS

In evaluating the results from the investigation, several results of major importance were observed.

Lagoons A and C were operated at a loading rate of 9-10 pounds of volatile solids per 1000 cubic feet per day. Lagoon A produced foul odors throughout the study. Both lagoons showed a rate of sludge accumulation which would fill them completely in approximately 2 years. Based on these criteria, lagoons A and C did not operate satisfactorily. The COD of the supernatant in these lagoons was about 1500 mg/l and 1200 mg/l respectively.

Lagoons B and D were loaded at a rate of 4-5 pounds of volatile solids per 1000 cubic feet per day. The COD of the supernatant in lagoon B, the deeper lagoon was approximately the same as the COD in lagoon D, about 1000 mg/l. The odor produced by lagoon B differed little in strength from that produced by lagoon D. Neither seemed too offensive.

Lagoons A and B were about 10 feet deep, approximately twice the depth of lagoons C and D. Lagoons A and B appeared to be approximately twice as efficient as lagoons C and D in the destruction of lignacious material present in the raw waste.

All lagoons showed a COD removal efficiency of 82-89 percent. Lagoons B and D showed the highest removal efficiency, and lagoon A, the lowest.

The major conclusions may be stated as follows:

1) An increased volatile solids loading rate raises the level of COD in the lagoon supernatant to a greater extent than does an increase in lagoon depth.

2) A loading rate of 10 pounds of volatile solids per 1000 cubic

feet per day is unsatisfactory for the successful operation of an anaerobic swine waste lagoon.

3) At a given loading rate, the efficiency of the lagoon in the decomposition of lignacious material in the raw waste is greatly increased by an increased depth of lagoon.

4) With respect to color, scum formation, and insect breeding, no noticeable differences were discovered among the lagoon depths and loading rates studied.

In the design of an anaerobic lagoon for the disposal of wastes from a swine confinement unit, the first item that must be known is the number of hogs which will be served by the lagoon. Knowing this and knowing the average manure production per hog and the average composition of the manure (Tables 1 and 2), the total amount of waste to be disposed of per day can be estimated. Based on this study, it is recommended that the design loading rate to be used should be between 5 and 10 pounds of volatile solids per 1000 cubic feet per day.

Naturally, the lowest possible loading rate will result in the most efficient lagoon performance. However, the loading rate to be used should be that which will result in acceptable lagoon performance and also in the least annual cost to the swine producer. The loading rate affects the annual cost in 2 ways: 1) the higher the loading rate, the faster the sludge accumulation, which will result in more frequent cleaning of the lagoons thereby increasing the annual cost, and 2) as the loading rate increases, the cost of lagoon construction will decrease because of the lesser liquid volume which will be required. Therefore, the optimum size of lagoon will be that which gives acceptable performance and results in a minimum total annual cost of construction and cleaning. The results of this investigation show that depths of at least 10 feet are practical when loading rates of approximately 5 pounds of volatile solids per 1000 cubic feet per day are used. It is recommended, therefore, that the lagoon be designed with a depth of at least 10 feet. Since it is generally less expensive to dig the lagoon deeper than to acquire additional land, the increased depth will result in a greater lagoon volume, thereby decreasing the loading rate, without greatly increasing the cost of construction.

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APPENDIX

Data Summary for Test Lagoons

Table 9. Characteristics of the raw waste

Sampling date	Day of run	Total solids mg/l	Volatile solids mg/l	Volatile solids as % of total solids	COD mg/l	Lb. COD / Lb.vol.sol.
Sept. 21	1	8,500	7,200	85	6,880	0.96
23	3	4,000	3,100	79	3,446	1.11
25	5	7,100	5,700	80	8,118	1.38
29	9	5,700	5,100	87	5,735	1.12
Oct. 1	11	20,200	13,000	89	7,703	0.43
3	13	24,500	22,200	91	17,268	0.78
5	15	5,600	4,700	84	8,383	1.78
7	17	10,800	9,100	84	15,591	1.71
9	19	7,800	6,600	84	9,720	1.47
No data collected during this period						
22	32	18,300	15,500	85	19,792	1.28
24	34	12,500	10,800	86	17,147	1.59
27	37	12,000	9,800	82	6,317	0.64
28	38	7,000	6,000	86	5,172	0.86
30	40	6,000	5,000	83	4,972	0.99
Nov. 1	42	9,200	8,000	87	8,728	1.09
3	44	6,600	5,400	83	8,440	1.56
5	46	4,200	3,400	80	8,528	2.51
7	48	10,800	9,000	83	6,008	0.67
9	50	5,300	4,200	79	12,290	2.92
11	52	7,600	6,300	84	10,004	1.59
13	54	6,800	5,600	82	10,170	1.82
15	56	8,300	6,900	83	10,496	1.53
17	58	12,900	10,500	81	12,560	1.20
27	68	9,900	8,400	85	8,070	0.96

