BIOLOGICAL TREATMENT OF CONFINED BEEF ANIMAL WASTES

by 632

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INTRODUCTION

The increase in confinement housing operations for animal feeding in recent years has created a problem in animal waste management. As of this date, the research on animal waste problems has not yet resulted in a satisfactory solution for the handling, treatment, and disposal of animal wastes. The wastes from confinement units can be a major source of water pollution even after treatment so ultimate disposal of animal wastes on land should continue to be a basic answer.

It is cited in the literature that a biologically degradable waste such as beef animal waste can most economically be treated by biological treatment methods, either anaerobic or aerobic, which employ microbes to decompose and stablize the organic wastes. This research has considered both anaerobic digestion and an aerobic system, the oxidation ditch.

The purpose of this research was to investigate the operational procedures, the operating problems, and treatment efficiencies for the two waste treatment facilities. It was also necessary to determine if these facilities could enable the livestock operator to handle, treat, and dispose of beef animal wastes in such a way that nuisance conditions could be reduced and that the wastes would not pollute the environment.

The study of using anaerobic digestion was based on the standpoint of solids liquification rather than wastes stabilization. Anaerobic digestion is a sensitive process requiring certain skilled operations. Since close supervision can not always be achieved under field conditions, the emphasis was placed on the limiting parameters of acid fermentation. This results in liquifying the organic solids so that they can more readily be degraded by further treatment or by land disposal.

It is estimated that about two hundred oxidation ditches are in operation for animal waste treatment across this country. It has been shown that the oxidation ditch system can be a potential animal waste treatment system. This system meets the following objectives: (1) reduces the wastes pollutional strength (2) decreases nuisance conditions (3) requires little mainteance and (4) operates at a low cost. This study centers on the operational procedures and the effluent quality.

This study gives field data and experiences on the operation of the two animal waste systems. The field study was conducted at the Beef Cattle Research Center of the Department of Animal Science and Industry. Laboratory analyses were done at the Sanitary Engineering Laboratory of the Department of Civil Engineering, both at Kansas State University.

The effluents from the two systems employed are still high in pollutional characteristics and can not be discharged directly into a watercourse.

LITERATURE REVIEW

Waste Characteristics

There is considerable variation in the characteristics of cattle wastes. This variation due to the physical, chemical, and biological properties of the waste, depends upon the characteristics of cattle as well as the feed ration, water comsumption, and evironmental conditions in which the animals grow.

The size, sex, breed, and health of the animal affects the feed conversion efficiency while the digestibility of the ration, the protein, fat, and fiber content affects the composition of the waste. Temperature, humidity, bedding materials, and facilities for holding the manure may be the most important environmental factor.

Wastes from cattle feedlots contain less liquid and more dry matter than domestic sewage. The quality and quantity of the wastes are important in determining the waste handling, treatment, and disposal system and as to whether or not the treatment methods for domestic sewage can be applied.

Wastes from current feedlot operations no longer contain litter and bedding materials, and are more representative of the actual excretions of animals than that in the past. Therefore only recent data on the waste properties can be applicable.

Loehr (1) estimated that the daily production of manure from an 800 lb beef animal is 6 percent of the body weight. The feed conversion relationships are shown in Table 1.

Table 1. Feed Conversion on an 800 lb Beef Animal (1)

Ration		dry matter		18.5 lb
		organic matter	17.6 lb	
		K_2O	0.29 lb	
		P_2O_5	0.18 lb	
		N	0.42 lb	
		water		54 lb
Body Weight Gained/day				2.5 lb
Waste		feces		34 lb
		urine		14 lb
	or	dry matter		11 lb
		organic matter	10 lb	
		K_2O	0.22 lb	
		P_2O_5	0.14 lb	
		N	0.34 lb	
		water		37 lb

Hart (2) noted that the daily manure production from a 950 lb beef animal was 60 lb of wet manure, containing 85 percent moisture and 3.1 percent nitrogen on a dry solids basis. Loehr and Agnew (3) reported that for a 900 lb steer, the daily manure production was 43 lb of feces and 17 lb of urine. The manure at 85 percent moisture contained 9 lb of total solids and 7 lb of volatile solids. Taiganides and Hazen (4) gave a guide value for average daily manure production from a 1,000 lb beef animal as follows: 64 lb wet manure, containing 10.24 lb total solids, 8.2 lb volatile solids, and 3.7 percent nitrogen on a dry solids basis.

Table 2 is an index of the pollutional strength of cattle wastes. Loehr (3) stated that manure from beef cattle might be more biodegradable and contained a greater percentage of nitrogen than the manure from dairy cattle. His estimation of the average pollutional characteristics of beef cattle and the comparision with domestic sewage are shown in Table 3. Population equivalent, PE, is based on 0.17 lb BOD_5, 0.55 lb total solids, and 0.033 lb total nitrogen per capita per day in common domestic sewage.

Table 2.- Pollutional Characteristics of Cattle Wastes

1,000 lb/animal	Beef Cattle		Bovine	Cattle
Total Solids lb/day	3.62	9.00	10.44	-
Volatile Solids lb/day	3.17	7.47	8.38	8.2
BOD_5 lb/day	1.02	1-2	1.53	1.28
BOD_5 lb/lb VS	0.32	0.28	0.183	0.156
COD lb/day	3.26	9.0	8.45	10.5
COD lb/lb VS	1.03	1.15	1.0	1.28
BOD_5/COD	0.31	0.40	0.183	0.122
Total Nitrogen lb/day	0.26	0.26	0.38	-
Ref. No.	1	3	5	4

Table 3.- Average Pollutional Characteristics of Beef Cattle Waste (1)

	BOD_5	Total Solids	Total N
Pounds /day/animal	1.0	10	0.3
PE	6	18	9

Anaerobic Digestion

In anaerobic digestion of cattle wastes, the complex organics contained in the manure are converted to simple soluble compounds, which the bacteria can utilize by enzymatic hydrolysis. These hydrolysis compounds are then broken down into volatile organic acids by a group of facultative and anaerobic bacteria commonly called "acid formers" and in turn, fermented to methane and carbon dioxide by the other group of strictly anaerobic bacteria known as " methane formers". The methane formers responsible for the waste stabilization are the most sensitive to environmental change and hence responsible for most digester upsets. Thus, for stable digestion of wastes, a balance must be established between the activities of the two groups.

Many different conditions can cause an unbalance between the two groups of bacteria, such as change in temperature, change in manure loading, or addition of some toxic substances. McCarty (6) noted that optimum temperature and pH for operation are above $30^{o}C$ and near 7, respectively. The decreased activities of methane formers are often observed following a rapid increase in volatile acids and a drop of pH.

Many laboratory studies with anaerobic digestion of animal wastes under controlled conditions has indicated that the anaerobic biological treatment system could be successful. The results from laboratory digestion units, two each for swine, dairy and beef cattle are listed in Table 4.

Table 4.- Characteristics of Mixed Liquor, Mixed and Heat Laboratory Anaerobic Digester

	Swine		Dairy Cattle		Beef Cattle	
Loading Rate lb VS /cf/day	0.4	0.194	0.185	0.215	0.32	0.16
pH	6.9	7.4	7.0	-	6.7	6.8
Volatile Acids mg/l	17,500	3,290	220	-	175	100
TS mg/l	-	-	-	-	41,170	18,640
VS %	80	74.6	85	77	64.6	79.5
BOD_5 mg/l	-	-	-	2,300	6,740	3,310
COD mg/l	-	-	-	13,500	41,160	21,980
BOD Red. %	-	-	-	-	56.2	57.0
COD Red. %	-	-	-	-	33.1	28.6
TS Red. %	23	54.6	46.7	-	35.8	41.9
VS Red. %	20	61.5	47.8	16.3	-	-
Temp. ^{o}C	20	35.5	36	35	35	35
Ref. No.	7	8	8	9	3	3

It is felt that the parameters of optimum performance of biological reactions, such as continuous feeding, complete mixing, adequate active organisms, greater than ambient temperature, freedom from toxic materials, and skilled supervision are unlikly to be reached in field operations. Indeed, some trouble has been experienced in both laboratory digestion and field operations (3,7,9,10).

Loehr (10) reported on anaerobic digestion of beef cattle wastes under field conditions that considerable attention and control was required to operate this system. Adverse conditions occurred in this system due to combinations of highly intermittent loading, low temperature, and lack of adequate microbial seed. A total of 2,300 pounds of lime was added to the anaerobic unit to buffer the unit until the numbers of methane bacteria could increase and utilize the volatile acids that had been produced.

Loehr and Agnew (3) conducted a laboratory study of anaerobic lagoons for the wastes from beef cattle feedlots at room temperatures of 20 ^{o}C to 30 ^{o}C. They found that some difficulty occurred in starting up the lagoons because of low pH and high volatile acids. During the start-up period, they recommended that alkalinity in the form of sodium bicarbonate should be added to increase the buffering capacity of the system. Table 5 presents the characteristics of the liquid layer that would be the effluent from such a lagoon.

Table 5.- Average Characteristics of Liquid Effluent From Laboratory Anaerobic Lagoons (3)

Loading Rate lb TS/cf/day	0.2	0.3
Theoretical Liquid Detention Time days	20	10
pH	6.9	6.6
Volatile Acids mg/l	340	400
Alkalinity mg/l	2,400	1,390
Total Solids mg/l	5,980	5,900
Volatile Solids %	64	63
COD mg/l	7,150	5,550
Total Kjeldahl Nitrogen mg/l	560	500

Loehr (11) also reported on a number of lagoons which had been built in Kansas to intercept the runoff from beef cattle feedlots and to treat some of the wastes from the feedlots and concluded that seasonal temperature variations would alter the effluent quality. During cold weather the quality would depend on the fraction of the solids removed by sedimentation in the lagoon. In warm weather the quality would be affected by the degree of mixing caused by gas production by active anaerobic action and by carryover of the solids that were unable to settle because of the mixing. The results pertinent to the quality of the effluent and of the settled solids are summarized in Table 6 and 7. The effluent is high in oxygen demanding material, solids, and nitrogen. Subsequent treatment units were advisable to remove the solids and most of the oxygen-demanding material.

Beef cattle waste treatment schemes investigated by Pratt et. al. (12) for the septic tank effluent included additional settling, aeration, and aeration with aluminum sulfate added. None of the treatment methods studied were successful. The low temperature during the trial was probably responsible for reduced biological activity because the bacteria could not live and function efficiently under these conditions.

Table 6.- Effluent Quality of Anaerobic Lagoons Treating Beef Cattle Feedlot Wastes -- Range Values (11)

Parameter	Feedlot A	Feedlot B	Feedlot C	Feedlot D
Cattle on Feed	9,000	2,000	4,000	3,000
BOD_5 mg/l	2,500-5,500	72-330	700	2,800
Ammonia as NH_3 mg/l	220-400	22-82	-	225
Chlorides as Cl mg/l	275-475	150-300	-	1,600
pH	7.0	7.8	-	6.7

Table 7.- Average Characteristics of Settled Solids of Beef Cattle Manure Lagoons (11)

Loading Rate lb VS/cf/day	0.085	0.255
Total Solids mg/l	37,600	46,000
Volatile Solids %	78	73
BOD_5 mg/l	5,950	5,000
COD mg/l	41,400	55,500
COD/BOD	6.9	11.1
Volatile Acids mg/l	700	-
Alkalinity mg/l	2,340	-

Oxidation Ditch

The in-the-building oxidation ditch is a modified form of the activated sludge system. The manure drops through a slotted floor into the ditch. In effect, the loading is uniform in the ditch. The mathematical equations for the aeration-only type of complete-mixing activated sludge system used by Dr. McKinney (13) can be applied to this system. These equations predict that the oxygen uptake rate in the oxidation ditch will be relatively low. An aeration device such as a rotor used in the ditch can be satisfactory. The high suspended solids concentration in the effluent from the aeration-only type of activated sludge system means that the solids must be removed prior to the discharge of the effluent to any watercourse.

The rotor provides both oxygenation and circulation of the mixed liquor. Kolega, et. al. (14) states that the oxygen transfer coefficient will increase with increase in the immersion depth, the diameter, and the speed of the rotor, but will decrease with an increase in liquid depth. In general, for use of the oxidation ditch system for animal wastes treatment, velocities of wastes in the ditch of 1 to 2 feet per second should be maintained (15,16). However, it has been reported that velocities up to 2 fps have resulted in more foaming during cold climate operation (17). Jones, et. al. (18) found that immersion of the rotor into the waste to about one-third of the liquid depth maintained adequate velocity and oxygenation. They also noted that a liquid volume of 200 to 250 cu. ft. of ditch volume per foot of rotor length served to maintain a velocity that prevented solids from settling in the ditch. Velocities of the waste seemed to be a limiting parameter in this system. However, if the rotor was operated at great enough speed and immersion to keep the solids in suspension, sufficient oxygen, from 1.2 to 1.5 lbs O_2 per hr. per ft. of rotor in tap water at zero dissolved oxygen level, would be supplied to the waste (16,18). Jones et. al. (16) with the results of their research recommended a ditch loading rate on a basis of 30 cu. ft. of liquid volume in the ditch per pound of daily BOD_5 added. Dale (19) also noted that as a continuous treatment system, water in a quantity of about 2 to 3 times that of the volume of manure added daily would need to be supplied.

Moore et.al. (17) noted that an 87 percent BOD_5 reduction was obtained with a summer operation at a loading rate of one beef animal per 140 cu. ft. of liquid volume. With a loading rate of one beef animal per 38 cu. ft. of liquid volume, the oxidation ditch system could be used to treat beef wastes in cold climates with temperatures around sub-freezing. In addition, they concluded that foam production was great enough to be a limiting parameter.

