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CHARACTERIZATION AND STAGED LAGOON TREATMENT OF

SWINE FEEDLOT WASTE

BY

ABRAHAM H. LOUDERMILK, JR., 1946-

A THESIS

Presented to the Faculty of the Graduate School of the

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ABSTRACT

Feedlot pollution is developing into a serious problem because of the trend toward intensive farming techniques and the increasing number of animals in confinement feeding operations. The purpose of this study was to characterize swine waste collected under a slotted feeding floor using a water-carriage system, and to evaluate the treatment of this waste in a staged lagoon system consisting of an anaerobic, a dual anaerobic-aerobic, and an aerobic lagoon.

A small feeding floor unit capable of maintaining 3 separate groups of animals, and a pilot 3-lagoon system were designed, constructed, and operated for a period of approximately 4 months. Three different feed rations, ranging from a simple to a complete mix, were employed in parallel studies. The operation of the feeding unit was evaluated, the wastes produced were characterized, and the ability of the lagoon system to treat the animal waste was investigated.

Collection of the swine waste in the water-filled pits under the slotted feeding floor, and daily removal of the fluidized waste essentially eliminated all odors associated with a typical feedlot. The resulting waste was much stronger than municipal waste, however, it could be effectively treated in the 3-stage lagoon system which was able to withstand high organic loadings without developing obnoxious odors or unsightly conditions.

ACKNOWLEDGMENT

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I. INTRODUCTION

Pollution is today an often used household word reflecting the growing concern the more affluent societies have over the destruction of natural resources. Here in the United States the more flagrant polluters are being forced by regulatory agencies to cease or curtail their operations until they have cleaned up their waste emissions into the air, land, or water. Steel mills, and power and heating plants are required to remove unburned carbon and sulfur oxide from their smoke stack effluents; plating industries, pharmaceutical and chemical plants are required to remove heavy metals or treat chemicals released from their production procedures before discharging their wastewaters into natural water bodies. These industries, as well as others, are the most obvious polluters and have consequently received the greatest amount of attention; however, once these sources of pollution are brought under control, the force of public opinion will be brought to bear on polluters that are not yet as widely recognized. Agriculture is such an industry and can contribute excessive solids that cause sludge banks, nutrients which accelerate algal growth, and excessive organic matter that causes depletion of dissolved oxygen.

Agriculture in its early form was not a polluter. A farmer raised as many animals of several species as he could successfully care for personally. The few cattle, sheep, and horses he had were allowed to graze in pastures, and their waste was scattered naturally without creating any odor or stream pollution problems. Any waste that collected around the barns was spread over the farmer's garden and pastures and was considered to be good fertilizer. These conditions closely approximated the natural state of a forest containing deer, bear, and other forms of wildlife. City people journeyed to the country to get away from the crowds and to enjoy the "good country atmosphere" of rural areas. Today the country atmosphere is not always good.

The trend in agriculture, as in other industries, is toward specialization. Specialization, aided by modern technology, allows the concentration of plants and animals and results in higher production per unit area with a corresponding concentration of waste products. All phases of agriculture have specialized. Hybridization of fruit trees and development of commercial pesticides increased the fruit yield per acre, but also encouraged indescriminate spraying of pesticides which resulted in fruit contamination, plant and animal deaths, and chemical pollution of water supplies. Intensive grain farming has caused silt, commercial fertilizer, and herbicide pollution in receiving streams due to runoff. Centralized milk production in dairies has contributed a highly biodegradable waste in the form of wasted milk. Concentration of animals in feedlots has resulted in a waste that contains excessive organic material and solids, and is rich in nutrients; in addition, the odor around these areas is very pronounced and disagreeable.

The relationship between the economics of intensive farming and the resulting pollution problems can best be shown using feedlots as an example. Initially, farmers fattened out the young animals they raised on their own farms in dirt lots behind the barn. In an effort to shorten the time required to obtain a return on their investment, some farmers bought the young animals and fattened them out in large dirt lots where they were grouped closely together. This method required that the feeder-farmer keep the animals for only 3 to 6 months (as opposed to 2 yr for cattle, 1 yr for sheep, and 10 months to 1 yr for swine), and minimized animal weight loss due to excess movement in search of food. The dirt lots became muddy, odorous mires during wet weather, while nearby streams were contaminated with wastes carried by stormwater runoff. Waste collecting on the animals' warm coats decomposed anaerobically with attendant odors and unhealthy animal environment. In an effort to improve animal health and production, the lots were paved (1); this paving increased the amount of waste washed into receiving streams. Solids not removed by stormwater were picked up with scoops and spread over any available field. When controlled tests showed that productivity could be increased when the animals were placed under shelter, feedlot managers began moving the smaller animals (poultry, sheep, and swine) into environmentally controlled buildings. The movement of cattle into such buildings has been much slower due to the large space requirement (2). Each step in this evolution allowed the feeder to increase the number of animals per unit area, and correspondingly improve the return on his investment. All of these conditions resulted in an enormous concentration of waste.

Rather than periodically scraping the floors and spreading the waste, a process requiring numerous man hours, the slotted feeding floor was developed. This floor consisted of parallel slats leaving gaps through which the waste was forced into pits below by the animals walking and laying down. The pits were normally of sufficient volume to allow storage for periods of up to 6 months (2), and the waste was removed when time permitted. Although this method solved the manpower problem, it did not completely solve the animal health problem. Noxious odors and dangerous gases evolved from the waste undergoing partial anaerobic decomposition in the pits, and vapor mists developed from the temperature difference between the waste and the air in the building. The odor problem is largely a function of the method and duration of manure storage (3); while odors can be controlled by the addition of lime or chlorine, the cost at present is prohibitive (4). If the pits are sufficiently deep for long storage, the waste is generally pumped into "honey wagons" and spread as a liquid slurry over the fields. Where storage is not available, the waste is washed away at frequent intervals and disposed of by some other means. Some feeders have tried with varying degree of success to utilize oxidation ditches located either inside or outside the animal buildings (5), while others have pumped the waste into lagoons or have built their facilities over the outer edge of the lagoon (6)(7).

The adaptation of municipal systems to treat animal wastes has not been very satisfactory. The primary reason for this is the difference in the character of the 2 wastes; municipal waste contains 99.9 percent water while feedlot waste consists mainly of solids with a little water (8). Another factor might be the antibiotics contained in the animal feed which would in part be discharged by the animals; their presence in the waste could inhibit microbial activity and thereby reduce the efficiency of biological treatment (6)(9).

Oxidation ditches have been employed primarily for odor control, and generally have not been able to produce an effluent which could be released to surface waters (5). Foaming has been reported as a problem in several installations (5), and failure in rotor operation could result in anaerobic decomposition and potential danger to animals and humans (10). Single and multiple cell facultative lagoons have in many cases been considered as failures because of their low effluent quality and excessive odor production (6)(7). However, a combination of an anaerobic lagoon or solids holding tank and a facultative lagoon or aerated pond has been reported to provide high treatment efficiency in terms of percent removal but low effluent quality in terms of oxygen demand and inorganic nutrient content. Activated sludge, trickling filtration, aerobic and anaerobic digestion have also been considered; they were found to be sensitive to antibiotics, shock loads, nutrients, and temperature, and expensive as a means of manure disposal (9). Trickling filters, however, have been successfully employed for treating dilute, settled farm wastes (5).

A system, in order to be acceptable as a feedlot waste disposal method, must meet the following criteria: (a) it must produce an effluent which meets the requirements of the regulatory agencies; (b) it should require simple operation and control since the farmer is a layman, unfamiliar with microbiological interrelationships and chemical interactions; (c) it must be able to withstand the shock loads which are normal to feedlot operations; and (d) it should operate without the production of unpleasant odors. Finally, without some governmental cost sharing plan to aid the already over-invested farmer, the system must be inexpensive or provide some monetary return. This return could be in the form of water and/or feed recycling, concentrated fertilizer, or some marketable product such as building blocks made from animal waste. This last requirement is of great importance to the small feeder with limited capital. The passage of laws and restrictions against the pollution caused by agriculture could conceivably affect the agricultural industry drastically. Unless a simple, inexpensive method of animal waste disposal can be developed and approved by antipollution agencies, the individual feeder will be replaced by the large corporation feedlots.

With the requirements as previously stated in mind, a feeding floor and waste treatment system combination was developed and evaluated in this study. The feeding unit consisted of a slotted floor over collection pits that held the waste and sufficient dilution water to suppress odors and facilitate waste removal. The pits were flushed daily into a lagoon system consisting of an anaerobic lagoon for settling and concentrating the solids, a dual anaerobic-aerobic lagoon for treating the settled anaerobic lagoon effluent, and an aerobic lagoon for polishing the dual lagoon effluent. The 3-stage lagoon system was designed in order to buffer the shocks loads expected in feedlot operations. Daily flushing of the pits provided the lagoons with a continuous loading, while at the same time reduced the opportunity for odor production. Evaluation studies consisted of characterizing the wastes produced by swine fed with rations differing in feed additive content, including antibiotic or other drug growth stimulants; and determining the treatability of the waste from swine on an antibiotic-free diet in the 3-stage lagoon system. It was the purpose of this study to obtain reliable data which could be used in the design of feedlot waste treatment systems utilizing the staged lagoon principle.

II. LITERATURE REVIEW

This review of literature was conducted in order to obtain design information on the characteristics and treatment by lagoons of the waste generated in confinement swine feeding. Because only limited data could be found on lagoons treating swine waste, data pertaining to the treatment of other animal wastes have also been presented when the information could be applied to swine waste disposal.

A. CHARACTERISTICS OF SWINE WASTE

Swine waste or manure consists mainly of undigested food and small amounts of excess nutrients and undigestible fibers. Modern technology has reduced the formulation of feeds to the level of a science, with the result that commercial rations are mixed to provide the maximum in feed quality and digestibility (11)(12). Even when homegrown grains are used, there are commercial supplements available to compensate for any probable deficiencies. Vitamins and trace minerals such as copper, iron, and zinc, are added to increase feed efficiency and rate of gain, while antibiotics and arsenicals are used to improve animal health. All these ingredients are formulated to provide a feed which is readily utilized by the animal with little undigestible waste. The rations fed today differ greatly from those used 10 to 30 yr ago. This difference in feed quality, the fact that bedding is no longer employed in confinement feeding, and changes in the animal environment have rendered data on the character of swine waste published 10 to 30 yr ago difficult to evaluate (13).

Data on the quantity, solids content, and organic strength of swine waste are presented in Table I, together with the available

TABLE I. CHARACTERISTICS OF SWINE WASTE-QUANTITY AND STRENGTH

Investigator and Date of Study	Manure	Solids			Oxygen Demand				Comments	Ref.
		Total		Volatile	BOD_5		COD	BOD/COD		
	lb/day* / animal	% of manure	lb/day / animal	% of total	lb/day / animal	mg O_2 / mg VS	mg O_2 / mg VS			
Van Slyke, 1937	8.4	13.0	1.09						Based upon 100-lb* animal.	13, 14
Salter & Schollen-berger, 1939	9.5	12.6	1.20							13, 15
Jeffrey, <u>et al</u>., 1963	9.3	17.8	1.66	87		0.30	1.56	0.19	Based upon a 100-lb animal.	7
Taiganides, 1964	7.0	16.0	1.12	85					Summary of recommended design values based upon data from a pen of hogs with a 100-lb avg weight.	13
Hart, 1964	2.8	28.2	0.80						Based upon a 100-lb animal.	16
Taiganides, <u>et al</u>., 1964	5.0	17.0	0.85	83	0.35	0.54	1.20	0.45	Based upon a 100-lb animal; waste scraped from floor; quantities largely estimated.	17
Clark, 1965			0.50	78.8		0.32	2.59	0.12	Calculated from his data; these reflected 24-hr waste accumulation of 280 hogs (150 lb avg weight) diluted with 240 gal of water.	6
Hart & Turner, 1965			0.79	78.5		0.32	1.20	0.27	Based upon a 100-lb animal; values used for lagoon operation	18
Howe, 1969			1.10 1.70		0.40 0.70			0.67-0.77	Animals kept in separate cages; waste includes spilled feed and water; 20 to 90-lb animals 100 to 300-lb animals.	19

*To convert lb/day/animal to kg/day/animal or lb to kg multiply by 0.454.

information on the conditions under which these values were obtained. The considerable variation in the data has been attributed (13) to the method of waste collection and the prevailing environmental conditions. For example, the characteristics of manure scrapped from solid floors will differ from those of waste obtained under slotted floors; waste collected during the winter will differ from that collected in the summer due to increased evaporation losses and the differences in water consumption (17).

Early investigators reported primarily on the amount of wet manure and total solids (TS) reflecting the agriculturalists' concern with the logistic problem of spreading the waste over the fields as a fertilizer. More recent investigators, however, have emphasized the organic strength of the waste, realizing that field spreading might in many cases be impractical, if not impossible, and that some other method of disposing of the waste had to be devised. Since lagoons were relatively inexpensive and essentially self-operating, they became popular with farmers as a means of waste disposal. Most researchers have expressed the biochemical oxygen demand (BOD) and chemical oxygen demand (COD) in a ratio to volatile solids (VS), because the variable water content of the waste rendered concentration (expressed in mg/l) a poor basis for comparison (5). The VS, BOD, and COD values can be influenced by the content and digestibility of the feed ration, the animals' environment, and the type of swine and its feed conversion characteristics (13).

Clark (6) has reported that 5-day BOD values determined for manure from an actual farm operation were very erratic. He found that the antibiotics used in the feed, whether they were passed through the animal or leached from wasted feed, were very inhibitory to bacteria. The 5-day BOD data were so erratic that the COD test was used; the COD values were consistant and in general agreement with the 20-day BOD data. Hart and Turner (18), and Jeffrey, et al. (7), have reported essentially the same values for the BOD/VS ratio as Clark, while Taiganides, et al. (17) have presented a higher value. Of the 3 groups, only Jeffrey, et al. indicated that their results were erratic; antibiotics were used as a feed additive by Jeffrey, et al. and copper oxide was employed by Taiganides, et al. There is limited information in the literature on the COD of swine waste and the reported values range from 1.20 to 2.59 mg/mg VS. As can be seen in Table I, there is no agreement on the BOD/COD ratio which ranged from 0.12 to 0.77.

Reported data on the fertilizing constituents (nitrogen, phosphorus, and potassium) of the waste are summarized in Table II. Additional values have been presented by Clark (6) and Howe (19), however, these investigators employed different and unclearly stated methods of expression, and their data cannot be compared to the values given in Table II. There is little information relative to the concentration of other elements and trace metals. Taiganides (13) has stated that 1,000 gal (3,785 l) of fresh manure would contain 47 lb (21.3 kg) calcium, 6.6 lb (3.0 kg) magnesium, 12 lb (5.5 kg) sulfur, 2.3 lb (1.05 kg) iron, 0.5 lb (0.23 kg) zinc, 0.35 lb (0.16 kg) boron, and 0.13 lb (0.06 kg) copper. Loehr (5) has reported that according to Benne, et al. (22), 1.0 ton (907 kg) of manure would contain 11.4 lb

TABLE II. CHARACTERISTICS OF SWINE WASTE-FERTILIZING CONSTITUENTS

Investigator and Date of Study	Total Solids	Nitrogen (as N)		Phosphorus (as P_2O_5)		Potassium (as K_2O)		Ref.
	lb/day animal*	% of TS	lb/day animal	% of TS	lb/day animal	% of TS	lb/day animal	
Van Slyke, 1937	1.09		0.042		0.029		0.034	13, 14
Salter & Schollenberger, 1939	1.20		0.051		0.032		0.062	13, 15
Taiganides, 1964	1.12	4.5	0.050	2.7	0.026	4.3	0.048	13
Taiganides, *et al.*, 1964	0.85	7.0	0.060					17
Hart & Turner, 1965	0.79	4.0	0.032	3.1	0.024	1.4	0.011	18
Baines, 1964		0.20-0.90		0.14-0.83		0.18-0.52		5, 20
Webber, *et al.*, 1968			0.066		0.037		0.022	9, 21

*To convert lb/day/animal to kg/day/animal multiply by 0.454.

(5.2 kg) calcium, 0.56 lb (0.25 kg) iron, 1.6 lb (0.72 kg) magnesium, 2.7 lb (1.23 kg) sulfur, and 9 lb (4.1 kg) fat. There is only this one reference to fat content.

It is the feed additives and other disease prevention practices which might add another dimension to animal waste treatment. According to Clark (6), following an epidemic of scours when extraordinarily large amounts of antibiotics and sulfa drugs were placed in the feed, a massive bacterial kill resulted because of drug carry-over to the lagoon which was being used to treat the waste. Drug carry-over was also indicated by the absence of plankton and presence of only low numbers of coliform and enterococcus organisms in a failing lagoon treating waste from swine fed approximately 250 ppm copper sulphate (6).

The problem of odor control in swine feedlot buildings is receiving much attention and research has been undertaken (23) to segregate the various odor compounds in an attempt to eliminate the health and building deterioration hazard representated by these materials and improve neighbor relations. Miner and Hazen (23) have suggested that ammonia and amines present at less than threshold odor concentrations, when combined were additive in their role as part of the hog-house odor, and Merkel, et al. (24) have outlined a procedure for segregating the components of this odor. Burnett and Dondero (25) have proposed a method of comparative evaluation of chemical elimination or modification (masking) of animal waste odors. They found that masking agents and couteractants were more effective than either de-odorants or digestive deodorants in odor control. Hammond, et al. (4) have evaluated the practicality and effectiveness of using lime and chlorine in suppressing odors from liquid hog manures and concluded that chlorine treatment was uneconomical, while lime treatment was only partially effective. The value of research on the elimination or suppression of animal waste odors has been discussed by Taiganides and White (10) in a paper summarizing the lethal concentrations of ammonia, methane, and hydrogen sulfide. These authors have pointed out that although the concentration of these gases rarely reach such levels inside the building, the animals would be in dangerous proximity to the liquid waste when they are kept on slotted floors over liquid holding pits. Actually, the swine would be more in danger from asphyxiation due to the low oxygen content of the atmosphere directly above the liquid slurry than from inhaling lethal quantities of the anaerobic decomposition gases. This danger would increase when the pits are stirred at a time when the animals would normally be sleeping. According to Taiganides and White (10), the best control measure is the elimination of the conditions responsible for odor production.

B. LAGOON TREATMENT OF ANIMAL WASTES

The disposal of animal wastes has not always been considered a problem, but when the need for treatment was recognized lagoons became a common means of handling animal wastes. Lagoons employed in confinement feeding operations must be designed for the stabilization of very strong organic wastes. Although the design of these agricultural units has varied greatly, the usual result is a single-cell facultative lagoon which often turns anaerobic; actually in practice, most of these lagoons act primarily as solids storage units and quickly fill up unless they are periodically cleaned (26).

The characteristics of the animal wastes lend themselves to the requirements of anaerobic digestion (26), and laboratory studies have been undertaken to evaluate the treatability of these wastes under anaerobic conditions. Jeffrey, *et al*. (7) conducted such a study and determined that for swine waste the critical loading was 0.15 to 0.17 lb VS/day/cu ft (2.40 to 2.72 kg VS/day/cu m). At 95°F (35°C) the digester reduced about 50 percent of the VS added producing approximately 13 cu ft gas/lb VS destroyed (0.8 cu m gas/kg VS destroyed) containing 32 percent carbon dioxide. Cross and Duran (27) have studied the effects of loading and temperature on the treatment of swine waste using 9, 3-l anaerobic digesters operated at 3 loading rates (3.2, 1.6, and 0.8 g VS/l digester capacity) and 3 temperatures [50, 70, and 90°F (10, 21, and 32°C)] for a period of 15 days. They concluded that the detention time used was insufficient to attain a constant VS level in the digesters, although for the same loading rate an increase in temperature resulted in improved digestion. It should be pointed out that both laboratory studies were made using fecal matter alone; however, in wastes removed from collection pits urine would be a definite constituent, and the ammonium ion which would be released could retard the biological activity and hence anaerobic treatment (28, p. 251). In addition, anaerobic lagoons treating animal wastes are normally of a size that makes impractical the use of mixing and heating frequently employed with digesters.

There is lack of uniformity in the literature in the expression used to define organic loading for anaerobic lagoons. Several investigators (7)(8)(13)(29) have used the expression lb VS/day/cu ft (kg VS/day/cu m) which is often employed with municipal digesters. However, Hart and Turner (18) have proposed the use of lb BOD/day/cu ft (kg BOD/day/cu m), reasoning that since the BOD/VS ratio was much less for animal manure than for municipal sewage, the term lb VS/day/cu ft (kg VS/day/cu m) lacked meaning. Hart (30) in a later publication suggested the use of a cu ft/animal (cu m/animal) basis; however, this parameter is still indirectly based on the lb BOD/lb live animal weight (kg BOD/kg live animal weight) relationship for each animal species. The concern for evaluating and designing on the basis of a particular animal waste is a result of research on the treatability characteristics of various animal wastes. Studies conducted by Hart (29) on chicken and dairy manures showed a great difference in the anaerobic treatability of the 2 wastes. This difference was also observed in later pilot plant experiments ran by Hart and Turner (18) and Jeffrey, et al. (7), and can be largely attributed to the constituents of the feed, and the process of digestion unique to each species (7).

Hart and Turner (18) have investigated the use of anaerobic lagoons for treating swine wastes. Three lagoons were made of concrete rings 4 ft (1.2 m) in diam and had a natural earth bottom with a 7-ft (2.1-m) depth. The lagoons were fed once a week through feed pipes which introduced the waste into their bottom and were operated for 232 days at loadings* of 0.00153, 0.00332, and 0.00432 lb BOD/day/cu ft (0.0245,

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*Loadings were also reported as 0.00495, 0.0108, and 0.0137 lb VS/day/cu ft (0.0791, 0.1725, and 0.2190 kg VS/day/cu m); 124, 67, and 45 cu ft/animal (3.47, 1.88, and 1.26 cu m/animal); and 388, 775, and 1180 lb BOD/day/acre (435, 868, and 1321 kg BOD/day/ha).

0.0532, and 0.0691 kg BOD/day/cu m), respectively. Hart and Turner reported the appearance on the surface of the lagoons of a thin lignaceous material which floated, then sank, and then formed again. Although, the reduction of organic material was not determined, the authors stated that the efficiency of these lagoons should have been equal to or better than comparably loaded poultry lagoons which were concurrently being investigated. Reductions in VS of 80.5, 85.8, and 84.9 percent, and in inorganic materials of 96.6, 96.9, and 94.6 percent were observed in the corresponding poultry lagoons. Since there was no effluent from the lagoons, the loss of inorganic materials indicated considerable quantities of organic materials were being lost through infiltration.

Although anaerobic lagoons can function as treatment units, they are not a complete treatment process. The effluents from these lagoons are still very high in pollutional strength and before they can be allowed to flow into natural water bodies they must receive additional treatment (26). Aerobic lagoons have been used to further treat the effluent.

Bhagat and Proctor (31) have studied a lagoon system treating wastes from a confinement dairy farm. Following removal of most of the manure from the feeding floor and loafing area by solids handling methods, the remaining manure was flushed to the lagoon system consisting of 3 lagoons in series. Unit 1 was anaerobic, while Units 2 and 3 were facultative. The system normally had no overflow and operated as an impounding and absorption lagoon. Samples taken from the 3 ponds during low and high flow conditions resulted in the following data (expressed in mg/1).

	Low Flow		High Flow	
	COD	BOD	COD	BOD
Waste entering Unit 1	12,600	4,000	5,200	1,370
" " " 2	1,800	450	1,700	300
" " " 3	1,500	300	1,500	280
Treated waste in Unit 3	2,000	250	1,800	200

The increase in COD concentration in Unit 3 was attributed by these authors to the presence of algae; they also reported that most of the BOD remaining in this pond was associated with algae and other suspended residues.

Clark (6) has reported on a lagoon system treating swine waste that was evolved rather than designed. Initially a lagoon was built 3 ft (0.91 m) deep using a 15-sq ft/hog (1.39-sq m/hog) allowance and was designed to have no overflow. It was remarkably unsuccessful. Another lagoon was built in series with a maximum working depth up to 7 ft (2.14 m), and the depth of the first lagoon increased to 5 ft (1.53 m). These modifications resulted in little improvement in odor problems. The addition of holding channels in the confinement house which provided storage of solids until they could be spread as a fertilizer, and of a large septic tank [20 x 20 x 8 ft (6.1 x 6.1 x 2.4 m)] ahead of the lagoons eliminated the odor production. The lagoons were operated for a period of 1 yr while receiving the following loading rates.

	Loading per Unit Area		Loading per Unit Volume	
	lb COD / day/acre	kg COD / day/sq m	lb VS / day/cu ft	kg VS / day/cu m
First lagoon	140-230	15.7-25.8	0.36-3.9	5.76-62.4
Second lagoon	120-140	13.4-15.7	0.36-0.67	5.76-10.7

The loading rate per unit area was essentially constant, except during periods of ice coverage when the waste was held on the ice surface and then when the ice melted a shock load resulted. The loading rate per unit volume, however, varied considerably because of the fluctuation of the water level in the lagoons. The lagoons were deep green in color and free of odor. There was an extremely high algal population, practically all of one species (Chlorella vulgaris); however, according to Clark (6) even with the high algal concentration, there was a total absence of dissolved oxygen in the lagoons. Samples of the lagoon supernatant* were centrifuged to completely remove the algae and used to determine the COD concentration; reductions in the order of 90 to 95 percent were observed. Throughout the year the system withstood severe organic and hydraulic shock loads, and only slight odor production was observed following shock loading as a result of ice melts (organic) and collected rainwater (hydraulic). The system was even subjected to a slug dose of antibiotics following an outbreak of scours, but within two weeks it had returned to "normal".

*Clark (6) stated that the lagoons were designed to have no discharge and implied that leakage to groundwater aquifers was prevented; it must be assumed, therefore, that evaporation losses equalled or exceeded the input to the lagoons.