Table 9. (Continued)

Sampling date		Day of run	Total solids mg/l	Volatile solids mg/l	Volatile solids as % of total solids	COD mg/l	Lb. COD / Lb.vol.sol.
Dec.	9	80	2,000	1,300	64	2,464	1.90
	16	87	6,800	5,200	76	8,580	1.65
	23	94	3,600	2,500	68	3,851	1.54
	30	101	7,500	5,700	77	8,960	1.57
Jan.	6	108	4,000	2,800	71	4,302	1.54
	13	115	4,500	3,400	75	4,934	1.45
	20	122	3,700	2,600	72	3,965	1.47

Table 10. COD of lagoon supernatant

Sampling date	Day of run	Lagoon COD mg/l A	B	C	D	E	F
Sept. 22	2	188	292	448	216	102	222
24	4	376	231	372	129	144	208
27	7	408	291	482	200	280	276
28	8	682	403	604	466	65	641
30	10	729	416	612	535	321	506
Oct. 2	12	716	419	604	443	380	529
4	14	677	450	541	391	393	539
6	16	800	525	396	535	530	425
8	18	827	577	728	587	581	734
No data collected during this period							
20	30	851	531	725	697	641	182
23	33	1,000	810	930	784	1,000	1,000
25	35	1,445	810	953	781	1,300	1,450
27	37	1,312	742	838	746	1,071	1,271
30	40	1,323	691	844	760	1,213	1,244
Nov. 1	42	1,257	644	889	857	1,170	1,337
3	44	1,521	887	1,076	912	1,138	1,280
5	46	1,617	933	1,345	952	1,315	1,315
7	48	1,455	861	1,139	833	1,231	1,199
9	50	1,555	1,024	1,301	984	1,414	1,354
11	52	1,516	987	1,172	948	1,214	1,160
13	54	1,524	980	1,244	964	1,330	1,285
15	56	1,438	945	1,224	960	1,328	1,272
17	58	1,518	1,518	1,052	1,300	1,321	1,310
19	60	1,690	1,501	1,139	1,250	1,411	1,458
27	68	1,700	1,077	1,398	1,162	1,410	1,434
Dec. 1	72	1,781	1,090	1,707	1,334	1,718	1,697
16	87	1,764	1,144	1,542	1,340	2,170[a]	1,820
23	94	1,961	1,045	1,555	1,289	-----	-----
30	101	1,931	1,073	1,565	1,465	-----	-----
Jan 6	108	2,153	1,214	914	1,347	-----	-----
13	115	2,237-	1,329	1,411	1,466	-----	-----
20	122	2,318	1,340	1,630	1,610	-----	-----

