THE UNIVERSITY OF MANITOBA

MESOPHILIC ANAEROBIC DIGESTION

OF HOG WASTES

BY

JOHN O. FINNIE

A THESIS

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ABSTRACT

The suitability of hog wastes from a Manitoba hog raising operation as a substrate for anaerobic digestion was evaluated with laboratory digesters. The digesters were operated at 35°C with once a day feeding and withdrawal at different loading rates and retention times.

Promising results were obtained with digesters operated on the separated solids (fecal) portion of the manure. Average daily gas yields of 10 cubic feet per pound of volatile solids destroyed (624 litres per kilogram) were obtained at a loading rate of 0.15 pounds of volatile solids per cubic foot of digester per day (2.4 grams per litre per day) and a 15 day retention time. Analysis of the gas showed an average methane content of 68%.

Laboratory digesters operated on representative samples of manure from the farrowing barn failed within a short period of time. Soaps and detergents in the wash water present in the manure from the farrowing barn were not thought to have interfered significantly with the digestion process. Signs of digester failure, accompanied by high NH_3-N levels were evident in all digesters operated on manures containing appreciable quantities of urine. Ammonia nitrogen, therefore, was thought to be a prime factor in unsuccessful digester operation.

This thesis covers laboratory and literature research work done at the University of Manitoba during the periods September 1971 to July 1972 and January 1974 to June 1974.

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NOMENCLATURE

ABS	Alkyl benzene sulfonate
B.t.u.	British thermal unit
$CaCO_3$	Calcium carbonate
CH_4	Methane
CH_3COOH	Acetic acid
CO_2	Carbon dioxide
g/L/d	Grams per litre per day
H^+	Hydrogen ion
H_2SO_4	Sulfuric acid
kg	Kilogram
L	Litre
lb VS/cf/d	Pounds of volatile solids per cubic foot per day
mg/L	Milligrams per litre
mL	Millilitre
N	Nitrogen
NaOH	Sodium hydroxide
NH_4^+	Ammonium ion
NH_3-N	Ammonia nitrogen
ppm	Parts per million (=mg/L)
TS	Total solids
VA	Volatile acids
VS	Volatile solids

1. INTRODUCTION

1.1 GENERAL

There are approximately seven million hogs on farms in Canada (1). Each hog produces roughly ten pounds (4.5 kilograms) of manure per day which means about 7×10^7 pounds (3×10^7 kilograms) of hog manure are produced in Canada daily. Forty to fifty percent of this manure, by weight (wet basis), is fecal matter; the remainder is the liquid portion, or urine (2). The basic feed for hogs consists of barley, oats, wheat, corn, peas and rapeseed to which vitamins, proteins, salts and minerals have been added. The hog's digestive system is such that a large portion of the feed passes through without being metabolized and a manure high in protein and digestable matter is produced. After pasteurization this manure may be successfully fed back to the animals as a feed supplement.

Methods of treating and/or disposing of hog wastes to reduce their polluting potential and large quantities are direct land disposal, aerobic or anaerobic decomposition (often followed by land disposal), and incineration. Hog wastes may be rich in fertilizing constituents, but untreated hog wastes spread on fields may drain into underground and surface water bodies and contribute to the water pollution problem (3). Incineration as a method of treatment is costly.

Sources of energy for our present way of life are rapidly decreasing. Our civilization is dependent on fossil fuels and hydro power for industrial, commercial and domestic purposes. We have progressed to such a stage that our entire way of life would be changed if our sources of energy were suddenly cut off. Water power is not an expendable commodity as fuel resources are, but it is limited. Fuel resources are being depleted and substitute fuels or new energy production methods must be found before our non-renewable energy sources are exhausted (4).

The anaerobic digestion process as a method of treating hog wastes has been evaluated by several researchers in the search for alternative sources of energy and fuel, and as an efficient and productive means of disposing of the large quantities of animal wastes being produced each year.

The many advantages of this method of waste treatment have encouraged its use in treating farm wastes (3):

(i) the organic content of the waste may be reduced by 40-50 percent or more;

(ii) the waste is well stabilized and needs little or no further treatment before final disposal;

(iii) the digested waste has no offensive odor;

(iv) rodents and flies are not attracted to the end products of digestion;

(v) the fertilizing constituents of the raw waste are conserved, and the fertilizer value of the digested solids is at least equal to that of the raw waste;

(vi) combustible, commercially valuable gases are produced during the process.

The advantages offered by an anaerobic treatment system along with the benefits available from the methane gas produced can offset the capital and operational costs for a properly equipped digester.

1.2 HISTORICAL

The anaerobic sludge digestion process is well known and widely practised in municipal sewage treatment plants. Methane production from the anaerobic decomposition of farm animal wastes, although in its infant stage in North America, has been practised for many years in other parts of the world. As early as 1860, Mouras, a French engineer, developed a "closed vault with a water seal which rapidly transformed all excrementitious matter to a liquid state" (5). In 1895, Donald Cameron designed and built a septic tank for the town of Exeter, England. Collecting the methane gas produced, he used it for street lighting in the vicinity of the plant (5).

Fong (6) reported that a Lord Iveagh built five digesters in the 1920's to produce methane gas from manure. The digesters were of a crude design, each consisting of a "strong metal cylinder, 28 feet high and 16 feet in diameter, with a heating device in the bottom, a paraffin engine for the mixing of the sludge and a gas collection chamber". The gas produced was piped to nearby dwellings for use in cooking. One digester, built at Pyrford, England in 1929 operated for many years, producing about 450 cubic feet (12 735 litres) of gas per day. When fully loaded, this digester held "165 cart-loads of manure suspended in water".

During World War II, the shortage of fuel in Germany led to the development of methane generating plants in rural areas where the farmers used the gas to power tractors (7). Others have also achieved success using methane gas to power farm tractors (3), to operate steam engines for generating electrical power (8), and in England methane gas produced from chicken droppings has been used successfully as a fuel for automobiles (9). More recently, researchers at the University of Manitoba have converted a pick-up truck fuel system to run on commercially-available methane gas.

In India, where fuel supply is a critical problem in rural areas, methane gas generating plants have been installed and used successfully for many years. Singh (10) reported that a farmer in Lucknow in northern India installed a 225 cubic foot (6367 litre) capacity bio-gas* plant in 1961 which provided gas for cooking, lighting, heating and for generating electricity. Singh also reported that a South African farmer at Johannesburg built a bio-gas plant in 1962. The manure from his 700-head hog operation produced enough gas to run a diesel generator continuously, day and night, providing power for lighting, heating, cooking and irrigation.

Historically, anaerobic digestion of animal wastes has been geared toward waste use for inexpensive generation of a useful fuel commodity. More recently, and prominently in the more developed countries, organic digestion has been a method of waste treatment and disposal rather than of waste management and use. The gas produced has usually been considered as only a disposable by-product.

1.3 JUSTIFICATION

Anaerobic digestion, and most specifically its application to municipal wastes, is a well documented subject. Parameters generally characteristic of both well-functioning and malfunctioning anaerobic digesters have been established. Researchers have attempted to apply

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*bio-gas: gas produced by anaerobic digestion of organic substances, such as manure.

these criteria to the anaerobic digestion of animal wastes and have met with some success. The results are not consistent, however, and the criteria cannot be universally applied. It is likely that animal manures from different locations may behave differently and produce unique results when subjected to anaerobic digestion. The type of feed, feed nutrients and water quality will have an effect on both the physical and chemical characteristics of the manure, and this may in turn affect the digestion process. (For example, the water supply for the hogs contributing to this study was brackish in nature - see Appendix D). Accordingly, varying digester operating procedures may have to be implemented for different hog manures.

With this in mind, laboratory studies of anaerobic decomposition of hog wastes from the University of Manitoba's Glenlea Research Station were begun as the initial phase of an Energy Potential from Livestock Wastes project sponsored by the Biomass Energy Institute, Inc. Knowledge obtained in the laboratory was to be used in further laboratory studies and applied to a large scale pilot plant installation at the University of Manitoba's Glenlea Research Station.

1.4 STUDY OBJECTIVES

The object of this study was to determine the suitability of using hog wastes from a Manitoba hog operation as a substrate for anaerobic digestion by operating a series of laboratory-scale anaerobic digesters at various loading rates and retention times for the purpose of assessing the parameters affecting the digestion process and the gas production capabilities of the system.

2. LITERATURE REVIEW

2.1 THE ANAEROBIC PROCESS

The anaerobic digestion process may be defined as the bacterial decomposition of organic wastes in the absence of free oxygen. Anaerobic digestion occurs in two distinct stages. The end products of the first, or liquefaction stage, are utilized in the second, or gasification stage. Equation 1, Figure 1, is a general equation which biochemically and microbiologically describes the anaerobic process (from Kormanik (11)).

In the first stage of the anaerobic process, a group of faculative and anaerobic bacteria ("acid formers") break down complex organics such as fats, proteins and carbohydrates into simpler organics such as sugars, peptides and amino acids. Although no waste stabilization occurs during the first stage, the complex organic matter is converted into a digestable form suitable for the second stage bacteria. Equation 2, Figure 1, is a summary of the first stage general biochemical reactions.