McKinney and Bella (15) suggested that the ditch system should be started neither with septic manure in the ditch nor with a house full of animals. The ditch should be filled with water to the operating level prior to the start of the rotor (15,16). Dale (19) noted that the temperature should be above 50°F in starting the operation. Frequent removal of the ditch contents and continuous operation of the aerator should be maintained.

Foaming difficulties were encountered in a number of ditch systems treating livestock manure (15,16,17,18,19,25). McKinney (15) found that foaming could occur at start up and with anaerobic conditions. If adequate oxygen was not maintained in the system, anaerobic bacteria would produce end products which were surface active materials so that foaming usually accompanied odor. Although foaming could be controlled with antifoam agents, the best way for foam control was to add more oxygen, either in free form or chemicals, to the wastes.

McKinney (15) also reported that nitrification-denitrification processes occurred in the same ditch system. As the system developed a good nitrifying bacteria population, the ammonia nitrogen was converted to nitrates. The nitrates acted as an oxygen reserve and prevented anaerobic conditions until denitrification occurred if the system did not have enough oxygen for total oxidation.

Scheltinga (20) noted that during the winter operation of the ditch, the pH was slightly lower than in summer, probably due to movement of the interaction of nitrogen compounds in the direction of nitrates.

Review of the literature showed that the use of oxidation ditch systems for animal waste treatment did provide satisfactory pretreatment prior to ultimate disposal. In general, this system provided stabilization of the animal wastes as well as elimination of odor and nuisance problems.

DESCRIPTIONS AND PROCEDURES

Field studies, both of an anaerobic digestion system and an oxidation ditch system, were conducted at the Beef Cattle Research Center of the Department of Animal Science and Industry at Kansas State University.

Anaerobic Digestion System

The system was designed as diagrammed in Figure 1. The building, which was enclosed on three sides, was divided into 20 pens for a total of 20 cattle in each. An outside feeding lot located at the south side of the building was also penned and served as a control unit. The digester measured 7 by 7 feet inside with a liquid depth of 8 feet. It was sealed and equipped with a 6" cast iron pipe which extended below the liquid surface for sampling and a 1" pipe connected to a gas meter for gas measurement. The contents were continuously mixed by an external electric motor. Overflow was into a 1,500 gallon septic tank so that a constant waste level in the digester could be maintained. The loading pit, with its bottom sloped to the digester, was 4 feet wide and 6 feet long. A 3 foot high opening between the loading pit and the digester was controlled by a wooden plate to adjust the loading rates.

Manure was scraped weekly into the loading pit while urine drained off or evaporated from the pens. A concrete slab was constructed between the building and the system for additional storage if the loading pit could not hold

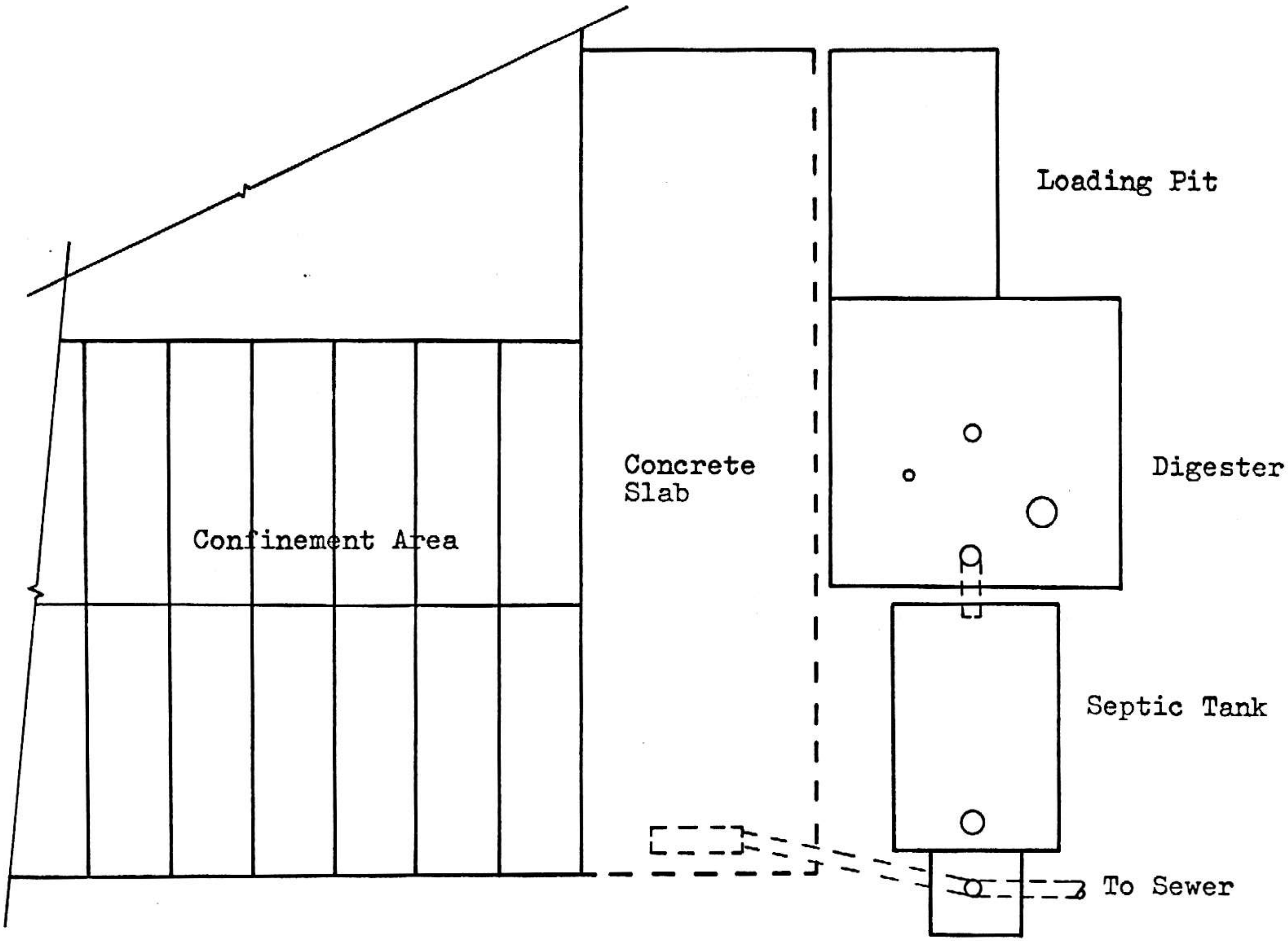

Figure 1. Schematic of Anaerobic Digestion System

the weekly manure. The septic tank overflowed into a 2' by 2' by 1½' sample pit which was connected by a drain from the concrete slab to a sewer. The area was graded to prevent rain or storm water from entering the digester.

Twenty cattle averaging about 700 lbs were placed in the building in December 1969 until taken off at market size in March 1970.

The feed ration, containing 98 percent sorghum grain, 1 percent salt, 0.5 percent urea and 0.5 percent limestone, was constantly fed throughout this first trial. The ingredients of the feed formula are given in Table 8. Grain varied with urea added to keep rations isonitrogenous at 12 percent on dry matter basis.

During the second trial, starting in July 1970, twenty cattle averaging 738 lbs were housed. The cattle were divided into groups and fed different rations in different periods for metabolism research. The ration and its ingredients are given in Table 9.

Samples were collected at random intervals, often twice a week, from the digester shortly after it was started into operation and the study was continued through May 1970 during the first trial. Sample collections for the second trial, starting in July 1970, were reduced to once a week.

Before putting in manure, the digester was filled with tap water, and no seeding was attempted. At the end of winter operation, the mixed liquor was pumped out and

Table 8.- The Ingredients of Ration, Anaerobic Digestion System (Dec. 1969-May 1970)

Ingredients		
Sorghum Grain		98.00 %
Salt		1.00 %
Urea		0.50 %
Limestone		0.50 %
Chlorotetracycline		7.80 mg/kg
Vitamin A		1653.00 IU/mg
Trace Mineral Premix		0.05 %
Manganese	4.40 %	
Iron	6.60 %	
Copper	1.32 %	
Cobalt	0.23 %	
Iodine	0.30 %	
Zinc	5.00 %	
Magnesium	20.00 %	
Sulfur	2.70 %	

Table 9.-Analysis of Rations, Anaerobic Digestion System (July - Sept. 1970)

Rations (%)	% H_2O	1*	2*	2A*
Silage Corn	65	60	51	51
Sun Cured Alfalfa	10	16	13	13
FL Milo	18	20	32	30
Prot. Supp.	10	4	4	4
Fat	2	0	0	2
Ingredients				
N E. M		41.50	47.20	50.00
N E. P		25.20	29.40	31.10
Crude Protein		8.50	8.57	8.43
Digestible Prot.		6.04	6.16	6.05
Air Dry C.P		13.80	12.98	12.70
Air Dry D.P		9.81	9.33	9.12
Calcium		0.56	0.51	0.51
Phosphorus		0.20	121.00	121.00
Crude Fiber		10.24	8.98	8.93
Dry Matter		55.40	59.40	59.70
Air Dry Feed		61.50	66.00	66.33
Fat		2.00	2.11	4.11

1* Starting Ration (July - August 15 1970)

2*, 2A*, A total of 20 cattle with 10 animals on each ration.

the digester was refilled with water for summer operation.

Sampling for laboratory analysis was performed by collecting the mixed liquor at the mid-depth of the digester from the 6" sample pipe. Temperature at the time of collection of the sample was recorded.

In order to evaluate the deviation of sampling distributions by mixing, total solids were determined once during the study for samples collected at six different points varying in depth throughout the digester.

Through laboratory analyses, the quality parameters of the mixed liquor were measured for pH, alkalinity, volatile acids, various forms of solids, chemical oxygen demand and nitrogen determinations of total nitrogen and ammonia.

Oxidation Ditch System

The building was 112 feet long, 28 feet wide with the same open end at the south side as the building in the anaerobic digestion system. The center workspace divided the building into two parts, each containing 20 pens with an independent oxidation ditch system under the slotted floor. Only the south side of the system was operated in this study. Figure 2 is a plan view of the oxidation ditch. It was a racetrack type ditch, with two aeration rotors run continuously at the mid-parts. It measured 108¼ feet long, 5 feet wide, and 4 feet deep. The ditch contents overflowed through a standpipe which maintained the liquid depth at 14 inches, giving a total of 1,238 cubic feet of liquid

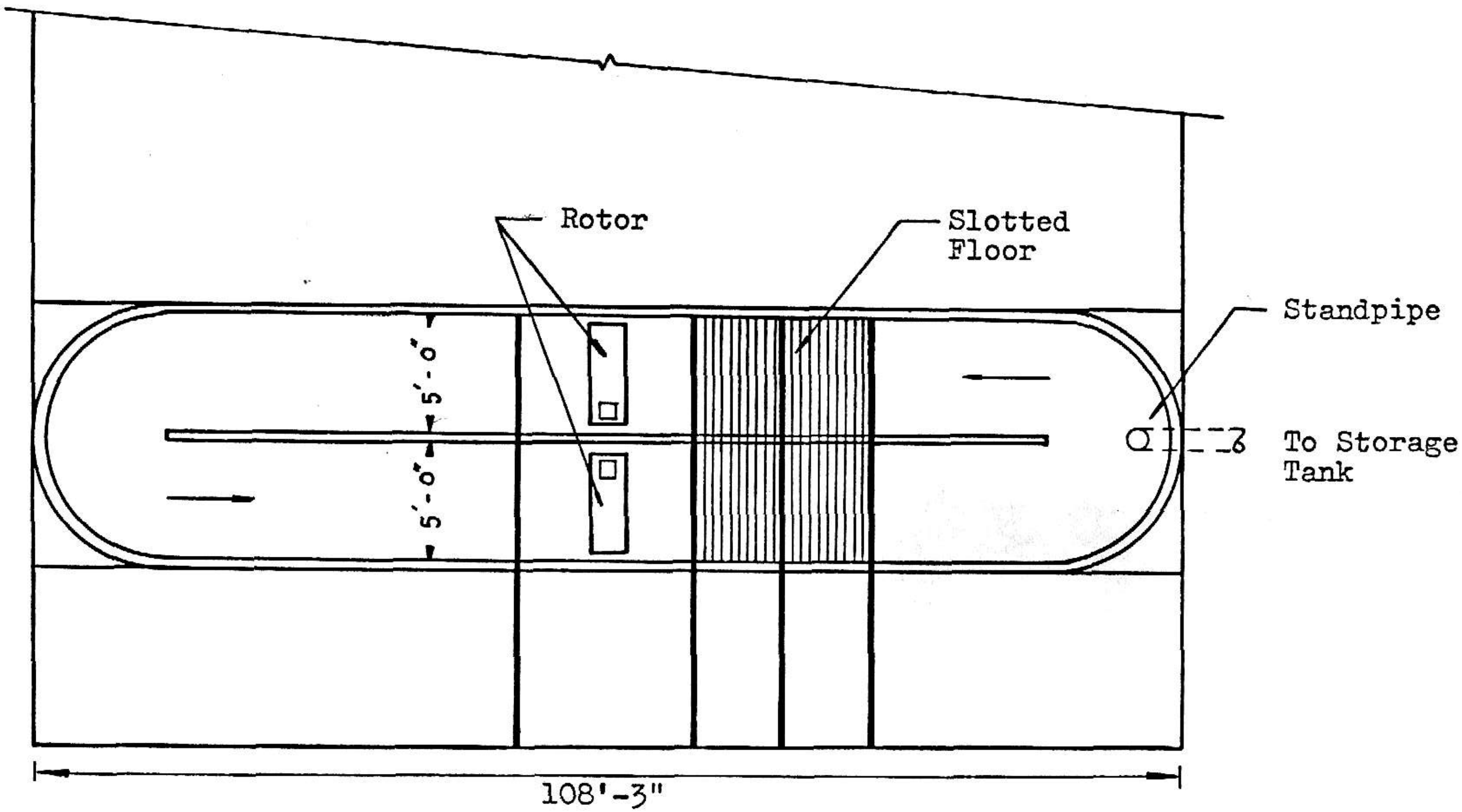

Figure 2. Plan View of the Oxidation Ditch System

volume. The rotors, each driven by a 2 HP motor, were operated at 200 r.p.m. and immersed 3 inches into the waste.