[a]Loading and sampling of lagoons E and F were discontinued after December 16

Table 11 (a). Loading rates for lagoon A

Date	Day of run	Lb. of volatile solids added	Lb. of COD added	Lb. vol. solids per 1000 ft^3-day	Lb. COD per acre-day	Hydraulic loading (ft.^{3})
1964						
Sept. 21	1	4.04	3.86	10.52	4,320	9.0
23	3	1.74	1.94	4.54	2,170	
25	5	3.30	4.56	8.60	5,090	
29	9	2.86	3.22	7.45	3,600	
Oct. 1	11	10.12	4.32	26.40	4,830	
3	13	12.47	9.70	32.50	10,800	
5	15	2.64	4.70	6.89	5,250	
7	17	5.11	8.76	13.34	9,780	
9	19	3.71	5.46	9.68	6,100	
No data collected during this period						
22	32	8.70	11.13	22.72	12,400	
24	34	6.07	9.63	15.84	10,800	
27	37	5.50	3.55	14.33	3,970	
28	38	3.37	2.90	8.80	3,240	
30	40	2.81	2.79	7.33	3,120	
Nov. 1	42	4.49	4.90	11.71	5,470	
3	44	3.03	4.74	7.90	5,290	
5	46	1.91	4.79	4.98	5,350	
7	48	5.05	3.37	13.18	3,760	
9	50	2.36	6.90	6.15	7,710	
11	52	3.54	5.62	9.24	6,280	
13	54	3.14	5.71	8.20	6,380	
15	56	3.88	5.89	10.11	6,580	
17[a]	58	5.90	7.05	15.40	7,860	
27[b]	68	9.44	9.06	2.46	1,012	18.0
Dec. 9[c]	80	1.46	2.77	1.09	885	
16[d]	87	5.84	9.62	4.34	3,076	
23	94	2.82	4.34	2.10	1,380	
30	101	6.40	10.06	4.76	3,210	
1965						
Jan. 6	108	3.14	4.84	2.34	1,540	
13	115	2.82	5.54	2.10	1,770	
20	122	2.92	4.28	2.17	1,368	

[a]Last loading performed on alternate day basis. Loading rates for this day calculated over period from November 17-18, a period of 2 days

[b]Loading rates for this day calculated over period from November 19-December 8, a period of 20 days

[c]Began once a week loading; rates based on 7-day interval

[d]Only lagoon A was loaded on this date

Table 11 (b). Loading rates for lagoon B

Date	Day of run	Lb. of volatile solids added	Lb. of COD added	Lb. vol solids per 1000 ft^3-day	Lb. COD per acre-day	Hydraulic loading (ft.^{3})
1964						
Sept.						
21	1	2.02	1.93	5.26	2,160	4.5
23	3	0.87	0.97	2.27	1,085	
25	5	1.65	2.28	4.30	2,545	
29	9	1.43	1.61	3.72	1,800	
Oct.						
1	11	5.06	2.16	13.20	2,415	
3	13	6.24	4.85	16.25	5,400	
5	15	1.32	2.35	3.44	2,625	
7	17	2.56	4.38	6.67	4,890	
9	19	1.86	2.73	4.84	3,050	
No data collected during this period						
22	32	4.35	5.57	11.36	6,200	
24	34	3.04	4.82	7.92	5,400	
27	37	2.75	1.78	7.16	1,985	
28	38	1.68	1.45	4.40	1,620	
30	40	1.40	1.40	3.67	1,560	
Nov.						
1	42	2.25	2.45	5.86	2.735	
3	44	1.52	2.37	3.95	2,645	
5	46	0.96	2.40	2.99	2,675	
7	48	2.53	1.69	6.59	1,880	
9	50	1.18	3.45	3.08	3,855	
11	52	1.77	2.81	4.62	3,140	
13	54	1.57	2.86	4.10	3,190	
15	56	1.94	2.95	5.06	3,290	
17	58	2.95	3.52	7.70	3,930	
27[a]	68	4.72	4.53	1.23	1,440	9.0
Dec.						
9[b]	80	0.73	1.38	0.27	440	
23[c]	94	1.41	2.17	1.05	345	
30	101	3.20	5.03	2.38	1,600	
1965						
Jan.						
6	108	1.57	2.42	1.17	770	
13	115	1.91	2.77	1.05	880	
20	122	1.46	2.14	1.08	680	

[a]Loading rate calculated on 20-day basis

[b]Lagoon not loaded on December 16, therefore loading rate calculated over a 2-week period