During the second stage, the organic acids formed in the first stage are converted into gaseous end products (methane and carbon dioxide) by a group of bacteria termed the "methane formers". Methane forming bacteria are strict anaerobes, are non-spore forming and are therefore very sensitive to environmental conditions. There are several types of methane forming bacteria and each type is characterized by its ability to digest certain types of organic compounds. The most important methane formers are those which live on acetic and propionic acids. These bacteria carry out the major portion of the waste stabilization process but their growth and utilization of acids is slow (5).

EQUATION NO. 1

$$\begin{bmatrix}\text{COMPLEX ORGANIC}\\ \text{MATTER}\end{bmatrix} \xrightarrow[\text{ANAEROBIC BACTERIA}]{\text{FACULATIVE AND}} \begin{bmatrix}\text{SIMPLE ORGANIC}\\ \text{COMPOUNDS}\end{bmatrix} \xrightarrow[\text{BACTERIA}]{\text{METHANE}} CO_2 + CH_4$$

EQUATION NO. 2

$$\begin{bmatrix}\text{COMPLEX ORGANIC}\\ \text{MATTER}\end{bmatrix} \xrightarrow[\text{ANAEROBIC BACTERIA}]{\text{FACULATIVE AND}} \begin{bmatrix}\text{SIMPLE SUGARS}\\ \text{PEPTIDES}\\ \text{GLYCEROL}\\ \text{FATTY ACIDS}\\ \text{AMINO ACIDS}\end{bmatrix} \xrightarrow[\text{ANAEROBIC BACTERIA}]{\text{FACULATIVE AND}} \begin{bmatrix}\text{ORGANIC ACIDS}\\ \text{ALDEHYDES}\\ \text{ALCOHOLS}\\ CO_2 + H_2\end{bmatrix}$$

EQUATION NO. 3

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

EQUATION NO. 4

$$\begin{bmatrix}\text{ORGANIC ACIDS}\\ \text{ALDEHYDES}\\ \text{ALCOHOLS}\\ CO_2 + H_2\end{bmatrix} + \begin{bmatrix}\text{SOLUBLE}\\ \text{INTROGENOUS}\\ \text{COMPOUNDS}\end{bmatrix} \xrightarrow[\text{BACTERIA}]{\text{METHANE FORMING}} \begin{bmatrix}\text{AMINES}\\ \text{AMMONIA}\\ \text{ACID CARBONATE}\\ CO_2, CH_4, H_2, N_2\end{bmatrix} + \begin{bmatrix}\text{MERCAPTANS}\\ \text{INDOLE}\\ \text{SKATOL}\\ H_2S\end{bmatrix}$$

AND

$$\begin{bmatrix}\text{AMINES}\\ \text{AMMONIA}\\ \text{ACID CARBONATE}\\ CO_2, CH_4, H_2, N_2\end{bmatrix} \xrightarrow[\text{BACTERIA}]{\text{METHANE FORMING}} CH_4 + CO_2 + \begin{bmatrix}\text{VERY SMALL AMOUNTS}\\ \text{OF OTHER GASES}\end{bmatrix}$$

EQUATION NO. 5

$$CH_3CH_2CH_2COOH \xrightarrow{(A)} \begin{array}{l} CH_3CH_2COOH \xrightarrow{(B)} CH_3COOH \xrightarrow{(C)} CH_4 + CO_2 \\ + \\ CH_3COOH \xrightarrow{(C)} CH_4 + CO_2 \end{array}$$

FIGURE 1: THE ANAEROBIC PROCESS
(FROM KORMANIK (11)).

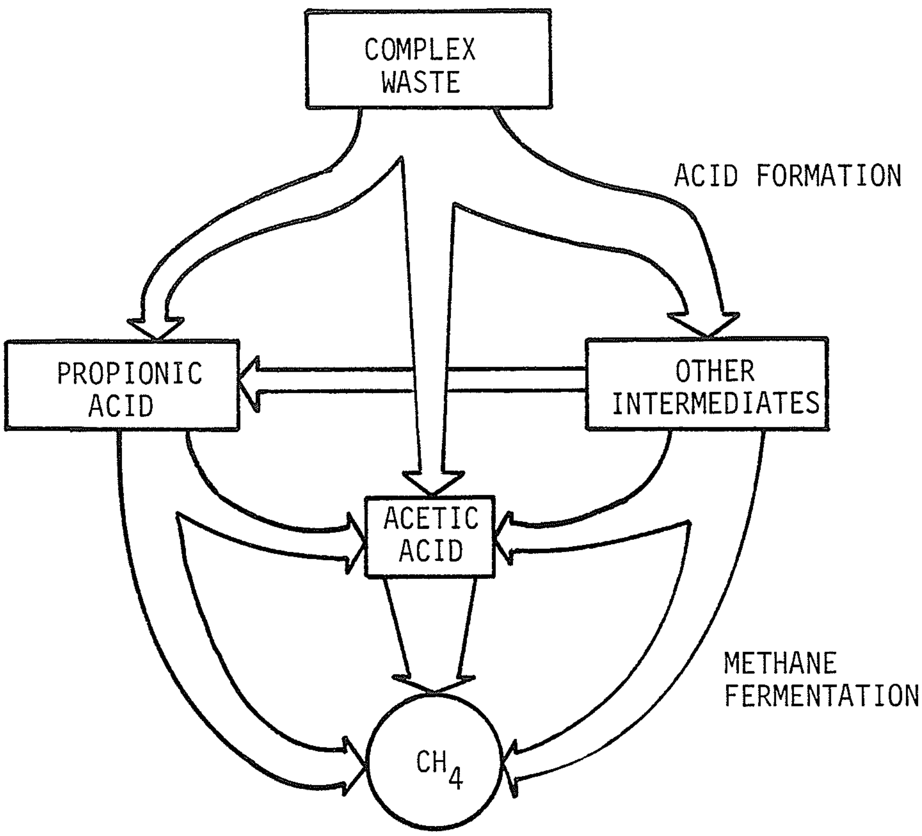

FIGURE 2. PATHWAYS IN METHANE FERMENTATION
(FROM McCARTY (12))

The anaerobic process is not completely operational until all the groups of methane formers are in production. Equation 4, Figure 1, depicts the second stage general biochemical reactions. Equation 5 is a summary of second stage reactions where A, B and C are different types of methane forming bacteria.

Waste stabilization in the anaerobic process requires a balance between the methane forming bacteria and the different acid forming bacteria. The two major volatile acid intermediates formed in anaerobic digestion are acetic acid and propionic acid. The importance of these two acids as precursors of methane is indicated in Figure 2 which illustrates the pathways by which complex organic materials are converted to methane gas (12). The fractions of the waste that are broken down into each group are dependent on the composition of the waste material and the efficiency of the different methane bacteria in the anaerobic environment.

2.1.1 Temperature

Temperature plays an important role in the life and death of bacteria. It has been observed that the rate of reaction for microorganisms increases with increasing temperature, doubling with about every $10^{\circ}C$ of rise in temperature until some limiting temperature is reached (13). According to the temperature range in which they function best, bacteria may be classified as cryophilic, mesophilic or thermophilic. Typical temperature ranges for bacteria in each of these categories are presented in Table 1.

TABLE 1. TYPICAL TEMPERATURE RANGES FOR VARIOUS BACTERIA (13).

Type	Temperature, °C	
	Range	Optimum
Cryophilic	-2 - 30	12 - 18
Mesophilic	20 - 45	25 - 45
Thermophilic	45 - 75	55 - 65

From experimentation and actual operating experience, it has been determined that the most practical optimum temperature for anaerobic digestion lies within the mesophilic range, preferably at about 35°C. Bacterial action diminishes almost directly with temperature below this range. Anaerobic digestion at thermophilic temperatures has not been widely attempted mainly because of the sensitivity of the thermophilic bacteria to slight changes in temperature (14) and due to energy requirements.

2.2 CONTROL PARAMETERS

Effective treatment can be obtained in anaerobic digestion if the process is operated under optimum environmental conditions. At sewage treatment plants, anaerobic digesters are monitored very closely but the waste treatment normally proceeds with a minimum of effort. Sudden changes in environmental conditions or the introduction of toxic materials into the digester may create an unbalanced system. Certain control parameters which indicate the operating condition of the digester are therefore used as a basis for determining the digester's operational efficiency.

2.2.1 Volatile Acids

Several researchers believe that the best indicator of digester operation is the volatile acids concentration (12). Volatile acids, as indicated previously, are the product of the liquefaction stage of anaerobic digestion. Complex organic matter is broken down into simpler organics consisting predominantly of organic fatty acids. The methane bacteria are responsible for the destruction of these volatile acids and utilize them in the production of methane. If the metabolism of the methane bacteria is adversely affected in some way, the gasification stage will cease and the volatile acids concentration will increase. Although investigations have indicated that concentrations of volatile acids even greater than 10,000 mg/L as acetic acid will not harm a biological system as long as the pH is kept in the desirable range (11), a sudden increase in volatile acids is normally one of the first indicators of digester unbalance and will usually indicate the onset of adverse conditions before other parameters such as pH, alkalinity or solids concentrations are affected. McCarty (12) emphasizes, however, that a high volatile acids concentration is the result of unbalanced treatment and not necessarily the cause. A high volatile acids concentration may not be harmful in itself but indicates that some other factor is affecting the bacteria. In normal, efficient digester operation, the volatile acids concentration ranges from 50 to 350 mg/L as acetic acid (11).