III. MODE OF STUDY

A system consisting of an anaerobic, a dual anaerobic-aerobic, and an aerobic unit was designed, constructed, and tested in an effort to evaluate the staged lagoon method of animal waste treatment and develop appropriate design values. The lagoons were fed with swine waste obtained from a slotted feeding floor and collection pit system which was built and operated as part of the study. The feeding floor was divided into 3 pen areas, each over a collection pit, to enable the characterization of the waste produced from animals fed 3 different feeds varying in the amount of nutritional and growth additives. Swine were used because of their smaller size, age at market weight, adaptability to confinement feeding, and availability.

The studies were conducted over a 4-month period, and this necessitated use of 2 groups of animals because the initial group reached market weight and were too large for the available pen space. The lagoons were also evaluated in 2 separate runs because initial operation of the system under heavy loading conditions resulted in failure of the lagoons requiring that the units be reseeded. All field work, including both the feeding floor and lagoon operations, was conducted at a farm* near Rolla, Missouri.

A. FEEDING FLOOR

The slotted feeding floor (Figure 1) was built in the lower floor of a 2-story building which had been used to grow and fatten both cattle and swine. The floor was built inside the building

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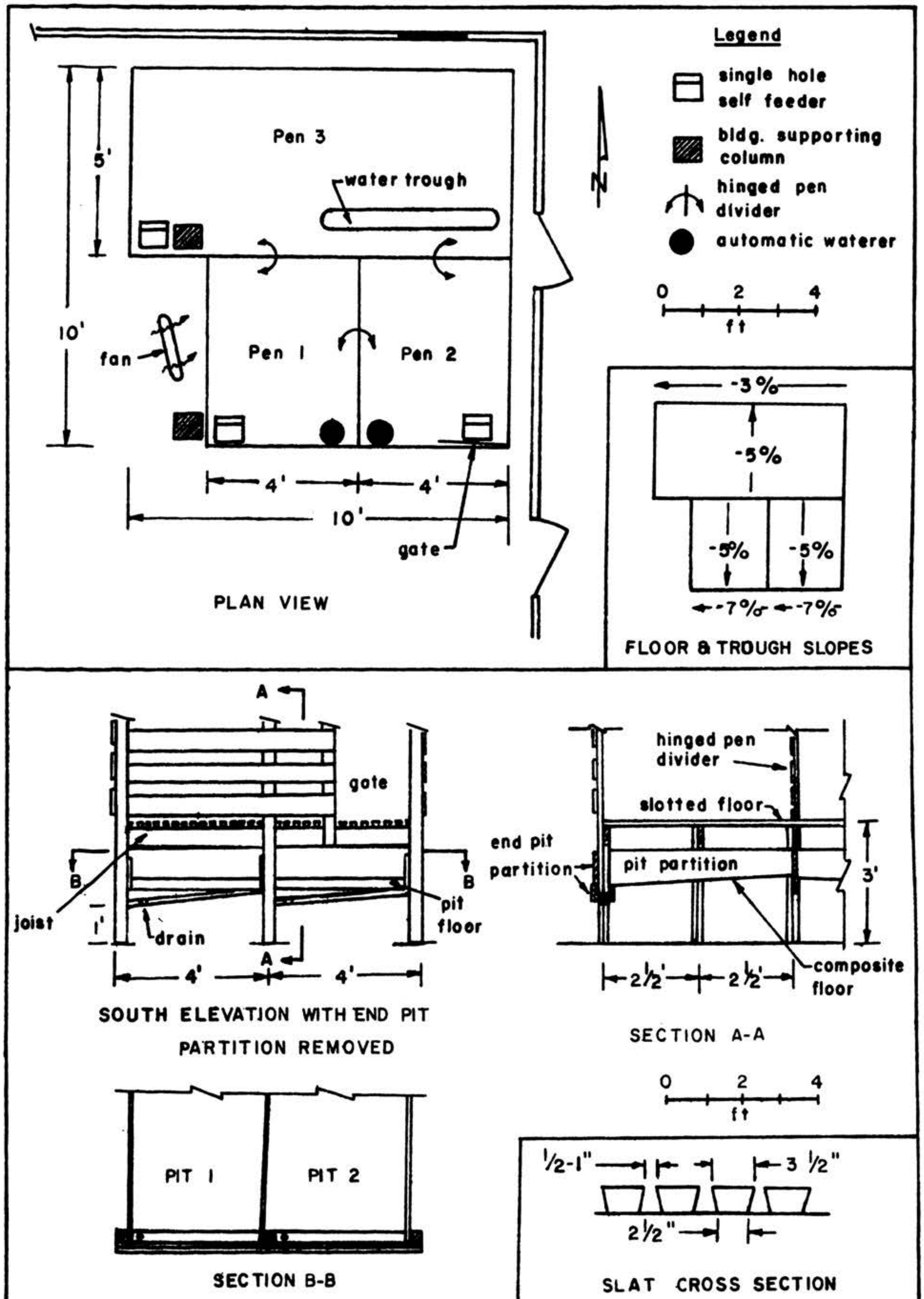
*The Floyd Snelson Farms, located 5 miles (8.05 km) from the campus on Highway F, 0.75 (1.21 km) miles from the junction with Highway 72.



1.0 ft = 0.3048 m 1.0 in. = 2.54 cm

FIGURE 1. THE FEEDING FLOOR AND COLLECTION PIT SYSTEM

because it was originally planned to start sampling during the winter months, however, because of difficulty in waterproofing the collection pits, sampling was not started until June, and consequently ventilation was more important than protection from the weather.

The feeding floor had a total area of 90 sq ft (8.36 sq m) and was constructed of rough sawn oak lumber supported by 5, 2-in. x 6-in. (5.08-cm x 15.24-cm) joists set on 2.5-ft (0.76-m) centers. It was divided into 3 pens with partitions which were made moveable to enable use of a single gate and loading chute. Pens 1 and 2 had an area of 20 sq ft (1.86 sq m) each, and were equipped with gravity flow self-feeders and automatic waterers. Pen 3 had an area of 50 sq ft (4.65 sq m) and was also provided with a self-feeder; however, one-half of a domestic water heater served as a water trough. The slats were made of 2-in. x 4-in. (5.08-cm x 10.16-cm) lumber cut to have a cross section with a top width of 3.5 in. (8.89 cm) and a bottom width of 2.5 in. (6.35 cm), and were laid on 4.25-in. (10.8-cm) centers.

The collection pits (Figure 1) were built on 2-in. x 4-in. (5.08-cm x 10.16-cm) joists nailed to the legs supporting the feeding floor. Corrugated metal roofing was employed to provide strength for the 0.25-in. (0.635-cm) plywood which constituted the bottom of the pits, while 1-in. (2.5-cm) dimension lumber formed their sides. The pits sloped at the rate of 5 percent draining into collection troughs sloped at a rate of either 7 percent (Pens 1 and 2) or 3 percent (Pen 3) to a drain hole.

Waterproofing the pits proved to be the most frustrating and time consuming phase of the study. Initially, polyethelene plastic sheets were used to line the pits; however, it was not found possible to seal cracks and holes formed where the plastic sheets were cut or folded, although several different techniques were tried. The plastic was then removed and the cracks and joints were sealed with a fiberglas mat* and resin finish coat.** The rough oak sides were primed with a latex enamel, and the bottom and sides of the pits were covered with 2 coats of epoxy paint.# The pits still leaked and a waterproofing sealant## was used to cover the points where leaks were thought to occur. When this step failed to stop leakage, the swine were placed on the floor and their waste allowed to collect in the pits for a period of 5 days, the supernatant was drained and the pits were refilled. This procedure was relatively effective in plugging leaks with waste, and so long as the troughs were not completely cleaned out there was essentially no leakage. This latter procedure is commonly used by farmers in waterproofing wooden water troughs.

B. LAGOON SYSTEM

A 3-stage lagoon system with anaerobic, dual anaerobic-aerobic, and aerobic lagoons was selected for evaluation in this study for several reasons: (a) a series of units, rather than a

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*Fiberglas tape and resin (No. 112), a product of Cope Plastics, Inc., St. Louis, Missouri.

**Evercoat marine resin finish (No. FE 2300), a product of the Fiber Glass-Evercoat Company, Cincinnati, Ohio.

#No. 0550 and 3850, a product of the Phelan Faust Paint Mfg. Co., St. Louis, Missouri.

##Epoxite, a product of Boyle-Midway, Inc., New York, New York.

larger single unit, enabled optimization of environmental conditions for specific biological processes; (b) the staged system allowed the operator better control over shock loadings by providing an equalizing settling basin in the form of the anaerobic lagoon; (c) the sludge in the anaerobic lagoon would be converted into a form more suitable for fertilizer than the raw waste was; and (d) the byproducts of the system, such as gas, recycled water, and fertilizer, could provide an economic incentive for this form of waste treatment.

The lagoon system is pictured in Figure 2 and appropriate construction details are shown in Figure 3. The anaerobic lagoon was made of a 55-gal (208-l) drum. The interior surface was thoroughly sand blasted and then coated with a primer* and 2 coats of epoxy paint.** The lower half of the drum was buried and dirt was mounded against the upper half. Initially, the full capacity [actually 60 gal (227 l) or 8 cu ft (0.224 cu m)] was utilized, but after a few days of operation the volume was reduced to 5.5 cu ft (0.154 cu m) in order to provide gas storage. The dual and aerobic lagoons were constructed of concrete to prevent the contamination of a water well about 50 ft (15.2 m) away. The concrete was made using a 1:5 cement to creek-run gravel and sand ratio. The wall thickness varied from 1.5 in. (3.8 cm) to 3.5 in. (8.9 cm). Leaks were found to occur at narrow spots in the walls and were incompletely plugged with either a mixture of clay

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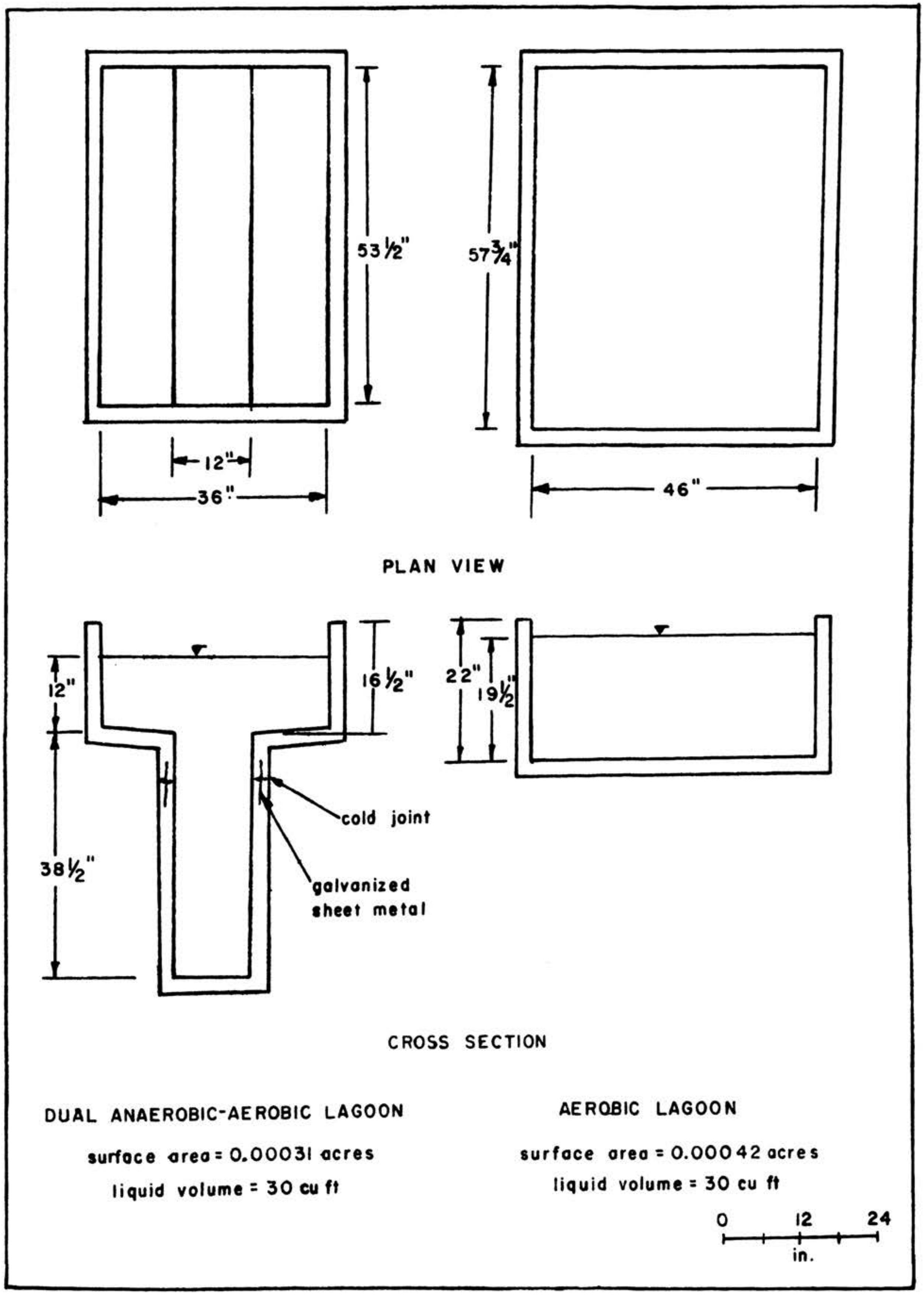
*Rust control primer (No. 49), a product of Sherwin-Williams, Cleveland, Ohio.

**No. 0550 and 3850, a product of the Phelan Faust Mfg. Co., St. Louis, Missouri.

From left to right: dual (with feeding barrel), aerobic, and anaerobic lagoons

FIGURE 2. THE 3-STAGE LAGOON SYSTEM



1 cu ft = 0.028 cu m 1 acre = 0.405 ha 1.0 in. = 2.54 cm

FIGURE 3. CONSTRUCTION DETAILS OF THE DUAL AND AEROBIC LAGOONS

and bentonite or a waterproofing sealant.* The dual lagoon was in the shape of a "T" after a design proposed by Ullrich (32). The leg on the "T" was an anaerobic trench 1-ft (0.30-m) wide providing 15 cu ft (0.42 cu m) of liquid volume. The arms of the "T" constituted an aerobic layer 1-ft (0.30-m) deep and 3-ft (0.91-m) wide, providing 15 cu ft (0.42 cu m) of liquid volume. The construction of this lagoon required the use of reinforcing metal scraps for structural strength and water sealing at the necessary cold joints (Figure 3). The aerobic lagoon had a liquid depth of 19.5 in. (49.5 cm) and a liquid volume of 30 cu ft (0.84 cu m).

The anaerobic lagoon and the anaerobic trench of the dual lagoon were initially seeded with digested sludge obtained from the Rolla, Missouri, Southeast Sewage Treatment Plant. After the anaerobic lagoon failed in Run 1, it was again seeded with digested sludge; however, sludge which had accumulated in the lagoon, was also retained in order to shorten the acclimation period. The aerobic portion of the dual lagoon and the aerobic lagoon were initially seeded with treated municipal wastewater obtained from the St. James, Missouri, waste stabilization lagoon. After the failure of the dual lagoon, which marked the end of Run 1, the aerobic portion was reseeded with previously acclimated liquid from the aerobic lagoon. The lagoon system was fed with the waste produced by the animals in Pen 1; these animals were maintained on a simple mix ration containing no antibiotics.

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*Epoxite, a product of Boyle-Midway, Inc., New York, New York.

C. ANIMALS

The swine used in this study were from the author's feeding herd* and were selected to provide a cross section of meat and lard type hogs in order to eliminate any prejudice in the data toward either type. The animals were of Duroc X Yorkshire or Duroc X Hampshire x Yorkshire breeding stock, and could be considered to have average or better production qualities. Ten animals were used during Run 1; they weighed 60 to 80 lb (27.2 to 36.3 kg) at the beginning of the study and averaged 184 lb (83.5 kg) at the end of Run 1. Six animals were used in Run 2 and consisted of 4 new animals weighing 30 to 35 lb (13.6 to 15.9 kg) and 2 animals weighing 107 and 140 lb (48.6 and 63.6 kg) which were retained from Run 1. The light weight of these 2 animals was felt to be a result of the crowded conditions in Pen 3 from where they came. The animal weighing 140 lb (63.6 kg) exhibited very erratic behavior when placed by himself in Pen 2. His repeated attempts to join the other animals suggested the reason for this behavior to be a social problem. This observation is mentioned only because his nervousness prompted the animal to continually rake his feed out of the feeder resulting in extreme feed wastage and hence disproportionately high solids content in the waste.

The animals were fed with single-hole self-feeders which were filled daily, except that in Run 2 the feeder in Pen 2 containing the animal previously mentioned was filled with just enough feed for 1 hog in order to reduce wastage. During Run 1, the animals in

*Produced on the Rosecrest Farms, located near Buffalo, Missouri.

Pens 1 and 2 were watered with the automatic, non-siphoning pressure type waterers which were connected to the farm pressure water system. During the hottest weather the hogs exhibited the natural tendency to create a cool wallow by scraping the water out of their water bowls onto the slotted floor. The water of course drained through the floor and the repeated efforts by the hogs filled the collection pits to overflowing. The installation of a large fan set to operate between 10 AM and 7 PM relieved to a great extent the temperature problem; in addition, during Run 2 the automatic units were disconnected and the animals were watered once a day in the waterer bowl in order to reduce wastage. The animals in Pen 3 were watered once a day in a trough formed by a one-half section of a domestic water heater. Any wastage in this pen resulted from the animals overturning the trough or laying in it and displacing the water.

D. ANIMAL FEEDS

Three feeds were used in this study and were either mixed by or obtained from a commercial feed supplier.* The constituents of each feed are shown in Table III, however, the relative concentration of each component was not available. Feed 1 was a simple mix consisting of a pulverized corn base with meat scraps and soybean meal added to supplement the protein, vitamin, and mineral content. Feed 2 also had pulverized corn as the grain base but was mixed with a commercial supplement** to provide additional protein, vitamins, and minerals and

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*Gaunt's Feed and Supply, Buffalo, Missouri.

**Super-Hog Supplement (No. 356), a product of Pay Way, Kansas City, Missouri.

TABLE III. FEEDS USED IN THE FEEDLOT OPERATION

Constituent	Feed 1 Simple Mix	Feed 2 Grain & Supplement	Feed 3 Complete Mix
Grain			
ground yellow corn	x	x	x
ground grain sorgham		x	x
Protein Supplements			
meat meal	x	x	
dried whey, dehydrated alfalfa meal		x	
wheat middlings		x	x
soybean meal	x	x	x
Mineral Supplements			
meat meal	x	x	
calcium carbonate, dicalcium phosphate, salt		x	x
potassium iodide			x
ethylene diamine dehydriodide		x	
Vitamin Supplement			
niacin, riboflavin supplement, vitamin A palymitate, D-activated animal sterol, alpha tocopheryl acetate, vitamin B_{12} supplement, calcium pantothenate		x	x
biotin, pyridoxine hydrochloride		x	
Trace Metal Additives			
iron carbonate, manganous oxide, cobalt carbonate, copper oxide, zinc oxide			x
disodium ethylene diamine tetra-acetate complexed with a mixture of: iron sulfate, manganese sulfate, magnesium oxide, zinc sulfate, cobalt sulfate, copper sulfate		x	
Fats			
hydrolyzed animal and vegetable fat (feed grade) with added preservatives BHA and BHT		x	x
Drug Additives			
oxytetracycline hydrochloride (0.001%)		x	
arsanilic acid (0.01%)			x
Miscellaneous Additives (amino acids, sugars, and preservatives)			
sodium gluconate, sodium citrate, glycine, lysine, lactose, fumaric acid		x	

a growth stimulant (0.001 percent oxytetracycline hydrochloride). Feed 3 was a commercially available complete mixed feed* containing 0.01 percent arsanilic acid as a growth stimulant. All feeds were formulated to correspond with the protein requirements of the body weight of the animals, so that in effect there were 6 feeds: 3 each with a protein content of 16 percent for the animals weighing between 50 and 125 lb (22.7 and 56.8 kg), and 3 with a protein content of 12 percent for the animals between 125 and 230 lb (56.8 and 104.4 kg).

E. FIELD WORK

The field work was conducted during the summer and early fall of 1971. It consisted of maintaining the animals,** removing the waste from the collection pits and refilling the pits with water, collecting raw waste and supernatant samples for laboratory characterization, feeding the lagoon system with waste from Pen 1, and collecting effluent samples for laboratory analysis. The feeding and watering procedures have been discussed in previous sections. Waste was withdrawn from the pits by gravity until the drainage consisted of such low flow that would have stalled a pump had one been used. This procedure resulted in some solids remaining on the pit floor and trough which was necessary in order to prevent pit leakage. The drainage hole was replugged, the solids on the pit floor were washed

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*Marvel Shoat Grow (No. 379) and Marvel Hog Fattener (No. 380), products of Pay Way, Kansas City, Missouri.

**Animals were maintained on the test site from February 1971, while different procedures were tried to waterproof the collection pits; they were placed on the slotted feeding floor beginning with May 1.

into the trough, and the pits were filled with water to a preset level. Pits 1 and 2 were filled to a depth providing a liquid volume of 27.7 gal (105 l), and Pit 3 to a depth corresponding to a volume of 50 gal (187.5 l) during Run 1 and 40 gal (151.4 l) during Run 2.

Initially (June 22 to July 5) the waste was drained from the pits into buckets and then poured over the top of 5-gal (18.9-l) sample bottles. Part of the waste was diverted into the container and the rest allowed to waste. The container was thoroughly shaken and a 1-gal (3.78-l) sample was obtained. This initial procedure was found incapable of providing representative samples and was changed within the first 2 wk of operation. In the modified procedure (used from July 6 through October 6), the waste was poured into 1 or 2, 32-gal (121-l) plastic garbage cans, and its volume was determined by measuring its depth in the can. The waste was then thoroughly mixed with a wood stirrer and samples were taken by inserting 1-gal (3.78-l) glass bottles into the container while the waste was still swirling. Since Pit 3 contained more waste than 1 plastic can could hold, the waste was collected and divided equally between 2 containers, and the sample was taken from either of these. Settled supernatant samples were obtained from the collection cans where the waste was allowed to settle for 24 to 48 hr (July 6 to 16), from the collection pits directly (July 18 to August 30), and from 3-l cylindrical jars where the waste was allowed to settle for 1 hr in the laboratory (September 6 through October 6). During Run 1 tests were made on samples collected daily; however, during Run 2 daily samples were composited into 3 or 4-day composites in order to reduce the total number of samples analyzed, thereby enabling more complete testing.

The lagoon system was fed Waste 1, produced by animals in Pit 1 which were maintained on Feed 1, in order to prevent any inhibitory action that might have been caused by the drugs contained in the other feeds and corresponding wastes. Throughout the study, the anaerobic lagoon was fed a well mixed portion of the total waste. The dual lagoon was fed a combination of anaerobic lagoon effluent and settled supernatant from the garbage containers in Run 1, and supernatant diluted with recycled effluent from the aerobic lagoon in Run 2. The aerobic lagoon, which was in operation primarily in Run 2, was fed with effluent from the dual lagoon.

F. LABORATORY TESTING

The wastes collected from the 3 pits and the corresponding supernatants were characterized by chemical oxygen demand (COD), biochemical oxygen demand (BOD), total solids (TS) and volatile solids (VS), ammonia nitrogen (NH_3-N) and organic nitrogen (Org-N), and pH determinations. The total waste was additionally evaluated using total phosphorus (Total-P), grease, and chloride determinations. The COD, BOD, and VS values were used to determine the organic strength of the wastes, while nitrogen and phosphorus served to evaluate nutrient content. Grease was measured because of its potential effect on the treatment system, and chlorides were determined in order to be assured that they would not interfere in the COD test.

Influent and effluent samples from each of the lagoons were analyzed for COD, TS and VS, and pH. These parameters were used to evaluate the performance of the lagoon system and to determine the loading rates and the efficiency of treatment. A limited number of nitrogen tests was run on the lagoon effluents, and volatile acids determinations were employed to better control the condition of the anaerobic lagoon during Run 2. At the end of the study the COD, VS and TS content of the sludges remaining in the anaerobic and dual lagoons were also determined.

All determinations, with the exception of the phosphorus test, were performed using the procedures outlined in Standard Methods (33); minor deviations from the standard procedures were in some cases necessary because of the nature of the animal waste, and these are indicated under each individual test. Total phosphorus was determined using the procedure recommended by Jankovic, et al. (34).

1. Chemical Oxygen Demand

The COD of the effluents from the dual and aerobic lagoons was determined using either undiluted or one-half strength samples; however, considerable dilution was required for the 3 wastes and their settled supernatants, the anaerobic lagoon effluent, and the sludges remaining in the lagoons at the end of the study. The initial method used for diluting the raw wastes consisted of pipeting quantities as low as 0.1 ml into the COD flasks and adding deionized water to bring the total volume to 20 ml. After obtaining some very erratic values, the dilution procedures was changed and thereafter dilutions were made utilizing either a broken tip pipet* or a graduated cylinder. The broken tip pipet was used to transfer the well mixed sample directly into the

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*A pipet with the tip broken off to enable measurement of samples containing solid matter.

COD flask whenever dilution was not necessary. For the higher strength wastes and effluents, a well mixed volume of raw sample was measured in a 10 or 25-ml graduated cylinder, transferred into a 500-ml cylinder, and diluted with deionized water. The mixture was vigorously agitated with a plastic stirring rod, and before settling could occur a 20-ml sample was withdrawn using a broken tip pipet and transferred to a COD flask. The mercuric sulfate, sulfuric acid containing silver sulfate, and potassium dichromate reagents were added along with pumice stones; the mixture was refluxed for 2 hr, and after cooling was titrated with ferrous ammonium sulfate using ferroin as an indicator (33, p. 495).