The cattle were housed in this building in December 1969 and the oxidation ditch had to be started into operation at that time. Unfortunately, during the start up period, the temperature was below the optimum range for starting. The south side of the building was open and no efforts were taken to prevent the ditch from freezing.

Severe foaming appeared in the ditch during the first three weeks, indicating the system was unable to develop an active aerobic bacterial mass. The decision was made to stop the rotor after four weeks of operation. The cattle were taken out at market size in April 1970. During this period, manure dropped into the ditch through the slotted floor and underwent anaerobic decomposition.

The operation was started again when 20 calves were placed in the building in July 1970. Before restarting the rotors, water was added to the ditch to dilute the accumulated manure to a workable level. The aeration system caught up soon after startup without any trouble.

The rations, with 5 animals on each ration, contained 90 percent sorghum grain, 10 percent alfalfa haylage, and 1 lb per head daily protein supplement. The ingredients of the rations are shown in Table 10.

Table 10.- Analysis of Rations, Oxidation Ditch System

Sorghum Grain	90 %
1. Dry Rolled Sorghum Grain	
2. Reconstituted Sorghum Grain	
3. Steam Flaked Sorghum Grain	
4. Popped Sorghum Grain	
Alfalfa Haylage	10 %
Protein Supplement	1 lb/head/day

Precent	(1)*	(2)*
Urea	17.2	21.9
Salt	12.9	12.9
Limestone	12.9	12.9
Trace Mineral	1.25	1.25
Vitamin A	0.44	0.44
Milo	54.51	49.81
Aureo Fac 10	0.8	0.8

(1)* Added with reconstitued sorghum grain
(2)* Added with dry rolled, steam flaked, and popped sorghum grain.

During the study, weekly observations and measurements were made in the field for the presence or absence of odor and foam in the system, dissolved oxygen, oxygen uptake rate, waste temperature, and water comsumption. Samples were also returned to the laboratory for analysis.

The dissolved oxygen measurements were made by reading a Precision Scientific Galvanic cell oxygen analyzer at the points in front of the rotor, mid-way of the ditch, and just behind the rotor. Temperature, at the same time, was also recorded. Since the dissolved oxygen in the wastes varied with liquid depth, the dissolved oxygen was measured as closely to the bottom of the ditch as possible. The precision of the dissolved oxygen measurements, considering the high solids content of the mixed liquor, might be questioned, however, it was of little importance since it indicated that aerobic conditions occurred.

The oxygen uptake rate on samples of mixed liquor, from the ditch, were determined in the following manner. At the same time that the dissolved oxygen measurements were made, samples were taken and put into a 1,000 ml flask and the dissolved oxygen content was increased by shaking it vigorously. The sample was then poured into a BOD bottle and allowed to overflow until air bubbles were expelled. The dissolved oxygen reading versus time was recorded by means of a Precision Scientific probe and the uptake rate determined from the data. The time delay of several minutes between sampling and testing most likely had some effect on this measurement (21,22). However, it was felt that this was the only possible way to evaluate the oxygen uptake of the wastes at the same time that the dissolved oxygen measurements were taken in field. Since the oxygen uptake rate affects the dissolved oxygen concentration, it is desirable to have these measurements made at the same time.

Laboratory analyses were made for pH, alkalinity, various solids determinations, chemical oxygen demand of mixed liquor and the soluble fractions, various nitrogen determinations of ammonia, nitrate and total nitrogen. General microscopic examinations were also made of the various types of microbes.

Laboratory Procedures

PH

PH values were obtained by using a pH meter, Corning model 7.

Alkalinity

Alkalinity was determined by titration with 1/50 N sulfuric acid to a pH of 4.5. The end point was measured with a pH meter during the titration. Normally a 50 ml sample was used. Since the mixed liquor at the end of the period had a high solid content, a 10 ml sample made up to 50 ml with distilled water was titrated. The results were expressed as mg/l as calcium carbonate.

Volatile Acids

Volatile acid determinations were obtained by the method described in Standard Methods for the Examination of Water and Wastewater (23). The results in mg/l were expressed in terms of acetic acid. Although the normalities of basic alcohol titrants decreased with time by the appearance of a white precipitate as mentioned in Standard Methods (23), volatile acid determinations were made only for ordinary process indications. Such changes are said to be nonsigificant according to Standard Methods (23).

Solids

Solids determinations included total solids, total volatile solids, and settleable solids.

Total solids were determined by drying a 100 ml sample in a crucible at 103 °C for 24 hours.

Volatile solids were determined by igniting the crucible with the solids retained after the total solids determinations in a muffle furnace at 600 °C for one hour.

Initially, suspended solids determinations were tried by using the membrane filter technique, either with an undiluted sample or with a diluted sample. Even with No. 40 Whatman filter paper, a 5 ml sample was impossible to filter. With a diluted sample, the experimental error was sigificant.

It was decided to determine suspended solids by centrifuging. A 10 ml sample was centrifuged for 5 min., solids were washed into a tared crucible, while the liquid portion was taken for filtration by using the membrane filter technique. The solids retained in the filter paper, if any, were also dried at 103 °C in order to account for the deviation of error in this method.

Settleable solids were determined by allowing a 1,000 ml sample to settle in a 1 liter graduated cylinder. The volume occupied by the settleable solids in 30 min. was recorded.

Chemical Oxygen Demand

Samples from the mixed liquor were so strong that a 1:100 dilution was necessary to perform the COD test according to Standard Methods (23). A 10 ml large opening pipette was used to pipette the samples mixed by magnetic stirring for this dilution. Soluble COD was also run on the samples after removing solids from the mixed liquor in the oxidation ditch system.

Nitrogen

Ammonia nitrogen was determined by the Direct Nesslerization Methods as described in Standard Methods (23) with 1:20 dilution of samples. Colors were measured by use of a Coleman Spectrophotometer, model 6C.

Total Kjeldahl nitrogen was determined by the Micro Kjeldahl Method by digesting a 5 ml sample of a 1:20

dilution. Ammonia produced was determined by following the same procedures as ammonia nitrogen determinations.

Nitrates were obtained by the Brucine Method as described in Standard Methods (23).

RESULTS

Since each system represents a different type of treatment and objective, the results will be presented separately for the two systems.

It must be pointed out here, that most analytical techniques employed in this study were according to Standard Methods (23) which were developed for common sewage analysis. For strong and heterogenous waste, such as beef animal waste, the tests might be subject to some variation. For example, the anaerobic digester contents were continuously mixed. Although a statistical analysis with 99 percent confidence, indicated the solids concentrations did not increase with depth the standard deviation of the total solids in the mixed liquor was ± 1,750 mg/l or 1.4 percent at 124,000 mg/l level as reported in the data. A probable error, to take into consideration laboratory errors for COD determinations, was assumed as follows:

s_1 = Probable error in pipetting the sample
= 0.2 ml/10 ml x 100 = 2.00 %

s_2 = Probable error in dilution
= 5ml/1,000 ml x 100 = 0.50 %

s_3 = Probable error in pipetting the diluted sample
= 0.2 ml/10 ml x 100 = 2.00 %

s_4 = Probable error in pipetting the dichromate solution
= 0.1 ml/5 ml x 100 = 2.00 %

s_5 = Probable error in titrating
= 0.1 ml/15 ml x 100 = 0.67 %

$$s = (s_1^2 + s_2^2 + s_3^2 + s_4^2 + s_5^2)^{1/2} = 3.6 \%$$

Thus, the results representing analyses of samples from the two systems might be subject to as much as 5 % error.

Anaerobic Digestion System

Trial I (December 1969 - May 1970)

To start up a "no seed" anaerobic digester at sub-freezing temperatures, prolonged unbalanced conditions can be predicted. It can be seen from Figure 3 that liquid temperatures in the unit were 0 °C to 4 °C in January. After the manure was initially added to the unit in January, the pH decreased almost linearly from a high of near 7 to a low of 5.2 during the first four weeks. Although pH was down to this unfavorable level, no efforts were made to correct the situation. The temperature was increasing gradually until it reached 20 °C at the end of April. The pH remained around 4.3 through most times of the trial.

Figure 4 gives the alkalinity and volatile acids data. The more manure that was added to the unit, the more the alkalinity increased. This increased buffer capacity, however, was limited and was not able to buffer the volatile acids, which were increasing at a faster rate. This resulted in a continuous decrease of the pH to below 4.5. The volatile acids data showed the values increased from an initial concentration of 1,000 mg/l to a maximum of 47,280 mg/l in four months. It was believed that little methane bacteria action existed in the anaerobic digester. The drop in volatile acids as well as in the other parameters in March were due to mechanical troubles of the mixing motor. While no manure was added to the system in the last month of the operation, volatile acids concentration decreased to about 30,000 mg/l at the end of the study.

The concentration of COD (Figure 5) increased steadily soon after manure was added to the digester until it reached over 180,000 mg/l at the 19th week. This demand appeared to decrease only after no load condition had existed for about three weeks. The relatively high COD in supernatant portion also can be seen from the data. The mixed liquor settled poorly as the total solids reached about 7 percent. No test was run on the supernatant after that time.

Solids data are shown in Figure 6 and 7. Data indicated that solids followed the same trends as COD data. The total and volatile solids content of the mixed liquor reached 14 percent and 12 percent respectively at the end of the 21st week tests. Volatile solids ranged from 73 percent to 87 percent of total solids with most values falling at 77 percent in the first two months and averaging 81 percent in the remaining twelve weeks. Suspended solids with 84 percent being volatile averaged 59 percent of total solids.

The ammonia nitrogen concentration was 2,500 mg/l at the end of the study while total Kjeldahl nitrogen was around 8,000 mg/l.

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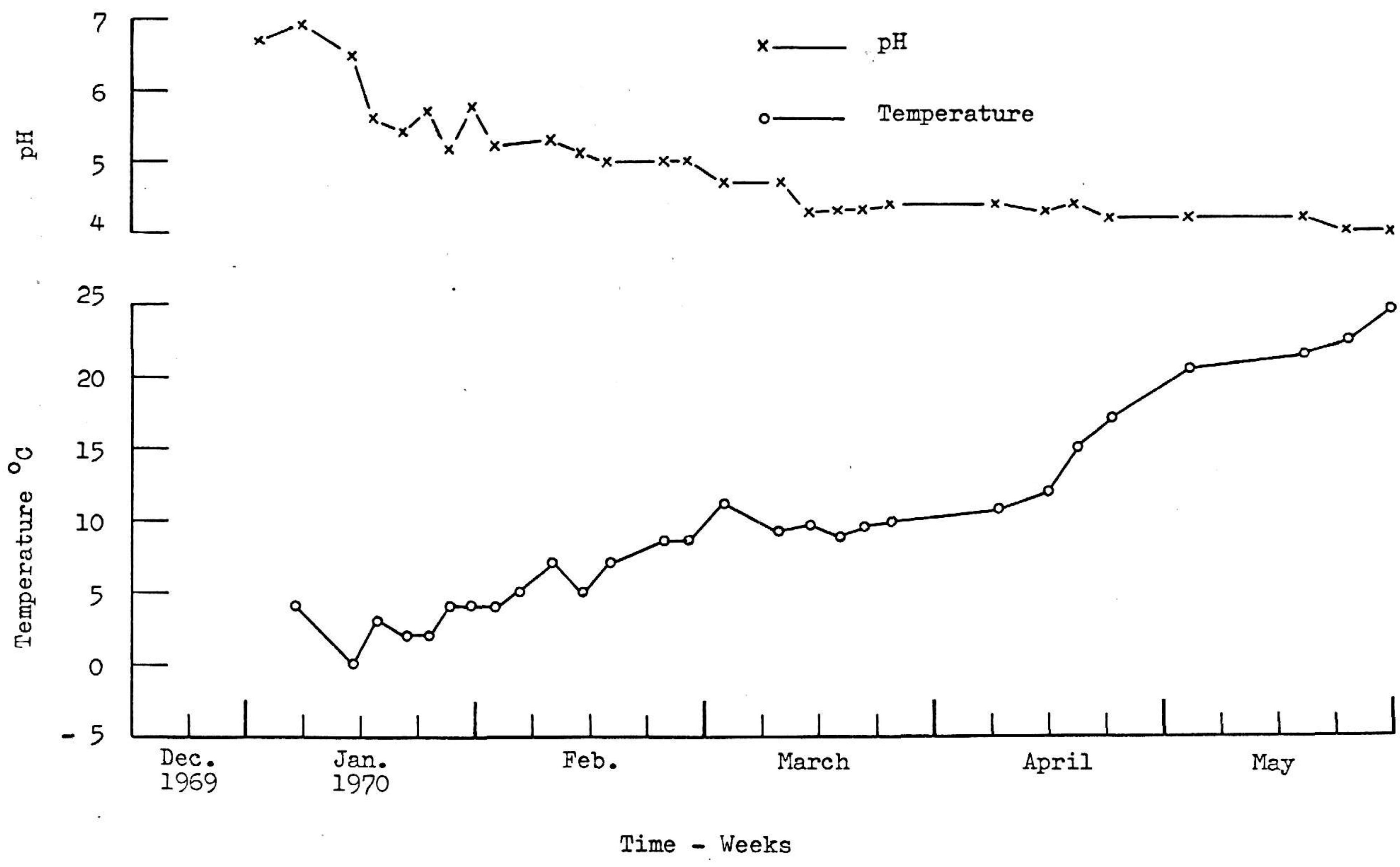

Figure 3. Temperatures and pH, Anaerobic Digestion System (Dec. 1969-May 1970)