2.2.2 pH

The most desirable pH range for biological life in an anaerobic environment is between 6.6 and 7.4 with a maximum tolerable range of about 6.4 to 7.8 (11). At pH levels below about 6.5, methane bacteria are inhibited by the free hydrogen ion concentration. At pH levels below 4.5, the digestion process will stop. High pH levels result in conversion of the volatile acids into their salts, which are not available to the gas forming bacteria (4).

2.2.3 Alkalinity

In a properly operating anaerobic digester, pH is maintained naturally by a bicarbonate buffer system due to the carbon dioxide produced during methane fermentation (30). McCarty (12) has illustrated that the pH is a function of the bicarbonate alkalinity and the fraction of CO_2 in the gas. McCarty comments on alkalinity: "the bicarbonate alkalinity is approximately equivalent to the total alkalinity for most wastes when the volatile acids concentration is very low. When the volatile acids begin to increase in concentration, they are neutralized by the bicarbonate alkalinity and in its place form volatile acids alkalinity. Under these conditions, the total alkalinity is composed of both bicarbonate alkalinity and volatile acids alkalinity." This relationship between volatile acids and alkalinity emphasizes the importance of maintaining a proper alkalinity concentration. The alkalinity acts as a "buffering agent".

The dynamics of buffer destruction and formation in the digester is illustrated by the following equations (30):

$$C_6H_{12}O_6 \xrightarrow{\text{(acid formers)}} 3CH_3COOH$$
(glucose) (acid formers) (acetic acid)

$$CH_3COOH + NH_4HCO_3 \longrightarrow CH_3COONH_4 + H_2O + CO_2$$
(acetic acid) (ammonium bicarbonate) (ammonium acetate)

$$CH_3COONH_4 + H_2O \xrightarrow{\text{(methane bacteria)}} CH_4 + NH_4HCO_3$$

The first equation represents the breakdown of glucose to acetic acid by acid-forming bacteria. The acid is neutralized, as shown in the second equation, by the bicarbonate buffer. If sufficient buffer is not present, the pH should drop and the conversion of acetate to methane, as shown in the third equation, would be inhibited. During the third reaction, the buffer consumed in the second reaction is reformed.

An equilibrium between buffer formation and destruction is maintained when the anaerobic process is proceeding satisfactorily. When an upset occurs, it is usually the methane bacteria rather than the acid formers that are affected, and buffer capacity is reduced. A low alkalinity (say <1000 mg/L) does not provide much of a safety factor for anaerobic treatment. An increase in volatile acids will be neutralized by the bicarbonate alkalinity resulting in a decrease in alkalinity and a drop in pH. A higher alkalinity (2500-5000 mg/L) will provide more "buffer capacity" so a larger increase in volatile acids may be handled with a minimum drop in pH. Alkalinity should be maintained in the 2000 to 5000 mg/L (as $CaCO_3$) range, at a level which exceeds the volatile acids concentration. An increase in volatile acids to a level which exceeds the alkalinity could result in the production of free volatile acids and a destruction of the buffering potential of the system. The result would be a drop in pH and a reduction in gas production (15).

2.2.4 Residue

Total and volatile solids analyses on the feed material are imperative in determining organic loading rates to the digesters. Subsequent solids analyses on the digesting material are necessary to determine the reduction in volatile solids occuring in the process. The reduction in volatile solids has been accepted as one of the measures of the digester's operational efficiency. In a well functioning digester, the volatile solids reduction should be about 50 per cent.

2.3 PROCESS INHIBITORS

There are many materials, both organic and inorganic, which may be toxic or inhibitory to the anaerobic process. Most of the research in this area has been done with sewage sludge digestion, but the results obtained can be applied to the anaerobic digestion of hog wastes.

Three potential causes of digester instability and ultimate failure are hydraulic and organic overloading and toxicity. Hydraulic overloading occurs when the retention time* is so low that the

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*For the purpose of this study, the retention time is defined as the hydraulic retention time, which is the effective digester volume divided by the daily feed volume.

organisms are flushed out of the system before they have had a chance to reproduce. Organic overloading can occur when an excess quantity of organic solids is introduced into the digester. Graef and Andrews (16) report that this causes an accumulation of volatile acids that can inhibit the methanogenic organisms. Toxicity failures are caused by the addition and accumulation of materials that are lethal to the methanogenic bacteria. These materials include heavy metals, detergents, ammonia and various cations.

2.3.1 Ammonia

Ammonia toxicity warrants additional discussion since the urea content of the hog wastes affects the ammonia concentration in the digester feed material, as is indicated by the following reaction:

$$\underset{\text{(urea)}}{H_2NCONH_2} + H_2O \xrightarrow[\text{enzymes}]{\text{bacterial}} CO_2 + 2NH_3 \qquad (31)$$

In anaerobic systems, ammonia will be in equilibrium as the ammonium ion or as dissolved ammonia gas:

$$NH_4^+ \rightleftharpoons NH_3 + H^+ \qquad (17)$$

With an increase in pH the equilibrium shifts to the right and more ammonia goes into solution. Loehr (15) reports the source of this ammonia as being either anaerobic degradation of nitrogenous compounds, such as proteins and urea, or the addition of ammonia compounds as a source of alkalinity.

McCarty (12) has found that the ammonia gas is inhibitory at much lower concentrations than the ammonium ion. At pH exceeding 7.4 to 7.6 and ammonia nitrogen concentrations between 1500 and 3000 mg/L, the ammonia gas can become inhibitory. When the ammonia nitrogen concentration exceeds 3000 mg/L, then the ammonium ion itself becomes quite toxic, regardless of pH. Albertson (18), in studies conducted to determine the cause of digester failure when increasing concentrations of solids were added, concluded that digester loading itself was not directly associated with the cause of failure. He recorded failures at loadings of 0.20, 0.27, and 0.44 lb VS/cf/d (3.2, 4.3 and 7.0 g/L/d). All of these failures, however, had one thing in common - an NH_3-N concentration in excess of 1250 mg/L, indicating that the NH_3 ion might have been the cause of failure.

2.3.2 Heavy Metals

Heavy metals have been blamed for many digester failures. Low, but soluble, concentrations of copper, zinc and nickel salts are quite toxic (12). Copper and zinc may be of prime concern since they are often used as supplements in livestock feed. Studies have indicated that copper and zinc concentrations as low as 10 mg/L resulted in complete inhibition of gas production from the anaerobic treatment of wastes (17). McCarty (12) reports that concentrations of the more toxic heavy metals (copper, zinc, nickel) which can be tolerated are related to the concentration of sulfides available to combine with the heavy metals to form insoluble sulfide salts. Such salts are inert and do not adversely affect the microorganisms. It should be noted that sulfides, by themselves, may be quite toxic to anaerobic treatment, as are the heavy metals. When combined, however, they form insoluble salts which have no detrimental effect (12).

2.3.3 Antibiotics

Antibiotics may be used in hog raising operations for animal disease control. They are most often used during periods of stress, for example when growing stock are moved into the finishing building. Administered to the animals by injection or in an antibiotic feed, the antibiotics may pass through the hog's digestive system and be present in the manure. Antibiotics, being a microbiological biocide, have been considered as perhaps being lethal to the methane forming bacteria (19).

2.3.4 Detergents

Detergents have also been shown to inhibit the anaerobic digestion process. In studies undertaken to investigate the effects of an anionic synthetic detergent on anaerobic sewage sludge digestion, Hernandez and Bloodgood (20) concluded that "a gradual increase in the concentration of alkyl benzene sulfonate (ABS) by periodic additions of an ABS solution to a laboratory digestion unit has no apparent effect on the digestion process until the concentration of the "added" ABS (ABS in excess of that present in the raw feed sludge) reaches a higher level, when a noticeable decrease in daily gas production may be expected". The "higher" level is variable and presumably dependent on individual digester operation. In their experiments, however, the "added" ABS concentration found to be wholly detrimental to the digestion process was 59 mg/L, although lower concentrations were temporarily inhibitory. The contents of the test unit at this stage exhibited an ABS concentration of 107 mg/L. The researchers concluded that it is not the concentration alone but the ratio of ABS to total solids that is the important relationship; an ABS concentration of 3.3 mg/g of total solids will result in a serious disruption of the digestion process.

Degens, et al, (21) conducted experiments to determine the influence of synthetic detergents on the methane fermentation of mixtures of raw primary and secondary sludge. The conclusion drawn from the experiment was that if the concentration of synthetic detergents investigated was not higher than 500 ppm active material in the raw sludge, there would be no interference with the methane fermentation.

2.4 RELATED RESEARCH

Anaerobic digestion of hog manure is not a new idea. Researchers have been experimenting in this field for the past forty-odd years. Differences in the experimental procedures and in the conclusions drawn by other researchers warranted documentation of the following work.