[c]Began once a week loadings

Table 11 (c). Loading rates for lagoon C

Date	Day of run	Lb. of volatile solids added	Lb. of COD added	Lb. vol solids per 1000 ft^3-day	Lb. COD per acre-day	Hydraulic loading (ft.^{3})
1964						
Sept. 21	1	2.02	1.93	10.95	2,160	4.50
23	3	0.87	0.97	4.71	1,085	11.00
25	5	1.65	2.28	8.95	2,545	12.63
29	9	1.43	1.61	7.75	1,800	11.00
Oct. 1	11	5.06	2.16	27.42	2,415	14.25
3	13	6.24	4.85	33.80	5,400	14.25
5	15	1.32	2.35	7.15	2,625	11.00
7	17	2.56	4.38	13.88	4,890	9.38
9	19	1.86	2.73	10.02	3,050	7.75
No data collected during this period						
22	32	4.35	5.57	23.60	6,200	20.76
24	34	3.04	4.87	16.41	5,400	12.63
27	37	2.75	1.78	14.90	1,985	4.50
28	38	1.68	1.45	9.11	1,620	
30	40	1.40	1.40	7.60	1,560	
Nov. 1	42	2.25	2.45	12.20	2.735	
3	44	1.52	2.37	8.25	2,645	
5	46	0.96	2.40	5.20	2,675	
7	48	2.53	1.69	13.70	1,880	
9	50	1.18	3.45	6.40	3,855	
11	52	1.77	2.81	9.60	3,140	
13	54	1.57	2.86	8.57	3,190	
15	56	1.94	2.95	10.51	3,290	
17	58	2.95	3.52	16.00	3,930	
27	68	4.72	4.53	2.56	1,440	
Dec. 9	80	0.73	1.38	0.57	440	
23	94	1.41	2.17	2.18	345	
30	101	3.20	5.03	4.95	1,600	
1965						
Jan. 6	108	1.57	2.42	2.44	770	
13	115	1.91	2.77	2.96	880	
20	122	1.46	2.14	2.26	680	

Table 11 (d). Loading rates for lagoon D

Date	Day of run	Lb. of volatile solids added	Lb. of COD added	Lb. vol solids per 1000 ft^3-day	Lb. COD per acre-day	Hydraulic loading (ft.^{3})
1964						
Sept. 21	1	1.01	0.97	5.48	1,080	2.25
23	3	0.44	0.49	2.36	548	15.25
25	5	0.83	1.14	4.48	1,270	15.25
29	9	0.72	0.81	3.38	900	12.00
Oct. 1	11	2.53	1.08	13.71	1,210	12.00
3	13	3.12	2.43	16.90	2,700	12.00
5	15	0.66	1.18	3.58	1,310	12.00
7	17	1.28	2.19	6.94	2,450	8.75
9	19	0.93	1.37	5.01	1,520	8.75
No data collected during this period						
22	32	2.18	2.79	11.80	3,100	10.37
24	34	1.52	2.44	8.20	2,700	2.25
27	37	1.38	0.89	7.45	900	
28	38	0.84	0.73	4.56	810	
30	40	0.70	0.70	3.80	780	
Nov. 1	42	1.13	1.23	6.10	1,360	
3	44	0.76	1.19	4.13	1,320	
5	46	0.48	1.20	2.60	1,340	
7	48	1.27	0.85	6.85	940	
9	50	0.59	1.73	3.20	1,930	
11	52	0.89	1.41	4.80	1,570	
13	54	0.79	1.43	4.29	1,550	
15	56	0.97	1.48	5.26	1,620	
17	58	1.47	1.76	8.00	1,970	
27	68	2.36	2.26	1.28	720	
1965						
Dec. 9	80	0.36	0.69	0.28	220	
23	94	0.70	1.09	1.09	172	
30	101	1.60	2.51	2.48	800	
Jan. 6	108	0.79	1.41	1.22	380	
13	115	0.95	1.39	1.48	440	
20	122	0.73	1.07	1.13	340	