The COD values of the high strength wastes proved to be erratic even after the change in dilution procedure was effected. A great deal of day to day variation could be expected because of the small number of animals producing the wastes and the very nature of the waste itself. Large particles of undigested or wasted ground grain were present in the waste and their hardness made homogenization impossible. Because it was believed that uneven distribution of these particles in the diluted sample transferred to the COD flask was responsible for the erratic values obtained, at least duplicate samples were run in order to reduce variation. Duplication of the COD values was attempted in various ways and most of the results obtained are summarized in Table IV. On all dilutions 2 samples were refluxed, and duplicate dilutions of the same or different strengths were made on several occasions. For example, 3 dilutions (2, 3, and 4 percent) of the same raw waste sample could be refluxing at the same

TABLE IV. EVALUATION OF THE DILUTION EFFECT ON THE COD DETERMINATION

Date	Waste 1					Waste 2					Waste 3				
	Total			Supernatant		Total			Supernatant		Total			Supernatant	
	Dilution		Avg	Dil.	Avg	Dilution		Avg	Dil.	Avg	Dilution		Avg	Dil.	Avg
	a	b		c		a	b		c		a	b		c	
	mg/1														
7/16	6,150 6,448	5,952 6,746	6,324			11,805 11,606	10,912 10,515	11,210			11,507 11,507	9,760 9,960	10,684		
7/18	5,978 5,488	4,704	5,390	1,803 1,803	1,803	8,918 9,604		9,261			21,560 21,364		21,462		
7/19	7,683 9,486	6,507 6,821	7,624	1,934 1,960	1,947	7,526 7,370	7,056 7,056	7,252	1,829 1,829	1,829	18,620 23,520	19,796 18,620	20,139		
7/21	13,808 15,316	11,606 17,705	13,109	2,354 2,354	2,354	8,570 8,332	8,253 9,047	8,551	2,063 2,036	2,050	15,078 14,880	14,880 13,689	14,632	2,909 2,936	2,922
7/27	11,740 12,043	13,461 12,651	12,474			5,870 5,668	5,769	5,769			16,800 16,396	12,145 11,658	14,249		
7/29	10,670 13,140	12,251 14,523	12,646			5,039 5,039	5,829 5,632	5,385			8,102 7,904		8,003		
7/30	12,740 12,740	15,190	13,557			14,504 15,386	13,034 14,798	14,431			15,484 18,228	15,484 15,092	16,072		
8/4	10,358 10,214	8,167 8,366	9,276			12,744 13,911	16,148 13,230	14,008			17,510 16,538	17,316 17,121	17,121		
8/6	8,864 10,358	9,462 11,255	9,985			12,848 13,645	16,832 16,135	14,865			14,143 16,135	13,745 14,143	14,542		
9/6-9/8	3,437 2,828		3,632	1,957 1,977	1,967	3,197 3,197		3,197	1,356 1,376	1,366	3,750 4,141		3,945	1,841 1,782	1,812
9/23-9/26	5,518 5,518		5,518	2,734 2,695	2,715	10,547 9,844		10,196	4,740 4,818	4,779	9,375 9,375		9,375	4,043 3,945	3,994
9/27-9/29	4,457 4,354		4,406	2,295 2,398	2,347	7,377 7,459		7,418	3,224 3,306	3,265	7,459 8,279		7,869	2,787 2,842	2,815
9/30-10/3	4,336 5,962	4,435 4,637	4,843	1,626 1,646	1,636	7,154 7,420	7,903	7,492	1,484 1,545	1,515	8,211 8,048	8,629	8,296	2,500 2,561	2,530
10/4-10/6	4,223 4,382		4,303	1,494 1,573	1,534	9,243 9,163		9,203	3,446 3,546	3,496	9,243 9,004		9,124	3,227 3,267	3,247

Note: The avg values have been reported in Table VIII, p. 51.

time in 6 different flasks, with 2 flasks for each dilution. These multiple determinations verified that the discrete grain particles together with the extreme dilution requirement did indeed affect the agreement of the values determined for the same waste. Duplicate samples of the supernatants that essentially contained no grain particles were in very good agreement with a maximum variation from the average of 2.6 percent, while the values for the total wastes varied as much as 10.3 percent from the average for the same dilution. Multiple determinations were, therefore, employed in the remainder of the study in order to improve the accuracy of the COD data.

2. Biological Oxygen Demand

The 5-day BOD (BOD_5) of selected samples of the total wastes, supernatants, and lagoon effluents was determined (33, p. 429) in order to evaluate the corresponding BOD/COD ratios. Dissolved oxygen (DO) was measured using the azide modification (33, p. 477). An appropriate volume of the sample was transferred to a 1-l graduated cylinder using a broken tip pipet and enough dilution water was added (siphoned) to fill to the 1-l mark. The mixture was gently mixed with a plunger-mixer and then siphoned into 2, 300-ml BOD bottles. One of the bottles was used to determine the immediate (15-min) DO content and the other was incubated* for 5 days at 20°C before determining the residual DO. Dilution water was prepared from deionized water which had been saturated with oxygen at room temperature and contained 1 ml/l each

*A Hotpack model 352700 refrigerated incubator was used; it was a product of the Hotpack Corporation, Philadelphia, Pennsylvania.

of phosphate buffer, magnesium sulfate, calcium chloride, and ferric chloride solutions and 2 ml/l of primary settled sewage obtained from the Rolla Southeast Sewage Treatment Plant. Blanks were made of the unseeded and seeded dilution water, and 3 dilutions were made of each sample in order to have a broad range of values. The DO was determined by treating the contents of the BOD bottle with 2 ml each of manganese sulfate, alkali-iodide-azide, and concentrated sulfuric acid, and titrating an appropriate portion of the sample with sodium thiosulfate solution using starch as an indicator.

3. Total, Volatile, and Settleable Solids

The evaporating dishes used in TS and VS determinations were dried* at 103°C, tared, fired** at 500°C, and tared again. A 100-ml volume of sample was evaporated on a steam bath, dried at 103°C for 1 hr, and weighed to determine TS. It was then ignited at 550°C for 15 to 20 min and reweighed, and the amount of material lost was used to compute VS (33, p. 535).

Settleable solids were measured by pouring a 1-l volume of the well mixed sample into an Imhoff cone, settling for 1 hr, and measuring the volume of solids settled (33, p. 539). Since the cones were only calibrated to 40 ml/l they had to be further calibrated to obtain readings of up to 500 ml/l.

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*A Precision-Thelco model 17 oven was used; it was a product of the Precision Scientific, Chicago, Illinois.

**A Hevi-Duty Type 054-PT furnace was used; it was a product of Lindberg Hevi-Duty, Watertown, Wisconsin.

4. Ammonia and Organic Nitrogen

Preliminary distillation (33, p. 224 & 453) was employed in determining NH_3-N because it was planned to subsequently measure Org-N and because the color and turbidity of the samples prevented direct nesslerization. An appropriate volume of sample* was diluted to approximately 500 ml with NH_3-free water** and buffered with 10 ml of phosphate buffer solution. The NH_3-N was steam-distilled# and the distillate was collected in an erlenmeyer flask containing 50 ml boric acid solution/mg NH_3-N expected in the sample. The distillate was titrated with 0.02N sulfuric acid solution using a methyl red-methylene blue indicator. When samples of the raw waste were tested, a piece of parafin was added prior to distillation to prevent excessive foaming (33, p. 454). A blank consisting of dilution water only was also run.

Initially, it was attempted to determine Org-N by digestion of the residual from the NH_3-N determinations (33, p. 244). This procedure was discontinued when it was found that the parafin used in some of the NH_3-N determinations clogged the aspirator employed to draw off the SO_3 fumes before digestion could be completed. It was late

*Five ml of the raw wastes or supernatants and 5 to 100 ml of the lagoon effluents were used.

**The NH_3-free water was prepared by distillation of deionized water which had been treated with 0.1 ml/l of concentrated sulfuric acid (33, p. 225); fresh deionized water was also found to be NH_3-free and was used because the requirements for dilution water exceeded the capacity for distillation of acid-treated water.

#A twin-unit Kjeldahl distillation apparatus was used; it was a product of the Precision Scientific Co., Chicago, Illinois.

in the study when the cause of the equipment failure was discovered and consequently few Org-N tests were run. After the parafin problem was identified total Kjeldahl-N, rather than Org-N, was measured.

An appropriate volume* of sample was diluted to 100 ml using NH_3-free water (alternately the residual sample remaining from the NH_3-N determination was used); 50 ml of a digestion reagent containing potassium sulfate, concentrated sulfuric acid, and red mercuric oxide was added, and the sample was digested** to convert Org-N to NH_3-N. The mixture was cooled, and the residue diluted to about 300 ml with NH_3-free water. A sodium hydroxide-sodium thiosulfate reagent was used to neutralize the dilution to the phenolphthalein end point, and the NH_3-N content of the digested sample was determined by distillation and collection of the distillate in boric acid. A blank consisting of dilution water was also run. The blanks appeared to contain significant amounts of NH_3-N and occasionally required more titrant than the sample. In addition, the indicator end point could not always be determined, and this occurred even after the preparation of different indicator solutions. This difficulty left the investigator without a true end point of titration. The reason(s) for the variation in color was (were) never established. The total Kjeldahl-N data presented report only the results of those tests not thrown out for any of the above reasons.

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*Five ml of the raw wastes or supernatants were used; Org-N and total Kjeldahl-N were not determined on the lagoon effluents.

**A twin-unit Kjeldahl digestion apparatus was used; it was a product of Precision Scientific Co., Chicago, Illinois.

5. Total Phosphorus

The method suggested by Jankovic, et al. (34) was used for the determination of Total-P. Because of the high organic content of the animal wastes, the method was evaluated to assure the adequacy of the recommended procedure. The amount of potassium persulfate added and the length of digestion time were varied, while the remaining procedure, including the addition of 2 ml of 5N sulfuric acid, was followed unchanged. It was concluded from the results of this study (Table V) that for this type of waste 1 g of potassium persulfate and 30 min digestion time were sufficient. The turbidity of the clear liquid immediately following digestion was also measured and found to be 1 to 2 Hach turbidity units. The material in suspension was large and distinct.

An appropriate volume* of sample was diluted to about 30 ml with deionized water, and following the addition of 1 g of potassium persulfate and 2 ml of 5N sulfuric acid, was digested for 30 min on a hot plate. The digested mixture was cooled and diluted to 1000 ml. Eight ml of a mixed reagent, containing sulfuric acid, ammonium molybdate solution, ascorbic acid solution, and potassium antimonyl tartrate solution, was pipeted into a 50-ml nessler tube, and the tube was filled to the 50-ml mark with the diluted sample. A blank was prepared in the same manner, using dilution water. The sample was read on a spectrophotometer** at a wavelength of 882 mμ and its phosphorus content was determined from a calibration curve.

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*Ten ml of Waste 1, and 5 ml of Wastes 2 and 3 were used.

**A Spectronic 20 colorimeter, equipped with a red sensitive phototube was used; it was a product of Bausch & Lomb Incorporated, Rochester, New York.

TABLE V. EVALUATION OF THE DIGESTION PROCEDURE FOR TOTAL PHOSPHORUS

Sample	Digestion Conditions		Phosphorus Concentration		
	Potassium Persulfate	Boiling Time	Measured P	Avg $\overline{P}$	$\frac{P-\overline{P}}{P}$
	g	min	mg/1 P		%
1	1	15	30	30.6	- 2
		30	30		- 2
		45	35		+14
	2	15	30		- 2
		30	28		- 8
2	1	15	76	75.6	+ 1
		30	76		+ 1
		45	74		- 2
	2	15	76		+ 1
		30	76		+ 1
3	1	15	74	68.8	- 8
		30	66		+ 4
		45	68		+ 1
	2	15	68		+ 1
		30	68		+ 1

6. Volatile Acids

A fresh sample of anaerobic lagoon effluent was centrifuged and 5 ml of the clear centrate was drawn into a silicic acid column with suction supplied by an aspirator (33, p. 577). The volatile acids were eluted from the column by 65 ml of a chloroform-butanol reagent. The eluted sample was purged with carbon dioxide-free air prepared by passing it through an Ascarite-filled tube, and then titrated with 0.02N sodium hydroxide using phenolphthalein as the indicator. The end point of titration was extremely difficult to determine, and the point at which the color changed for about 30 sec was used. A blank consisting of acidified distilled water was also run following the same procedure and the difference in titrant volumes was used to compute the concentration of volatile acids in the sample.

7. Grease

Since the waste was extremely difficult to filter, the test recommended for testing sludge (33, p. 412) was used. Samples were acidified (33, p. 409) by adding 1 ml concentrated sulfuric acid/80 g waste and stored at 2°C; this resulted in a pH of about 1 and the pH of the sample was adjusted to 2 prior to the grease determination. The procedure outlined in Standard Methods recommended mixing 20 g of sample (pH 2) with 25 g of magnesium sulfate and grinding the solidified sample into a fine powder before placing in an extraction thimble; however, after repeated test failures due to the mixture becoming impermeable during extraction, the sample volume was reduced to 15 g and the magnesium sulfate to 20 g. The extraction thimble of the soxhlet extraction apparatus was prepared using a layer of glass wool to prevent passage of contaminating materials, then the mixed and powdered sample, and finally glass beads to provide even distribution of the solvent. The extractor was connected to a preweighed 250-ml round bottom flask placed in a heating mantle. Sufficient n-hexane was added to activate the siphon and the heating rate adjusted to provide 20 cycles/hr. After extracting for 4 hr, the system was cooled, the extractor disconnected and replaced by a condenser, and the solvent distilled off to near dryness. The residue was air-dried and the amount of grease determined.

In order to express the grease content of the sample as a percentage of dry solids, as is recommended in Standard Methods, the dry solid content of the sludge was also determined. Because the low pH of the acid-treated sample was conducive to digestion of the organic matter, the pH was raised to 7 before the solids test was run. Corrections were made to compensate for the reagents added for storage and neutralization.

8. Chlorides

The potentiometric method (33, p. 377) was employed due to the turbidity and color present in the waste and the relative freedom from interference that this method possesses. Ten ml of sample was diluted to 100 ml with deionized water, acidified with sulfuric acid, and boiled for 5 min; 3 ml of 30 percent hydrogen peroxide was added and boiling continued for 15 min. The sample was adjusted to 100 ml, turned alkaline with sodium hydroxide, filtered, turned acidic with nitric acid, and titrated with silver nitrate using a silver-coated electrode* and the mv scale of a pH meter.** The titration was carried to the point where the change in potential per unit additon of titrant (mv/ml) was essentially zero. This was done because a plot of data comparing change in reading (mv/ml) vs volume of titrant (ml) used showed that there were several peaks; and true end point was taken to be the highest peak in the curve.

9. pH Value

A pH meter** was employed to determine pH values.

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*A Beckman 39261 electrode was used; it was a product of Beckman Instruments, Inc., Fullerton, California.

**A Fisher Accumet pH meter model 210 was used; it was obtained from the Fisher Scientific Company, St. Louis, Missouri.

IV. PRESENTATION OF RESULTS

The data presented in this section are the product of over 3.5 months of actual field work and laboratory analysis of 2 separate, yet related activities: Characterization of swine waste produced by a slotted feeding floor operation; and evaluation of the capability of a 3-lagoon system to treat this waste. The study was further divided into 2 runs. In the feedlot operation, Run 1 was terminated when the initial group of animals reached market weight and were replaced, while in the lagoon operation failure of the units under study necessitated reseeding and marked the beginning of Run 2. The sequence and details of the feedlot and lagoon operations are summarized in Table VI. That there was a difference of a few days between the corresponding runs made little difference.

A. WASTE CHARACTERIZATION

The treatability of the feedlot waste in a biological system, rather than its value as a fertilizer, was the primary objective of the characterization study. The effective handling of the waste was also a main consideration, and the water-carriage system was selected for this purpose because it helped suppress the odors normally associated with feeding floors, facilitated the transportation of the waste, and converted it into a form more suitable for lagoon treatment. Waste characteristics are presented in terms of mg/1, the usual method of expressing the strength of domestic and industrial wastes. Many of the parameters are also given in a ratio to VS or TS, or on a per animal basis. This was done to permit comparison with the values reported in the literature (Tables I & II,

TABLE VI. SEQUENCE AND DETAILS OF FEEDLOT AND LAGOON OPERATIONS

Run	Feedlot Operation				Lagoon Operation*					
					Anaerobic		Dual		Aerobic	
	Time Period	Pen	No of animals	Feed Used	Time Period	Influent	Time Period	Influent	Time Period	Influent
1	6/22 to 9/2/71	1	2	Feed 1 Simple Mix	6/22 to 7/17/71	Total waste	6/28 to 8/1/71	Anaerobic lagoon effluent + settled waste supernatant	N/A	Lagoon being waterproofed
		2	2	Feed 2 Grain + Supplement	7/18 to 8/1/71	Settled waste sludge				
		3	6 or 5	Feed 3 Complete Mix	8/2 to 8/31/71	Total waste	8/2 to 8/12/71	Settled waste supernatant	8/1 to 8/19/71	Settled waste supernatant
2	9/3 to 10/10/71	1	1	Feed 1 Simple Mix	9/1 to 10/6/71	Total waste	8/12 to 9/6/71	Settled waste supernatant	8/20 to 10/6/71	Dual lagoon effluent
		2	1	Feed 3 Complete Mix			9/6 to 10/6/71	Settled waste supernatant + aerobic lagoon effluent		
		3	4	Feed 2 Grain + Supplement						

*Lagoons fed Waste 1 only.

p. 9 & 12), and to compensate for the dilution factor which was an external variable, controllable by the feeder.

The collection of the animal waste in dilution water, coupled with its daily removal from the pits, formed a material approaching the appearance of domestic sewage. Because the waste could be easily separated into settled supernatant and sludge components, which conceivably could be treated independently, the characteristics of the supernatant were also determined. Several methods for obtaining the supernatant were employed, including settling for periods of 24 to 48 hr in the collection cans, direct withdrawal from the collection pits prior to draining, and settling for 1 hr in the laboratory.

The well water used for dilution had the following characteristics:

pH, units	7.2
TS, mg/l	400
VS, mg/l	60
Total Hardness, mg/l as $CaCO_3$	292
Alkalinity, mg/l as $CaCO_3$	280

Its TS and VS content would be reflected in the corresponding characteristics of the animal waste, especially the settled supernatant, and this must be taken into consideration when comparing the results of this study to the findings of other investigations using different methods of collection.

A considerable variation in the concentration of the various paramters was anticipated because of the fluctuation in dilution water content, the natural variation in waste production by the animals, and the wastage of both feed and water. The small number of animals contributing to the waste, necessary under the test conditions, magnified this variation.

1. Odor and Physical Condition

These characteristics are described in Table VII and are based on several subjective evaluations made by the author. Of particular importance in the design of collection pits using flushing water would be the relative ease with which the waste was removed from the collection pits. Waste 1 could be drained readily by gravity and a small amount of flushing water, while Waste 3 compacted to such an extent that the settled solids could be removed only after they had been broken up with a water or mechanical force. Waste 2 fell between the other 2, and on an arbitrary scale of 1 (Waste 1) to 5 (Waste 3) defining the ease of complete solids removal, it would have had a rating of 3.

2. Physical and Chemical Characteristics

The physical and chemical characteristics of the 3 wastes are presented in Table VIII, and the range of values encountered during the study is summarized in Table IX. The data reported for August 2 (Table VIII) reflect the characteristics of the wastes after they had been allowed to remain in the collection pits for 72 hr. Wastes 2 and 3 were undisturbed during this period, while Waste 1 was affected by the withdrawal of the small volumes which were necessary to maintain the lagoon system. This long-term accumulation test was done in order to evaluate the effect of waste retention in the pits on odor production. It was found that the odor increased in direct proportion to time, and at the end of the 3 days it was quite concentrated

TABLE VII. CHARACTERIZATION OF FEEDLOT WASTES-ODOR AND PHYSICAL CONDITION

Characteristic	Waste		
	1	2	3
Odor	Typical odor of soured corn	Typical odor of soured corn but to a lesser extent than Waste 1	Concentrated odor usually associated with swine feedlots but very different from Wastes 1 and 2.
Color	Yellow-brown	Greenish-brown to dark green depending upon concentration	Greenish-brown to dark green depending upon concentration
Composition, appearance, and rheology	Consisted essentially of small discrete particles of wasted corn and organic solids; was not prone to flocculate and easy to fluidize for effective removal.	Contained wasted corn but in lesser quantity than Waste 1; tended to compact during settling and was more difficult to flush from pit than Waste 1.	Consisted of finely divided material with few wasted grain particles; was very flocculent and required a considerable amount of flushing to be effectively removed.

TABLE VIII. CHARACTERIZATION OF FEEDLOT WASTES-PHYSICAL AND CHEMICAL DATA
Waste 1

Date	Run	Sample	Total Waste							Settled Supernatant						
			TS mg/l	VS mg/l	VS % of TS	Settl. Solids ml/l	COD mg/l	COD/VS	pH	TS mg/l	VS mg/l	VS % of TS	VS/VS Settled / Total	COD mg/l	COD/VS	pH
6/22			2,814	1,885	67.0	44	7,782	4,128	7.0							
6/23			4,085	3,031	74.2	36	7,987*	2.635	7.0							
6/24			5,627	4,398	86.9	40	6,502	1.478								
6/25			4,664	3,375	72.4	53	6,882	2.039	6.8							
6/26			5,544	4,321	78.0	43	47,600	11.016	6.8							
6/27			4,296	3,154	73.4	42	6,478	2.054	6.6							
6/28			7,313	5,894	80.6	57	7,600	1.289	6.7							
6/29			5,073	3,897	76.8	41	4,800	1.232	6.9							
6/30			2,870	1,929	67.6	14	3,318	1.711	7.4							
7/1			4,729	3,512	74.3	45	10,231	2.913	7.0							
7/2			7,871	6,185	78.6	83	10,926	1.767	7.1							
7/3			6,063	4,457	73.5	45	8,200	1.840	7.1							
7/4			6,462	5,085	78.7	51	7,653	1.505	7.0							
7/5			5,456	4,189	79.8	70	8,704	2.078	6.9							
7/6			6,545	5,242	80.1	60	7,616	1.453	7.2	2,115	1,075	50.8	0.205	2,611	2.429	
7/7			5,592	4,321	77.2	49	8,467	1.960	7.7	2,014	1,075	53.4	0.249	3,052	2.839	
7/8	1	daily				53	9,173		7.6							
7/9			3,609	2,596	71.9	52	5,588	2.153	7.1	1,860	996	53.5	0.384	2,966	2.978	
7/11			4,027	2,758	68.5	40	7,112	2.579	7.2	1,364	698	51.2	0.253	1,707	2.446	
7/12			5,003	3,669	73.3	121	6,104	1.664	7.1	1,838	891	48.5	0.243	2,275	2.553	7.2
7/13			3,827	2,855	74.6	83	5,622	1.969	7.4	1,742	935	53.7	0.327	2,436	2.605	7.5
7/16			4,197	3,187	75.9	49	6,324*	1.984	6.9	1,777	978	55.0	0.307	1,487	1.520	7.1
7/18			4,239	3,305	78.0	25	5,390*	1.631	7.2	1,625	904	55.6	0.274	1,803*	1.994	7.8
7/19			4,899	3,820	78.0	64	7,624*	1.996	7.4	1,707	960	56.2	0.251	1,947*	2.028	8.0
7/21			8,509	7.148	84.0	131	13,109*	1.834	6.0	2,055	1,276	62.1	0.179	2.354*	1.845	6.5
7/22			5,822	4,760	81.8	83				1,870	1,095	58.6	0.230			
7/26			6,310	5,293	83.9					2,152	1,251	58.1	0.236			
7/27			4,499	3,120	69.3	58	12,474*	3.998		2,121	1,230	58.0	0.394	2,536	2.062	
7/29			8,253	6,993	84.7	93	12,646*	1.808	6.5	2,996	2,000	66.8	0.286	3,873	1.937	6.6
7/30			9,978	8,190	82.1	85	13,557*	1.655	6.7	2,262	1,365	60.3	0.167	2,195	1.608	7.1
8/2			17,599	14,390	81.8	218	31,362*	2.179	6.6	3,451	1,942	56.3	0.135	5,666	2.917	6.9
8/4			6,643	5,368	80.8	81	9,276*	1.728	6.8	2,781	1,782	64.1	0.332	3,187	1.788	7.4

TABLE VIII (Cont.). CHARACTERIZATION OF FEEDLOT WASTES-PHYSICAL AND CHEMICAL DATA
Waste 1 (Cont.)

Date	Run	Sample	Total Waste TS mg/l	Total Waste VS mg/l	Total Waste VS % of TS	Total Waste Settl. Solids ml/l	Total Waste COD mg/l	Total Waste COD/VS	Total Waste pH	Settled Supernatant TS mg/l	Settled Supernatant VS mg/l	Settled Supernatant VS % of TS	Settled Supernatant VS/VS Settled/Total	Settled Supernatant COD mg/l	Settled Supernatant COD/VS	Settled Supernatant pH
8/5	1	daily	4,822	3,539	73.4				6.7	1,974	1,130	57.2	0.319			7.7
8/6			7,681	6,223	81.0	80	9,985*	1.605	7.0	2,854	1,636	57.3	0.263			7.8
8/7			9,497	7,565	69.4					1,883	1,040	55.2	0.156			
8/9			6,655	5,267	79.1					1,172	678	57.8	0.129			
8/10			2,589	1,843	71.2				7.5	893	478	53.5	0.259			7.6
8/11			2,774	2,003	72.2				7.0	919	418	45.5	0.209			7.5
8/12			6,823	5,321	78.0				7.1	2,181	1,374	63.0	0.258			8.1
8/13			4,151	2,895	69.7				7.2	1,953	902	46.2	0.312			8.2
8/14			6,733	5,075	75.4				7.0	2,671	1,446	54.1	0.285			8.0
8/17			11,676	9,059	77.6				5.9							
8/18			4,708	3,576	76.0					1,790	998	55.8	0.279			
8/19			4,865	3,720	76.5				6.3	1,868	1,075	57.5	0.289			6.7
8/20			3,439	2,603	75.7				6.9	1,662	1,062	63.9	0.408			6.7
8/21			3,463	2,617	75.6					1,194	615	51.5	0.235			
8/22			3,147	2,221	70.6				7.1	1,763	986	55.9	0.444			
8/23			4,854	3,833	79.0				6.9	1,991	1,250	62.8	0.326			6.9
8/24			2,855	2,164	75.8					1,159	692	59.7	0.320			
8/25			2,816	1,953	69.4				7.6	1,843	1,147	62.2	0.587			7.7
8/26			3,704	2,786	75.2				7.2	2,040	1,337	65.5	0.480			7.1
8/27			3,110	2,135	68.6				7.3	2,154	1,387	64.4	0.650			7.2
8/28			4,521	3,305	73.1				7.2							7.2
8/30			6,428	4,717	73.4					5,517	3,126	56.7	0.663			
9/6-9/8	2	Composite	2,900	2,172	74.9		3,632*	3.099		1,499	866	57.8	0.399	1,967*	2.271	
9/9-9/12			2,042	1,448	70.9		2,461*	1.700		1,371	840	61.3	0.580	1,857*	2.211	
9/13-9/15			3,033	2,219	73.2		4,336*	1.954		1,722	1,023	59.4	0.461	2,119*	2.071	
9/16-9/19			3,540	2,625	74.2		4,257*	1.725		1,918	1,168	60.9	0.445	2,208*	1.890	
9/20-9/22			4,381	3,191	72.8		6,997*	2.193		2,515	1,573	62.5	0.493	2,978*	2.108	
9/23-9/26			3,792	2,796	73.7		5,518*	1.974		1,965	1,159	59.0	0.415	2,715*	2.343	
9/27-9/29			3,270	2,359	72.1		4,406*	1.868		1,756	871	49.6	0.369	2,347*	2.695	
9/30-10/3			3,409	2,495	73.2		4,843*	1.941		1,720	1,008	58.6	0.404	1,636*	1.623	
10/4-10/6			3,677	2,597	70.6		4,303*	1.657		1,843	979	53.1	0.377	1,534*	1.569	

*Avg of at least duplicate determinations.