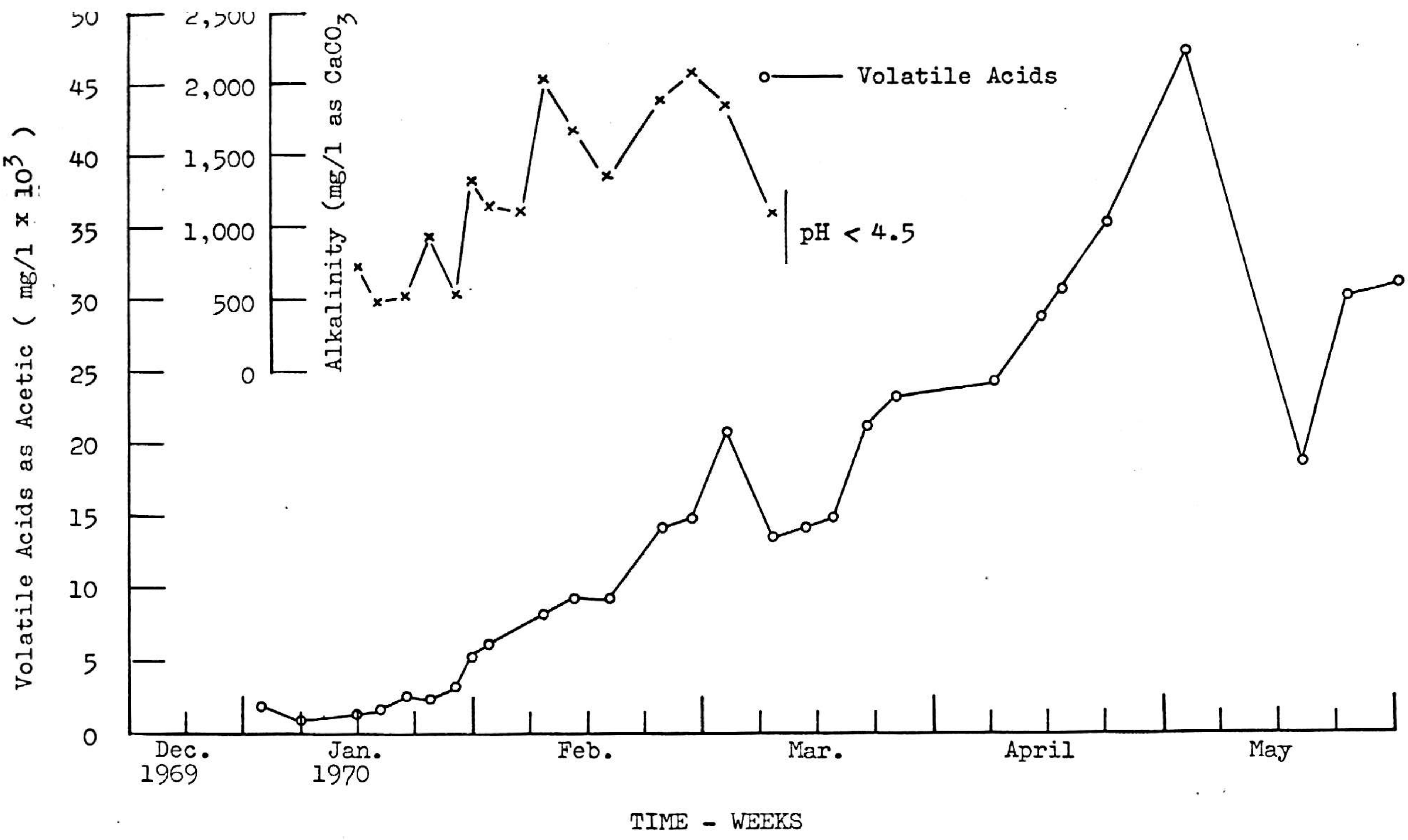

Figure 4.- Alkalinity and Volatile Acids, Anaerobic Digestion System (Dec.1969-May 1970)

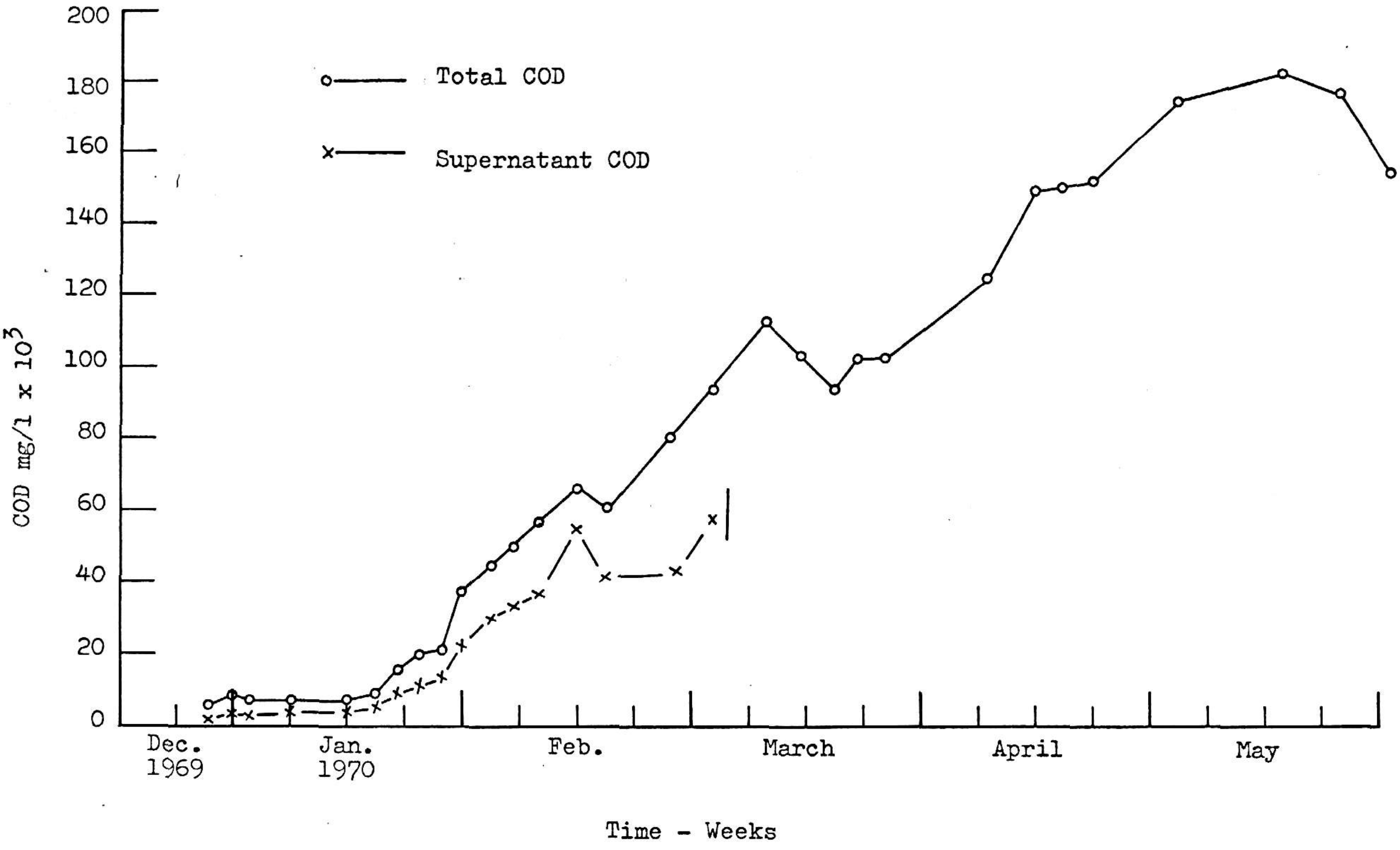

Figure 5. Chemical Oxygen Demand, Anaerobic Digestion System (Dec. 1969-May 1970)

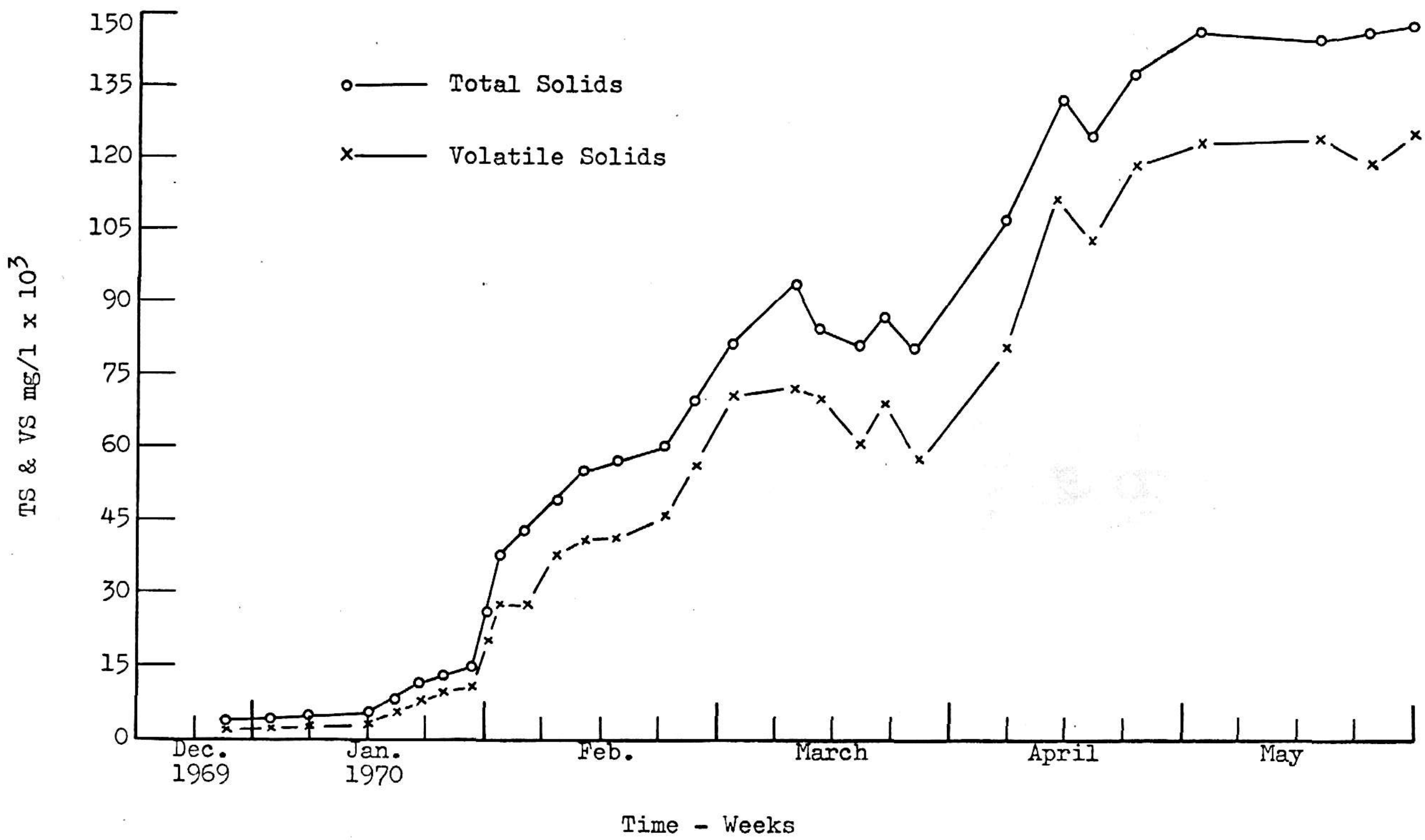

Figure 6. Solids, Anaerobic Digestion System (Dec. 1969 - May 1970)

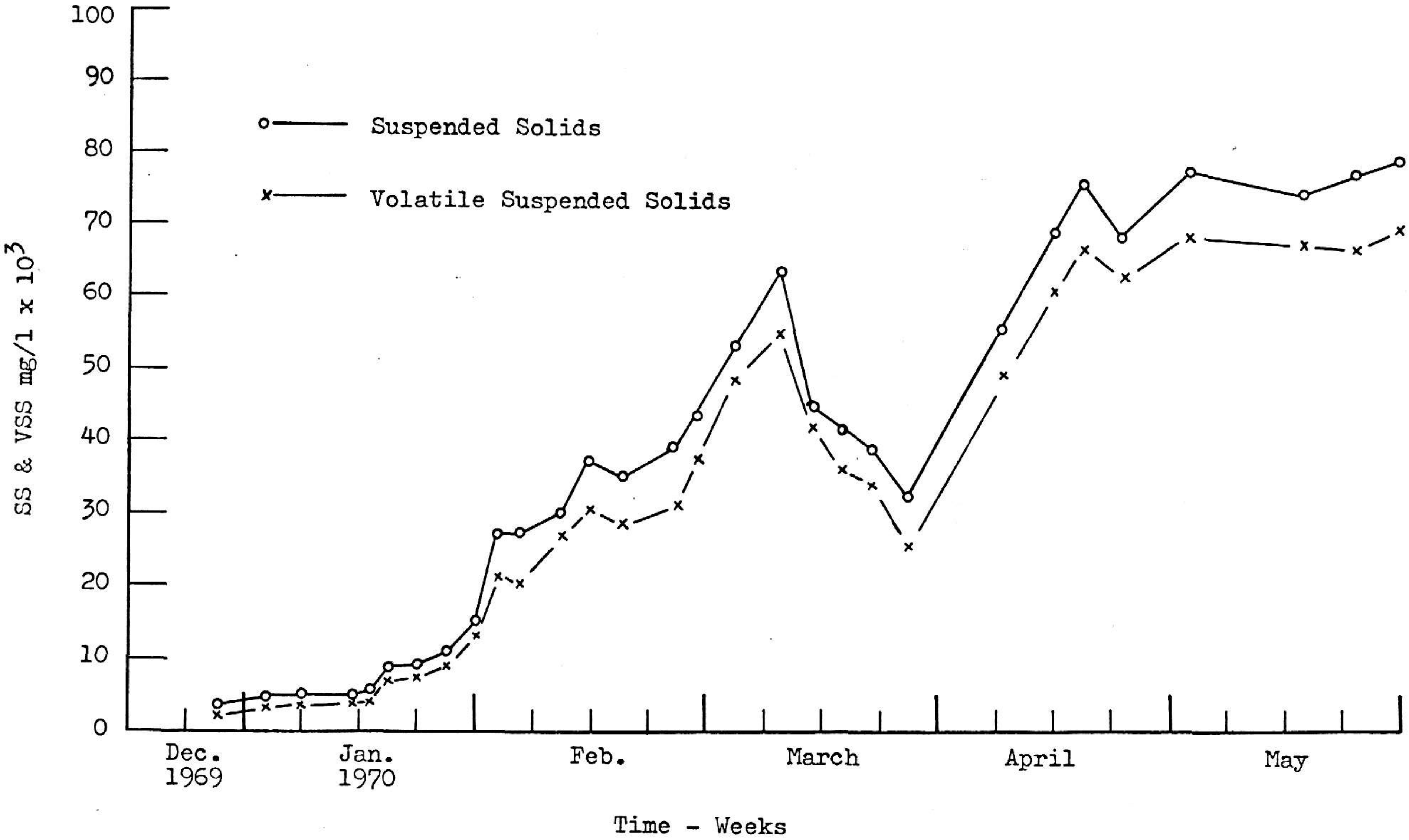

Figure 7. Solids, Anaerobic Digestion System (Dec. 1969-May 1970)

Trial II (July-September 1970)

At the end of the first trial, almost all of the contents in the anaerobic digester were pumped out, leaving a small portion of solids settled in the bottom of the unit. Tap water was added up to the overflow level. Prior to scraping the manure into the system, the contents were tested for pH, volatile acids, and alkalinity. The results are plotted in Figure 8.