Jeffrey, et al, (2) conducted anaerobic digestion studies to determine the digestion characteristics of various animal wastes. The object of their experiments was to determine the allowable loadings in pounds of volatile solids per day per 1000 cubic feet of digester capacity, the per cent reduction of volatile solids obtainable and the gas production characteristics. The results indicated that when the loadings to digesters operating at 20 day displacement were increased above 175 lb VS/day/1000 cubic feet of digester (2.8 g/L/d), the gas production began to drop off and the volatile acids concentration began to increase. These changes both indicate a breakdown of the digestion process. The tests concluded that the allowable volatile solids loading for hog waste digesters was between 0.15 and 0.17 lb VS/day/cubic foot of digester (2.4 and 2.7 g/L/d). Gas production was approximately 8 cubic feet/lb VS added (499 L/kg) and exhibited a CO_2 content of 32 per cent.

Taiganides, et al, (3) satisfactorily digested hog wastes at a loading rate of 0.2 lb VS/day/cubic foot of digester capacity (3.2 g/L/d) at a detention period of less than 10 days. For design purposes they found the required digester capacity to be approximately one cubic foot (28 litres) per hog produced per year. Average gas production was 7.8 to 10.3 cubic feet/lb VS added (486 to 642 L/kg). The methane content of the gas was about 59%.

Gramms, et al, (22) conducted anaerobic digestion studies to determine the optimum loading rate for treatment of dairy bull, swine (hog) and poultry wastes, and the resulting reduction of volatile matter. Hog wastes used in the experiment were fecal floor scrapings diluted with tap water to a slurry having a 10% solids content. Results obtained from temperature controlled anaerobic digesters operated on hog wastes at 10 and 15 days retention times and loading rates of 0.12 and 0.24 lb VS/cf/day (1.9 and 3.8 g/L/d) indicated that (i) anaerobic digesters for hog wastes should not be loaded at rates greater than 0.24 lb VS/cf/day (3.8 g/L/d) and should have retention times between 12 and 16 days, and (ii) although substantial reductions in volatile solids may be achieved through anaerobic digestion, ultimate disposal of the wastes may still be a problem unless a long-term digestion process is utilized. Ammonia nitrogen (NH_3-N) levels in the feed material ranged from 190 to 570 mg/L.

Depending upon loading rates and retention times, volatile acids, alkalinity and NH_3-N concentrations within the digesters varied but reached levels of 1090 mg/L (as acetic acid), 7130 mg/L (as $CaCO_3$) and 1010 mg/L (as N), respectively. It should be noted that the feed material contained little, if any, urine. Gas production ranged from 7.9 to 13.2 cubic feet per lb VS destroyed per day (490 to 823 L/kg/d).

A literature review by Smith (23) on laboratory studies by various researchers revealed that digesters operating on hog wastes containing urine were seldom successful unless the loading rates were very low ($\leq$0.075 lb VS/cf/day (1.2 g/L/d)) and the retention times fairly high ($\geq$22 days). Alternatively, digesters operated on manure floor scrapings (solids) diluted with tap water were successful, even at relatively high loading rates and short retention times. Smith reported one such digester loaded at 0.24 lb VS/cf/d (3.8 g/L/d), 10 day retention with intermittent mixing, operating successfully and producing 13.2 cubic feet of gas per pound VS removed from the digester (824 L/kg).

Fong (6) successfully digested hog manure at 37°C at a loading rate of 0.25 lb VS/cf/d (4.0 g/L/d) and a retention period of 10 days. The resulting gas production was about 14.5 cubic feet/lb VS destroyed/day (905 L/kg/d) and exhibited a methane content of 59%. Fong recommended anaerobic digesters for hog manure not be loaded at rates exceeding 0.25 lb VS/cf/d (4.0 g/L/d). Higher rates may result in ammonia accumulation which is detrimental to the digestion process. For good reductions in volatile solids, the retention time should be between 15 and 18 days. Increased loading rates and/or decreased retention times (other parameters remaining constant) were found to increase the quantity of gas produced per pound of volatile solids destroyed. An increase in the loading rate, however, was also found to decrease the percent methane in the digester gas.

3. EXPERIMENTAL PROCEDURE

3.1 APPARATUS

The laboratory digestion unit (Figure 3) consisted of a four litre glass aspirator bottle having a feed tube and gas vent line at the top and a sludge withdrawal tap at the bottom. Mixing was accomplished either with CANLAB magnetic stirrers on a 3-hour on / 3-hour off cycle, or by periodic manual agitation. Gas production was determined by liquid displacement of a saturated solution of sodium sulfate in a 5% sulfuric acid solution.

The contents of the digesters were maintained at 35°C by housing the units in a constant temperature chamber or by keeping them in a constant temperature water bath.

3.2 OPERATIONAL DETAILS

Hog manure was collected as required from the Glenlea Research Station, 15 miles (24 kilometres) south of Winnipeg. To ensure homogeneous samples, the manure was well agitated by a pump prior to removal from the holding pits beneath the rearing barns. The manure was screened and/or allowed to settle to concentrate urine and fecal portions when they were required separately. Samples were stored at 4-5°C until required.

Each digester held 4 litres of digesting sludge. Initially, the digesters were seeded with four litres of anaerobic digester sludge from the City of Winnipeg North End Sewage Treatment Plant. Each day a predetermined volume of manure plus tap water (as required to meet the loading rate and retention time criteria) was added to the digesters and an equal volume of digested sludge was removed. Prior to each feeding, the digester contents were agitated thoroughly to ensure homogeneity of sample. An example calculation of how feed rates were determined may be found in Appendix E.

Measurements of temperature, pH, alkalinity, volatile acids, total and volatile solids and ammonia nitrogen were taken routinely during the study. The total daily volume of gas evolved and its methane content were also recorded.

Digesters were operated until either steady state conditions were reached or digester failure appeared evident. Digester failure was considered imminent in this study when gas production dropped progressively and volatile acids and alkalinity and/or NH_3-N concentrations in the digester exceeded those levels considered acceptable for effective digester operation.

3.2.1 First Series

The first series of digesters (units 1, 2, 3) were operated on manure from the farrowing barn, at loading rates of 0.50, 0.25 and 0.10 lb VS/cf/d (8.0, 4.0 and 1.6 g/L/d) and retention times of 8, 16 and 40 days, respectively. Digesters were housed in a 35°C constant temperature chamber and mixing was accomplished with CANLAB magnetic stirrers.

3.2.2 Second Series

Units 4, 5 and 6 were operated at loading rates of 0.12, 0.10 and 0.12 lb VS/cf/d (1.9, 1.6 and 1.9 g/L/d) and retention times of 10, 5 and 10 days, respectively. Manure from the farrowing barn was used as substrate for all three digesters, but was separated into liquid and feces fractions for use in units 5 and 6 respectively. Digesters in this series were also housed in a 35°C constant temperature chamber and mixing was accomplished with magnetic stirrers.

3.2.3 Third Series

Units 7a, 7b, 8a and 8b were all operated on the feces fraction of manure obtained from the breeding and replacement barn. Units 7a and 7b operated at a loading rate of 0.12 lb VS/cf/d (1.9 g/L/d) and a 15 day retention time; units 8a and 8b operated at a loading rate of 0.15 lb VS/cf/d (2.4 g/L/d) and a 15 day retention time. All four digesters were maintained at 35°C in a constant temperature chamber and mixing was accomplished with magnetic stirrers (Figure 6).

3.2.4 Fourth Series

For the fourth and final series of digesters (units 9a, 9b, 10a and 10b), manure from the breeding and replacement barn was used as a substrate. Units 9a and 9b operated at a loading rate of 0.12 lb VS/cf/d (1.9 g/L/d) and a 15 day retention time; units 10a and 10b operated at a loading rate of 0.25 lb VS/cf/d (4.0 g/L/d) and a retention time of 18 days. In this series, the digesters were held in a 35°C constant temperature water bath and mixing was accomplished by manual agitation - four times per day on weekdays, twice per day on weekends.