Table 11 (e). Loading rates for lagoon E

Date	Day of run	Lb. of volatile solids added	Lb. of COD added	Lb. vol solids per 1000 ft^3-day	Lb. COD per acre-day	Hydraulic loading (ft.^{3})
1964						
Sept. 21	1	0.50	0.48	4.48	540	1.10
23	3	0.22	0.25	2.11	274	14.10
25	5	0.42	0.57	3.98	635	10.85
29	9	0.36	0.40	3.45	450	10.85
Oct. 1	11	1.46	0.54	12.12	605	7.60
3	13	1.56	1.22	14.96	1,350	5.98
5	15	0.33	0.59	3.17	655	4.35
7	17	0.64	1.10	6.14	1,225	4.35
9	19	0.46	0.68	4.46	760	1.10
No data collected during this period						
22	32	1.09	1.40	10.45	1,550	1.10
24	34	0.76	1.22	7.29	1,350	
27	37	0.69	0.44	6.60	450	
28	38	0.42	0.36	4.02	405	
30	40	0.35	0.35	3.36	390	
Nov. 1	42	1.06	0.62	5.42	680	
3	44	0.38	0.60	3.65	660	
5	46	0.24	0.60	2.30	670	
7	48	0.68	0.42	6.10	470	
9	50	0.29	0.86	2.78	965	
11	52	0.50	0.70	4.27	785	
13	54	0.40	0.72	3.78	775	
15	56	0.48	0.74	4.65	810	
17	58	0.78	0.88	7.05	985	
27	68	1.18	1.13	1.13	360	2.25
Dec. 9	80	0.18	0.34	0.24	110	
23	94	0.35	0.54	0.96	169	
30	101	0.80	1.26	2.19	400	

Table 11 (f). Loading rates for lagoon F

Date	Day of run	Lb. of volatile solids added	Lb. of COD added	Lb. vol solids per 1000 ft^3-day	Lb. COD per acre-day	Hydraulic loading ($ft.^3$)
1964						
Sept. 21	1	1.01	0.97	9.69	1,080	2.20
23	3	0.44	0.49	4.22	548	15.20
25	5	0.83	1.14	7.95	1,270	11.95
29	9	0.72	0.81	6.90	900	11.95
Oct. 1	11	2.53	1.08	24.24	1,210	11.95
3	13	3.12	2.43	29.92	2,700	10.33
5	15	0.66	1.18	6.34	1,310	8.70
7	17	1.28	2.19	12.28	2,450	7.09
9	19	0.93	1.37	8.92	1,520	3.82
No data collected during this period						
22	32	2.18	2.79	20.90	3,100	21.70
24	34	1.52	2.43	14.58	2,700	
27	37	1.38	0.89	13.21	900	
28	38	0.84	0.73	8.05	810	
30	40	0.70	0.70	6.71	780	
Nov. 1	42	1.13	1.23	10.83	1,360	
3	44	0.76	1.19	7.30	1,320	
5	46	0.48	1.20	4.60	1,340	
7	48	1.27	0.85	12.19	940	
9	50	0.58	1.73	5.56	1,930	
11	52	0.89	1.41	8.54	1,570	
13	54	0.79	1.43	7.57	1,550	
15	56	0.97	1.48	9.30	1,620	
17	58	1.47	1.76	14.10	1,970	
27	68	2.36	2.26	2.26	720	4.50
Dec. 9	80	0.36	0.69	0.48	220	
23	94	0.70	1.09	1.92	172	
30	101	1.60	2.51	4.39	300	

Table 12. Temperature of lagoon supernatant

Date	Day of run	Lagoon liquid temp., °F.					
		A	B	C	D	E	F
Sept. 22, 1964	2	63	63	63	63	63	63
24	4	61	61	61	61	61	61
27	7	59	59	59	59	59	59
28	8	59	59	59	59	59	59
30	10	59	59	59	59	59	59
Oct. 2	12	59	59	59	59	59	59
4	14	58	58	58	58	58	58
6	16	57	57	57	57	57	57
8	18	56	56	54	54	50	50
20	29	53	53	50	51	48	49
23	32	52	52	50	50	48	48
25	34	52	52	50	50	49	49
27	37	54	54	53	53	52	52
30	40	53	53	51	51	50	50
Nov. 1	42	52	52	51	51	50	50
3	44	53	53	51	51	50	50
5	46	54	54	54	54	53	53
7	48	54	54	52	51	50	50
9	50	53	53	52	52	50	50
11	52	53	53	52	52	50	50
13	54	53	53	52	52	50	50
15	56	53	53	51	51	50	50
17	58	52	52	50	50	48	48
19	60	49	49	47	47	46	46
27	68	42	42	39	39	38	39
Dec. 1	72	37	39	36	38	36	37
16	87	37	38	36	38	36	34
23	94	34	34	34	34	32	34
30	101	34	34	32	34	32	32
Jan. 6, 1965	108	34	36	36	36	-	-
13	115	33	34	32	34	-	-
20	122	34	32	32	32	-	-