Although a large quantity of water was added, the pH of the contents remained at 4.2, the same as at the end of the first trial. Initial volatile acids and alkalinity were 2,400 mg/l and 700 mg/l respectively. The theoretical amount of lime was added to try to raise the pH of the contents, but more volatile acids which were being produced resulted in the pH still remaining at a low level. A total of 136 lbs of lime and 150 lbs of ammonia phosphate was added during the 17-day period before manure was added. At the 17th day, the pH was 5.1 while the alkalinity and volatile acids were 4,875 mg/l and 17,760 mg/l respectively. It is believed that the solids left in the digester were still being actively decomposed resulting in production of volatile acids.

Tap water was then added to the system to displace the sour contents until the volatile acids concentration was reduced to 672 mg/l. This was before the manure was scraped to the anaerobic digester.

The cattle for this trial, being fed for metabolism research, produced a large volume of manure with different characteristics. As the manure was put into the loading pit, the upper portion of the manure in the pit dried and prevented the next week's manure from being washed by the mixed liquor into the anaerobic digester. No more wastes were loaded to the system due to this operational problem in September.

It can be seen from Figure 9 that although temperatures were above 25 °C during most times of this trial, pH still remained at low levels.

Volatile acids and alkalinity data are given in Figure 10. Volatile acids concentrations increased to over 14,000 mg/l in one month. In the second week of August, tap water was added to the system to try to solve the operational problem prior to the addition of more manure to the unit. This resulted in a decrease in volatile acids as shown in the data. A gradual increase in alkalinity from an initial concentration of 100 mg/l to a high of 2,700 mg/l did not provide sufficient buffer capacity to overcome the effect of acids being produced.

The COD values (Figure 11), which were low at start up, reached a peak concentration of 45,500 mg/l in two months. As no manure was added in September, this demand appeared to decrease. The COD in the supernatant, again, showed relatively high concentrations averaging 87 percent of the total COD.

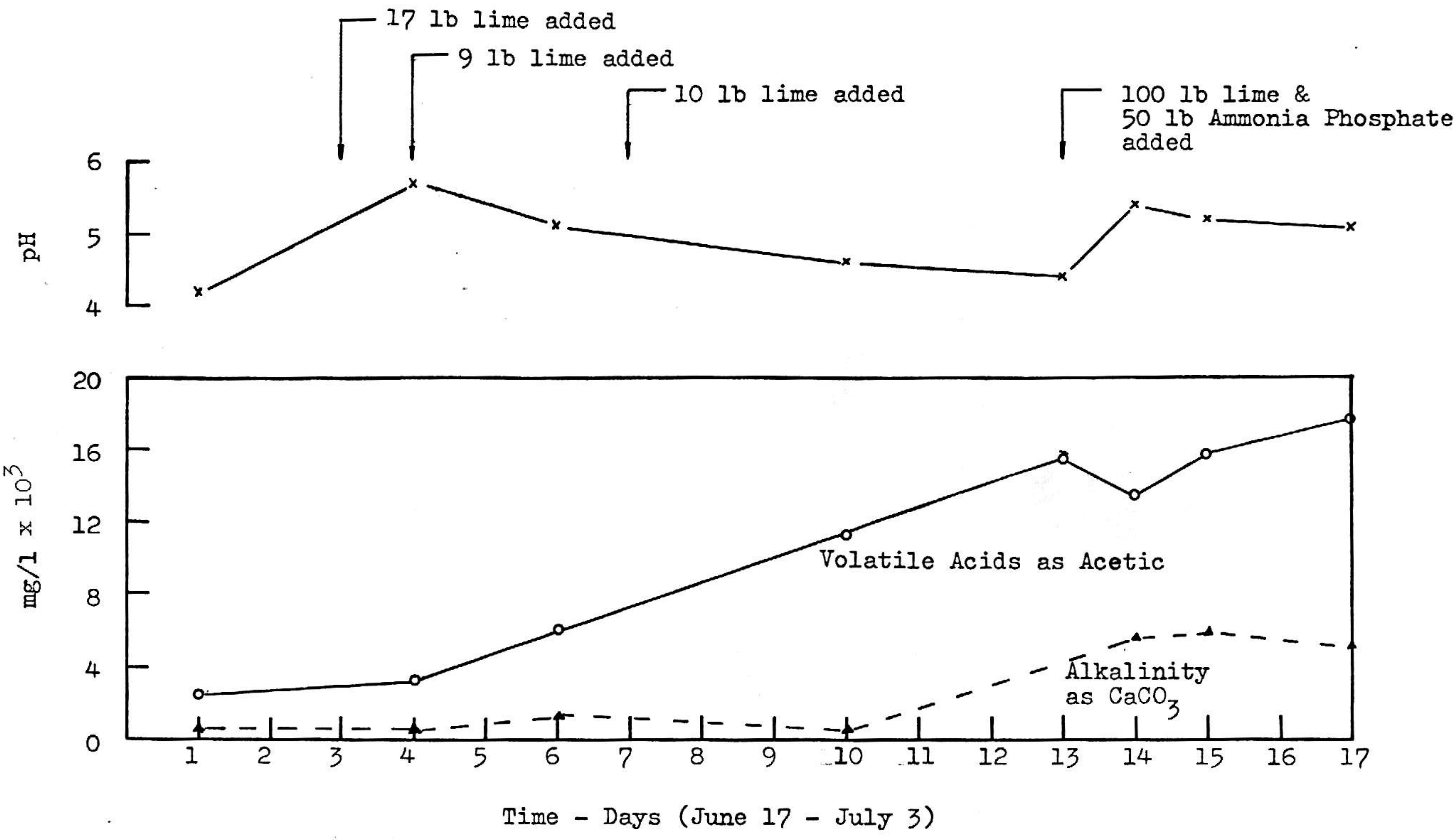

Figure 8. pH and Volatile Acids - Alkalinity Relationship, Anaerobic Digestion System (No-load period)

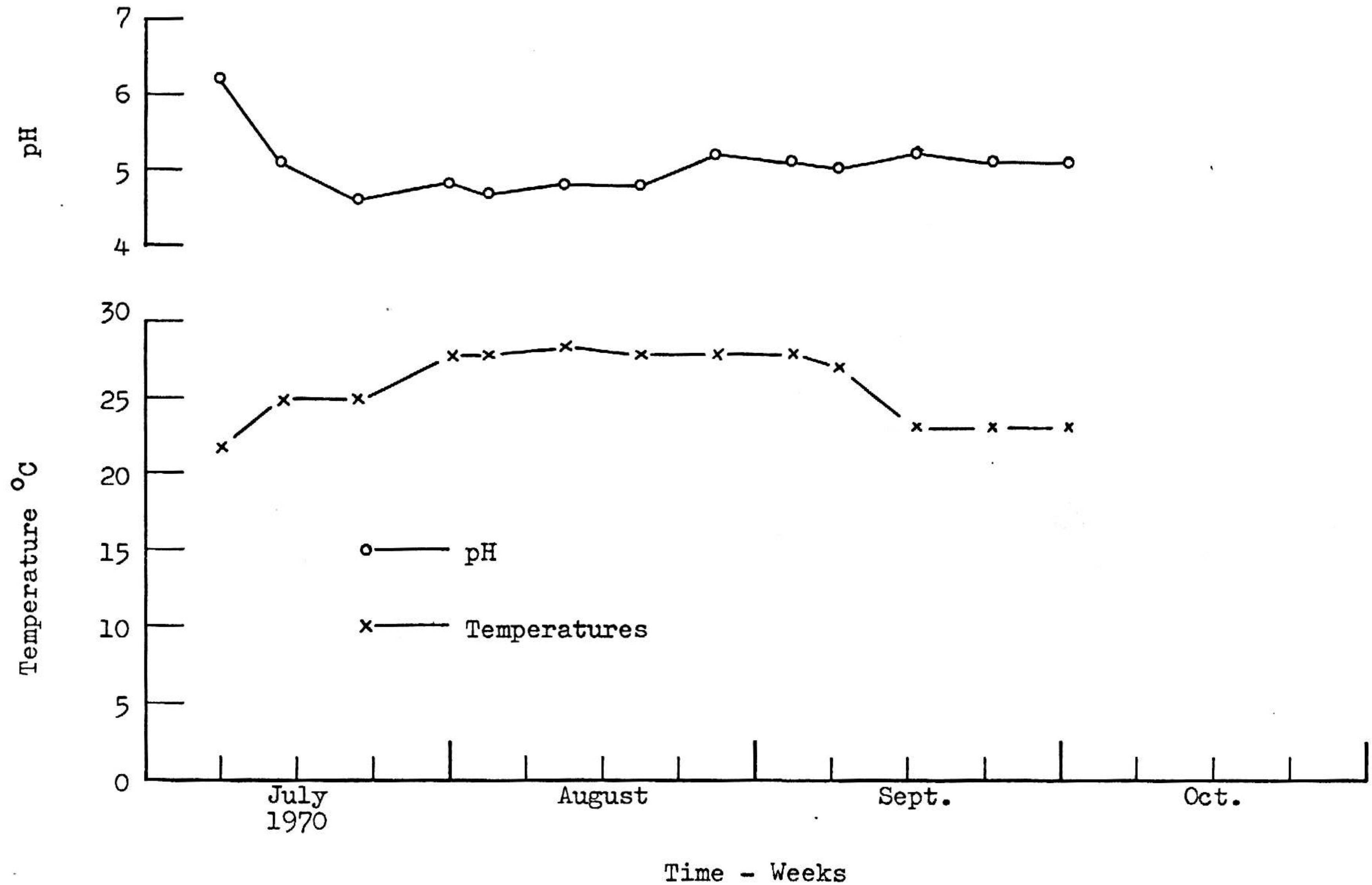

Figure 9. Temperatures and pH, Anaerobic Digestion System (July - Sept. 1970)

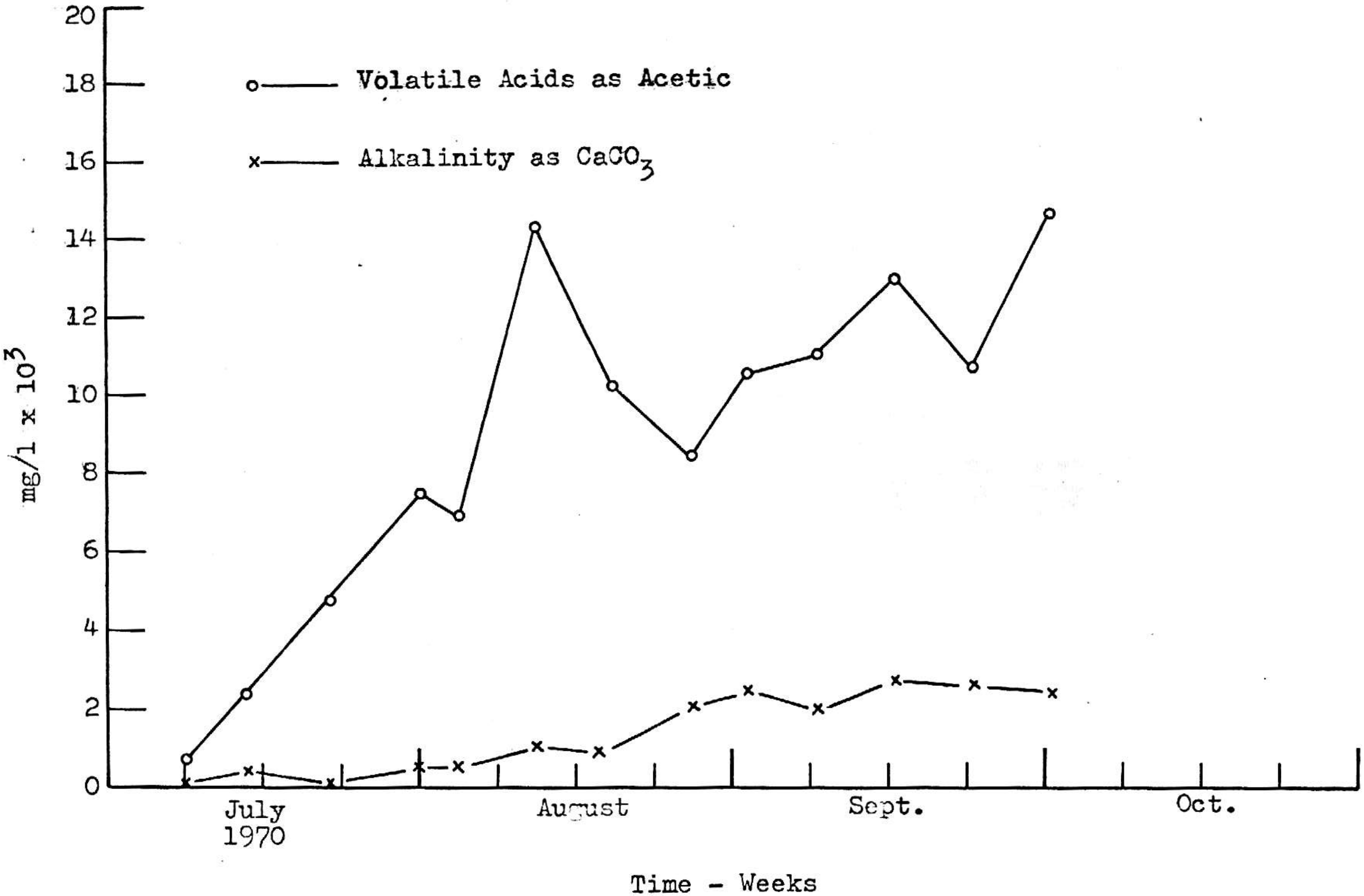

Figure 10.- Alkalinity and Volatile Acids, Anaerobic Digestion System (July-Sept. 1970)