TABLE VIII (Cont.). CHARACTERIZATION OF FEEDLOT WASTES-PHYSICAL AND CHEMICAL DATA
Waste 2

Date	Run	Sample	Total Waste							Settled Supernatant						
			TS	VS		Settl. Solids	COD	COD/VS	pH	TS	VS		VS/VS	COD	COD/VS	pH
			mg/l	mg/l	% of TS	ml/l	mg/l			mg/l	mg/l	% of TS	Settled / Total	mg/l		
6/22			4,100	2,337	59.4	62	8,192	3.362	6.9							
6/23			5,115	3,740	73.1	40	3,875*	1.036	6.9							
6/24			6,389	4,667	73.0	38	11,786	2.525								
6/25			6,265	4,636	74.0	106	13,358	2.881	7.0							
6/26			7,393	5,720	77.4	55	10,800	1.888	6.7							
6/27			4,341	2,956	68.1	27	7,286	2.465	6.5							
6/28			9,511	7,645	80.4	96	14,400	1.884	6.1							
6/29			6,759	5,245	77.6	68	9,600	1.830	6.4							
6/30			6,197	4,760	76.8	49	7,052	1.482	6.9							
7/1			6,557	4,933	75.2	63	8,296	1.682	6.7							
7/2			7,178	5,631	78.4	82	10,586	1.880	6.9							
7/3			10,340	8,365	80.9	82	15,033	1.797	6.4							
7/4			5,885	4,493	76.3	122	18,586	4.137	6.5							
7/5			7,799	6,304	80.8	96	14,008	2.222	6.5							
7/6			7,881	6,415	81.4	55	11,424	1.781	7.1							
7/7	1	daily	6,938	5,593	80.6	73	8,971	1.604	7.3	2,520	1,418	56.3	0.254	3,974	2,803	
7/8						85	9,173		7.2					4,133		
7/9			6,499	5,063	77.9	73	9,347	1.848	6.5					4,592		
7/11			4,209	2,881	69.2	41	6,604	2.215	7.0							
7/12			7,245	5,748	79.3	73	8,594	1.495	6.7							
7/13			5,250	4,170	79.4	49	8,835	2.119	6.4							
7/16			6,819	5,305	77.8	73	11,210*	2.113	6.2	2,318	1,272	54.9	0.240	3.240	2.547	6.5
7/18			5,605	4,543	81.1	41	9,261*	2.039	6.8	1,794	1,011	56.4	0.223	2,430	2.404	7.4
7/19			4,481	3,398	75.8	190	7,252*	2.134	7.0	1,762	1,024	58.1	0.301	1,829*	1.786	7.3
7/21			7,324	5,910	80.7	85	8,551*	1.447	7.0	2,100	1,138	54.2	0.193	2,050*	1.801	7.5
7/22			7,684	5,998	78.1	49				2,156	1.141	52.9	0.190			
7/26			4,260	3,128	73.4					2,210	1,212	54.8	0.387			
7/27			4,283	2,896	67.6	32	5,769*	1.992		2,023	963	47.6	0.333	1,673	1.737	
7/29			4,633	3,175	68.5	33	5,385*	1.696	7.9	2,877	1,519	52.8	0.478	2,608	1.717	8.1
7/30			10,272	7,867	76.6	120	14,431*	1.834	6.9	3,778	2,221	58.8	0.282	3,763	1.694	7.1
8/2			19,739	15,043	76.2		32,583*	2.345	6.5	4,934	2,538	51.4	0.169	4,876	1.921	6.8

TABLE VIII (Cont.). CHARACTERIZATION OF FEEDLOT WASTES-PHYSICAL AND CHEMICAL DATA
Waste 2 (Cont.)

Date	Run	Sample	Total Waste							Settled Supernatant						
			TS mg/l	VS mg/l	VS % of TS	Settl. Solids ml/l	COD mg/l	COD/VS	pH	TS mg/l	VS mg/l	VS % of TS	VS/VS Settled/Total	COD mg/l	COD/VS	pH
8/4			10.493	8,196	78.1		14,008*	1.709	6.7	2,495	1,364	54.7	0.166	2,922	2.142	7.2
8/5										2,434	1,367	56.2				7.6
8/6			8,844	6,699	75.7	121	14,865*	2.219	6.9	3,167	1,739	54.9	0.260	3,452	1.985	7.1
8/7										2,906	1,455	50.1				
8/10			5,800	4,557	78.6				6.9	1,429	822	57.5	0.180			7.0
8/11			6,076	4,617	76.0				7.1	1,644	856	52.1	0.185			7.4
8/12			9,187	7,370	80.2				6.8	2,209	1,168	52.9	0.158			7.8
8/13			5,575	4,009	71.9				6.4	2,446	1.162	47.5	0.290			7.0
8/14			5,106	3,461	67.8				7.7	2,443	1,180	48.3	0.341			7.7
8/17	1	daily	5,690	4,068	71.5				6.1	2,004	975	48.7	0.240			6.5
8/18			7,980	5,925	74.2					2,727	1,419	52.0	0.240			
8/19			6,351	4,631	72.9				6.4	2,359	1,257	53.1	0.270			6.8
8/20			5,382	3,981	74.0				6.5	2,651	1,588	59.9	0.399			6.4
8/22			7,351	5,570	75.7				6.5	3,400	2,028	59.6	0.364			
8/23			4,296	3,085	71.8				6.7	2,458	1,393	57.8	0.452			6.8
8/25			3,730	2,559	68.6				6.8	2,409	1,442	59.9	0.564			6.7
8/26			4,438	3,295	74.2				6.4	2,600	1,636	66.8	0.527			6.3
8/27			6,146	4,669	76.0				6.5	3,006	1,760	58.5	0.377			6.4
8/28			10,404	8,121	78.1				6.7	4,788	3,086	64.5	0.380			6.4
8/30			9,107	6,393	70.2					5,452	3,196	58.6	0.499			
9/6-9/8			2,803	1,926	68.7		3,197*	1.660		1,587	857	54.0	0.445	1,366*	1.594	
9/9-9/12			3,050	2,218	72.7		3,418*	1.541		1.740	1,045	60.1	0.471	1,486*	1.422	
9/13-9/15			4,189	3,072	73.3		5,561*	1.810		2,137	1,312	61.4	0.427	2,464*	1.878	
9/16-9/19			3,314	2,195	66.2		3,841*	1.750		2,007	1,196	59.6	0.545	2,129*	1.780	
9/20-9/22	2	Composite	5,320	3,746	70.4		8,342*	2.227		2,893	1,599	55.3	0.427	3,037*	1.900	
9/23-9/22			7,007	5,472	81.7		10,196*	1.863		3,613	2,243	62.1	0.410	4,779*	2.131	
9/27-9/29			5,242	3,752	71.5		7,418*	1.977		2,729	1.563	57.2	0.417	3,265	2.089	
9/30-10/3			5,190	3,769	72.6		7,492*	1.988		2,588	1,476	57.0	0.418	1,515*	1.026	
10/4-10/6			7,344	5,536	75.4		9,203*	1.662		2,971	1,772	59.6	0.320	3,496*	1.973	

*Avg of at least duplicate determinations.

TABLE VIII (Cont.). CHARACTERIZATION OF FEEDLOT WASTES-PHYSICAL AND CHEMICAL DATA
Waste 3

Date	Run	Sample	Total Waste							Settled Supernatant						
			TS mg/l	VS mg/l	VS % of TS	Settl. Solids ml/l	COD mg/l	COD/VS	pH	TS mg/l	VS mg/l	VS % of TS	VS/VS Settled/Total	COD mg/l	COD/VS	pH
6/22	1	daily	4,311	2,924	67.8	42	6,144	2.101	8.2							
6/23			6,472	4,195	64.8	70	6,758*	1.611	8.1							
6/24			8,020	5,357	66.8	76	8,940	1.669								
6/25			12,907	9,721	75.3	60	6,072	0.625	7.2							
6/26			7,636	5,738	75.1	40	48,800	8,505	7.0							
6/27			6,149	4,335	70.5	58	6,072	1.401	7.4							
6/28			6,635	4,891	73.7	60	11,200	2.290	7.7							
6/29			8,657	6,552	75.7	80	14,800	2.259	7.5							
6/30			8,242	6,227	75.6	68	15,762	2.531	7.8							
7/1			8,130	6,011	73.9	75	12,167	2.024	8.0							
7/3			11,232	8,503	75.7	100	14,076	1.655	7.5							
7/4			10,632	8,088	76.1	93	14,486	1.791	7.6							
7/5			14,394	11,450	79.5	173	24,616	2.150	7.2							
7/6			16,478	13,250	80.4	159	25,296	1.909	7.1							
7/7			17,177	13,626	79.3	182	23,385	1.716	7.8							
7/8						322	29,837		7.6							
7/9			15,756	12,774	81.1	283	28,244	2.211	7.2							
7/11			9,975	7,296	73.1	173	16,459	2.256	7.8							
7/12			11,862	9,315	78.5	116	9,036	0.970	7.5							
7/13			25,536	21,144	82.8	173	38,353	1.814	7.2							
7/16			8,611	6,416	74.5	70	10,684*	1.665	7.7	2,617	1,469	56.1	0.229	2.895	1.971	7.7
7/18			18,871	15,360	81.4	196	21,462*	1.397	7.4	3,429	1,864	54.4	0.121	3,868	2.075	7.8
7/19			13,628	10,706	78.6	231	20,139*	1.881	7.5	2,426	1,301	53.6	0.122			8.5
7/21			11,718	9,257	79.0	218	14,632*	1.581	7.2	2,627	1,476	56.2	0.159	2,922*	1.980	7.7
7/22			19,766	15,941	80.6	156				3,077	1,665	54.1	0.104			
7/26			14,600	11,667	79.9					3,040	1,600	52.6	0.137			
7/27			11,178	8,783	77.9	116	14,249*	1.622		2,688	1,405	52.3	0.161	2,996	2.132	
7/29			6,295	4,717	74.9	106	8,003*	1.697	8.0	2,807	1,435	51.1	0.304	2,750	1.917	8.5
7/30			11,721	9,112	77.7	100	16,072*	1.764	7.7	3,871	1,927	49.8	0.211	3,842	1.994	8.6
8/2			58,330	42,552	73.0		145,182*	3.411	7.2	8,636	4,040	46.8	0.095	5,654*	1.400	8.3

TABLE VIII (Cont.). CHARACTERIZATION OF FEEDLOT WASTES-PHYSICAL AND CHEMICAL DATA
Waste 3 (Cont.)

Date	Run	Sample	Total Waste TS mg/l	Total Waste VS mg/l	Total Waste VS % of TS	Settl. Solids ml/l	COD mg/l	COD/VS	pH	Settled Supernatant TS mg/l	Settled Supernatant VS mg/l	Settled Supernatant VS % of TS	VS/VS Settled/Total	COD mg/l	COD/VS	pH
8/4			13,924	10,630	76.3	131	17,121*	1.611	7.8	3,962	1,947	49.7	0.183	3,710	1.905	8.5
8/5										5,700	3,043	53.4				8.7
8/6			13,648	9,748	71.4	135	14,542*	1.493	7.7	5,495	2,636	48.0	0.270	4,648	1.763	8.7
8/7										5,196	2,829	47.8				
8/10			11,499	8,557	74.4				7.3	2,910	1,557	53.5				7.5
8/11			17,039	13,354	84.2				7.0	3,546	1,891	53.3				7.3
8/12			11,930	9,231	77.4				7.2	4,037	2,235	55.4	0.242			7.9
8/13			21,320	16,892	79.2				7.0	6,145	4,042	65.8	0.239			7.2
8/14			13,532	10,061	74.3				7.2	4,074	1,959	48.1	0.195			8.1
8/17	1	daily	15,895	12,030	75.7				6.0	4,389	2,240	51.0	0.186			6.5
8/18			11,315	8,521	75.3					4,072	2,409	59.2	0.283			
8/19			14,948	11,851	79.3				6.6	5,195	3,186	61.3	0.269			6.9
8/20									6.4	5,981	3,658	61.2				6.3
8/22			7,664	5,612	73.2				7.0	3,256	1,757	54.0	0.313			6.5
8/23			9,652	7,247	75.1				6.7	4,746	2.725	57.4	0.376			6.7
8/25			13,052	10,107	77.4				7.0	4,193	2,472	59.0	0.245			6.9
8/26			9,039	7,299	80.8				6.6	3,668	2,081	56.7	0.285			6.6
8/27			9,445	7,139	75.6				6.6	3,903	2,149	55.1	0.301			6.5
8/28			9,424	7,169	76.1				7.1	3,850	2,340	60.8	0.326			7.0
8/30			16,704	13,091	78.4					3,472	2,127	61.3	0.162			
9/6-9/8			7,655	1,824	68.7		3,945*	2.163		1,611	862	53.5	0.473	1,812*	2.102	
9/9-9/12							4,363*			1,947	1,124	57.7		2,767*	2.017	
9/13-9/15			4,543	3,414	75.1		7,158*	2.097		2,257	1,231	54.5	0.361	3,384*	2.749	
9/16-9/19			12,575	10,547	83.9		15,282*	1.449		4,643	2,850	61.4	0.270	6,423*	2.254	
9/20-9/22	2	Composite	12,749	11,134	87.3		19,702*	1.770		4,833	3,106	64.3	0.279	5,923*	1.907	
9/23-9/26			7,657	6,108	79.8		9,375*	1.535		3,118	1,870	60.0	0.306	3,994*	2.136	
9/27-9/29			6,410	4,869	76.0		7,869*	1.616		2,425	1,345	55.5	0.276	2.815*	2.093	
9/30-10/3			5,675	4,391	77.4		8,296*	1.889		2,246	1,236	55.0	0.281	2,530*	2.047	
10/4-10/6			6,762	5,224	77.3		9,124*	1.747		2,810	1,582	56.3	0.303	3,247*	2.052	

*Avg of at least duplicate determinations.

TABLE IX. CHARACTERIZATION OF FEEDLOT WASTES-SUMMARY OF PHYSICAL AND CHEMICAL DATA

Waste	Range of Values	Total Waste						Settled Supernatant						
		TS	VS		COD	COD/VS	pH	TS	VS		VS/VS Settled/total	COD	COD/VS	pH
		mg/1	mg/1	% of TS	mg/1			mg/1	mg/1	% of TS		mg/1		
	Run 1													
1	Min	2,589	1,843	67.0	3,318	1.232	6.3	893	418	45.5	0.129	1,487	1.520	6.5
	Max	11,676	9,059	86.9	47,600	11.016	7.7	5,517	3,126	66.8	0.650	3,873	2.978	8.2
	Avg	5,310	4,083	75.8	9,348	2.335	7.0	1,993	1,147	57.0	0.311	2,636	2.312	7.4
	Run 2													
	Min	2,042	1,448	70.6	2,461	1.657		1,371	840	49.6	0.369	1,534	1.569	
	Max	4,381	3,191	74.9	6,997	3.099		2,515	1,573	62.5	0.663	2,978	2.343	
	Avg	3,338	2,433	72.8	4,528	2.012		1,812	1,054	58.0	0.438	2,151	2.087	
	Run 1													
2	Min	3,730	2,337	59.4	3,875	1.036	6.1	1,429	822	47.5	0.564	1,673	1.694	6.3
	Max	10,493	8,365	81.4	18,586	3.364	7.9	3,778	3,196	66.8	0.158	4,592	2.803	8.1
	Avg	6,578	4,994	75.2	10,218	2.045	6.8	2,619	1,460	55.3	0.313	3,056	2.062	7.0
	Run 2													
	Min	2,803	1,926	66.2	3,197	1.541		1,587	857	54.0	0.320	1,366	1.026	
	Max	7,344	5,536	81.7	10,196	2.227		3,613	2,243	62.1	0.545	4,779	2.131	
	Avg	4,829	3,521	72.5	6,519	1.831		2,474	1,451	58.5	0.431	2,615	1.755	
	Run 1													
3	Min	4,311	2,924	64.8	6,072	0.625	6.0	2,426	1,301	47.8	0.104	2,750	1.763	6.3
	Max	25,536	21,144	84.2	48,800	8,505	8.2	6,145	4,042	65.8	0.376	4,648	2.132	8.7
	Avg	12,147	9,375	76.3	17,152	2,014	7.3	3,944	2,187	54.9	0.226	3,454	1.967	7.5
	Run 2													
	Min	2,655	1,824	68.7	3,945	1.449		1,611	862	53.5	0.270	1,812	1.907	
	Max	12,749	11,134	87.3	19,702	2.163		4,833	3,106	64.3	0.473	6,423	2.749	
	Avg	7,378	5,939	78.2	9,457	1.783		2,877	1,690	57.6	0.319	3,655	2.151	

Note: Values for all columns were determined indepenently from Table VIII; data obtained on August 2 represented a 3-day accumulation of waste in the pits and were not considered in preparing this table.

and noticeable at some distance away from the feeding floor. The values obtained from the samples collected on August 2 were not considered in the preparation of Table IX.

The concentrations of TS and VS determined for the wastes and supernatants (Tables VIII & IX) varied widely from day to day and with the individual wastes; however, this did not significantly affect the VS/TS ratio which remained fairly constant. Over the study period, VS averaged 75.4, 74.8, 76.6 percent of the TS for Wastes 1, 2, and 3, respectively, with an overall average of 75.6 percent. These values were lower than the 78.5 to 87.0 percent range reported in the literature (Table I, p. 9) as a result of the presence of dilution water which had a VS/TS ratio of 15 percent; had dilution water not been employed, the VS/TS ratios for the raw wastes would have been well within this range.*

The VS/TS ratios for the settled supernatants were also in good agreement and averaged 57.2, 56.1, and 55.5 percent for Wastes 1, 2, and 3, respectively, with an overall average of 56.3 percent. This ratio was influenced by the dilution water even more than the total waste. Corresponding values were not found in the literature. A comparison of the VS in the supernatant to the VS in the total waste did not produce values in close agreement. This was attributed to

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*As an example, the average VS and TS concentrations for Waste 1, Run 1, were (Table IX) 4,083 and 5,310 mg/l; the corresponding VS/TS ratio was 76.9 percent. The actual amount of animal-produced VS and TS would have been (4,083 - 60) and (5,310 - 400) mg and the corresponding ratio 81.9 percent.

the variation in settling time, the type of waste, and the method of sample collection.

Solids production on a per animal basis, a common method of expressing feedlot wastes, is presented in Table X and summarized below for each run.

Run	Waste	Contributing animals	Avg Weight* lb**	TS Avg	TS Range	VS Avg	VS Range
				lb/day/animal**			
1	1	2	206	0.62	0.35-1.12	0.48	0.24-0.92
	2	2	209	0.85	0.45-1.62	0.64	0.30-1.26
	3	6-5	166	0.77	0.32-1.21	0.60	0.24-0.96
2	1	1	185	0.76	0.64-0.92	0.56	0.48-0.67
	2	4	65	0.40	0.27-0.51	0.29	0.18-0.38
	3	1	195	1.75	1.09-2.39	1.45	0.84-2.00

*The weight of the animals was determined on August 23 (Run 1) and October 9 (Run 2).
**To convert lb to kg or lb/day/animal to kg/day/animal multiply by 0.454.

The TS and VS produced during Run 1 averaged 0.75 (0.34) and 0.58 (0.26) lb/day/animal (kg/day/animal). These values are very close to the average data obtained for Waste 3 which are statistically better averages because of the larger number of animals involved. The average weight of the 9 swine in Run 1, was 185 lb (84 kg). There were initially 6 swine contributing to Waste 3, but on August 17 an animal weighing 183 lb (83 kg) suffered an accident and had to be removed. This change was taken into account in the preparation of Table X. Solids production did not vary according to animal weight, and the per animal values did not, therefore, possess any readily apparent correlation with weight gain.

TABLE X. CHARACTERIZATION OF FEEDLOT WASTES-SOLIDS PRODUCTION PER ANIMAL

Date	Waste											
	1				2				3			
	No. of Animals	Waste Volume gpd**	Total Solids# lb/day/animal##	Volatile Solids# lb/day/animal##	No. of Animals	Waste Volume gpd**	Total Solids# lb/day/animal##	Volatile Solids# lb/day/animal##	No. of Animals	Waste Volume gpd**	Total Solids# lb/day/animal##	Volatile Solids# lb/day/animal##
7/16		32	0.56	0.43		30	0.85	0.66		37	0.44	0.33
7/18		36	0.64	0.50		36	0.84	0.68		44	0.15	0.94
7/21		25	0.89	0.74		26	0.79	0.64		48	0.78	0.62
7/22		26	0.63	0.52		25	0.80	0.62		42	1.15	0.93
7/26		25	0.66	0.55		36	0.64	0.47		42	0.85	0.68
7/27		24	0.45	0.31		25	0.45	0.30		42	0.65	0.51
7/29		24	0.83	0.70		34	0.66	0.45		37	0.32	0.24
7/30		27	1.12	0.92		27	1.16	0.89	6	38	0.62	0.48
8/4		28	0.78	0.63		37	1.62	1.26		42	0.81	0.62
8/6		23	0.72	0.58		23	0.85	0.64		38	0.72	0.51
8/7		51	0.55	0.39		39	0.94	0.74		47	0.75	0.56
8/12	2	24	0.68	0.53	2	30	1.15	0.92		41	0.68	0.52
8/13		24	0.42	0.29		30	0.70	0.50		41	1.21	0.96
8/14		23	0.65	0.49		32	0.68	0.46		41	0.77	0.57
8/17		11	0.54	0.42		28	0.66	0.47		40	0.88	0.67
8/18		27	0.53	0.40		24	0.80	0.59		39	0.74	0.55
8/19		33	0.67	0.51		27	0.71	0.52		40	0.99	0.79
8/20		50	0.72	0.54		40	0.89	0.66		38		
8/22		34	0.45	0.31		34	1.04	0.79		44	0.56	0.41
8/23		34	0.69	0.54		43	0.77	0.55	5	40	0.64	0.48
8/25		37	0.43	0.30		48	0.75	0.51		45	0.98	0.76
8/26		32	0.49	0.37		42	0.78	0.58		57	0.86	0.69
8/27		27	0.35	0.24		34	0.87	0.66		40	0.63	0.48
8/28		24	0.45	0.33		24	1.04	0.81		35	0.55	0.42
9/16-9/19*		22	0.64	0.48		39	0.27	0.18		23	2.39	2.00
9/20-9/22*	1	25	0.92	0.67	4	38	0.42	0.30	1	21	2.26	1.98
9/30-10/3*		25	0.69	0.51		35	0.38	0.28		23	1.09	0.84
10/4-10/6*		26	0.80	0.57		22	0.51	0.38		33	1.24	0.96

*Computed using TS and VS values determined on 3 or 4-day composites.

**To convert gal to l multiply by 3.785.

$$\#\frac{\text{(TS or VS) mg/l} \times 8.34\ \text{lb/gal} \times \text{(waste volume)gpd} \times 10^{-6}}{\text{No. of animals}};$$

TS and VS values from Table VIII.

##To convert to kg/day/animal multiply by 0.454.

Values determined during Run 2 were obtained from samples composited on an equal volume basis over 3 or 4-day periods. The values determined for Waste 3 reflect the inordinately high feed wastage in Pen 2. Solids production by the smaller pigs (Waste 2) was considerably less, while production by a larger animal (Waste 1) was in close agreement with values observed in Run 1.

Settleable solids (Table VIII) averaged 60, 73, and 129 ml/l for Wastes 1, 2, and 3, respectively, and were determined during Run 1 only. As much as 10 percent of the settled solids in Wastes 1 and 2 consisted of wasted corn particles. Settling was essentially complete within the first 10 min of the test for all 3 wastes, and Imhoff cone readings taken after 1 hr in many cases yielded smaller values than those observed after 10 min. This was apparently caused by the evolution of gas bubbles from the sediment which buoyed the lighter, settled particles to the surface.

The pH values for Wastes 1, 2, and 3 averaged 7.0, 6.8, and 7.3, respectively (Table IX). The settled supernatants had, with very few exceptions, higher pH values than the corresponding total wastes averaging 7.4, 7.0, and 7.5, respectively.

Data on the COD of the 3 wastes and supernatants are tabulated in Table VIII and the range of values is given in Table IX. Values determined prior to July 5 were excluded from the averages shown in Table IX because the sample dilution technique had not yet been standardized. The COD values in general fluctuated with the VS concentration, but the COD/VS ratios exhibited considerable variation. Average values of this ratio for various wastes were as follows:

Run	Waste	COD/VS Total Waste	COD/VS Settled Supernatant
1+2	1	2.008	2.148
	2	1.890	1.916
	3	1.750	2.064
	avg(1+2+3)	1.884	2.049

A relatively wide range of 1.20 to 2.59 has been reported in the literature for the COD/VS ratio, and the values determined in the present study fall within this range. Although an evaluation of the data given in the literature (Table I, p. 9) would indicate that the ratio is at least partially affected by animal weight, the data obtained in this investigation apparently do not reinforce this conclusion.