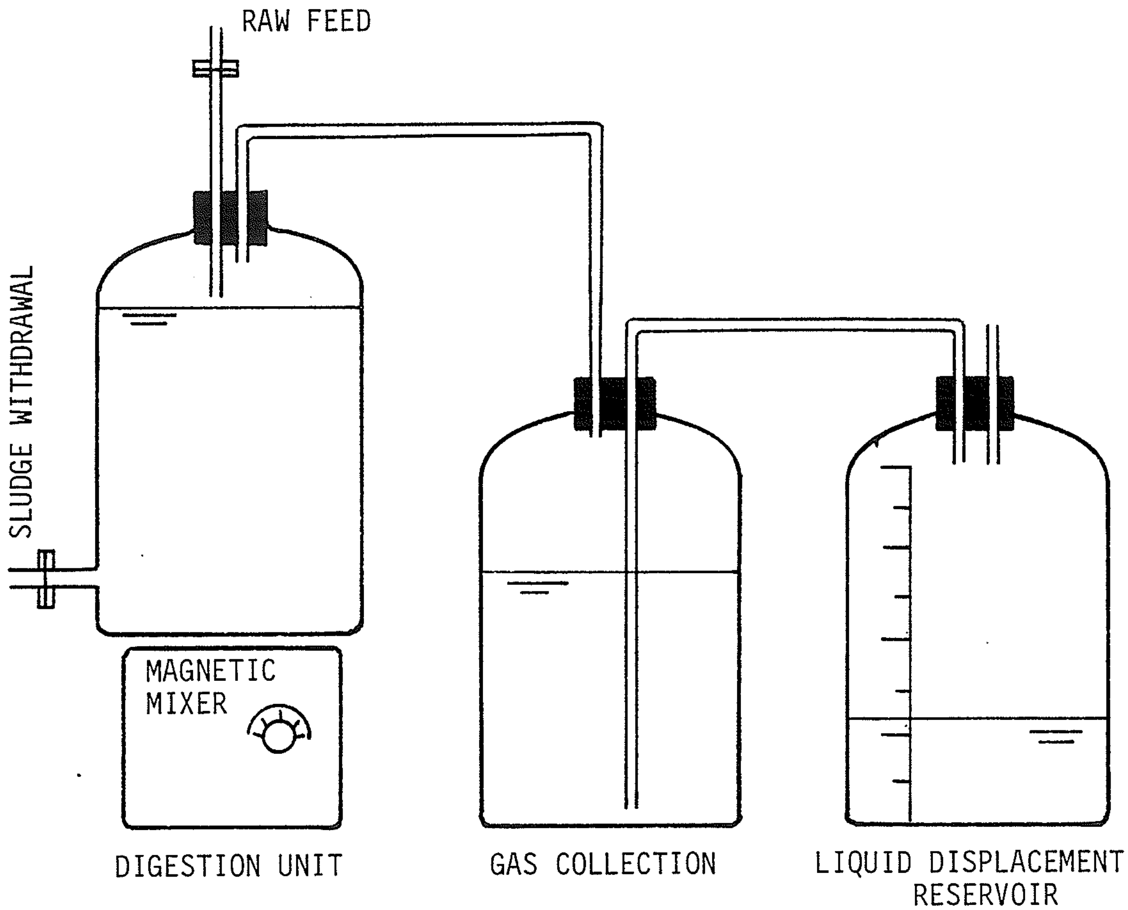

FIGURE 3. DIGESTION APPARATUS

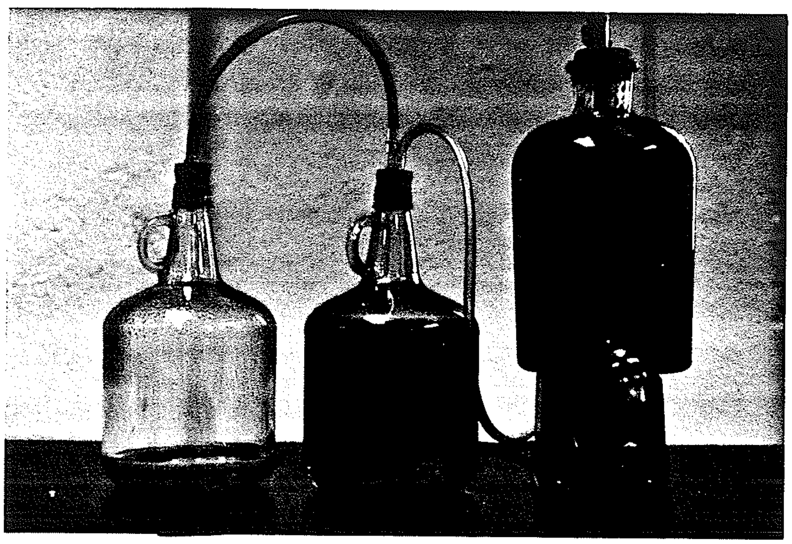

FIGURE 4. DIGESTER UNIT & GAS COLLECTION APPARATUS

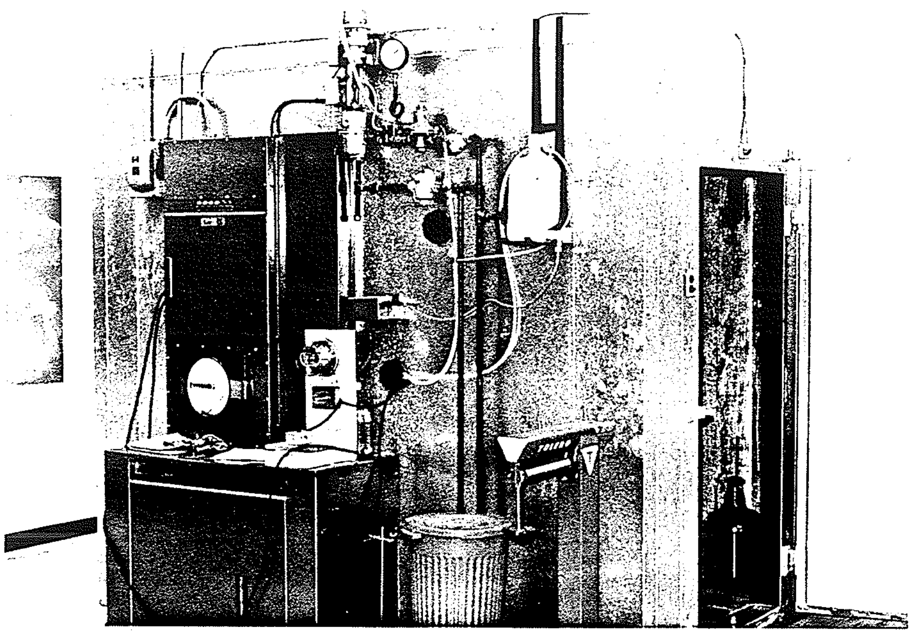

FIGURE 5. CONSTANT TEMPERATURE CHAMBER

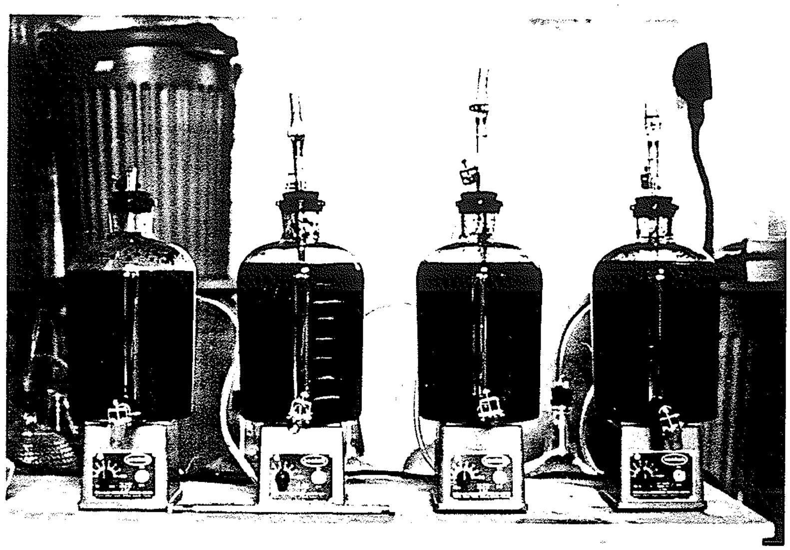

FIGURE 6. DIGESTER UNITS 7a, 7b, 8a & 8b INSIDE TEMPERATURE CHAMBER

3.3 LABORATORY ANALYSES

All analyses, with the exception of volatile acids, were conducted in accordance with procedures outlined in Standard Methods (24). Alkalinity (section 201) and pH (section 221) were determined potentiometrically with a Radiometer model 29 pH meter. The pH 3.7 (methyl orange) endpoint was selected for alkalinity determinations. Total and volatile solids analyses were conducted in accordance with section 224 (A & B). All weight measurements were made with a Mettler H.18 Analytical Balance. Ammonia nitrogen was collected in boric acid and its concentration determined titrimetrically (sections 212, 135).

Volatile acids determinations were conducted with the aid of a HACH DR Colorimeter (HACH Chemical Company, Ames, Iowa). The laboratory procedure is outlined in Appendix A.

Gas composition (percent methane) was determined with a Pye Series 104 Gas Chromatograph fitted with a flame ionization detector. Separation and identification of methane was provided by a 3/16", eight foot, stainless steel column packed with Porapak R. Nitrogen at a flow rate of 20 mL/min. was used as the carrier gas; column temperature was maintained at 27°C.

4. EXPERIMENTAL RESULTS

Results of the experimental phase are presented in Table 2 and in Figures 7 to 20. Table 2 is a concise summary of the operational details for each digester in the study. Figures 7 to 20 depict graphically the monitoring results for each digester unit; these results may be found in detailed tabular form in Appendix B.