Table 13. Air temperature, wind velocity, and precipitation during period of observation

Date	Day of run	Air temp., °F.		Wind vel., revs.	Precip. in	
		Max.	Min.		Rain	Snow
Sept. 21	1	67	55	43	+	-
22	2	73	53	26	0.74	-
23	3	65	40	116	0.18	-
24	4	55	43	202	-	-
25	5	80	40	81	-	-
26	6	79	53	287	+	-
27	7	59	37	134	-	-
28	8	63	32	63	-	-
29	9	73	37	36	-	-
30	10	73	43	84	-	-
Oct. 1	11	78	51	212	-	-
2	12	77	47	162	.04	-
3	13	76	43	194	-	-
4	14	65	41	164	-	-
5	15	58	35	133	-	-
6	16	57	32	84	-	-
7	17	68	40	161	-	-
8	18	62	42	185	-	-
9	19	49	25	110	-	-
10	20	54	23	40	-	-
11	21	49	40	111	.20	-
12	22	57	41	36	-	-
13	23	67	35	29	-	-
14	24	70	40	48	-	-
15	25	73	41	114	-	-
16	26	80	46	116	-	-
17	27	75	45	94	-	-
18	28	58	36	162	-	-
19	29	47	28	124	+[a]	+
20	30	70	22	132	-	-
21	31	65	42	150	-	-
22	32	52	27	53	-	-
23	33	54	27	40	-	-
24	34	75	30	75	-	-
25	35	71	40	101	-	-
26	36	69	43	57	-	-
27	37	66	45	89	-	-
28	38	63	37	74	-	-
29	39	53	30	89	-	-
30	40	71	31	98	-	-
31	41	75	45	167	-	-

[a]Trace

Table 13. (Continued)

Date		Day of run	Air temp., °F.		Wind vel., revs.	Precip. in	
			Max.	Min.		Rain	Snow
Nov.	1	42	68	45	112	.15	-
	2	43	75	46	81	.05	-
	3	44	72	54	117	-	-
	4	45	63	47	137	.09	-
	5	46	51	42	56	-	-
	6	47	60	41	123	-	-
	7	48	66	40	27	-	-
	8	49	67	43	74	-	-
	9	50	65	48	135	-	-
	10	51	65	38	96	-	-
	11	52	73	48	176	-	-
	12	53	69	46	257	-	-
	13	54	65	78	114	-	-
	14	55	73	42	205	-	-
	15	56	68	45	112	.36	-
	16	57	47	32	167	-	-
	17	58	48	81	94	-	-
	18	59	43	28	119	-	-
	19	60	34	24	102	-	-
	20	61	32	11	325	.02	.08
	21	62	17	-1	261	-	-
	22	63	50	8	177	-	-
	23	64	50	25	137	-	-
	24	65	44	26	76	-	-
	25	66	57	25	105	-	-
	26	67	50	11	215	-	-
	27	68	35	20	125	.03	+
	28	69	34	15	199	-	-
	29	70	18	5	193	-	-
	30	71	15	-6	104	-	-
Dec.	1	72	30	11	Discontinued, freeze	T	.10
	2	73	29	18	over	.09	1.8
	3	74	24	15		T	T
	4	75	23	13		-	-
	5	76	21	0		-	-
	6	77	23	17		T	T
	7	78	33	15		-	-
	8	79	32	18		-	-
	9	80	35	24		-	-
	10	81	38	28		.65	-
	11	82	44	28		.02	-
	12	83	41	31		-	-
	13	84	36	19		-	-
	14	85	35	6		-	-
	15	86	38	9		-	-