Chloride tests were made to check for potential interference in the COD determinations. The cloride content of 11 composited waste samples ranged from 27 to 106 mg/l and averaged 48 mg/l. This concentration was too low to have an effect on the COD tests in view of the significant dilution of the refluxed samples.

The BOD data are given in Table XI. Also listed in this table are the corresponding BOD/COD and BOD/VS ratios when the tests were ran on the same sample, except that the BOD/VS values shown after September 13 are based on VS concentrations determined on 3 or 4-day composites. Because the BOD/VS ratios, especially for Wastes 1 and 3, were in fair agreement, all BOD data were combined to determine the following average values.

Waste	BOD/VS	BOD/COD Measured	BOD/COD Calculated
Total Waste (1+2+3)	0.68	0.40	0.36
Settled Supernatant (1+2+3)	1.21	0.61	0.59

TABLE XI. CHARACTERIZATION OF FEEDLOT WASTES-BOD DATA

Waste	Date	Total Waste				Settled Supernatant		
		BOD_5 mg/l	$\frac{BOD}{VS}$	$\frac{BOD}{COD}$	$\frac{\text{lb BOD}}{\text{day/animal}}$*	BOD_5 mg/l	$\frac{BOD}{VS}$	$\frac{BOD}{COD}$
1	8/4	2,300	0.43	0.25	0.27	2,100	1.18	0.66
	8/12					2,000	1.45	
	8/13					1,650	1.83	
	8/18	3,400	0.95		0.38	1,160	1.16	
	8/20					1,000	0.94	
	9/13-9/15	1,000	0.45	0.23		700	0.68	0.33
	9/16-9/19	1,400	0.53	0.32	0.26			
	9/28	1,750	0.73	0.40				
	10/1	1,800	0.72	0.38		1,350	1.34	0.83
	10/6	1,450	0.56	0.34	0.31			
2	8/12					2,000	1.71	
	8/13					2,100	1.81	
	8/20					2,000	1.26	
	9/28	5,000	1.33	0.67				
3	8/13					4,100	1.02	
	8/20					4,400	1.20	
	9/16-9/19	4,100	0.39	0.27	0.79			
	9/28	3,700	0.76	0.47				
	10/1	3,300	0.75	0.41	0.64			
	10/6	2,400	0.46	0.26	0.66			

*To convert to kg BOD/day/animal multiply by 0.454.

The calculated BOD/COD ratios were obtained by dividing the average BOD/VS values by 1.884 and 2.049 which were the average COD/VS values for the total waste and settled supernatant. These BOD relationships were all higher than those reported in the literature (Table I, p. 9). When the BOD data for Waste 1 were expressed on a per animal basis, however, they were found to be in close agreement with the values presented in the literature, with the average value being 0.32 lb/day/animal (0.145 kg/day/animal). The high values for Waste 3 were discounted because of the excess wastage of animal feed during Run 2, and more extensive evaluation was prevented because of difficulties with the BOD test, including insufficient dilution and variable strength seed material which resulted in many test results being discarded.

3. Nutrient Content

The results of NH_3- and Total-N determinations are presented in Table XII, together with the corresponding N/TS and N/COD ratios, and values are given for both the total wastes and settled supernatants. Comparable Total-P data are tabulated in Table XIII and are for total wastes only. The main interest in nutrients was their availability for microbial utilization in the lagoon system. Based on average characteristics determined using all values obtained for the 3 wastes, the BOD_5: NH_3-N: Total-P (BOD:N:P) relationship was established as follows:

a. TS and VS Basis

Using average:

$$\frac{VS}{TS} = 0.756 \quad \frac{BOD}{VS} = 0.68 \quad \frac{COD}{VS} = 1.884 \quad \frac{NH_3\text{-}N}{TS} = 0.041 \quad \frac{P}{TS} = 0.0096$$

TABLE XII. CHARACTERIZATION OF FEEDLOT WASTES-NITROGEN DATA

Waste	Date	Total Waste							Settled Supernatant		
		NH_3-N			Total-N				NH_3-N	Total-N	
		mg/l	N/TS	N/COD	mg/l	N/TS	N/COD	lb/day/animal**	mg/l	mg/l	N/COD
	7/26	412	0.065		545	0.086		0.057			
	7/30	213	0.021	0.016							
	8/2	476	0.027						459		
	8/6	381	0.050	0.038							
	8/10	179	0.069		213	0.082					
	9/22 *								361	647	0.217
1	9/25 *								146		
	9/26 *								104		
	9/27-9/29*	118	0.036	0.027							
	10/1 *	134	0.039	0.028					174	325	0.199
	10/3 *	118	0.034	0.024							
	10/4 *	129	0.035	0.030							
	10/6 *	73	0.020	0.017	437	0.119	0.102	0.095			
	10/7 *	90	0.025								
	7/26	257	0.060		976	0.229		0.147			
	7/30	400	0.039	0.028							
	8/2	588	0.030						560		
	8/6	496	0.056	0.033							
	8/10	179	0.031		314	0.054					
	9/22 *								599	918	0.302
2	9/25 *								339		
	9/26 *								260		
	9/27-9/29*	267	0.051	0.036							
	10/1 *	241	0.047	0.032					246	537	0.354
	10/3 *	286	0.055	0.038							
	10/4 *	325	0.044	0.035	919	0.125	0.100	0.042			
	10/6 *	381	0.056	0.041							
	10/7 *	358	0.053								
	7/26	602	0.041		1,277	0.088		0.075			
	8/2	1,221	0.030						1,388		
	8/6	683	0.050	0.047							
	8/10	538	0.047		952	0.083					
	9/22 *								389	935	0.158
3	9/25 *								148		
	9/26 *								179		
	9/27-9/29*	210	0.034	0.027							
	10/1 *	207	0.037	0.025					174	588	0.232
	10/3 *	313	0.055	0.038							
	10/4 *	196	0.029	0.021	918	0.136	0.101	0.253			
	10/6 *	168	0.025	0.018							
	10/7 *	162	0.024								

*N/TS and N/COD ratios based on TS and COD values determined on 3 or 4-day composites.

**Waste volumes required in calculations are from Table X; to convert to kg/day/animal multiply by 0.454.

TABLE XIII. CHARACTERIZATION OF FEEDLOT WASTES-
TOTAL PHOSPHORUS DATA

Waste	Date	Total-P mg/l	$\frac{P}{TS}$ *	$\frac{P}{COD}$ *	$\frac{\text{lb P}}{\text{day/animal}}$ **
1	9/30	33			0.00578
	10/1	34			0.00709
	10/2	36	0.0102	0.0072	0.00780
	10/3	36			0.00780
	10/4	30			0.00675
	10/5	37			0.00802
	10/6	33	0.0091	0.0077	0.00715
	Avg	34.1	0.0097	0.0075	0.00720
2	9/30	64			0.00480
	10/1	66			0.00454
	10/2	67			0.00475
	10/3	44	0.0116	0.0080	0.00348
	10/4	68			0.00425
	10/5	68			0.00581
	10/6	100	0.0075	0.0085	0.00604
	Avg	68.1	0.0095	0.0083	0.00481
3	9/30	66			0.01431
	10/1	54			0.00900
	10/2	80			0.01534
	10/3	70	0.0119	0.0081	0.01342
	10/4	76			0.01457
	10/5	80			0.01467
	10/6	68	0.0110	0.0082	0.01332
	Avg	70.6	0.0115	0.0082	0.01332

*P/TS and P/COD ratios based on TS and COD values determined on 3 or 4-day composites.

**Waste volumes required in calculation from Table X; to convert to kg P/day/animal multiply by 0.454.

the following relationships can be computed:

BOD:N:P = 100:7.96:1.86 and COD:N:P = 100:2.88:0.67

b. COD Basis

Using average (measured):

$$\frac{BOD}{COD} = 0.40 \qquad \frac{NH_3\text{-}N}{COD} = 0.030 \qquad \frac{P}{COD} = 0.0079$$

the following relationships can be computed:

BOD:N:P = 100:7.5:1.98 and COD:N:P = 100:3.00:0.79

The BOD:N:P ratios computed by either approach were in close agreement and well exceeded the recommended 100:5:1 relationship which is considered desirable for aerobic waste assimilation (35, p. 65).

According to Loehr (5, p. 194), variations in the nitrogen content of wastes produced by animals fed equivalent protein feeds would be the result of differences in animal feed conversion, wastage, and the amount of concentrates in the feed. Since the nitrogen values obtained in this study did not follow the pattern suggested by Loehr with respect to feed additives,* differences in the nitrogen content of the 3 wastes were attributed to animal characteristics and feed wastage, and all corresponding values were employed in determining the average NH_3- and Total-N concentrations.

The amount of Total-P released per animal was not the same for the 3 wastes. The difference in the amounts released by Waste 1 [0.00720 lb/day/animal (0.00327 kg/day/animal) avg] and Waste 2

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*The amount of feed additives increased from Feed 1 to Feed 3, yet the average NH_3-N/TS for Wastes 1, 2, and 3 were 0.038, 0.047, and 0.037 mg/l, respectively, and the average Total-N/TS were 0.096, 0.136, and 0.102 mg/l.

[0.00481 lb/day/animal (0.00218 kg/day/animal) avg] was attribtued to the size of the animals; Waste 1 was produced by 1 animal weighing 185 lb (84.0 kg) and Waste 2 was produced by 4 animals weighing an average of 65 lb (29.5 kg). This is further verified by the corresponding average P/TS values of 0.0097 and 0.0095, and the almost equal value of 0.0115 for Waste 3. The high per animal Total-P production observed in Waste 3 probably resulted from the excessive animal feed wastage in the corresponding pen.

4. Other Characteristics

During the waste characterization study the presence of a significant amount of grease was observed. In order to make a quantitative estimate of the grease content of the waste, 9 samples were analyzed and the following results were obtained.

	Grease, % of TS		
Date	Waste 1	Waste 2	Waste 3
10/1	3.44	2.33	7.83
10/2	1.66	3.68	
10/3	6.37	4.44	5.15
10/4	9.36		
Avg	5.21	3.48	6.49

The average of all 9 tests equaled 4.92 percent. On this basis 1 ton (907 kg) of waste solids would produce 98 lb (45 kg) of grease material.

The small number of values obtained for Wastes 2 and 3 resulted from experimental difficulties in the conduct of the test, namely the fact that several flasks supposedly containing the extracted grease material were found to weigh less than the tare. A reason for this difficulty was not established.

Although plate counts were not run as part of the study, a simple comparison was made which demonstrated the effect feed additives might produce on a biological system. A 2-l sample of each of the wastes was set aside in the laboratory for a period of over 3 months. Within 2 days, Waste 1 appeared to have turned anaerobic and was black in color. It was approximately 3 wk before Waste 2 became similar in appearance, while Waste 3 never lost the look of a fresh waste. The odor of Waste 3 also remained unchanged, while the odor of the other 2 wastes resembled that of the field anaerobic lagoon.

An effort was made to determine the heavy metal content of Wastes 2 and 3 using an atomic absorption spectrophotometer.* Unfortunately, too many interfering components were present to allow successful measurement, although the samples had been clarified by filtration through a 0.45-μ membrane filter at a rate of 25 ml/hr prior to metal analysis. A substance, tentatively identified as carbon, was present in such quantities as to clog the injector needle of the atomic absorption unit.

B. WASTE TREATMENT

The system proposed and evaluated in this study for treating swine feedlot waste consisted of an anaerobic lagoon, a dual anaerobic-aerobic lagoon, and an aerobic lagoon. The method of operation

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*Model 303, a product of the Perkin-Elmer Corporation, Norwalk, Connecticut; this instrument was available in the Geochemistry Laboratory of the Department of Geology and Geophysics, University of Missouri-Rolla.

initially proposed called for the total waste to be fed in sequence through the 3 lagoons; however, on the basis of the experience gained during the course of the study, the sequence of operation was altered as shown in Figure 4 and Table VI (p. 47). Waste 1 was used exclusively, and the lagoons were fed daily on a volume basis to simulate the anticipated mode of operation in an actual feedlot.

1. Run 1

During this run the anaerobic and dual lagoons were operated in series, and the aerobic lagoon was not used because it had not yet been completely waterproofed. The study began on June 28 (Day 0) when the anaerobic lagoon was seeded with digested sludge from a local waste treatment plant. The operating conditions and performance of the anaerobic lagoon are shown in Table XIV and Figure 5. The lagoon was initially operated with a volume of 8.0 cu ft (0.22 cu m) and until Day 13 was fed 9 l of total waste. The average VS loading during this period was 0.01 lb/day/cu ft (0.16 kg/day/cu m). Odor production was slight although evolution of gas bubbles indicated that gas was being produced. The effluent was clear and inoffensive, and had a low VS and COD concentration. The reason for the high COD value on Day 11 cannot be fully explained, however, it is possible that a disproportionately high amount of the floating surface material was present in the sample.

In order to shorten the detention time and increase the loading, the volume fed to the lagoon was increased gradually from 9 to 20 l (Days 13 to 18), and on Day 22 the volume of the lagoon was reduced

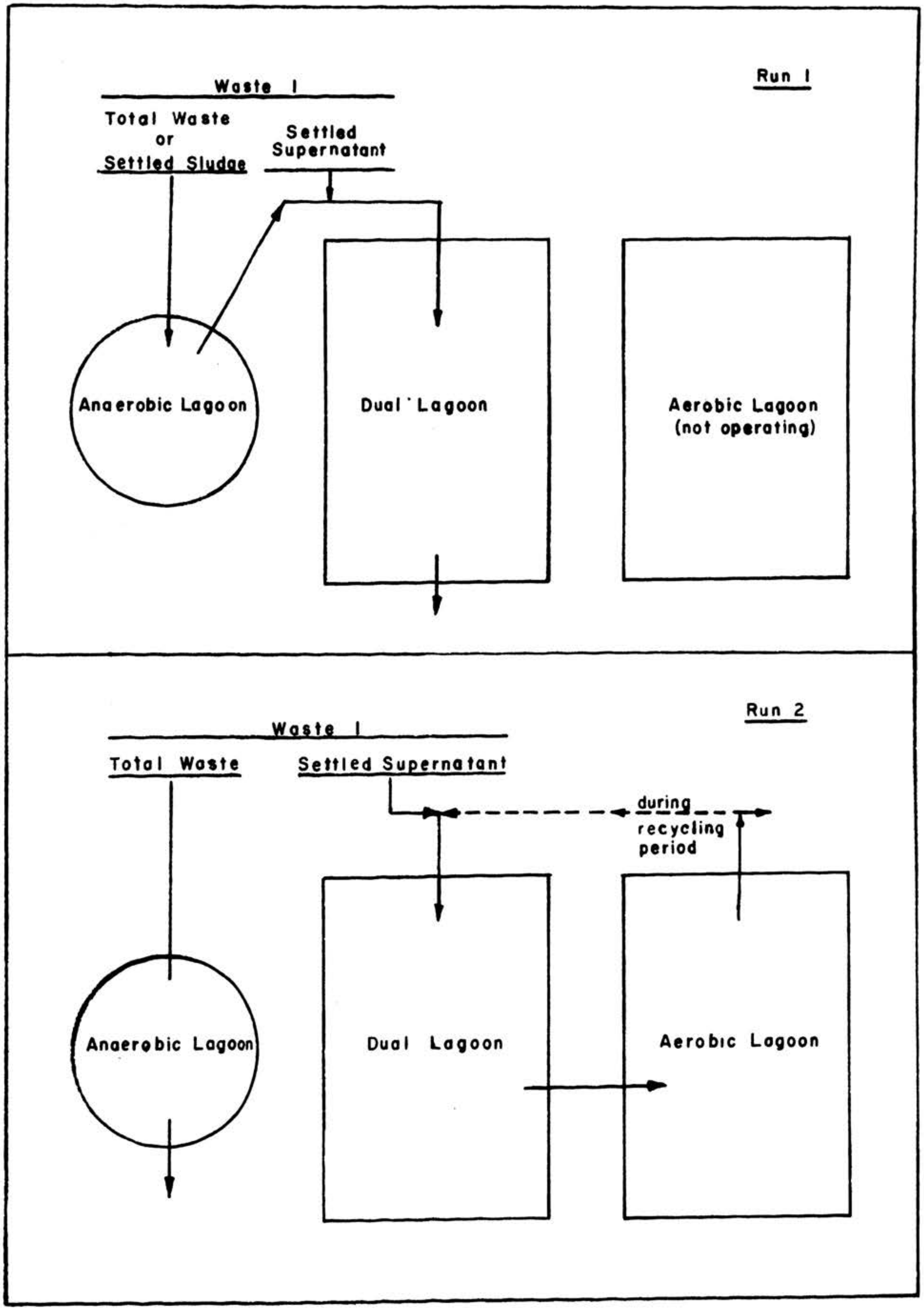


FIGURE 4. LAGOON FEEDING SCHEDULE

TABLE XIV. ANAEROBIC LAGOON OPERATION AND PERFORMANCE-RUN 1

Date	Time in Operation	Volume Loading	Detention Time	Organic Loading VS	Organic Loading COD	Lagoon pH	Influent VS	Influent COD	Effluent VS	Effluent COD	Removal VS	Removal COD
	days	1	days	lb/day/cu ft**			mg/1				%	
7/1	3			0.0087			3,512					
7/2	4			0.0153		7.2	6,185					
7/3	5			0.0110		7.5	4,457					
7/4	6			0.0126		7.6	5,085					
7/5	7	9	25.2	0.0104		7.5	4,189					
7/6	8			0.0130			5,242					
7/7	9			0.0107	0.0210		4,321	8,467	369	288	91.5	96.6
7/9	11			0.0064	0.0138	7.0	2,596	5,588	250	5,039	90.3	9.8
7/11	13			0.0068	0.0176	7.0	2,758	7,112	465	325	83.1	95.3
7/12	14	12	18.9	0.0121	0.0202	7.0	3.669	6,104	235	245	93.6	95.5
7/13	15			0.0094	0.0185	7.1	2,855	5,600	319	312	88.1	94.5
7/16	18	15	15.1	0.0131	0.0261	7.1	3.187	6,324		259		95.9
7/18	20		11.3	0.0203	0.0426	7.0	3,685	7,742	328	310	91.1	96.0
7/19	21*				0.1036	7.1		18,816	393	380		98.0
7/21	23			0.1419	0.2217	6.9	17,722	27,676	542	702	96.9	97.5
7/22	24			0.0799			9,974		785		92.1	
7/26	28								3,281			
7/27	29			0.0896	0.2124		11,181	26,516	3,174		72.2	
7/29	31	20		0.1134		6.0	14,164		3,038		78.6	
7/30	32		7.8	0.1341	0.1711	5.9	16,743	21,364	1,727		89.8	
8/2	35					6.1			1,606			
8/4	37			0.0430	0.0743	6.0	5,368	9,276	1,791		66.6	
8/5	38			0.0283		6.0	3,539		1,939		45.2	
8/6	39			0.0498		6.1	6,223		2,358		62.1	
8/7	40			0.0606	0.0800		7,565	9,985	1,783		73.2	
8/9	42			0.0211			5,267		8,105			
8/10	43	10	15.6	0.0074		6.1	1,843		1,754		4.8	
8/11	44			0.0080		5.9	2,003		6,730			
8/12	45	Reseeded with sludge from dual lagoon trench										
8/13	46			0.0116		6.1	2,895		1,679		42.0	
8/14	47			0.0203		6.0	5,075		1,687		66.8	
8/17	50			0.0363			9,059		1,701		81.2	
8/18	51			0.0143			3,576		2,213		38.1	
8/19	52			0.0149		5.4	3,720		1,868		49.8	
8/20	53			0.0104		5.7	2,603		2,316		11.0	
8/21	54			0.0105			2,617		3,309			
8/22	55	10	15.6	0.0089		5.7	2,221		2,474			
8/23	56			0.0154		5.6	3,833		2,465		35.7	
8/24	57			0.0087			2,164		2,913			
8/25	58			0.0078		5.7	1.953		2.583			
8/26	59			0.0112		6.3	2,786		2,397		14.0	
8/27	60			0.0086		6.2	2,135		2,319			
8/28	61			0.0132		6.3	3,305		2,246		32.0	
8/30	63			0.0189			4,717		2,271		51.9	

*Lagoon volume reduced to 5.5 cu ft from 8.0 cu ft on day 22.

**To convert kg/day/cu ft multiply by 0.454.

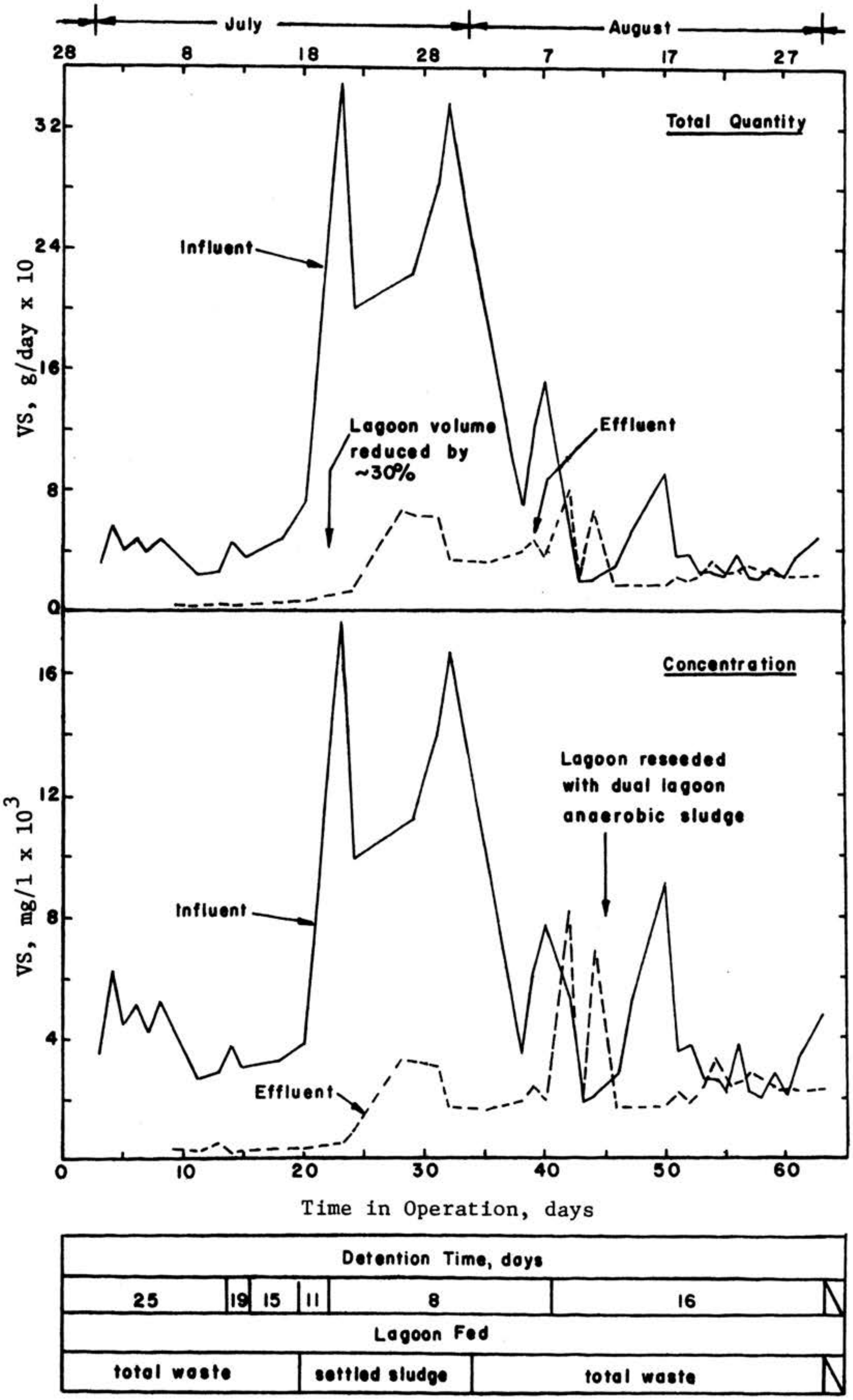


FIGURE 5. ANAEROBIC LAGOON PERFORMANCE (VS DATA)-RUN 1

by 31 percent to 5.5 cu ft (0.15 cu m) to allow for gas storage. In addition, the feed was changed to settled waste sludge (Day 20) in an effort to increase the VS content. These measures did provide a stronger organic influent and decreased the detention time to 7.8 days, but at the same time resulted in a series of shock loadings. Use of settled sludge magnified the variations due to small animal numbers, defecation, and feed wastage. As a result, the loading rate from Day 20 to 34 fluctuated from 0.02 to 0.13 lb VS/day/cu ft (0.32 to 2.08 kg VS/day/cu m), although the volume loading remained constant at 20 l.

Volatile solids and pH were the only control parameters employed, and consequently the shock loadings were not immediately discernable. The pH dropped and excessive odor production followed. The odor was so offensive as to force the tenants of a nearby house to leave whenever the lagoon was uncovered. It was obviously due in part to the layer of greasy scum that developed during the high loading period.

When it became obvious from the odor and declining pH that the system was failing, the waste fed to the lagoon was changed back to the total waste (Day 34) and the volume was reduced to 10 l (Day 42). In a further attempt to revive the bacterial population, 50 percent of the lagoon contents were replaced with material from the anaerobic trench of the dual lagoon (Day 45), and commercial lime was added in increasing amounts to raise the pH. From Day 43 to 63 the lagoon was fed at an average loading rate of 0.013 lb VS/day/cu ft (0.214 kg VS/day/cu m). These measures failed to improve the performance of the lagoon. The effluent VS concentration attained a relatively steadystate which had the appearance of VS reduction whenever the influent concentration was high, but also indicated negative treatment when the influent concentration was low (Figure 5). The lagoon acted merely as an equalization basin from which odorous gases evolved and prevented solids from settling out. Since none of the remedial measures succeeded in restoring the required biological balance, two-thirds of the lagoon content were removed and replaced with digested sludge from the Rolla plant.