DIGESTER UNIT	1	2	3	4	5	6	7a
Loading (lb VS/cf/d)	.50	.25	.10	.12	.10	.12	.12
Loading (g VS/L/d)	8.0	4.0	1.6	1.9	1.6	1.9	1.9
Retention Time (days)	8	16	40	10	5	10	15
Test Duration (days)	26	26	26	24	13	33	36
DIGESTER INFLUENT							
Physical Character	urine + feces	urine + feces	urine + feces	urine + feces	liquid fraction	feces	feces
Source (Barn No.)	1	1	1	1	1	1	3
pH	7.2	7.2	7.2	7.1	7.3	7.4	7.5
Alkalinity (mg/L $CaCO_3$)	12,000	12,000	12,000	7,500	10,000	2,400	1,900
Volatile Acids (ppm acetic)	11,000	11,000	11,000	-	-	-	1,400
% total solids	8.4	8.4	8.4	3.0	1.9	2.6	3.3
% volatile solids	75.0	75.0	75.0	64.0	42.0	78.0	85.0
Volatile solids (mg/L)	63,300	63,300	63,300	19,000	8,000	20,000	28,000
NH_3-N (mg/L)	-	-	-	1,650	2,200	600	460
DIGESTER OPERATION							
Volume (litres)	4	4	4	4	4	4	4
pH (average)	7.5	7.7	7.8	7.6	7.7	7.6	7.4
Alkalinity (mg/L $CaCO_3$)	3400 rising to 9200	3400 rising to 7600	3400 rising to 6200	3000 rising to 8200	3000 rising to 7800	3360	3600
Volatile acids (ppm acetic)	340 rising to >8000	340 rising to 4800	340 rising to 2300	350 rising to >6000	275 rising to >5000	325	300
NH_3-N (mg/L)	-	-	-	150 rising to 2100	150 rising to 1790	630	606
Volatile solids red'n (avg. %)	42	43	49	41	negligible	55	48
Daily Gas Production (mL)	1150 dropping to 200	1775 dropping to 275	1430 dropping to 350	4000 dropping to 375	3375 dropping to 420	2750	2360
% CH_4 (avg.)	<35 & dropping	<35 & dropping	<35 & dropping	<40 & dropping	-	55	64
Comment	failure	failure	failure	failure	failure	successful	successful

TABLE 2 DIGESTER OPERATIONAL SUMMARY

DIGESTER UNIT	7b	8a	8b	9a	9b	10a	10b
Loading (lb VS/cf/d)	.12	.15	.15	.12	.12	.25	.25
Loading (g VS/L/d)	1.9	2.4	2.4	1.9	1.9	4.0	4.0
Retention Time (days)	15	15	15	15	15	18	18
Test Duration (days)	33	33	33	33	33	36	36
DIGESTER INFLUENT							
Physical Character	feces	feces	feces	urine + feces	urine + feces	urine + feces	urine + feces
Source (Barn No.)	3	3	3	3	3	3	3
pH	7.5	7.5	7.5	7.1	7.1	6.6	6.6
Alkalinity (mg/L $CaCO_3$)	1,900	2,400	2,400	10,600	10,600	10,250	10,250
Volatile Acids (ppm acetic)	1,400	1,800	1,800	5,625	5,625	9,750	9,750
% total solids	3.3	4.1	4.1	4.6	4.6	10.2	10.2
% volatile solids	85.0	85.0	85.0	62.0	62.0	72.4	72.4
Volatile solids (mg/L)	28,000	35,000	35,000	28,500	28,500	74,000	74,000
NH_3-N (mg/L)	460	580	580	2,400	2,400	2,100	2100
DIGESTER OPERATION							
Volume (litres)	4	4	4	4	4	4	4
pH (average)	7.4	7.3	7.3	7.6	7.7	7.5	7.5
Alkalinity (mg/L $CaCO_3$)	3600	3400	3300	<6000 rising to 10,000	<6000 rising to 9200	5600 rising to 9000	5600 rising to 8500
Volatile acids (ppm acetic)	420	330	320	500 rising to >5000	500 rising to 330	400 rising to >3000	400 rising to >5000
NH_3-N (mg/L)	547	523	515	550 rising to 2860	500 rising to 2400	420 rising to 2400	450 rising to 2260
Volatile solids red'n (avg. %)	52	48	49	<35	<34	<34	<32
Daily Gas Production (mL)	2350	2560	2790	4000 dropping to 1600	4000 dropping to 2400	5300 dropping to 4000	5350 dropping to 3000
% CH_4 (avg.)	64	68	68	-	-	-	-
Comment	successful	successful	successful	failure	failure	predicted failure	predicted failure

TABLE 2 DIGESTER OPERATIONAL SUMMARY
(cont.)

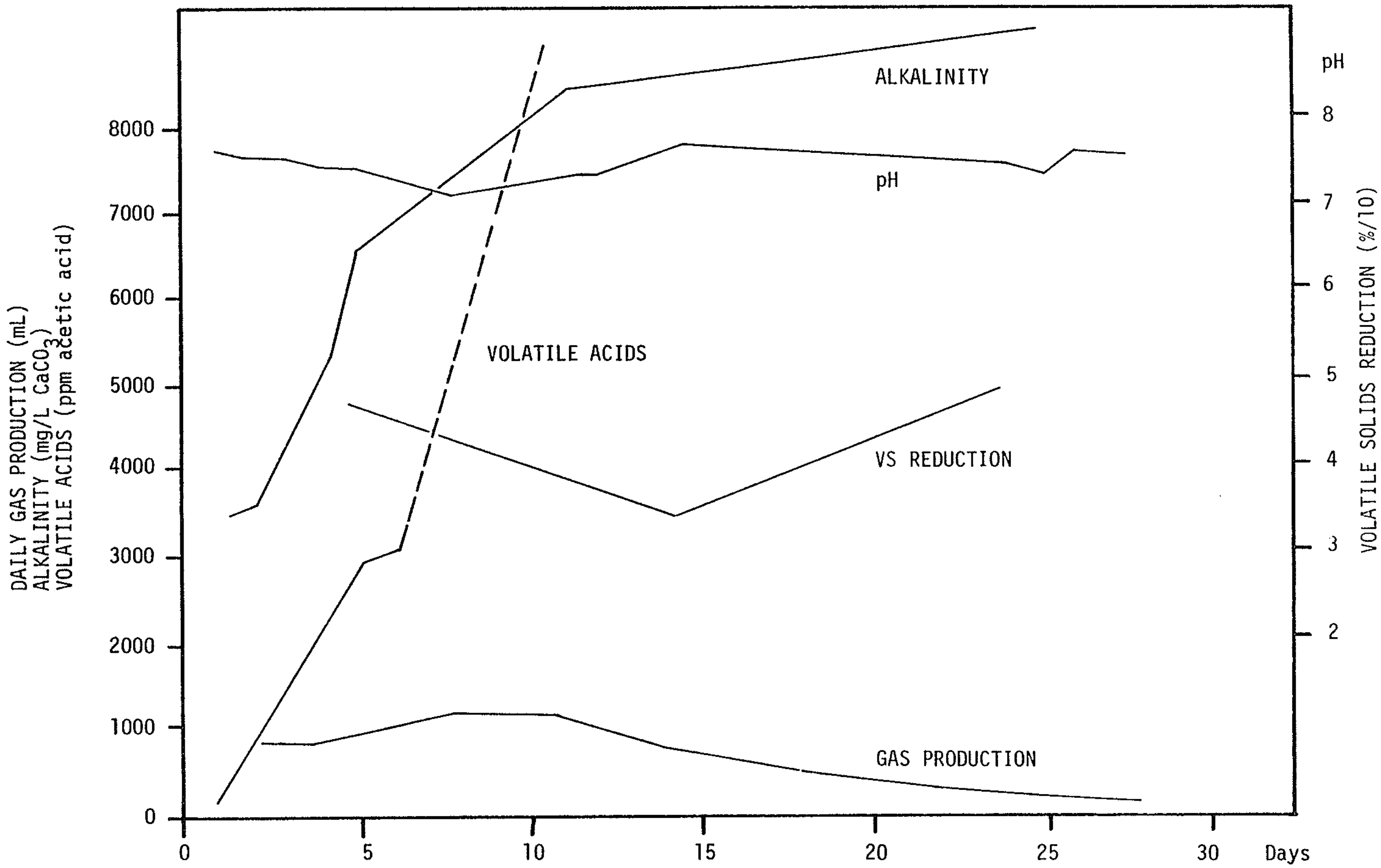

FIGURE 7. DIGESTER UNIT 1 PERFORMANCE vs. TIME
(Loading 0.5 lb VS/cf/d (8.0 g/L/d) - urine + feces, Retention 8 days)