Table 13. (Continued)

Date		Day of run	Air temp., °F.		Wind vel., revs.	Precip. in	
			Max.	Min.		Rain	Snow
Dec.	16	87	35	3		-	-
	17	88	5	-12		-	-
	18	89	20	-10		-	-
	19	90	24	10		.03	1.2
	20	91	22	3		T	T
	21	92	36	13		-	-
	22	93	45	15		-	-
	23	94	55	31		-	-
	24	95	44	14		-	-
	25	96	16	10		T	T
	26	97	19	-1		-	-
	27	98	26	1		-	-
	28	99	32	16		.02	1.00
	29	100	35	30		.04	-
	30	101	37	29		-	-
	31	102	35	17		-	-
Jan.	1	103	35	31		.16	-
1965	2	104	34	17		.05	-
	3	105	34	8		-	-
	4	106	40	21		-	-
	5	107	39	19		-	-
	6	108	38	23		T	-
	7	109	42	35		T	-
	8	110	42	11		T	T
	9	111	14	-1		-	-
	10	112	33	0		-	-
	11	113	36	10		-	-
	12	114	30	5		-	-
	13	115	20	2		-	-
	14	116	12	-3		.04	1.80
	15	117	11	0		.08	1.00
	16	118	16	-13		-	-
	17	119	32	-1		-	-
	18	120	29	5		-	-
	19	121	33	12		-	-
	20	122	32	9		-	-

Presentation and Analysis of Data for Large Treatment Lagoon

A full size lagoon has been in operation at the Iowa State University Swine Nutrition Farm since 1963. This lagoon disposes of the wastes from a confinement unit which normally houses approximately 600 hogs. The lagoon is composed of 2 cells. The first cell is 9 feet deep with a surface area of 0.16 acre. The second cell is 4 feet deep with a surface area of 0.48 acre. The two cells are not partitioned. Periodic sampling of the lagoon contents by the Department of Agricultural Engineering of Iowa State University indicate only slight differences between the characteristics of the supernatant in the first and second cells. Therefore, only the results obtained by sampling of the supernatant in the first cell will be discussed here. The data for solids, COD, and BOD, are presented in Table 14.

During the months of October and November, 1964, the COD in the large lagoon ranged from 720 tp 940 mg/l. The average value during the period was 822 mg/l, as computed from the values shown in Table 14. A comparison has been made between these results and the results obtained from the 2 deeper test lagoons, lagoons A and B. Data from lagoons A and B are used in the comparison because their depths are approximately the same as the depth of the first cell of the large lagoon. The COD values shown in Table 15 for lagoons A and B are the average values for the period from November 1 to 19, 1964, when the lagoons seemed to be fairly stable in operation.

The data in Table 15 show that the performance of the test lagoons correlates quite well with the performance of the large lagoon, based

Table 14. Properties of swine manure lagoon supernatant (effluent from first cell, collected at division between first cell and second cell)

Sampling date		Solids Total mg/l	Solids Volatile mg/l	COD mg/l	BOD mg/l
1964					
Mar	12	2680	1780		880
	16	1300	530		1120
	19	1430	630		830
	20	1400	620		790
	24	1620	690	1150	890
Apr	1	1460	630		900
	2	1550	590		860
	3	1400	450		860
	6	1510	630		760
	9	1370	630		900
	15	1370	620		850
	23	1370	630		920
May	1			1130	
	7	1580	770	1210	970
	13	1410	710		910
June	3	2020	770	1500	
	11			1650	1250
	24	1590	720	1490	
	25				1100
	30	1830	860	1780	
July	7	1650	760	1630	
	8				1180
	14	2190	1080	1700	
	15				1230
	21	1900	840	1740	
	23				1020
	28	2070	950	1320	
	30			1660	850
Aug	4	1830	910	1480	
	6				800
	11	1970	1020	1300	
	18	1920	1060		
	19			1140	
	20				320
	26			980	
Sept	4			1040	220
	11				290
	15	1610	690	810	

Table 14. (Continued)