The dual lagoon was operated concurrently with the anaerobic lagoon and was initially fed a combination of the anaerobic lagoon effluent and the settled waste supernatant. The operating conditions and performance characteristics of the dual lagoon during Run 1 are presented in Tables XV and XVI and Figure 6. Until Day 13 the lagoon was fed a total volume of 20 l; thereafter the feed was gradually increased in order to shorten detention time and increase organic loading. As can be seen in Figure 6, beginning with Day 21 the influent VS concentration, as well as total quantity fed to the lagoon, increased rapidly. As a result of the increased loading, the appearance of the dual lagoon changed from a rich green water body having the characteristics of a functioning aerobic system to a lagoon on the verge of failure with floating scum and algal mats. Any slight agitation brought black colored water and gummy material resembling anaerobic sludge back to the surface, which had to be cleared regularly of algal mats that incorporated gas bubbles and undigested organic material. During this period, the 15-cu ft (0.42-cu m) anaerobic trench was receiving an average loading of 0.0091 lb VS/day/cu ft

TABLE XV. DUAL LAGOON OPERATION-RUN 1

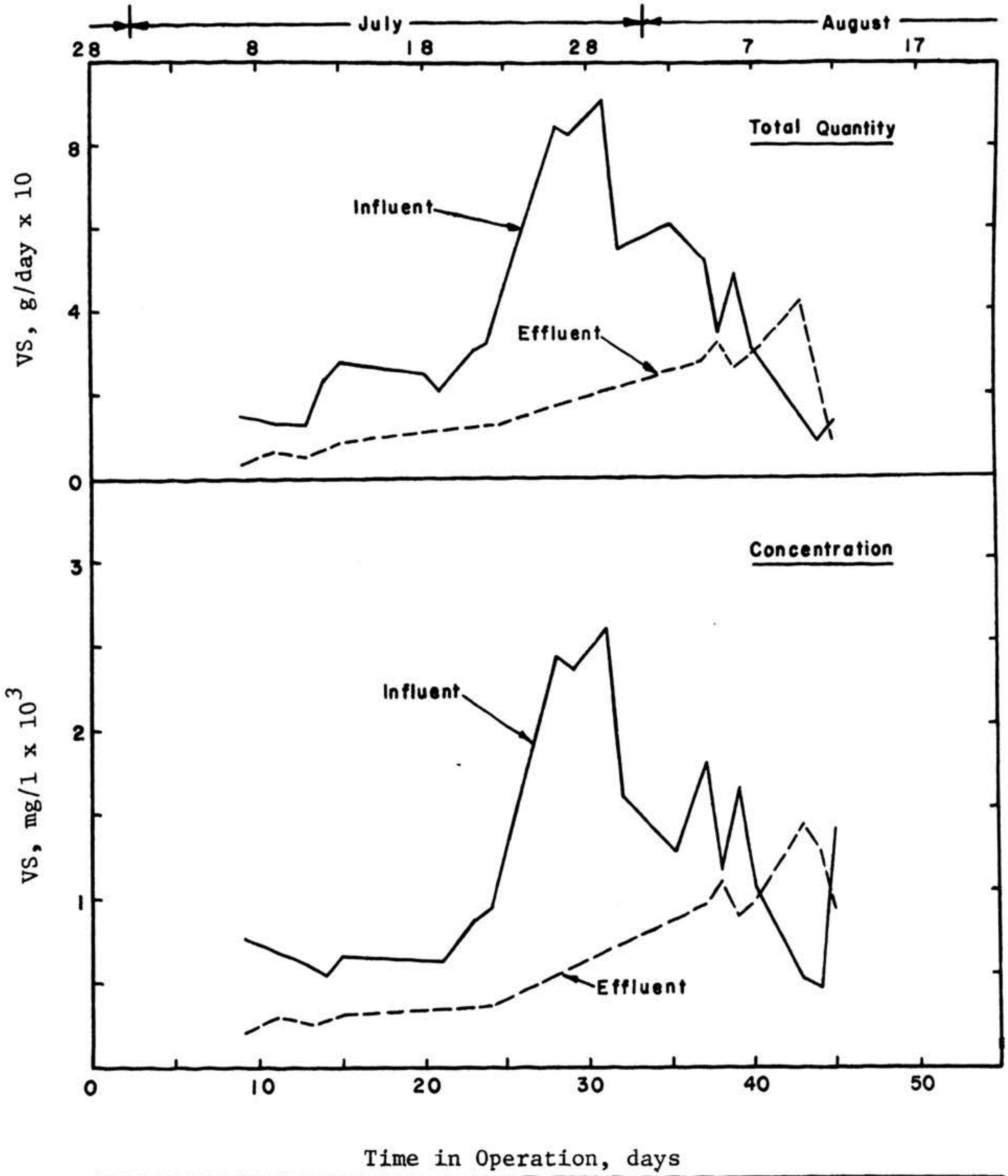
Date	Time in Operation	Volume Loading: Settled Supernatant Waste 1	Volume Loading: Anaerobic Lagoon Effluent	Detention Time	Organic Loading: VS lb/day / cu ft *	Organic Loading: COD lb/day / acre #
	days	l		days		
7/7	9				0.0022	260
7/9	11	11	9	42.5	0.0019	561
7/11	13				0.0017	156
7/12	14		12	38.6	0.0019	201
7/13	15	15		31.4	0.0026	290
7/16	18	20	15	24.3		242
7/18	20			21.2	0.0036	304
7/19	21	14		25.0	0.0031	251
7/21	23				0.0044	355
7/22	24				0.0047	
7/26	28		20		0.0124	
7/27	29	15		24.3	0.0120	
7/29	31				0.0133	
7/30	32				0.0081	
8/2	35				0.0090	
8/4	37				0.0079	688
8/5	38				0.0050	
8/6	39	30	Feeding	28.3	0.0072	
8/7	40		Discon-		0.0046	
8/9	42		tinued		0.0030	
8/10	43				0.0021	
8/11	44	20		42.5	0.0012	
8/12	45	10		85.0	0.0020	

*Applied to the anaerobic trench which constituted 50% of the lagoon volume; to convert to kg/day/cu m multiply by 16.

#Applied to the aerobic section which occupied 100% of the surface area; to convert to g/day/sq m multiply by 0.112.

TABLE XVI. DUAL LAGOON PERFORMANCE-RUN 1

Date	Time in Oper-ation	Lagoon pH	Settled Super-natant Waste 1			Anaerobic Lagoon Effluent			Anaerobic Effluent + Supernatant			Dual Lagoon Effluent			Removal		
			COD	TS	VS	COD	TS	VS	COD	TS	VS	COD	TS	VS	COD	TS	VS
	days		mg/1												%		
7/7	9	8.5	3,052	2,014	1,075	288	726	369	1,808	1,434	757	115	655	194	93.6	54.3	74.4
7/9	11	7.6	2,966	1,860	996	5,039	702	250	3,899	1,339	660		689	282		48.5	57.3
7/11	13	7.6	1,707	1,364	698	325	700	465	1,085	1,065	593	216	633	238	80.1	40.6	59.9
7/12	14	7.8	2,275	1,838	891	245	635	235	1,216	1,215	549	244			80.0		
7/13	15	7.8	2,436	1,742	935	312	640	319	1,492	1,252	661	160	569	291	89.2	54.6	56.0
7/16	18	8.0	1,487	1,777	978	259			960			131			86.4		
7/18	20		1,803	1,625	904	310	768	328	1,057	1,197	616						
7/19	21		1,947	1,707	960	380	923	393	1,025	1,246	626						
7/21	23	7.5	2,354	2,055	1,276	702	1,114	542	1,410	1,517	857		732	331		51.7	61.4
7/22	24			1,870	1,095		1,436	785		1,622	918		781	348		51.8	62.1
7/26	28			2,152	1,251		4,989	3,281		3,773	2,411						
7/27	29		2,063	2,121	1,230		4,711	3,174		3,601	2,340						
7/29	31		3,873	2,996	2,000		4,770	3,038		4,010	2,593						
7/30	32		2,195	2,262	1,365		3,101	1,727		2,741	1,572						
8/2	35	7.2		3,451	1,942		2,948	1,606		3,164	1,750						
8/4	37	7.5	3,187	2,781	1,782								1,724	937		38.0	47.4
8/5	38	7.7		1,974	1,130								1,729	1,057		12.4	6.5
8/6	39	7.2		2,854	1,636								1,686	860		40.9	47.4
8/7	40			1,883	1,040								1,653	953		12.2	8.4
8/9	42			1,172	678	Feeding Discontinued			N/A								
												Lagoon lost all green color					
8/10	43	7.2		893	478								2,260	1,404			
8/11	44	7.3		919	418								2,204	1,251			
8/12	45	6.0		2,181	1,374								1,570	888		28.0	35.4



Detention Time, days					
43	39 → 25	24	28	43	85

Lagoon Fed		
settled supernatant + anaerobic effluent	settled super.	

FIGURE 6. DUAL LAGOON PERFORMANCE (VS DATA)-RUN 1

(0.0041 kg VS/day/cu ft) which was comparable to that applied to the anaerobic lagoon during the early period of operation. On Day 37, the use of the anaerobic lagoon effluent as part of the dual lagoon influent was discontinued due to its low pH and high organic content, and the volume of settled supernatant was increased to 30 l. This measure was taken in an effort to revive the failing system, but the aerobic portion of the dual lagoon was in such a condition that a heavy rain on the night of Day 42 resulted in the apparent precipitation of all the algae. Thereafter, although the effluent COD and VS concentration decreased, the lagoon was black in color and produced numerous gas bubbles and slight odor.

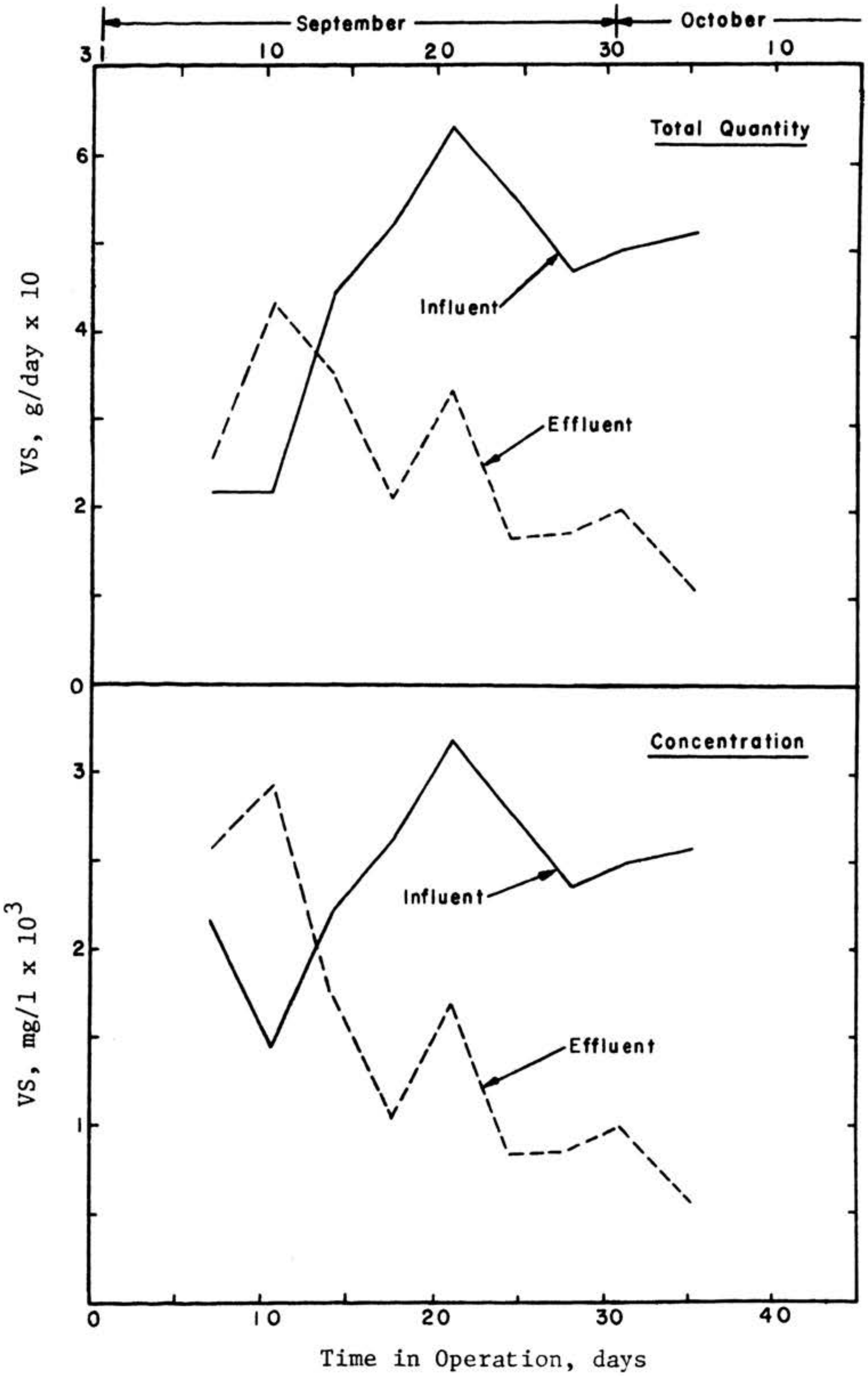
2. Run 2

On August 31, two-thirds of the anaerobic lagoon liquid volume was replaced with digested sludge and this marked the beginning of Run 2 (Day 0). The operating and performance characterisitics of the lagoon during this run are given in Table XVII, and the VS and COD data are plotted in Figures 7 and 8. In view of past experience, volatile acids were used as an indicator of the condition of the lagoon. The total waste volume fed to the lagoon was progressively increased until it reached 20 l (Day 13) and was then kept constant; this resulted in a detention time of 7.8 days and an average loading of 0.021 lb VS/day/cu ft (0.336 kg VS/day/cu m) throughout the remainder of the run. No attempt was made to further increase the loading rate, both because the 7.8-day detention time was considered to be relatively low for anaerobic microorganisms, and because previous experience using the high-concentration settled sludge had not proved successful.

TABLE XVII. ANAEROBIC LAGOON OPERATION AND PERFORMANCE-RUN 2

Date	Time in Operation	Volume Loading	Detention Time	Organic Loading		Volatile Acids (as CH_3COOH)	Influent			Effluent			Removal		
				VS	COD		TS	VS	COD	TS	VS	COD	TS	VS	COD
	days	1	days	lb/day/cu ft*		mg/l							%		
8/31	0	0	N/A	N/A		1,792	Lagoon reseeded with digested sludge								
9/6-9/8	6-8	10	15.6	0.0087	0.0145	868	2,900	2,172	3,632	4,088	2,564	4,228			
9/9-9/12	9-12	15	10.4	0.0087	0.0148		2,042	1,448	2,461	3,311	2,916	3,532			
9/13-9/15	13-15			0.0178	0.0348	96	3,033	2,219	4,336	3,063	1,762	2,734		20.6	36.9
9/16-9/19	16-19			0.0210	0.0341		3,540	2,625	4,257	1,979	1,058	1,543	44.1	59.7	63.8
9/20-9/22	20-22			0.0256	0.0561	240	4,381	3,191	6,997	2,901	1,687	2,311	33.8	47.1	67.0
9/23-9/26	23-26	20	7.8	0.0224	0.0442	360	3,792	2,796	5,518	1,847	842	1,276	51.3	69.9	76.9
9/27-9/29	27-29			0.0189	0.0353		3,270	2,359	4,406	1,784	870	1,106	45.4	63.1	74.9
9/30-10/3	30-33			0.0200	0.0388		3,409	2,495	4,843	2,014	998	1,280	40.9	60.0	73.6
10/4-10/6	34-36			0.0208	0.0345	336	3,677	2,597	4,303	1,492	589	398	59.5	68.8	90.8

*To convert to kg/day/cu m multiply by 16.



Organic Loading, lb VS/day/1,000 cu ft*									
	9	18	21	26	22	19	20	21	

*To convert to kg/day/1,000 cu m multiply by 16.

FIGURE 7. ANAEROBIC LAGOON PERFORMANCE (VS DATA)-RUN 2

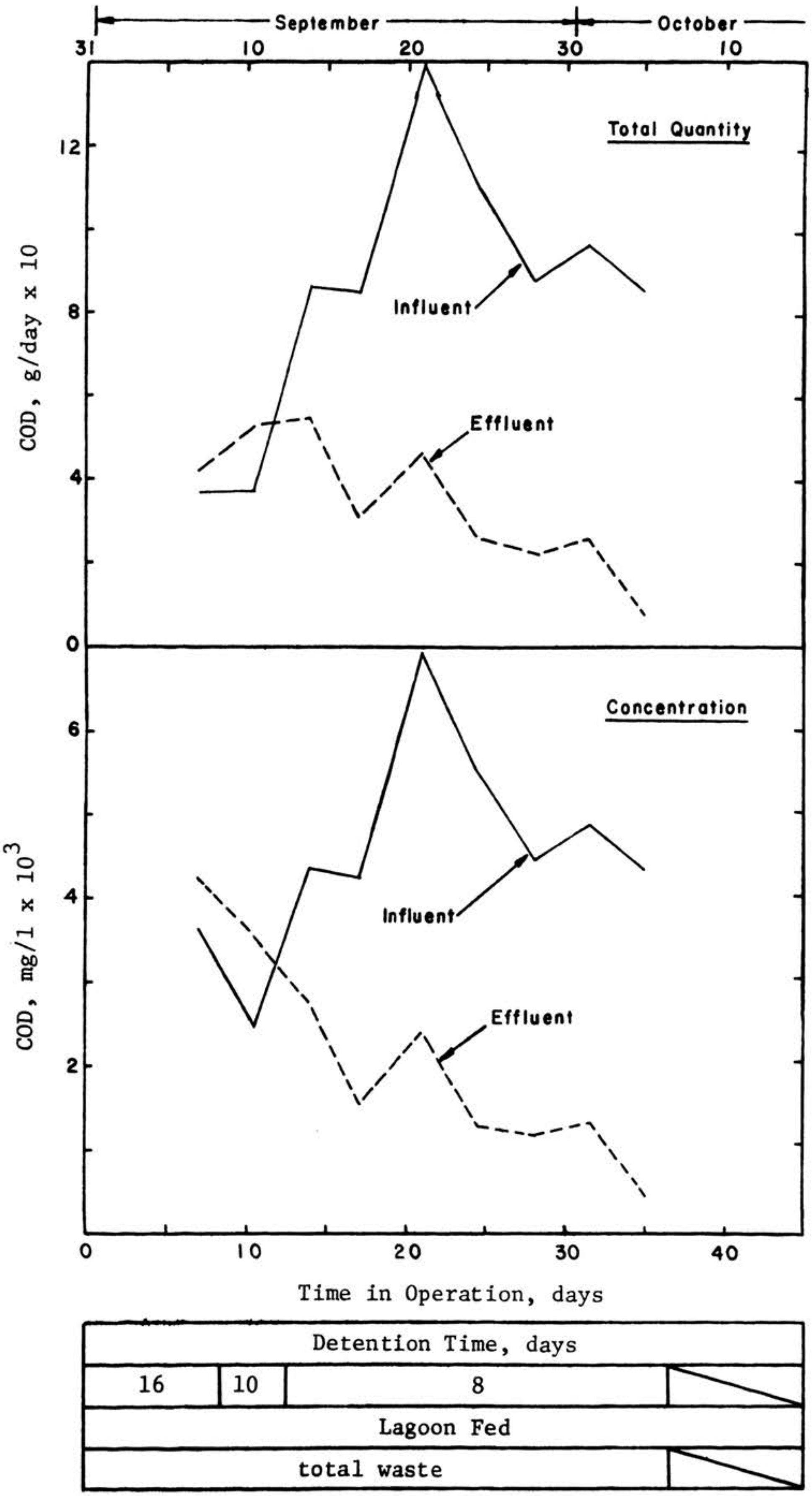


FIGURE 8. ANAEROBIC LAGOON PERFORMANCE (COD DATA)-RUN 2

Initially, the concentration of effluent VS and COD was high (Figures 7 & 8), and this was thought to be a condition carried over from Run 1 because of the residual sludge left in the lagoon during reseeding. The VS and COD concentrations began to rapidly decline after Day 10 and had not reached equilibrium at the end of the run (Day 36). Even though the percent reductions were not equal to those experienced at a lower loading rate during Run 1, the efficiency of the system continued to improve as it approached equilibrium.

At the completion of the run, the lagoon was emptied and the sludge analyzed. It was about 1-ft (0.30-m) in depth and comprised about one-third of the total lagoon volume. This meant that the actual liquid detention had decreased to approximately 50 percent of the theoretical, or to 3.9 days, as the sludge was built up. The sludge had an average solids content of 9.1 percent, 50.2 percent of which was volatile, and a COD concentration of 63,988 mg/l.

The dual lagoon was reseeded on August 12 (Day 0) with previously acclimated wastewater from the aerobic lagoon. The effluent from the dual lagoon was not introduced into the aerobic lagoon until Day 7, when it appeared that the dual lagoon was going to regain its aerobic character. The operating conditions of the 2 lagoons are tabulated in Table XVIII, and performance characteristics are shown in Table XIX and Figures 9 and 10.

Following Day 7, 20 l of settled supernatant was put through the 2-lagoon system without any recycling. During the week of August 29 (Day 17) swine from the initial group of animals that had reached market weight were removed from the floor and replaced with the second

TABLE XVIII. DUAL AND AEROBIC LAGOON OPERATION-RUN 2

Date	Time in Oper-ation	Volume Loading				Detention Time (raw waste basis)			Organic Loading		
		Dual Lagoon			Aerobic Lagoon*	Dual Lagoon	Aerobic Lagoon	Total	Dual Lagoon		Aerobic Lagoon
		Settled Supernat. Waste 1	Recycled Aerobic Effluent	Recycle Ratio					VS	COD	
									lb/day** / cu ft	lb/day# / acre	
	days	1			1	days					
8/12	0	Dual lagoon reseeded with treated wastewater from aerobic lagoon previously acclimated to settled supernatant Waste 1; dual lagoon did not lose black color until Day 5.									
8/13	1	10				84.9			0.0013		
8/14	2								0.0021		
8/17	5	8			0	106.2	N/A	N/A	0.0106		
8/18	6	10				84.9			0.0015		
8/19	7								0.0016		
8/20	8								0.0031		
8/21	9								0.0018		
8/22	10		0	N/A					0.0029		
8/23	11								0.0037		
8/24	12				20				0.0020		
8/25	13								0.0034		
8/26	14	20				42.5	42.5	85.0	0.0039		
8/27	15								0.0041		
8/30	18								0.0092		
9/6-9/8	25-27								0.0025	283	145
9/9-9/12	28-31			4	100				0.0025	267	142
9/13-9/15	32-34								0.0030	305	121
9/16-9/19	35-38								0.0034	318	148
9/20-9/22	39-41	30	80	2.67	110	28.3	28.3	56.6	0.0069	643	147
9/23-9/26	42-45								0.0068	781	191
9/27-9/29	46-48	40		2	120	21.2	21.2	42.4	0.0051	675	260
9/30-10/3	49-52								0.0059	470	273
10/4-10/6	53-55								0.0058	440	231

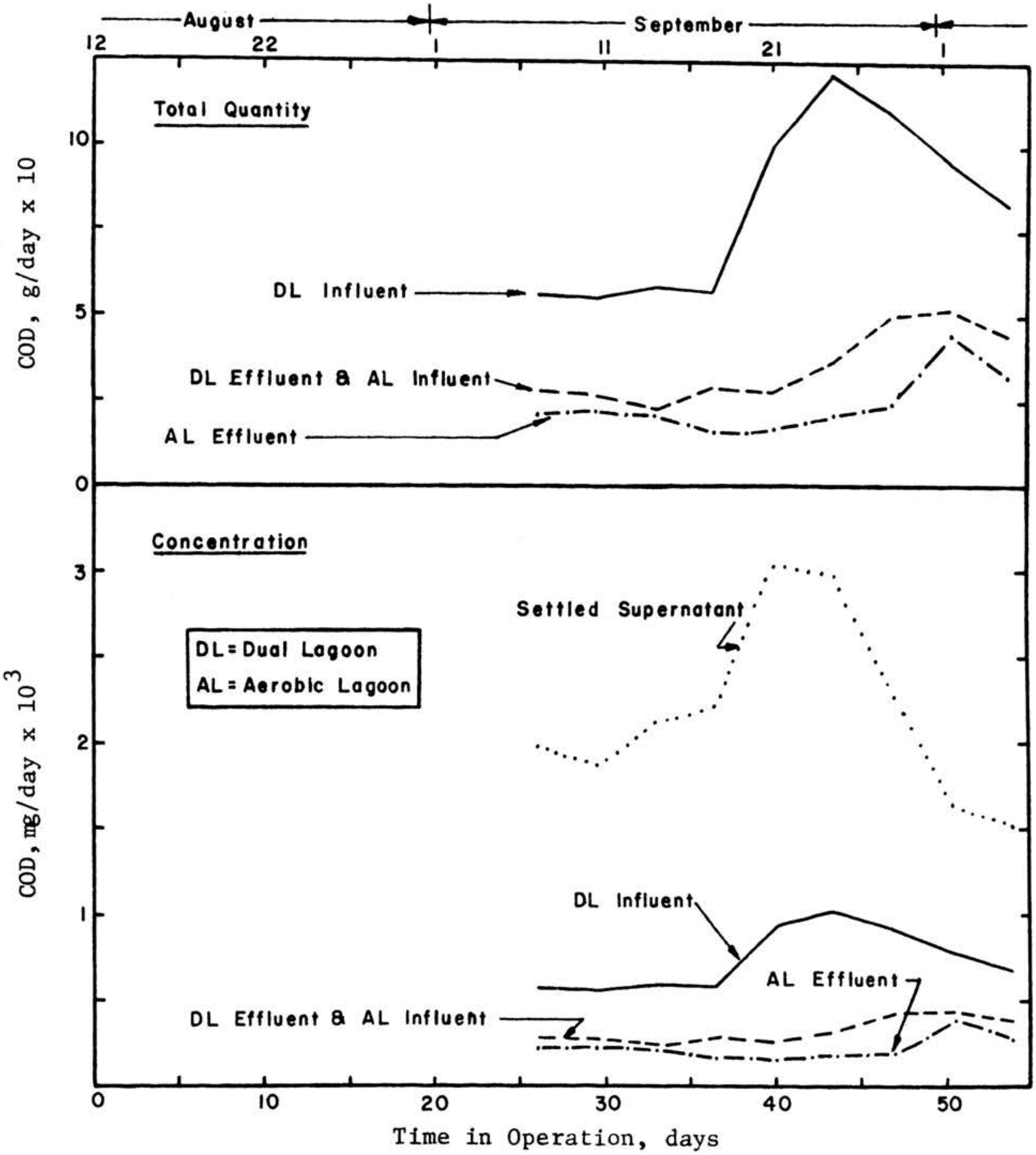
*The aerobic lagoon influent consisted of the dual lagoon effluent.