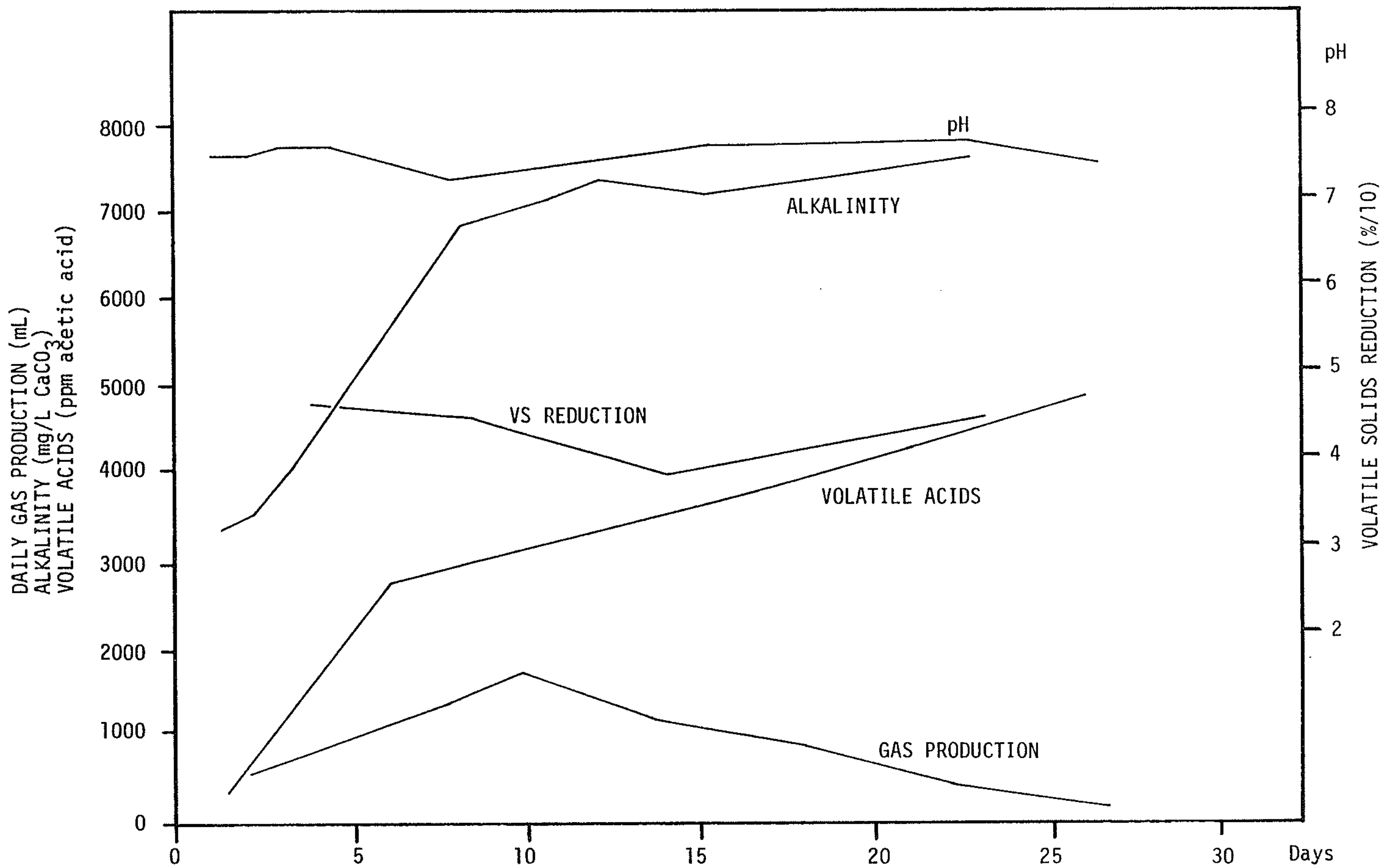

FIGURE 8. DIGESTER UNIT 2 PERFORMANCE vs. TIME
(Loading 0.25 lb VS/cf/d (4.0 g/L/d) - urine + feces, Retention 16 days)

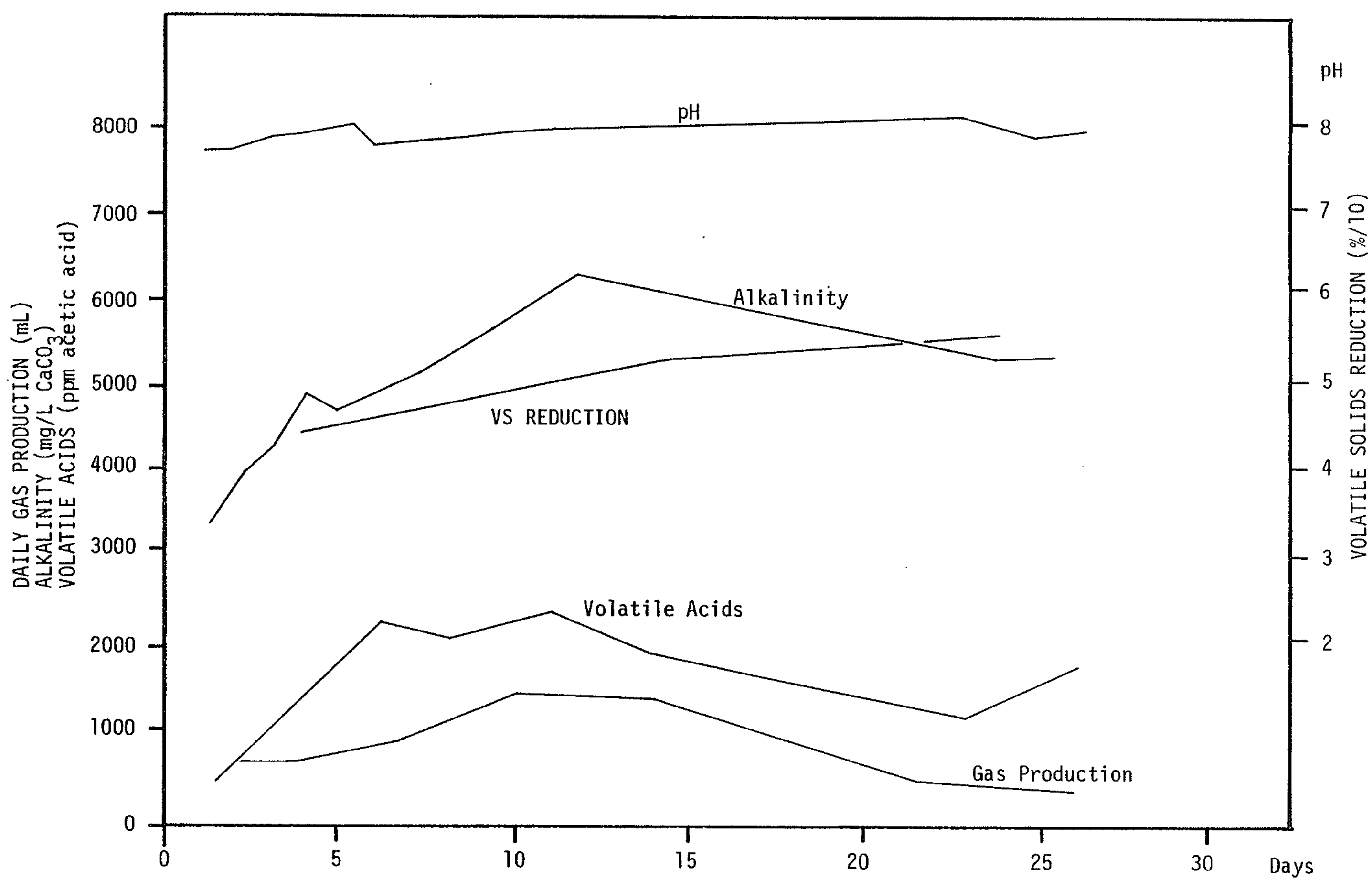

FIGURE 9. DIGESTER UNIT 3 PERFORMANCE vs. TIME
(Loading 0.10 lb VS/cf/d (1.6 g/L/d) - urine + feces, Retention 40 days)

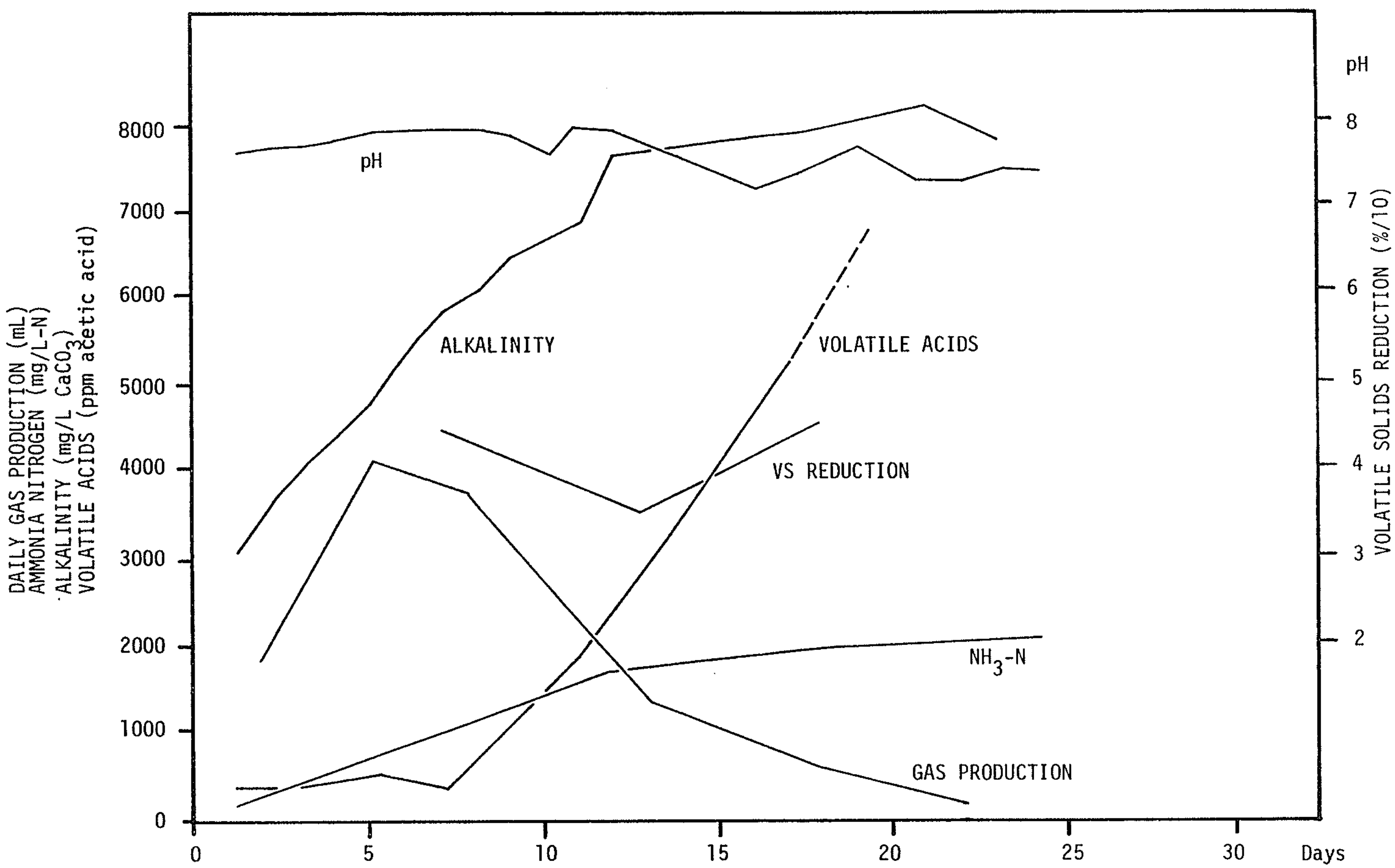

FIGURE 10. DIGESTER UNIT 4 PERFORMANCE vs. TIME
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - urine + feces, Retention 10 days)