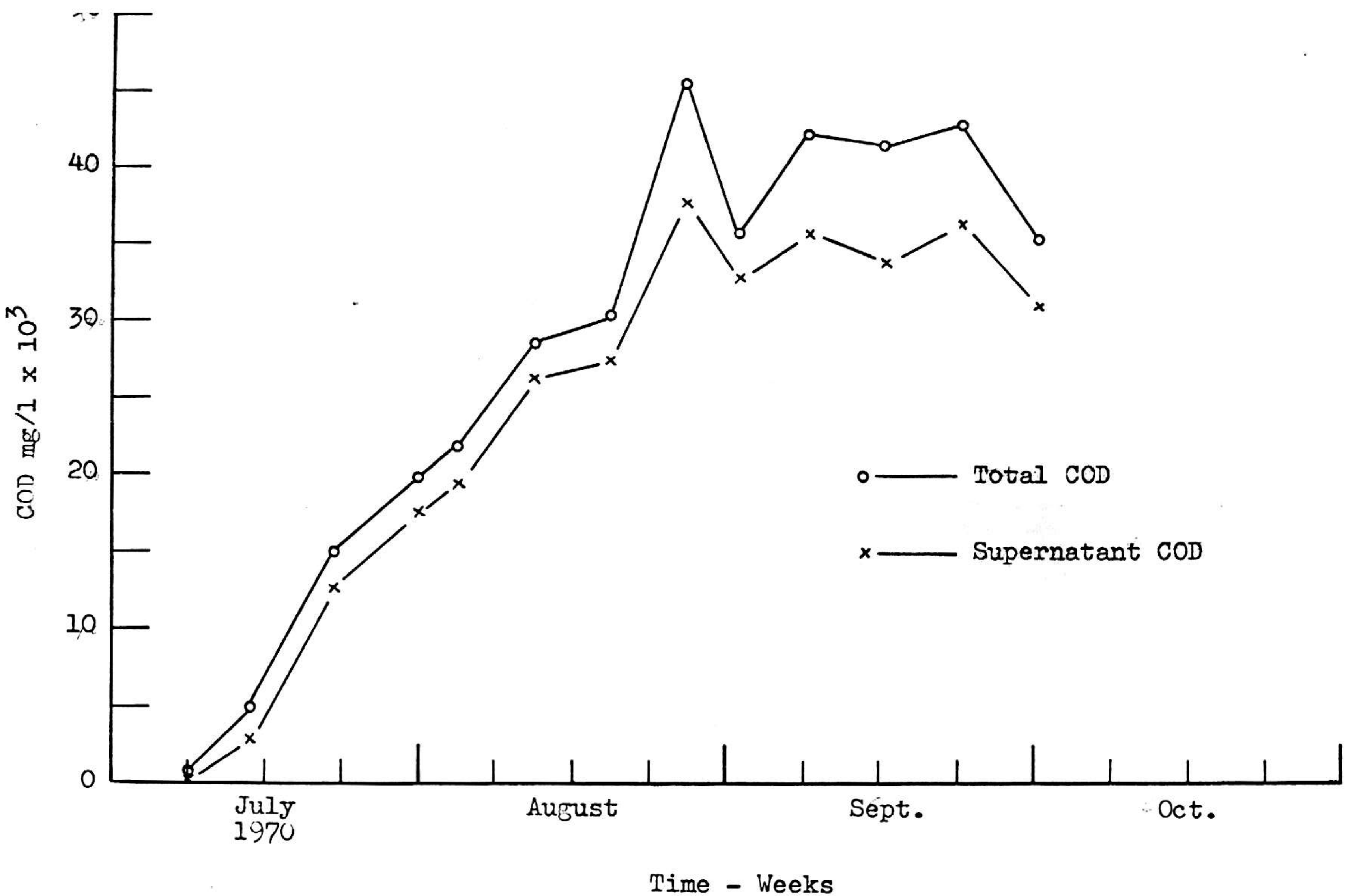

Figure 11. Chemical Oxygen Demand, Anaerobic Digestion System
(July-Sept. 1970)

Figure 12 and 13 present the solids data. Total solids increased from 1,000 mg/l to 23,000 mg/l in two months with 76 percent being volatile. Data on the suspended solids fraction showed that it averaged 50 percent of the total solids with most values being 86 percent volatile.

Ammonia nitrogen concentrations in the mixed liquor increased from less than 10 mg/l to 300 mg/l in this trial while total Kjeldahl nitrogen concentrations were near 1,000 mg/l at the end period.

<u>Oxidation Ditch System</u>

The initial COD concentration from the mixed liquor was 35,000 mg/l (Figure 15). This high value was due to the buildup of the accumulated manure produced during the winter time in the ditch. The initial COD dropped to 20,285 mg/l over a two week period. As more manure was produced and dropped into the ditch, the COD rose back to 33,760 mg/l through only a four day period. In order to obtain more uniform operation, some mixed liquor was wasted weekly by adding tap water to cause overflow. The COD concentration was reduced to around 26,000 mg/l in the beginning of August, then no further solids removal was done throughout the operation. As the system reached equilibrium conditions in August, the COD remained little changed at about 32,000 mg/l until it decreased to 25,000 mg/l on October 9, as the cattle were taken off on October 7. This high COD concentration was due to the buildup of non-biodegrable matter.

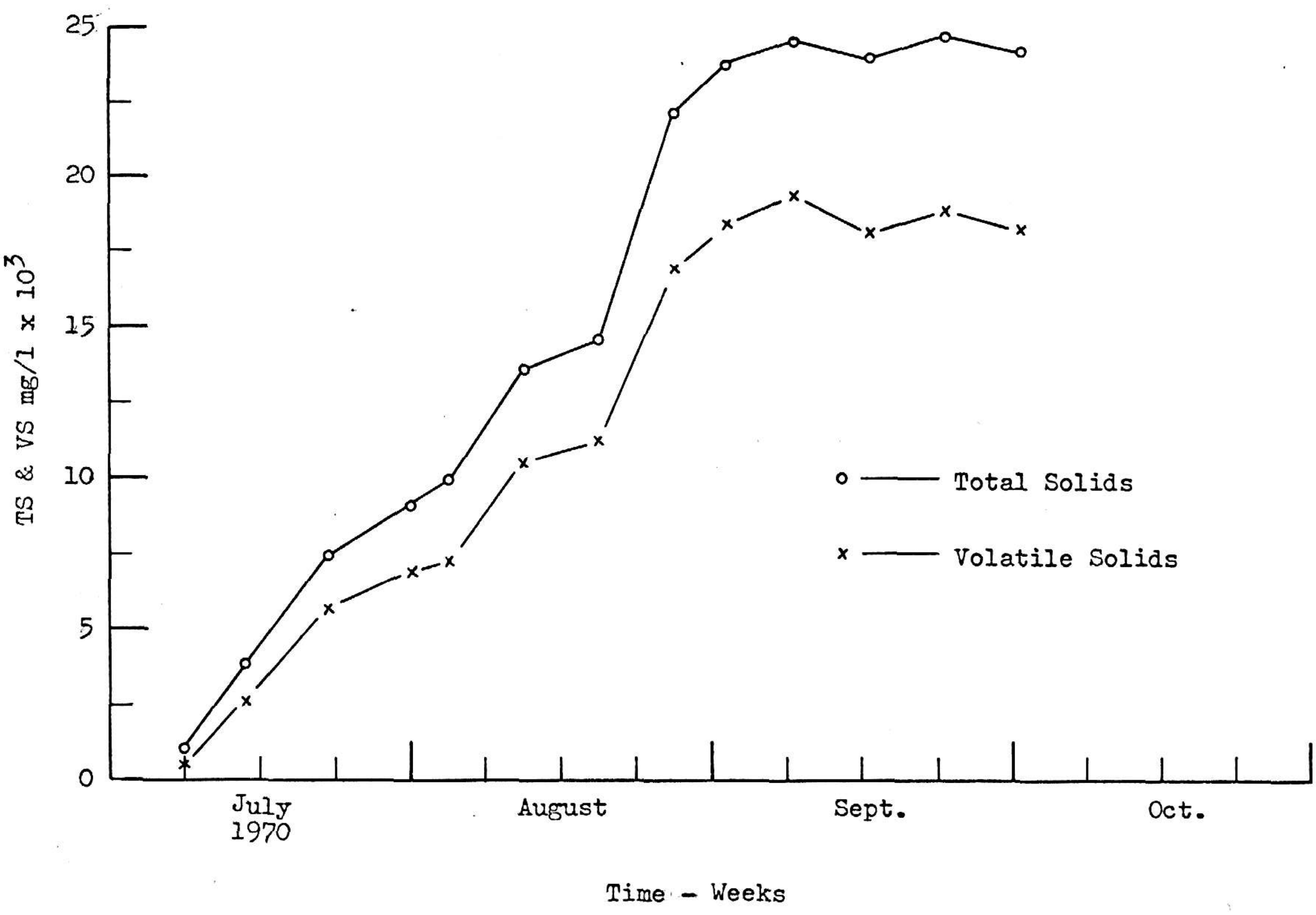

Figure 12. Solids, Anaerobic Digestion System (July - Sept. 1970)

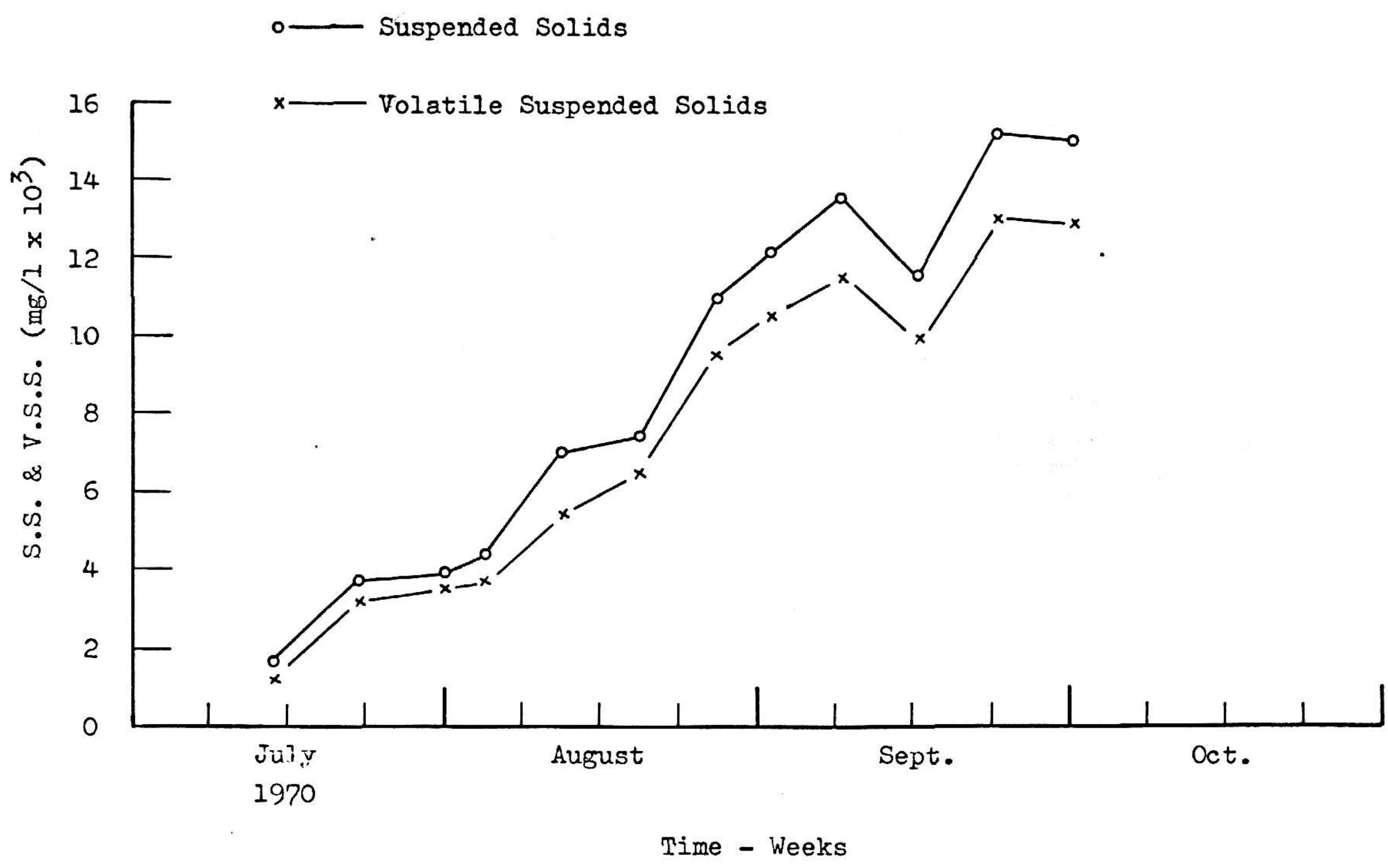

Figure 13.- Solids, Anaerobic Digestion System (July - Sept. 1970)

The soluble COD values being 2 percent of the total COD ranged from 500 mg/l to 800 mg/l with most values being about 650 mg/l. The soluble COD data indicated that the quality of the effluent from the ditch could be greatly improved by solids removal.