**Applied to the anaerobic trench which constituted 50% of the lagoon volume; to convert to kg/day/cu m multiply by 16.

#Applied to the aerobic section of the dual lagoon or the aerobic lagoon (both of equal surface area and volume); to convert to g/day/sq m multiply by 0.112.

TABLE XIX. DUAL AND AEROBIC LAGOON PERFORMANCE-RUN 2

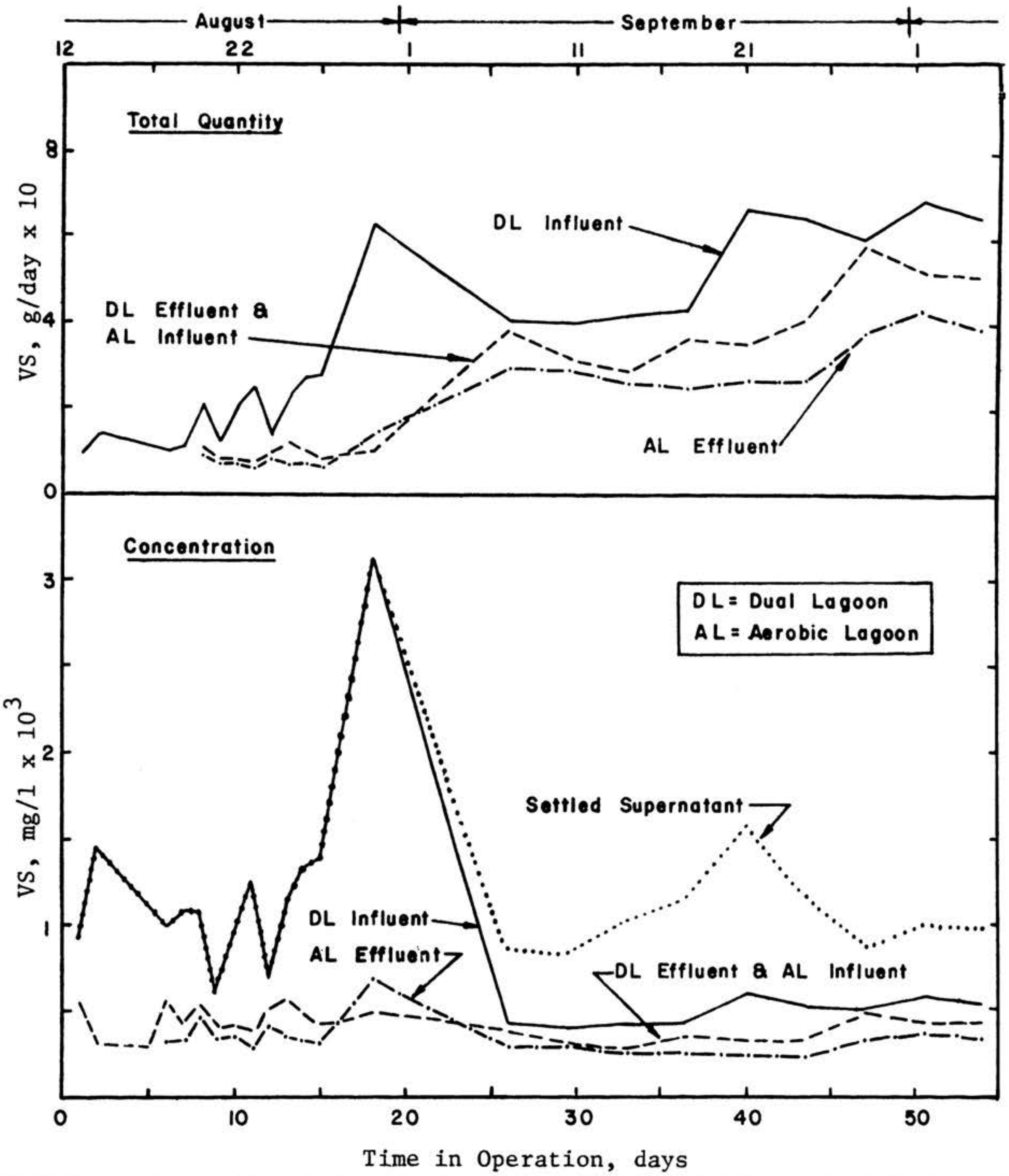
Date	Time in Oper-ation	Settled Super-natant Waste 1			Settled Super-natant + Recycle			Effluent						Overall Removal		
								Dual Lagoon			Aerobic Lagoon					
		COD	TS	VS	COD	TS	VS	COD	TS	VS	COD	TS	VS	COD	TS	VS
	days	mg/1												%		
8/13	1		1,953	902					1,257	550						
8/14	2		2,671	1,446					974	325						
8/17	5		11,676	9,059					1,037	294						
8/18	6		1,790	998					1,185	561		656	333		63.4	66.6
8/19	7		1,868	1,075					949	426		645	303		65.5	71.8
8/20	8		1,662	1,062					1,049	547		740	428		55.5	59.7
8/21	9		1,194	615					1,011	412		690	332		42.2	46.0
8/22	10		1,763	986		N/A			1,006	410		720	364		59.2	63.1
8/23	11		1,991	1,250					963	374		661	292		66.8	76.6
8/24	12		1,159	692					1,005	508		681	416		41.2	39.9
8/25	13		1,843	1,147					1,135	581		631	353		46.7	69.2
8/26	14		2,040	1,337					1,012	494		642	338		68.5	74.7
8/27	15		2,154	1,387					956	417		646	303		70.0	78.2
8/28	16								890	428						
8/30	18		5,517	3,126					1,022	498		1,257	699		77.2	77.6
9/6-9/8	25-27	1,967	1,499	866	561	874	412	279	832	376	209	718	299	89.4	52.1	65.5
9/9-9/12	28-31	1,857	1,371	840	550	873	400	278	780	319	223	749	290	88.0	45.4	65.5
9/13-9/15	32-34	2,118	1,722	1,023	590	904	415	232	755	293	208	700	263	90.2	59.3	74.3
9/16-9/19	35-38	2,208	1,918	1,168	573	935	434	285	793	355	164	689	250	92.6	64.1	78.6
9/20-9/22	39-41	2,978	2,515	1,573	922	1,166	605	257	761	314	151	660	242	94.9	73.8	84.6
9/23-9/26	42-45	2,715	1,965	1,159	1,020	1,116	539	306	837	338	172	691	229	93.7	64.8	80.2
9/27-9/29	46-48	2,346	1,756	871	913	1,086	500	416	990	489	197	751	315	91.6	57.2	63.8
9/30-10/3	49-52	1,636	1,720	1,008	793	1,127	577	437	942	439	370	830	360	77.4	51.7	64.3
10/4-10/6	53-55	1,533	1,843	979	686	1,175	542	370	980	425	263	841	323	82.8	54.4	67.0



Lagoon	Organic Loading, lb COD/day/acre*								
DL		280	270	310	320	640	780	680	470	440
AL		150	140	120	150		190	260	270	230

*To convert to g COD/day/sq m multiply by 0.112.

FIGURE 9. DUAL AND AEROBIC LAGOON PERFORMANCE (COD DATA)-RUN 2



<table>
<tr><td>Lagoon</td><td colspan="7">Detention Time (raw waste basis), days</td></tr>
<tr><td>DL</td><td>85</td><td>106</td><td>85</td><td colspan="2">43</td><td>28</td><td>21</td></tr>
<tr><td>AL</td><td colspan="3">N/A</td><td colspan="2">43</td><td>28</td><td>21</td></tr>
<tr><td rowspan="2">DL</td><td colspan="7">Recycled Aerobic Effluent/Settled Supernatant</td></tr>
<tr><td colspan="4">N/A</td><td>4</td><td>2.7</td><td>2</td></tr>
</table>

FIGURE 10. DUAL AND AEROBIC LAGOON PERFORMANCE (VS DATA)-RUN 2

group of animals. In preparation for marketing all animals were placed on Feed 1 on August 29, and consequently the animal which was transferred from Pen 3 to Pen 1 on September 5 (Day 24) had already been on Feed 1 for 1 wk. Because of the continuous change in the number of animals maintained on the floor during that period, samples were not taken; however, the lagoons were still fed on a regular basis. Because by Day 18 the dual lagoon appeared to have reached maximum peak loading conditions, beginning with Day 25, 80 l/day of aerobic effluent was recycled through the dual lagoon. This was done in order to provide dilution for the concentrated waste, supply a better balanced microbial population for treating the waste, and afford an added source of oxygen. The volume of settled waste was increased to 40 l, thereby decreasing the detention time (on a raw waste basis) in each lagoon to 21.2 days. As a result, the loading rate in the dual lagoon (raw waste basis) and aerobic lagoon (total influent basis) reached up to 781 and 273 lb COD/day/acre (87 and 33 g COD/day/sq m), respectively, without any indication of failure.

Supplemental BOD determinations made during the run produced the following results:

Lagoon	Date	Time in Operation days	BOD Influent mg/l	BOD Effluent mg/l	BOD Removal %
Dual	9/17	36	689*	510	26
Aerobic			510	21	96
Dual	9/26	45	684*	120	83
Aerobic			120	51	58
Dual	10/4	53	578*	135	77
Aerobic			135	62	54

*Calculated from corresponding COD values using a BOD/COD ratio of 0.59.

The NH_3-N content was also determined in a few effluent samples, and the following values were obtained.

	Anaerobic Lagoon		Dual Lagoon		Aerobic Lagoon	
Date	Time in Operation days	NH_3-N mg/l	Time in Operation days	NH_3-N mg/l	Time in Operation days	NH_3-N mg/l
10/1	31	610	50	18	50	10
10/6	36	235	55	62	55	44
10/7	37	213	56	11	56	8
10/8	38	258	57	20	57	20

The appearance of the dual and aerobic lagoons was altered during the recycling period. The surface of the dual lagoon cleared up and became heavily populated with single cell algae, while the aerobic lagoon lost its original deep green color in favor of a more pale shade of green. On Day 16 the aerobic lagoon had become infested with an excessive population of a small red scavenger which made the liquid surface to appear red. This animal, tentatively identified as a crustacean of the Cladocera Order (33, p. 808), removed a great portion of the algal population and resulted in a pH drop from 9.5 to 7.8. Following the introduction of recycle, however, the scavenger never again appeared to reach such numbers but was often observed in both lagoons.

At the completion of Run 2, the lagoons were drained and the sludges analyzed. The depth of sludge in the dual lagoon was approximately 1-ft (0.30-m) in depth; it had a solids content of 8.4 percent, of which 53.7 percent was volatile, and a COD of 71,314 mg/l. The sludge in the aerobic lagoon was only 1-in. (2.5-cm) deep and had a slimy consistency; the solids concentration was 10 percent, 71 percent of which was volatile.

V. DISCUSSION

Collection of swine waste in water-filled pits under a slotted feeding floor, and daily removal of the fluidized waste essentially eliminated all odors associated with a typical feedlot. The waste produced in this operation was much stronger than municipal waste; however, it could be effectively treated in a 3-stage lagoon system which was able to handle high organic loadings without developing obnoxious odors or unsightly conditions.

The volume of water used in the collection pits was determined by the pit design and the minimum water depth thought necessary to suppress odors. The criterion used in selecting the required depth was that any location on the pit floor where solid material might have landed be covered with at least 0.5 in. (1.3 cm) of water. The waste developed under these conditions averaged 14.5 gal/day/animal (54.9 l/day/animal) in Pits 1 and 2; leakage which frequently occurred in Pit 3 caused the waste volume to fluctuate widely and made the establishment of an average value difficult. The volume of waste produced is an important consideration, both in terms of the amount of water and size of waste treatment system required, and further research is needed to develop a pit design which would minimize water requirements while suppressing odors.

The feeding floor and collection pit facility was especially developed and operated for this investigation. It was consequently necessary to limit its size to fit the available space and allow the author to maintain it in addition to his other research responsibilities.

The need to utilize 3 different animal feeds for comparative studies necessitated that the feeding floor area be divided into 3 sections, thereby further reducing the size of each individual pen. Although the pens did provide the required area per animal,* they were too small to allow the normal animal movement necessary for optimum efficiency in forcing the solids through the slots. This was in part compensated for by using a completely slotted floor. The pen size also restricted the number of animals which could be used and this magnified the proportion of feed and water wasted per animal. Use of a completely slotted floor further contributed to the amount of wasted feed. In a partially slotted floor, a common type favored by farmers due to the reduced cost of construction, some of the wasted feed would be picked up by the animals because the feeders would be located on the solid portion of the floor. The traffic around the feeders and the natural tendency of the animals to defecate away from the feeding area, would effectively prevent the build up of solids on the partially slotted floor.

The water used in the collection pits significantly reduced the odor normally associated with feedlots. This was verified by the significant decrease in odor experienced when the initial group of animals, which had been kept for an interim period on a concrete feeding floor, was transferred to the slotted floor. Under test

*The University of Missouri-Columbia Extension Division recommends (36) confinement areas of 4 and 9 sq ft/head (0.37 and 0.84 sq m/head) for animals under 100 lb (45.4 kg) and from 100 lb (45.4 kg) to market weight; the feeding floor used in this study provided a minimum of 8 sq ft/head (0.74 sq m/head).

conditions, a slight odor was observed near the pens and was attributed to material which had not been pushed through the slots and had collected around the feeders and in the corners. It is believed that the small size of the pens forced the animals to defecate excessively against the partitions and around the feeders, and consequently aggravated the odor problem. This condition should not exist in a full size feeding facility. Odor was also quite noticeable whenever the waste was drained from the pits. Agitation of the waste as it fell into the transfer buckets probably released anaerobic decomposition gases. When the waste was allowed to accumulate in the pits for a period of 3 days (July 31 to August 2), the odor became progressively much stronger. Daily removal of the waste from the pits is, therefore, recommended to minimize odor.

The pits in the experimental unit were sloped at a rate of 5 percent. This slope was found to be too gradual to remove all the solids by gravity flow alone, especially in Waste 3, and residual solids had to be washed into the trough while the pits were being refilled. Use of an increased slope for the pit floor and troughs, and continuous rapid-rate waste withdrawal should create sufficient scouring velocities to eliminate this problem. It is also recommended on the basis of the experience gained in this study, that a minimum 1-in. (2.54-cm) water depth be maintained in the pits. At times solids tended to build up on the feeding floor, and when finally pushed through the slots formed a mass not covered by the 0.5-in. (1.27-cm) minimum water depth used. Part of the water required in the pits could be furnished by recycling effluent from the waste treatment system, provided that salts and other refractory substances do not build up in the recycling process to the point where they might inhibit the biological system used to treat the waste.

The characteristics of the 3 wastes studied, both total and settled supernatant, are summarized and comparatively evaluated in Table XX and Figure 11, with emphasis on the effects produced by animal feed. In addition, Table XX reflects differences resulting from the use of daily or composite samples, and gives the 95 percent confidence interval (95% CI) for each average value. The 95% CI provides an estimate of the reliability of the arithmetic average and represents the range in which there is a 95 percent chance that the true value of the average of a future sample would lie. This confidence interval was determined using the following equations (33, p. 23).

$$95\%\ CI = \bar{x} \pm t\sigma/\sqrt{n} \quad \text{and} \quad \sigma = [\Sigma(x-\bar{x})^2/(n-1)]^{0.5}$$

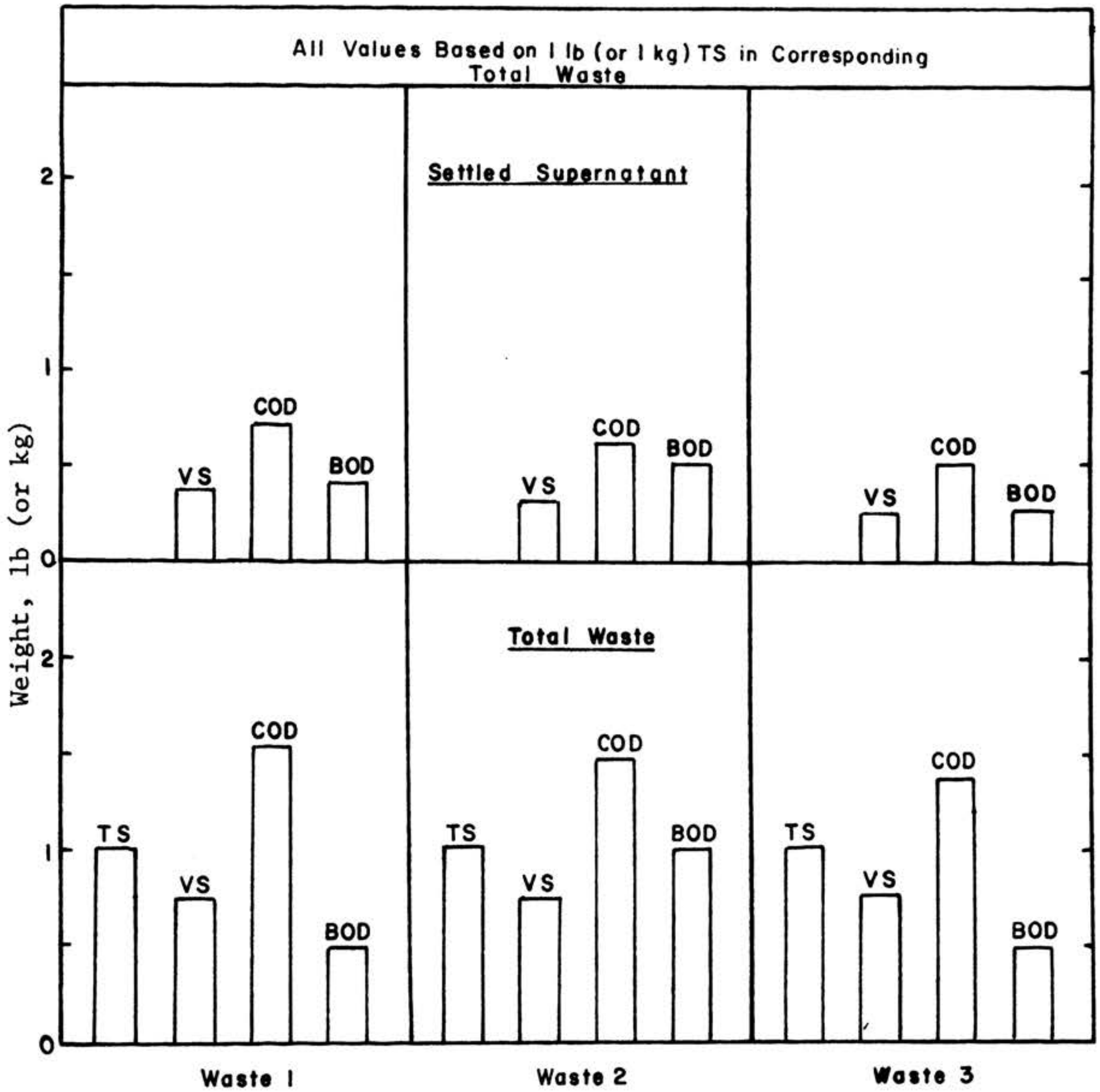
where, σ = standard deviation
n = number of values determined
x = individual value
$\bar{x}$ = arithmetic average or mean
t = constant depending on n (the following values were used: $n = 8$, $t = 2.46$; $n = 9$, $t = 2.36$; $n = 10$, $t = 2.26$; and $n > 10$, $t = 1.96$)

The feeds studied represented commonly used types and differed in the amount of growth additives incorporated, varying from a simple mix to a commercially made complete mix. Since supplemental nutrients are employed in order to improve animal health, feed conversion efficiency, and rate of weight gain, it was expected that there could be some variation in the characteristics of the waste produced by animals fed different rations.

TABLE XX. EFFECT OF ANIMAL FEED AND SAMPLING CONDITIONS ON WASTE CHARACTERISTICS-
A STATISTICAL EVALUATION

Relationship	Type of Sample	Time Period	Waste								
			1			2			3		
			n*	avg	95%CI**	n*	avg	95%CI**	n*	avg	95%CI**
VS/TS Total Waste	daily	6/22-8/30	52	0.758	±0.044	47	0.752	±0.053	45	0.763	±0.071
	composite	9/6-10/6	9	0.728	±0.016	9	0.725	±0.044	9	0.782	±0.060
	total	6/22-10/6	61	0.754	±0.063	56	0.748	±0.064	53	0.766	±0.072
VS/TS Settled Supernatant	settled 24-48 hr	7/4-8/30	36	0.570	±0.054	30	0.553	±0.071	29	0.549	±0.082
	settled 1 hr	9/6-10/6	9	0.580	±0.071	9	0.585	±0.017	9	0.576	±0.034
	total	7/4-8/30	45	0.572	±0.067	39	0.561	±0.093	38	0.555	±0.089
VS (Settled Supernatant) / VS (Total Waste)	settled 24-48 hr	7/4-8/30	36	0.311	±0.274	28	0.313	±0.227	24	0.226	±0.152
	settled 1 hr	9/6-10/6	9	0.438	±0.100	9	0.431	±0.085	8	0.319	±0.108
	total	7/4-8/30	45	0.336	±0.355	37	0.342	±0.164	32	0.249	±0.198
COD/VS Total Waste	daily	7/4-7/30	16	2.006	±0.290	16	1.923	±0.139	16	1.733	±0.181
	composite	9/6-10/6	9	2.012	±0.517	9	1.831	±0.568	8	1.783	±0.321
	total	7/4-10/6	25	2.008	±0.222	25	1.890	±0.120	24	1.750	±0.212
COD/VS Settled Supernatant	daily	7/4-7/30	14	2.188	±0.916	10	2.062	±0.604	8	1.967	±0.175
	composite	9/6-10/6	9	2.087	±0.242	9	1.755	±0.281	9	2.151	±0.224
	total	7/4-10/6	23	2.148	±0.614	19	1.916	±0.546	17	2.064	±0.177

*Number of values available.
**The 95% confidence interval.



Relationships Used

Waste	VS/TS	VS/VS*	COD/VS	BOD/VS	BOD/COD
Total Waste 1	0.75		2.01		0.32
2	0.75		1.89		0.67**
3	0.77		1.75		0.35
Settled Supernatant 1		0.44	2.15	1.23	
2		0.43	1.92	1.59	
3		0.32	2.00	1.11	

*Based on 1-hr settling.

**Reflects a single determination.

FIGURE 11. COMPARISON OF WASTE CHARACTERISTICS CONSIDERING ANIMAL FEED THE ONLY VARIABLE

The waste characteristic most affected by the animal feed was the degree of settling which occurred within a given period of time. Waste 3 flocculated and settled readily (Table VII, p. 50) and as a result a smaller percentage of the VS remained in the settled supernatant compared to the other 2 wastes which exhibited essentially equivalent characteristics (Table XX). The fact that relatively more of the VS settled in Waste 3 would explain why this waste had a high COD/VS average for the supernatant, but had the lowest corresponding value for the total waste. The VS/TS average values for the 3 total wastes were in very close agreement; the same degree of agreement was not found for the settled supernatants (although the 95% CI values were fairly close), reflecting the difference in settleability of the 3 wastes. The COD/VS average ratios of the total wastes indicated a fairly close agreement between Wastes 1 and 2, but the confidence interval of Waste 3 did not encompass the average value of Waste 1. There was little difference in the BOD/VS or BOD/COD ratios for Waste 1 (simple mix) and Waste 3 (complete mix), however, the high sample dilution which was necessary for the BOD test would have negated any inhibition due to the feed additives in Waste 3.

Figure 11 illustrates the variation in organic strength of the wastes and their supernatants using a uniform TS weight as a basis and considering animal feed to be the only variable. The relationships used in the preparation of this figure were taken from Table XX (VS/TS, VS/VS, COD/VS) and Table XI, p. 63, (BOD/VS, BOD/COD). These relationships were chosen because they represented the maximum amount of available data. The increased settleability of Waste 3 is evident in Figure 11 and could be an important consideration in the selection of a treatment system for the animal waste. Although the characteristics of the total waste were essentially the same, there would be a 51 percent increase in the BOD of the settled supernatant using Feed 1 rather than Feed 3.

There were other variables, however, besides animal feed. The limited number of swine contributing to the waste and their varying weights would intensify the differences in individual animal characteristics, such as feed conversion efficiency, rate of gain, health, disposition, and type (lard or bacon). With the exception of disposition and type, all other animal characteristics would be expected to improve with the use of feed additives.