Sampling date		Solids		COD mg/l	BOD mg/l
		Total mg/l	Volatile mg/l		
1964					
Sept.	21				390
	23	1640	990	720	
	30				730
Oct.	7			740	380
	14			820	390
	28	1260	780	940	500
Nov.	6	1420	830	890	
	13			720	
1965					
Jan.	25	1384	621	748	
Feb.	6	1240	610	1083	
Mar.	13		756	1430	
	20	1250	741	934	
Apr.	9	873	470	780	
	30	1177	573	1065	
May	5	1339	627	1340	
	14	1214	437	1213	
	21	1584	883	1046	
	27	1320	550	806	
June	11	1368	557	749	
	16	1324	496	672	
	23	1531	660	790	
July	1	1552	676	832	
	28	1214	434	506	
Aug.	10	1085	374	480	

Table 15. Comparison of supernatant COD and volatile solids concentration between the test lagoons and the large treatment lagoon

Lagoon	Depth (ft)	Loading rate lbs vol. sol. / 1000 cu ft/day	COD mg/l	Volatile solids mg/l
A	9.83	9.65	1537	1060
B	9.83	4.88	1019	840
Large lagoon	9.0	3.0	822	800

on the COD of the lagoon supernatant.

During other periods of the year, as shown in Table 14, the COD in the large lagoon was much higher and more variable than the COD during October and November. During the latter part of the period of record for the large lagoon, beginning sometime after August 10, 1965, the COD rose to nearly 5000 mg/l. The reason for this is not known, but may have been associated with heavy rains experienced at about that time. Table 14 also shows that the COD in the large lagoon began to increase about the end of January, 1965, reaching a peak value in March of that year. Figure 5 shows that the test lagoons also experienced a rise in COD at about this time. Since no further data were obtained on the test lagoons after January 20, it can not be established whether the test lagoons also reached a peak value.

The COD in the large lagoon appeared to be greater during periods of warmer weather and less during periods of colder weather. It might be expected that increased microbial activity during warmer weather should result in the lower values of COD in the supernatant. However, as evidenced by the sludge samples obtained from the small lagoons, many of the solids in the raw waste settle directly to the bottom of the lagoon. Much of the degradation which takes place in an anaerobic lagoon takes place in this sludge layer. Thus, during periods of colder weather, the concentration of solids in the supernatant tends to be relatively low due to this settling out process and the lack of biological activity to stir up the sludge layer.

On the other hand, during periods of warmer weather and increased biological activity, the solids concentration in the supernatant tends to be relatively high. The increased biological action causes an increase in gas production in the sludge layer. The gas rising to the surface caused a mixing action to occur in the lagoon, which results in an increase in the concentration of solids throughout the lagoon liquid. Thus, though the lagoon might be more efficient at this time in the destruction of volatile waste solids, the COD observed in the supernatant would tend to be relatively high.

Another factor which might increase the solids concentration and therefore the measured COD in the supernatant is the presence of a scum layer on the lagoon during the warmer months of the year. Scum was present to some degree on the small test lagoons, and on the large lagoon until late into the fall season when the lagoons began to freeze over. These scum layers were easily broken up by gentle agitation with a pole. It is probable that they were also broken up to some degree by factors such as wind, rain, the mixing action in the lagoons caused by rising gases, or by the bursting of the gas bubbles upon reaching the surface of the lagoon.

These factors would be in effect mainly during warmer periods of the year, when the lagoons would be free from ice. Even though scum was brushed away during sampling, it is probable that the upper surface layers of the lagoon would have a relatively high concentration of solids due to the presence of the scum layer. These solids would naturally increase the COD found in surface samples of the lagoon liquid during warmer periods of the year.

Two conclusions may be drawn from the preceding discussion.

1) The results obtained from the first cell of the large treatment lagoon correlate approximately with the results obtained from lagoons A and B. Therefore, it appears that the results obtained from the test lagoons may be applied reasonably to the performance of a full size lagoon.

2) From the period of record of the large lagoon, it appears that the COD in the supernatant of an anaerobic lagoon is greatest during periods of relatively warmer weather, and less during periods of colder weather. Since the test lagoon study occurred during a relatively cool weather period, the results may not be indicative of summer performance.