Solids data are plotted in Figure 16 and 17. The solids could not be separated upon standing prior to the start of aeration, due to the anaerobic accumulation of the manure in the ditch. Total solids as well as suspended solids showed an initial decrease after start up then rose steadily back to 40,000 mg/l and 35,000 mg/l respectively in the end of July. Further flushing in August reduced the solids to a more workable level. With the system in equilibrium state, the solids increased almost linearly with time. It can be seen from the data that between the second week of August and the end of September, the total solids rose from about 27,000 mg/l to 38,000 mg/l. Total volatile solids were 73 percent of total solids, while volatile suspended solids were 81 percent of suspended solids.

The dissolved oxygen data given in Table 11 indicated that the two aerators were capable of maintaining excess oxygen in the wastes. At no time did oxygen deplete at the point where the mixed liquor returned to the aerator. The aerators were submerged 3 inches in an overall waste depth of 14 inches. If the liquid depth were less than 14 inches,

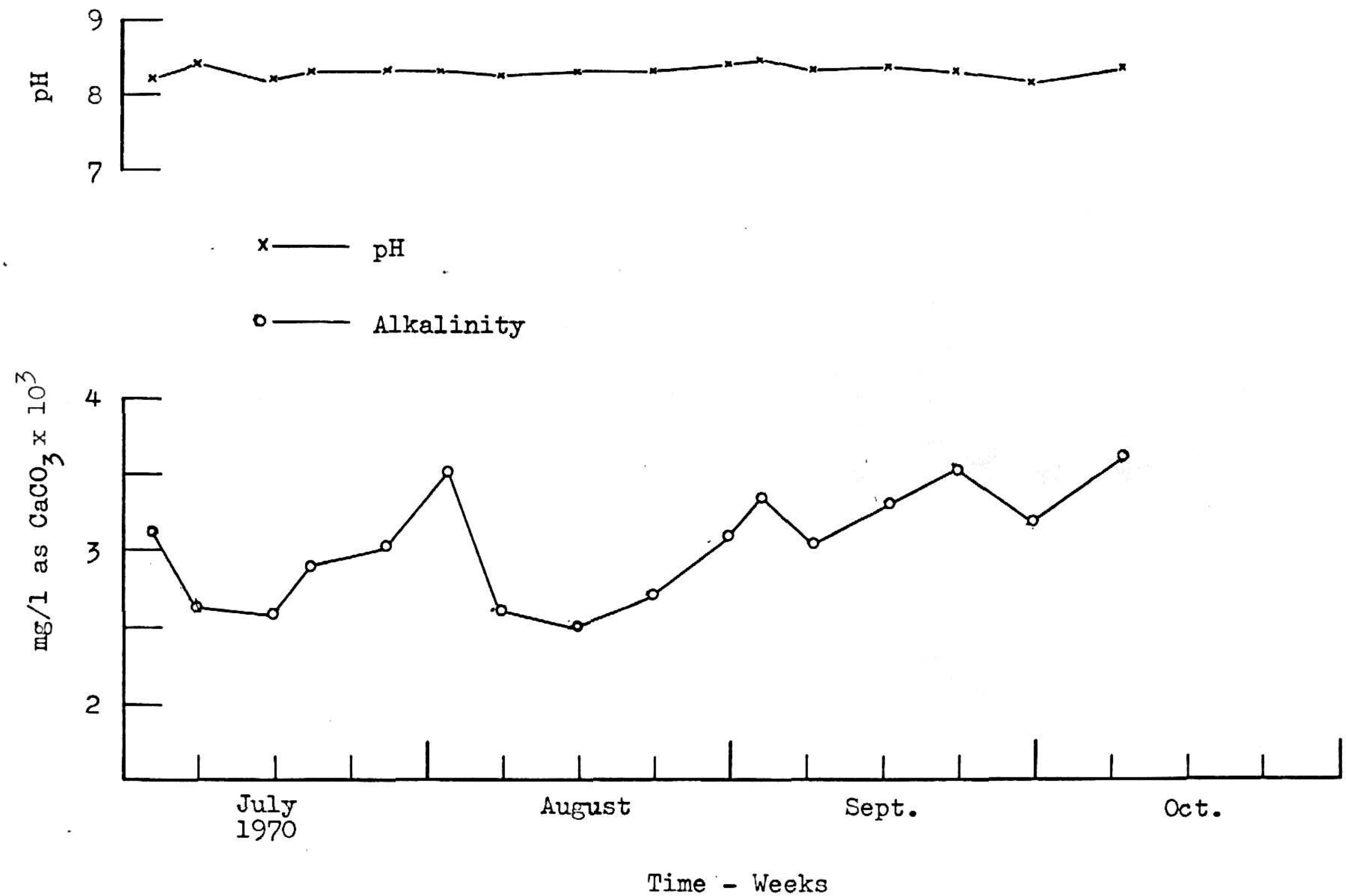

Figure 14. Alkalinity and pH, Oxidation Ditch System (July-Oct. 1970)

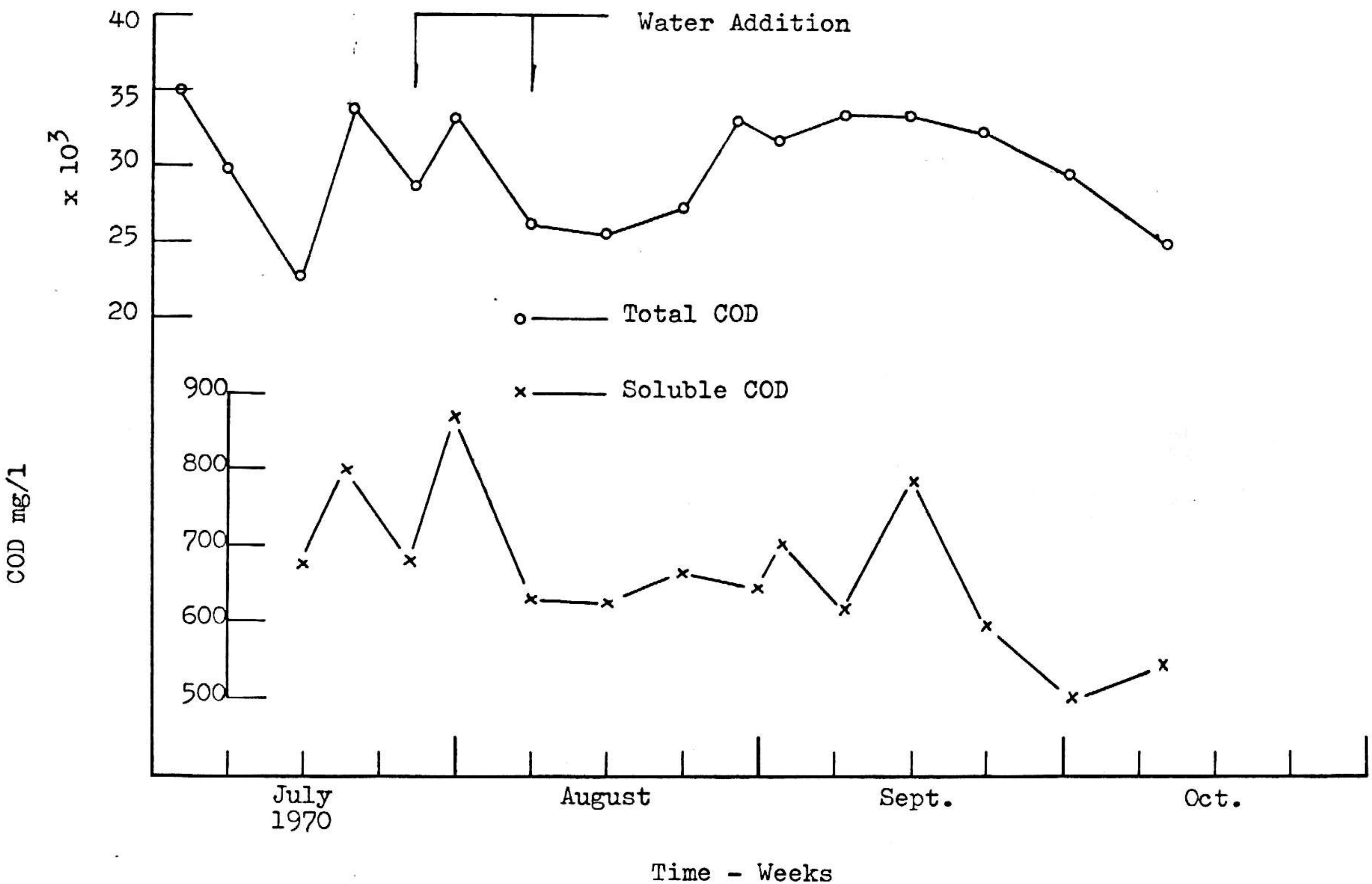

Figure 15. Chemical Oxygen Demand, Oxidation Ditch System

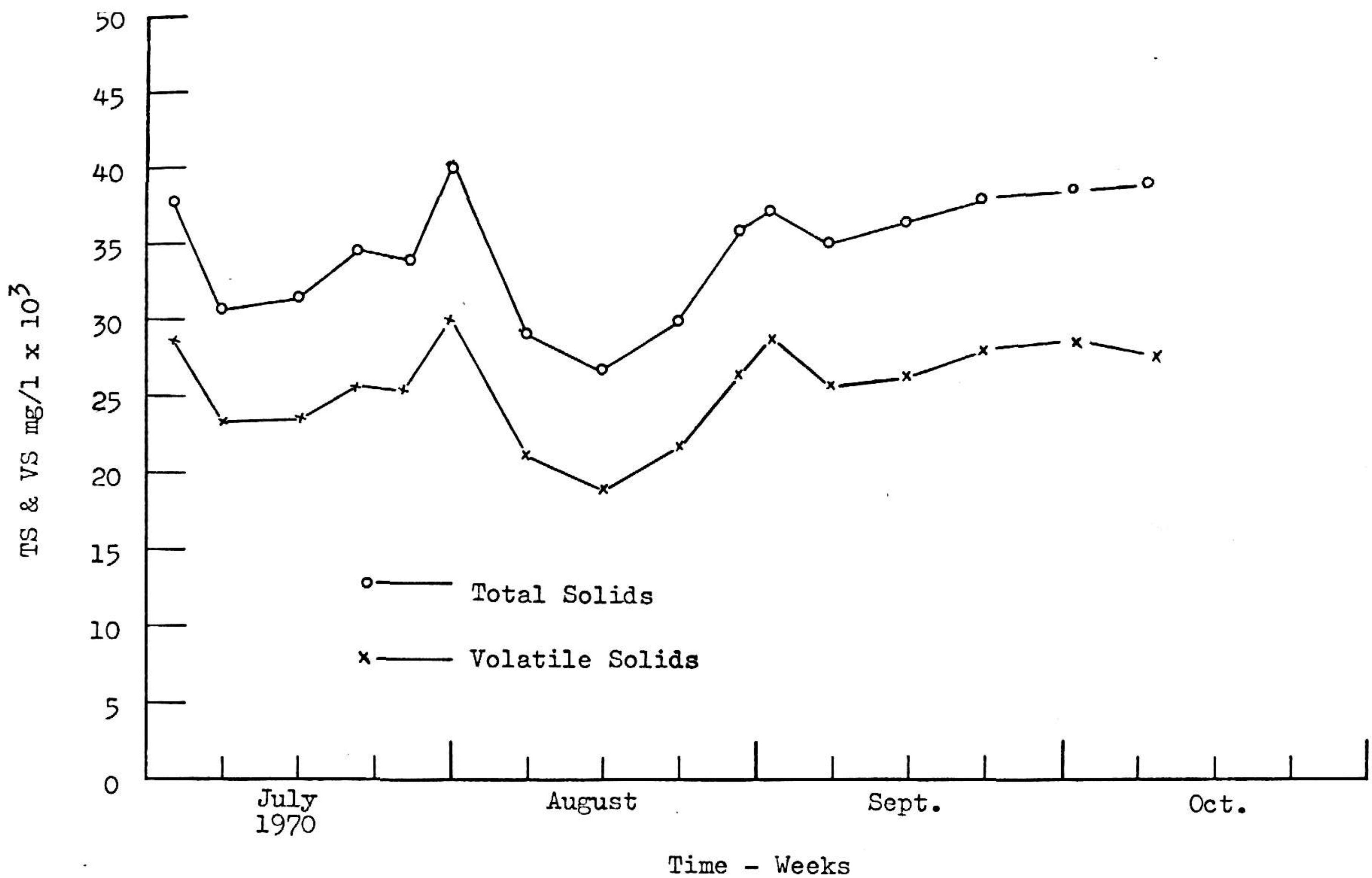

Figure 16. Solids, Oxidation Ditch System

Figure 17. Solids, Oxidation Ditch System (July-Oct. 1970)

then the rotor immersion depth could not be maintained at 3 inches and oxygen transfer would decrease. Summer operations caused a large water evaporation rate resulting in the need to add water frequently. Occassionly, enough water was not added to the ditch, causing a reduction in the oxygen transfer efficiency of the aerators. Dissolved oxygen in the wastes in front of the rotors showed about 3 mg/l twice during the sampling periods. Actually, anaerobic conditions were observed by dissolved oxygen measurements at the corners and at the edges of the ditch where waste velocities were greatly reduced due to high solids content in the ditch. However, data showed that oxygen did exist at all times in the major path of the flow.