Since in a feedlot operation the animal feed used and the quality of animal (inherited characteristics) fattened would normally vary, Table XXI has been prepared to present the overall average characteristics of the swine waste. This table provides the general design values necessary for an industry whose product and method of production can be altered in a very short period of time. The tabulation of single value averages is believed to be justified so long as there is a corresponding presentation of background information concerning the animal feeds and weights and the sampling and analysis procedures used. This information should be taken into account when comparisons are made with past investigations or when preparing for future research. Regretably, the data which were found in the literature were generally

TABLE XXI. AVERAGE CHARACTERISTICS OF SWINE WASTE FROM A SLOTTED FEEDING FLOOR-WATER CARRIAGE SYSTEM

Relationships			
Line	Characteristic	Total Waste	Settled Supernatant*
1	VS, % of TS	75.6	56.3
2	COD, % of VS	188.4	204.9
3	BOD, % of VS	68.0	121.0
4	% of COD	40.0	61.0
5	NH_3-N, % of TS	4.1	
6	% of COD	3.0	
7	Total-N, % of TS	11.1	
8	% of COD	10.1	24.4
9	Total-P, % of TS	0.96	
10	% of COD	0.79	
11	Grease, % of TS	4.92	

Total Waste Quantity and Concentration (at 14.5 gal/day/animal**)				
Line	Characteristic	lb/day/animal#	mg/1	Notes
12	TS##	0.75	6,200	
13	VS##	0.58	4,800	
14	COD##	1.09	9,042	using line 3
15	BOD##	0.32	2,650	
16	NH_3-N+	0.031	250	using line 5
17	Total-N+,++	0.083	686	
18	Total-P+	0.0072	60	
19	Grease+	0.037	306	using line 11

*Data for 1-hr settling.
**Or 54.9 1 waste/day/animal.
#To convert to kg/day/animal multiply by 0.454.
##From animals weighing 150-220 lb (68-100 kg).
+From animals weighing 45-220 lb (20.5-100 kg).
++Excludes data from Pen 2 during period of extreme feed wastage.

presented without such background information (Tables I and II, p. 9 & 12).

The water leached most of the biodegradable organic matter from the animal waste solids and transferred it to the liquid phase. This is evidenced by a 52.5 percent increase in the BOD/COD ratio (Table XXI) of the settled supernatant compared to the total waste. It is further indicated by a comparison of COD/VS ratios; the COD/VS ratio of the settled supernatant was only 8.8 percent greater than the corresponding total waste value, while the BOD/VS ratio was 78 percent higher. The compacted animal solids after falling into the pits dissociated, increasing the surface area available for microbial breakdown and releasing the soluble and suspendable material into the liquid phase.

The solids production per animal values shown in Table XXI reflect animal weights between 150 and 220 lb (68 and 100 kg). Efforts to correlate animal weight to solids production were unsuccessful, although it was observed that animals in the 45 to 65-lb (20.5 to 29.5-kg) feeder pig range produced approximately 50 percent less solids per day (see p. 59). Similar values presented in the literature (Table II) for animals weighing 100 lb (45.4 kg) were generally higher, ranging from 0.79 to 1.20 lb/day/animal (0.36 to 0.55 kg/day/animal). The reason for this difference cannot be explained, especially since the water-carriage system used in this study contributed additional TS. In designing a treatment system to handle this waste, the author recommends the use of the values in Table XXI; this recommendation is based on the wide variation in daily solids production experienced during the study and a more specific knowledge of the animals producing the waste.

The staged lagoon system used to evaluate the treatability of the waste was designed on the basis of information available in the literature using the author's best estimate of waste characteristics and volume, and appropriate loading rates. In designing and building the lagoons, consideration was also given to the protection of underground water supplies by preventing seepage and to inexpensive construction using readily available materials and methods. Although the system was developed to operate in series with the total waste introduced in the anaerobic lagoon and the effluent discharged from the aerobic lagoon, it had the capability to function under different operational modes. In the course of the study, the total waste was handled as initially planned or was separated by presettling into a sludge which was fed to the anaerobic lagoon and a supernatant which was introduced directly to the dual lagoon, either alone or together with the anaerobic lagoon effluent. The aerobic lagoon effluent was either discharged or in part recycled through the dual lagoon. This flexibility of operation enabled the study of the staged system components individually or in an integrated combination.

The anaerobic lagoon, which actually functioned as an unheated, unmixed sludge digester, performed well when fed total waste at average loadings up to 0.02 lb VS/day/cu ft (0.32 kg VS/day/cu m) effecting VS and COD reductions in excess of 75 and 65 percent, respectively, with minimal odor production. When the loading was increased to about 0.08 lb VS/day/cu ft (1.28 kg VS/day/cu m) by feeding settled waste, the lagoon failed and neither a reduction in organic loading nor the controlled addition of lime were able to restore it to operation. The digested sludge remaining in the lagoon at the end of the study, after 3.5 months of operation, had a TS content of 9.1 percent, 50.2 percent of which was volatile, and occupied 50 percent of the total liquid volume. The large build up of sludge was attributed in part to the disproportionate amount of seed sludge used to start the lagoon twice during the 3.5-month period; however, accumulation of sludge must be taken into consideration in the design of the lagoon and provision must be made for its removal and disposal. Since feedlots are generally located in rural areas, the disposal of sludge by spreading over fields as a fertilizer should not pose a problem.

The dual lagoon was successfully loaded at an average rate of 592 lb COD/day/acre (66.3 g/day/sq m) and removed an average of 80 percent COD while aerobic lagoon effluent was being recycled at a volume rate of 2 times the influent. The corresponding BOD loading was 349 lb/day/acre (39.1 g/day/sq m) and the BOD removal also averaged 80 percent. During this loading period the lagoon was fed settled waste supernatant with an average COD and BOD content of 2,058 and 1,255 mg/l, respectively, and the loading rates reflect the organic strength of the influent settled waste only. The sludge build up in the anaerobic trench was much greater than expected since the lagoon influent consisted of settled supernatant and/or anaerobic lagoon effluent, with the possible exception of the loading period between July 21 and August 2 when the anaerobic lagoon was being revived and the total waste was passing through it and into the dual lagoon essentially unaltered. At the end of the study, sludge occupied one-third of the anaerobic trench volume and had a TS content of 8.4 percent, 53.7 percent volatile. Although not as digested as the anaerobic sludge the reduced volatile fraction would indicate that anaerobic digestion was occurring.

In designing the dual lagoon, the total volume was divided equally between the aerobic layer and the anaerobic trench. On the basis of the experience obtained during this study, it is recommended that the 2 lagoon components be designed individually; the aerobic portion on the basis of a COD or BOD loading per unit surface area and the anaerobic portion on the basis of a VS loading per unit volume. It is also recommended that provisions be made for the periodic withdrawal of digested sludge from the anaerobic trench and that the anaerobic lagoon effluent be delivered through multiple outlets over the trenches and below the aerobic zone.

The aerobic lagoon functioned as a polishing lagoon and as a source of recycling water. This lagoon received maximum COD and BOD loadings of about 239 and 83 lb/day/acre (26.8 and 9.3 g/day/sq m), respectively, with corresponding COD and BOD removals of 35 and 56 percent. It should be noted that the value for the BOD loading was based on a limited number of tests and is probably high when compared to the COD loading which reflects a larger number of observations. Although the dual-aerobic lagoon combination effected overall COD reductions in the neighborhood of 90 percent (Table XIX, p. 85), the quality of the aerobic lagoon effluent was too low (COD values ranged from 150 to 370 mg/l) to be discharged directly into a stream and was high in algal content. It is, therefore, recommended that the detention time in this lagoon be increased by reducing the loading and increasing the depth.

The lagoon system was fed Waste 1 exclusively and time did not permit the evaluation of the other 2 wastes. Because these wastes were produced by animals maintained on a more complete ration containing feed additives, additional studies to determine the effect, if any, these additives might have on the microbial population of the treatment system would be of great value.

In order to place the findings of this study in the perspective of an actual feeding operation, a staged lagoon system was designed for a feedlot with a capacity of 1,000 head and the results are presented in Table XXII and Figures 12 and 13. The 1,000 head capacity was chosen because this size feedlot is becoming common as a medium-sized operation, and at this production level the majority of feeders have switched to confinement feeding.

On the basis of an average of 6 sq ft/animal (0.56 sq m/animal), 6,000 sq ft (560 sq m) of feeding floor area would be required by the feedlot. The total area was divided into 36, 12-ft x 16-ft (3.66-m x 4.87-m) pens placed in 2 rows on either side of a 5-ft (1.53-m) alley. The pen floors are 67 percent slotted and the collection pits were designed to contain 14.5 gal (54.9 l) of waste per animal. The pit floors and troughs were sloped at a rate of 8.3 percent, and high pressure nozzles were located at strategic points to facilitate the effective removal of sludge in the daily flushing operation. Details of the feeding floor are shown in Figure 13.

TABLE XXII. DESIGN OF A STAGED LAGOON SYSTEM FOR A SWINE FEEDLOT OF 1,000-HEAD CAPACITY

Design Criteria

Feedlot capacity = 1,000 animals   Volume of waste = 14.5 gal/day/animal

Waste Strength			Lagoon Characteristics						
Characteristic	lb/day 1,000 animals	mg/l	Lagoon	Loading Rate: lb VS / day/cu ft	Loading Rate: lb COD / day/acre	Removal TS (%)	Removal VS (%)	Removal COD (%)	Removal BOD (%)
TS	750	6,200	Anaerobic	0.02		60	65	70	55
VS	580	4,800	Dual-area		300	45	60	80	80
COD	1,093	9,042	trench	0.01					
BOD	320	2,650	Aerobic		200	30	30	30	50

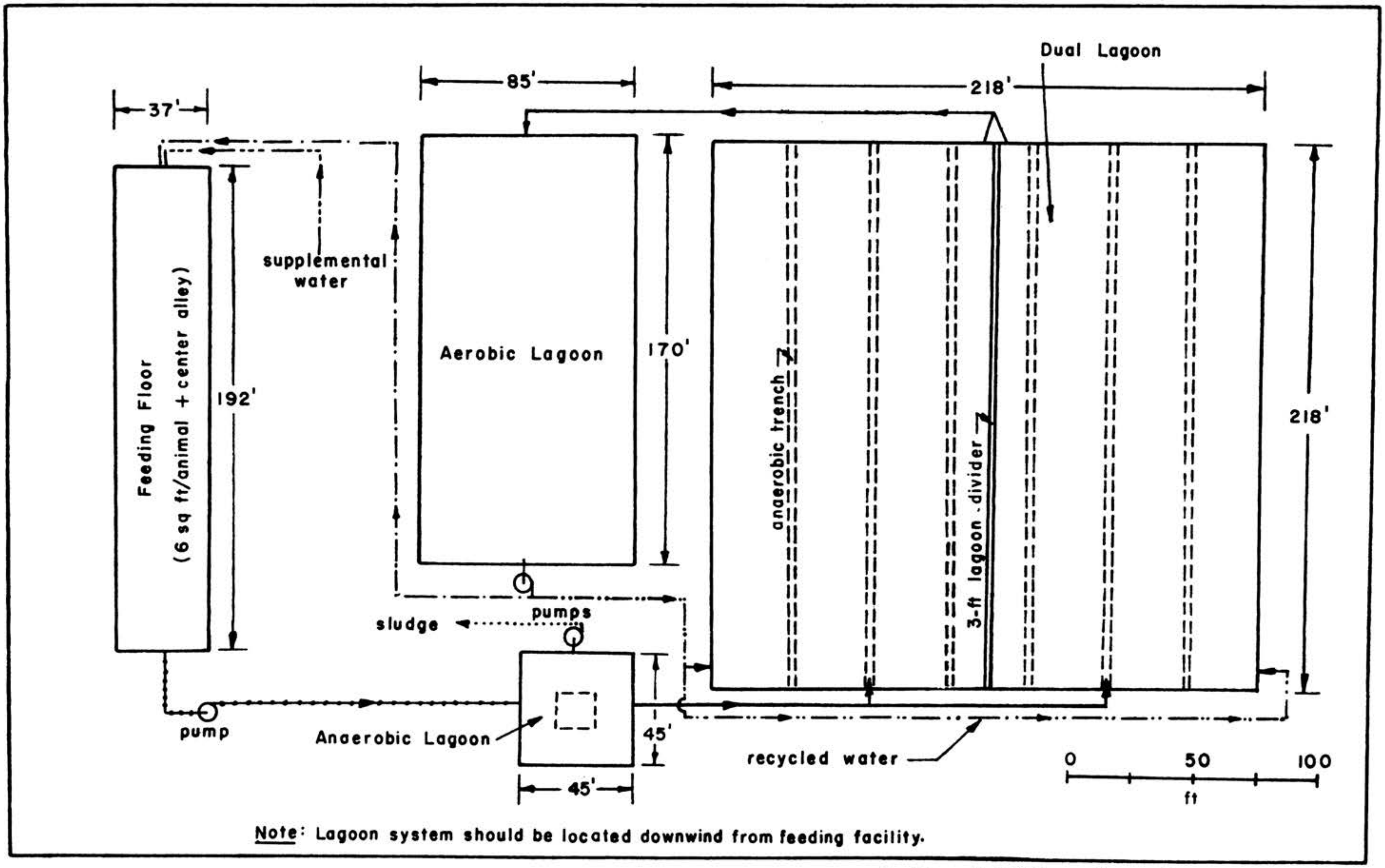
Computations

Lagoon	Computations	Effluent lb/day
Anaerobic	Volume = 580÷0.02 = 29,000 cu ft Select D = 15 ft + 1 ft o/b = 16 ft Select L/W = 1 ∴ L = 45 ft W = 45 ft Note: slope sides 33% ∴ center water D = 17 ft Influent volume = 14,500÷7.48 = 1,940 cu ft/day Theoretical detention = 29,000÷1,940 = 15 days Considering sludge: 9% TS, 1.04 sp gr, 60% VS reduct. Sludge build up (750x0.6 - 580x0.65) + 0.4x580x0.65 = 224 lb/day or 224 ÷ (1.04x62.4x0.09) = 38.3 cu ft/day or at 6-month withdrawal = 38.3x6x30 = 6,894 cu ft Min detention = (29,000 - 6,894) ÷ 1,940 = 11.4 days	TS 300 VS 203 COD 328 BOD 144
Dual	Area = 328÷300 = 1.09 acres or 47,480 sq ft Anaerobic trench volume = 203÷0.01 = 20,300 cu ft Select aerobic area L/W = 1 ∴ L = 218 ft W = 218 ft D = 2.5 ft + 1.5 ft o/b = 4 ft Select anaerobic trench D = 5 ft sides sloped 10% W = 3.5 ft top L = 218 ft No. of trenches = 20,300 ÷ (5x3x218) = 6 Liquid volume = (6x5x3x218 + 2.5x47,480) = 138,430 cu ft Theoretical detention = 138,430÷1,940 = 71 days	TS 165 VS 81 COD 66 BOD 29
Aerobic	Area = 66÷200 = 0.33 acre or 14,375 sq ft Select L/W = 2 ∴ L = 170 ft W = 85 ft D = 2 ft + 1.5 ft o/b = 3.5 ft Theoretical detention = (2x14,375) ÷ 1,940 = 15 days	TS 116 VS 57 COD 46 BOD 15

Summary of Design Findings

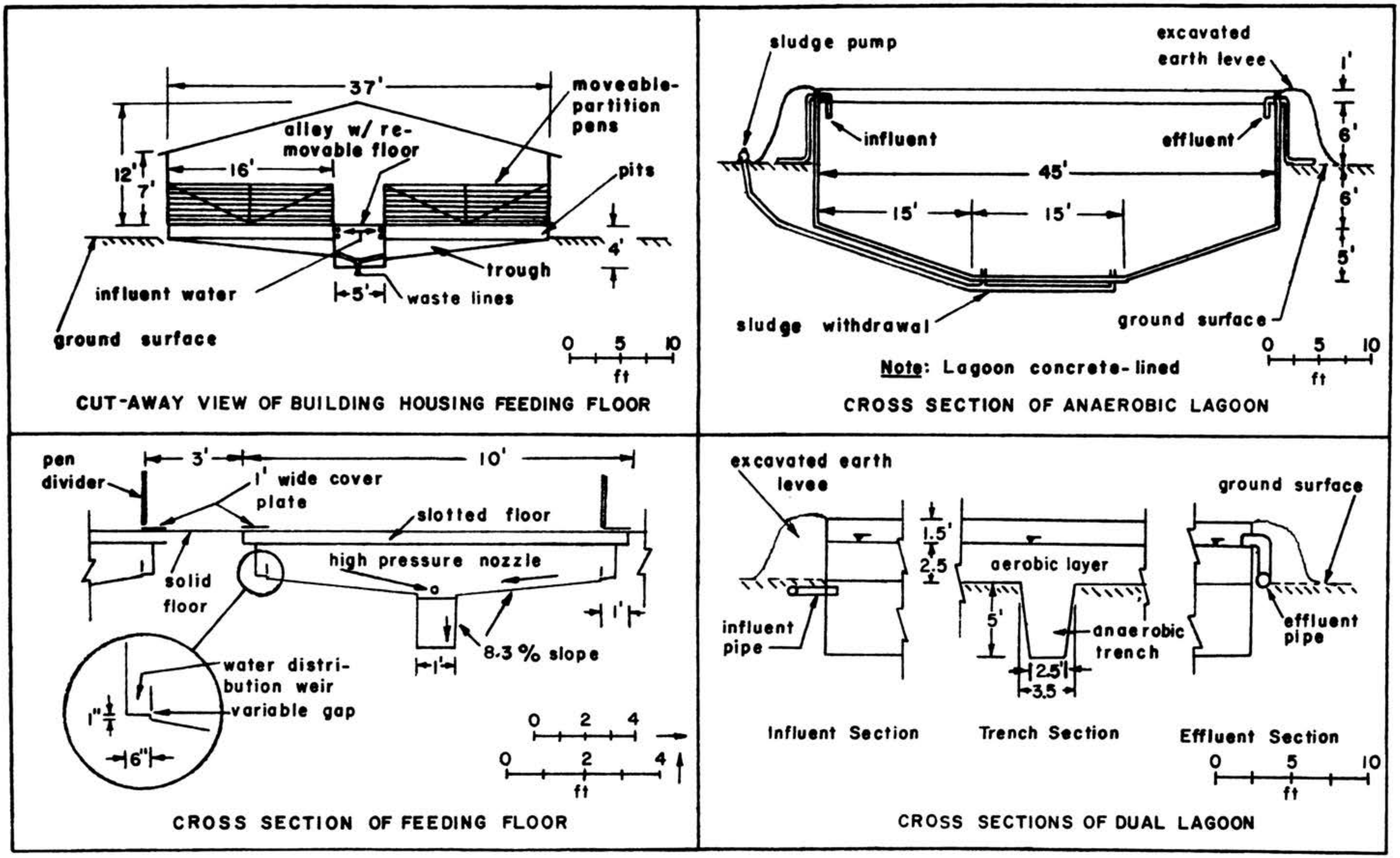
Lagoon	Effluent Strength TS (mg/l)	VS (mg/l)	COD (mg/l)	BOD (mg/l)	Dimensions D (ft)	L (ft)	W (ft)	Size area (acres)	Size volume (cu ft)	Detention (days)
Anaerobic	2,481	1,679	2,713	1,191	18	45	45	0.05	29,425	15
Dual-Aerobic	1,364	670	546	240	4	218	218	1.09	138,480	71
Anaerobic					5	1,353	3.5	0.11	19,620	
Aerobic	959	471	381	124	3.5	170	85	0.33	28,900	15

Note: 1 ft = 0.3048 m; 1 acre = 0.405 ha; 1 cu ft = 0.028 cu m.



1 ft = 0.3048 m 1 sq ft = 0.0929 sq m

FIGURE 12. SCHEMATIC OF OPERATION FOR PROPOSED FEEDING FACILITY AND STAGED LAGOON SYSTEM



1.0 ft = 0.3048 m 1.0 in. = 2.54 cm

FIGURE 13. CONSTRUCTION DETAILS OF PROPOSED FEEDING FACILITY AND STAGED LAGOON SYSTEM

The proposed treatment system consists (Figure 12) of an anaerobic lagoon for settling, storing, and treating the solids; a dual lagoon for treating the anaerobic lagoon effluent; and an aerobic lagoon for further polishing the dual lagoon effluent. The waste characteristics (Table XXII) were based on the summary values presented in Table XXI, and the design criteria selected (Table XXII) reflect the experience obtained in this investigation, supported when appropriate with data reported in the literature.

The anaerobic lagoon was designed on the basis of an organic loading of 0.02 lb VS/day/cu ft (0.32 kg VS/day/cu m); in terms of BOD this loading would be 0.011 lb/day/cu ft (0.176 kg/day/cu m) and is comparable to values reported in the literature (36, p. 202). Design computations and recommendations are given in Table XXII. The lagoon will have a liquid volume of 29,000 cu ft (812 cu m) and will provide a detention time of 15 days. In order to maintain a low surface area to volume ratio, needed for maximum heat retention, the lagoon was designed to have a maximum liquid depth of 17 ft (5.18 m). It is recommended that 11 ft (3.35 m) be built below the natural ground surface with the remaining depth provided by levees constructed from the excavated earth in order to reduce construction cost. To prevent groundwater pollution, the floor and walls of the lagoon should be lined with concrete. To concentrate the sludge and aid in its removal, the bottom of the lagoon was reduced to an area 15-ft (4.57-m) square from an area at the top 45-ft (13.72-m) square; the depth has been adjusted to compensate for the volume lost. It is expected that sludge withdrawal would be integrated into the overall feedlot operation and that its frequency, determined by the management of the crop and pasture lands and their availability for fertilization, would probably not average more than 2 times a year. Assuming a 6-month sludge accumulation, the detention time of the liquid could be reduced to approximately 11.5 days, however, this will provide more than 2 to 3 times the minimum 3 to 5-day period reported by Loehr (26).

The dual lagoon was designed at a surface loading of 300 lb COD/day/acre (33.6 g COD/day/sq m) for the aerobic layer and a volume loading of 0.01 lb VS/day/cu ft (0.16 kg VS/day/cu m) for the anaerobic trench. The depth of the aerobic layer was selected to be 2.5 ft (0.76 m) to discourage rooted aquatics. The depth and average width of the trenches were set at 5 and 3 ft (1.53 and 0.92 m), respectively, to facilitate excavation with readily obtainable construction equipment, and the side walls of the trenches were sloped at a rate of 10 percent to minimize erosion. The lagoon has been divided by a partition into 2 parts capable of independent operation. This was done in order to enable periodic maintenance and sludge removal without disruption of operation. The long detention time (71 days), coupled with the recommended capability for recycling aerobic lagoon effluent, should provide the dual lagoon with sufficient capacity to handle increased loadings resulting either from the temporary failure of the anaerobic lagoon or the feeding of a larger number of animals in the feedlot. The dimensions and design characteristics of the dual lagoon are summarized in Table XXII, the mode of operation is outlined in Figure 12, and construction details are given in Figure 13.

The aerobic lagoon was designed (Table XXII) at a rate of 200 lb COD/day/acre (22.4 g COD/day/sq m) and was provided with a depth of only 2 ft (0.61 m) to assure that aerobic conditions would be maintained. A rectangular shape was selected for this lagoon to minimize the possibility of short circuiting. Although not indicated in the operational schematic (Figure 12), facilities might have to be provided for the removal of algae prior to discharging the lagoon effluent. Also, lining of the lagoon might be necessary to control rooted aquatic plants; alternately, the lagoon depth might be increased, the decision depending on local construction economics.

It is estimated that the staged lagoon system will provide overall COD and BOD removals of better than 95 percent, with corresponding effluent concentrations of approximately 390 and 125 mg/l (Table XXII). The anticipated percentage reduction in COD and BOD far exceeds the minimum value of 85 percent recommended by the Missouri Effluent Guidelines (37) for discharge into the Missouri and Mississippi Rivers. The remaining COD and BOD concentrations, however, are greater than the guideline values of 150 and 50 mg/l, reflecting the highly concentrated character of the animal waste. Because the volume of waste is low, the total amount of oxygen demand discharged would be in effect small.

VI. CONCLUSIONS

On the basis of the findings of this study the following conclusions were made.

1. The use of a slotted swine feeding floor equipped with water-filled collection pits, and daily removal of the fluidized waste essentially eliminated the odors normally associated with a feedlot operation.

2. The use of different feeds ranging from a simple to a complete mix had no appreciable effect on the characteristics of the animal waste, other than its settleability which resulted in the characteristics of the settled supernatants differing to a greater degree.

3. The volume of the fluidized waste averaged 14.5 gal/day/animal (54.9 l/day/animal), and the waste produced by swine in the 150 to 220-lb (68 to 100-kg) weight range had the following major characteristics.

TS	0.75 lb/day/animal,	or 0.34 kg/day/animal,	and	6,200 mg/l
VS	0.58 " "	0.26 " "		4,800 "
COD	1.09 " "	0.49 " "		9,042 "
BOD	0.32 " "	0.15 " "		2,650 "

4. The nutrient content of the fluidized waste (BOD:N:P = 100:7.5:1.85) was more than sufficient to support active microbial growth.

5. A staged lagoon system consisting of an anaerobic lagoon for settling, storing, and digesting the waste solids, a dual anaerobic-aerobic lagoon for treating the anaerobic lagoon effluent, and an aerobic lagoon for further polishing the dual

lagoon effluent was able to effectively handle the high waste organic loadings without developing obnoxious odors and unsightly conditions.

6. The following organic loading rates were found adequate for the design of the components of the staged lagoon and would provide a treatment system capable of achieving overall reductions in BOD and COD in excess of 95 percent.

Anaerobic lagoon	0.02 lb VS/day/cu ft	0.32 kg VS/day/cu ft
Dual lagoon		
Anaerobic trench	0.01 " "	0.16 " "
Aerobic layer	300 lb COD/day/acre	33.6 g COD/day/cu m
Aerobic lagoon	200 " "	22.4 " "

7. A treatment system designed to handle the waste from 1,000-head capacity swine feedlot would have the following size requirements.

Anaerobic lagoon	29,000 cu ft or	812 cu m
Dual lagoon		
Anaerobic trench	20,300 "	568 "
Aerobic layer	1.09 acre	0.441 ha
Aerobic lagoon	0.33 "	0.134 "

VII. SUGGESTIONS FOR FURTHER RESEARCH

From the experience gained in this study the following suggestions for further research are offered.

1. The treatability of the fluidized waste produced by swine on different feed rations should be evaluated, especially the effect feed additives might have on the microbial system.
2. The possibility of using the treated lagoon effluent to flush the waste from the collection pits should be investigated, with emphasis on the build up of inorganic salts and other refractory substances and its effect on the biological system.
3. The potential use of the treated lagoon effluent as a source of animal drinking water should be studied, and the possibility of recycling feed additives that might pass through the animal and the treatment system unaltered should be examined.
4. The optimum ratio of liquid to solids in the collection pits for odor suppression should be determined in an effort to conserve water requirements.
5. The relative effectiveness of the aerobic layer and anaerobic trench in the dual lagoon, and the optimum design relationships of the 2 biological zones should be established.

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VITA

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