Oxygen uptake rates averaged 43 mg/l per hour during the sampling periods and are also presented in Table 11. The lowest value of 21 mg/l per hour at the end of the period was due to the "no load" conditions. Normally as oxygen uptake rates decrease, there should be an increase in dissolved oxygen level in the system. The data didn't show this, probably because of the sampling variations. This variation in the analysis was mainly caused by the high solids contained in the mixed liquor. However, the oxygen uptake rates data indicated that this activated sludge system was functioning properly in spite of this variation.

Table 11. Oxygen Data, Oxidation Ditch System

Date	Dissolved Oxygen (mg/l) Front	Midpoint	Back	Oxygen Uptake mg/l/hr.	Temp. °C
7-14	5.6	4.0	2.8	24.0	24.0
7-17	5.6	4.1	0.8	45.0	22.5
7-24	5.7	1.7	1.0	60.0	20.5
7-30	4.4	1.4	0.4	37.1	25.0
8-6	4.7	3.8	1.5	56.4	26.0
8-13	6.8	5.8	0.8	63.4	22.5
8-20	4.0	2.3	0.4	33.0	21.5
8-28	5.6	3.2	1.4	40.6	21.0
9-1	3.3	1.9	0.5	37.2	23.6
9-8	6.4	4.8	1.6	67.2	19.4
9-15	5.5	2.8	1.1	24.4	19.2
9-22	2.7	1.8	0.9	54.1	20.0
9-29	7.5	5.0	1.8	45.0	15.0
10-9	8.4	7.0	4.9	21.0	10.0

Routine microscopic examinations of the sludge revealed that the protozoa, either stalked ciliates or rotifers, were present at all times in the mixed liquor samples except in the September 22 sample in which dissolved oxygen was only 2.7 mg/l in the wastes in front of the rotor and depleted faster along in the ditch. Rotifers appeared more often than stalked ciliates did. No sludge worms were found. The microscopic examinations comfirmed the dissolved oxygen data, indicating that the system was in good operation.

The nitrogen data in Table 12 revealed that most of the nitrogen in the mixed liquor existed as organic nitrogen tied up in the sludge cells. The total Kjeldahl nitrogen averaged 1,160 mg/l and changed little throughout the operation. In the aerobic biological process, the nitrogen in the biologically degradable organic matter, such as urine, was converted to ammonia by metabolic reactions. Since the pH of the mixed liquor was always around 8.3 and alkalinity was in high concentration (Figure 14), some ammonia was probably lost to the atmosphere as the flow was aerated by the rotors. The system developed a good nitrifying bacteria population and nitrification converted most of the ammonia to nitrate. No ammonia odor was present in the building during the operation. Data indicated that ammonia nitrogen concentrations were about 20 mg/l while nitrate concentrations were 44 mg/l during most of the times.

Table 12. Nitrogen Data, Oxidation Ditch System

Date	NH_3-N mg/l	NO_3-N mg/l	Total Kjeldahl Nitrogen mg/l
7-14	16.0	24.0	1,160
7-17	21.0	86.0	980
7-24	21.0	34.0	840
7-30	43.5	18.0	1,256
8-6	17.0	45.0	960
8-13	18.0	41.0	940
8-20	15.0	58.0	1,120
8-28	26.0	71.0	1,250
9-1	17.5	40.0	980
9-8	7.8	40.0	1,180
9-15	16.0	45.0	1,600
9-22	35.5	38.0	1,240
9-29	15.5	40.0	1,360
10-9	17.5	40.0	1,420

It was believed that anaerobic conditions existed in a small part of the ditch such as at the corners and along the side. Since the nitrate concentration remained nearly unchanged during the three months test, it was believed that denitrification was occurring at about the same rate as nitrification.

Since the confinement units are only partially over the slotted floor, the manure generated on the solid concrete floor did not contribute to the ditch loadings. However, it was observed that the major part of the manure produced was deposited into the ditch. With an assumption of 70 percent of the manure produced by one animal, containing 9 lb total solids, 7 lb volatile solids, and 8 lb COD added daily to the system, the theoretical calculation shows that this system achieved a reduction in total solids, volatile solids, and COD of 63.5%, 57%, and 64% respectively.

DISCUSSION

Anaerobic Digestion System

The steady increase in the volatile acids concentrations comfirmed that the metabolism of the solids by acid formers was continuous throughout the operation. The data demonstrated that even under low temperatures and low pH conditions, acid fermentation could still be achieved. The methane formers were severly inhibited by the low temperature and low pH conditions. If methane fermentation is a desirable goal, the doctrines such as pre-seeding, higher than amibent temperatures, and controlled conditions are necessary for the performance of this system. However, this is not the case of this study.

The COD continuously increased during the operation, indicating that the system was not in a balanced condition. However, the high oxygen demand materials in the supernatant portion indicated that much of the wastes were in the form of dissolved and fine solids. These partially decomposed solids would probably be easily metabolized and stabilized by further aerobic treatment. If the volatile acids are primarily in the form of acetic acids as would be expected, then about 20 percent of the total COD of the digester contents can be assumed to come from solubilization of solids.

Since the major objective of this study was solids liquification, it was felt that the solids data were the most meaningful. The data obviously reflected the effect of acid fermentations. Low percentage of suspended solids to total solids indicated that much of the solid material was solubilized. Since the solids had to be scraped into the digester, it can be assumed that there would be little initial dissolved material due to the low moisture conditions. These liquified wastes may have an advantage for land disposal as they would be more easily adsorbed by the soil layer where soil bacteria would play the role of waste stabilization.

Additional information is available to confirm the acid fermentation in this system. The percentage of volatile suspended solids to volatile solids in the winter and summer operations averaged 59 percent and 57 percent respectively. The ratio appeared to decrease with time through the operation. The ratio reveals that approximately 40 percent of the organic solids are in the soluble form.

Ammonia nitrogen concentrations above 2,000 mg/l are thought to inhibit the methane formers (6). However, in this operation, these high ammonia concentrations were not present until well after the inhibition occurred. In general, high ammonia nitrogen concentrations will provide a good buffer capacity to the system, but this can not be obtained by this operation because of the greater increase of volatile acids.

It was felt that only long run data could be used to adequately evaluate a system. Because of the operational problems encountered in the second trial, no evaluation could be drawn from that data. However, the results from trial II confirmed the effectiveness of the winter operation. Difficulties were experienced with some sludge retained as seed. The initial content of the anaerobic digester was high in volatile acids and low in pH. Sludge such as this only resulted in inhibition of the biological activites.

Generally, in the treatment of domestic sewage one of the most difficult processes to operate is the anaerobic digestion system. However, using the process of anaerobic digestion only for solids liquification, little attention need be paid to the performance of this system. In addition to solids liquification for a liquid handling system, the anaerobic digester can act as a solids holding system prior to land disposal. Although solids contents were up to 14 percent in the mixed liquid, no difficulty was experienced when the digester contents were pumped out.

It was demonstrated by this study that the intermittent manure additions to the system did not affect the acid fermentation. A system which can tolerate a shock loading is important for animal waste management.

Although the anaerobic digestion of beef animal wastes was satisfactory from the view of solids liquification, the effluent from the system was high in oxygen demanding materials, solids, and nutrients that could not be discharged to a receiving stream. Fortunately, the quantity of the effluent from a system as this was quite small since only little water was initially added to maintain the liquid level.

Oxidation Ditch System

This study has demonstrated that the oxidation ditch system provides a successful, odorless process for beef animal wastes treatment.

Foaming problems encountered in the startup period in the winter resulted in failure. Low temperatures appear to be a limiting parameter in starting the ditch. Indeed, there was some evidence that a good bacterial population was unable to develop when the ditch was started at low temperature (24). It was felt that if the ditch could be started at a warmer temperature to allow active organisms to develop and then adapt to the low temperature, the foam trouble could be eliminated. The building is open on one side which will result in winter freezing regardless of when the process is started. Although a three month's accumulation of manure was deposited in the ditch, no serious foaming occurred during the summer operation.

It would be desirable to have some water added daily to the ditch to displace a portion of the mixed liquor. The appearance of the mixed liquor in the ditch was of the "feathery and cloudy" forms indicating that the manure was oxidized. The soluble COD data comfirmed that most of the organic wastes was being degraded. The slight increase in the soluble COD only occurred after little water was added to the ditch and little effluent was discharged for an extented period.

The live bacterial cells and the buildup of non-biogradable materials contributed to the high COD in the mixed liquor. This was confirmed by the VSS:SS ratio. In spite of the high COD and solids values, it can be stated that the waste is well stabilized because of the low soluble COD concentrations.

It was noted that during most of time, the dissolved oxygen in the wastes was above 5 mg/l. The oxygen uptake rates remained relatively constant which indicated that the system did not suffer oxygen problems.

The results show that the two rotors in this system as operated with speeds of 200 r.p.m. and immersion of 3 inches were capable of maintaining strictly aerobic conditions in the ditch. When rotor immersion depth was less than 3 inches, the dissolved oxygen content would decrease. Water addition to maintain the liquid level in the ditch became the important operational factor for the system.

It was found that with a loading rate of one beef animal per 60 cu. ft. of liquid volume the system could be operated satisfactorily. This means that the system can handle one pound daily BOD_5 per 45 cu. ft. of liquid volume in the ditch without creating problems. A liquid volume of 155 cu. ft. per foot of rotor length can maintain an adequate velocity and oxygenation in the wastes.

A satisfactory nitrogen balance was obtained in this system. Although low ammonia contents in the mixed liquor might be attributed to the ammonia being stripped from the wastes by the agitation of the rotor, the remaining ammonia nitrogen was essentially reduced by the nitrification process. However, low ammonia nitrogen and high nitrate nitrogen concentrations revealed the metabolism of the organic matter. The presence of either nitrifying bacteria or protozoa indicated that the activated sludge system was able to maintain an adequate active organism population.

The system provides sufficient stabilization of the beef animal wastes, eliminates nuisance problems, and offers simple operation. However, the results indicate that further treatment or ultimate disposal on land of the effluents is necessary.

CONCLUSIONS

The following conclusions are made from this study:

1. Anaerobic digestion of beef animal wastes for solids liquification only eliminates the skilled supervision normally required of anaerobic systems if methane formation is an objective.
2. Acid fermentation resulting in solids liquification is not seriously affected by low temperature and low pH. An increase in volatile acids concentrations could still be obtained as the liquid temperatures dropped to around 4 ^{o}C. The pH values of 4.0 seemed to have no inhibition to acid forming bacteria.
3. If designed for acid fermentation only, the anaerobic digestion system can tolerate intermittent and shock loadings. This is essential for the feedlot operators schedule.
4. Results indicate that about 40 percent of the organic solids are liquified. These solids are converted to volatile acids. This only changes the form of the organic matter. The process does not destroy it.
5. The liquified wastes may reduce the problems of handling and ultimate land disposal of the wastes from confinement beef units. The anaerobic digestion system can also be used as a solids holding system. The solids liquification

may be one answer to the animal wastes management problem. Odors are contained in the digester.

6. The study has demonstrated that the oxidation ditch system provides good stabilization of beef animal wastes.
7. Foaming problems become a limiting factor in the startup of an oxidation ditch system in low temperature.
8. The operation of the two rotors at a speed of 200 r.p.m. and an immersion of 3 inches in a total liquid depth of 14 inches served to maintain an adequate velocity and strictly aerobic conditions in the ditch.
9. Water additions to maintain the liquid level and for periodic removal of a portion of the ditch contents are important in operating the oxidation ditch. This make up for evaporation increases the labor costs for this system.
10. The results of the loading rate of one beef animal per 60 cu. ft. of liquid volume indicate that the oxidation ditch system achieved a reduction in COD, total solids, and volatile solids of 64%, 63.5%, and 57% respectively.
11. Data from this study indicate that the effluents from both the anaerobic digestion and oxidation ditch systems will require further treatment prior to discharge to any watercourse, or preferably it should be applied to land for ultimate disposal.

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BIOLOGICAL TREATMENT OF CONFINED BEEF ANIMAL WASTES

by

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ABSTRACT

An anaerobic digestion system and an oxidation ditch system are employed in this study to investigate the treatment, handling, and disposal of the confined beef animal wastes.

Considering only acid fermentation, the process permits the use of the anaerobic digester under little skilled supervision for manure liquification. Uncontrolled field environmental factors, such as low temperatures, low pH, and intermittent and shock loading do not inhibit the acid forming bacterial activities which are responsible for liquifying the organic solids. The liquified manure is more readily degradable for further treatment, can be returned to the soil for agricultural irrigation, and has less pollutional strength for disposal on land. The anaerobic digestion system for solids liquification can be one answer to handling, holding, and disposal of the confined beef animal wastes.

The oxidation ditch system, with a loading of one animal per 60 cu. ft. of liquid volume, provides a potential treatment of beef animal wastes. The two rotors in this system, with a speed of 200 r.p.m. and an immersion depth of 3 inches, are capable of maintaining adequate waste velocity and oxygenation.