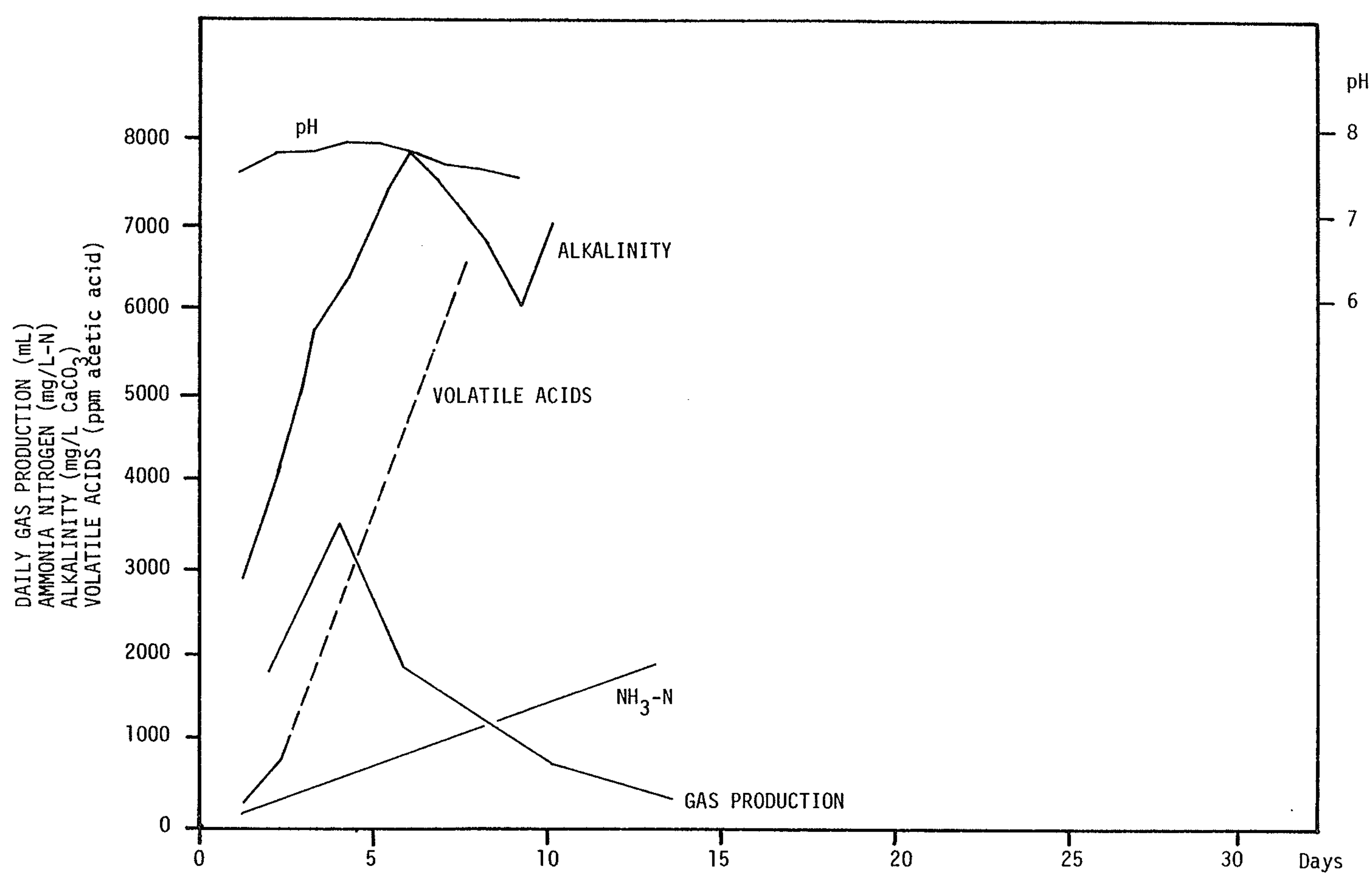

FIGURE 11. DIGESTER UNIT 5 PERFORMANCE vs. TIME
(Loading 0.10 lb VS/cf/d (1.6 g/L/d) - liquid, Retention 5 days)

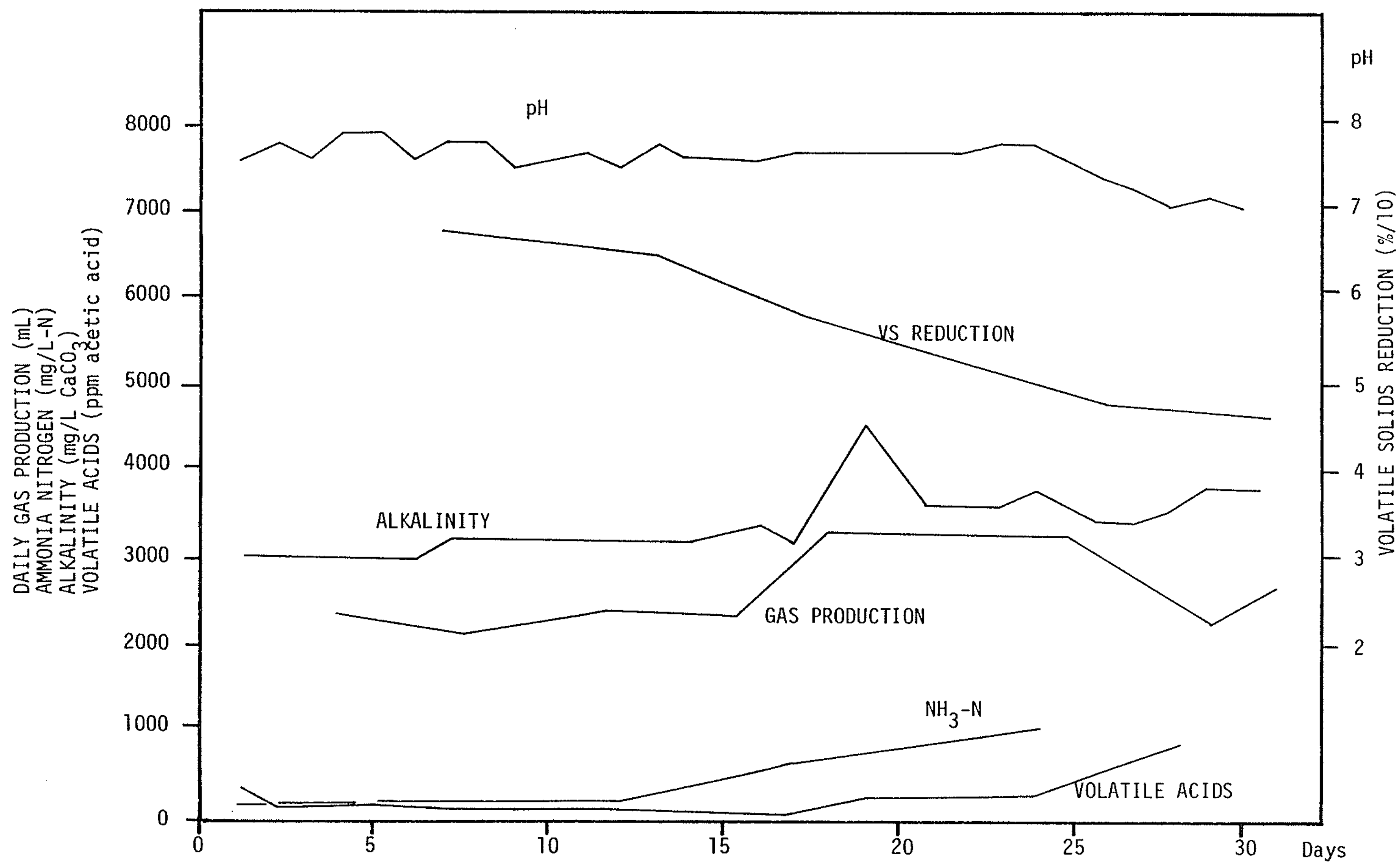

FIGURE 12. DIGESTER UNIT 6 PERFORMANCE vs. TIME
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - feces, Retention 10 days)

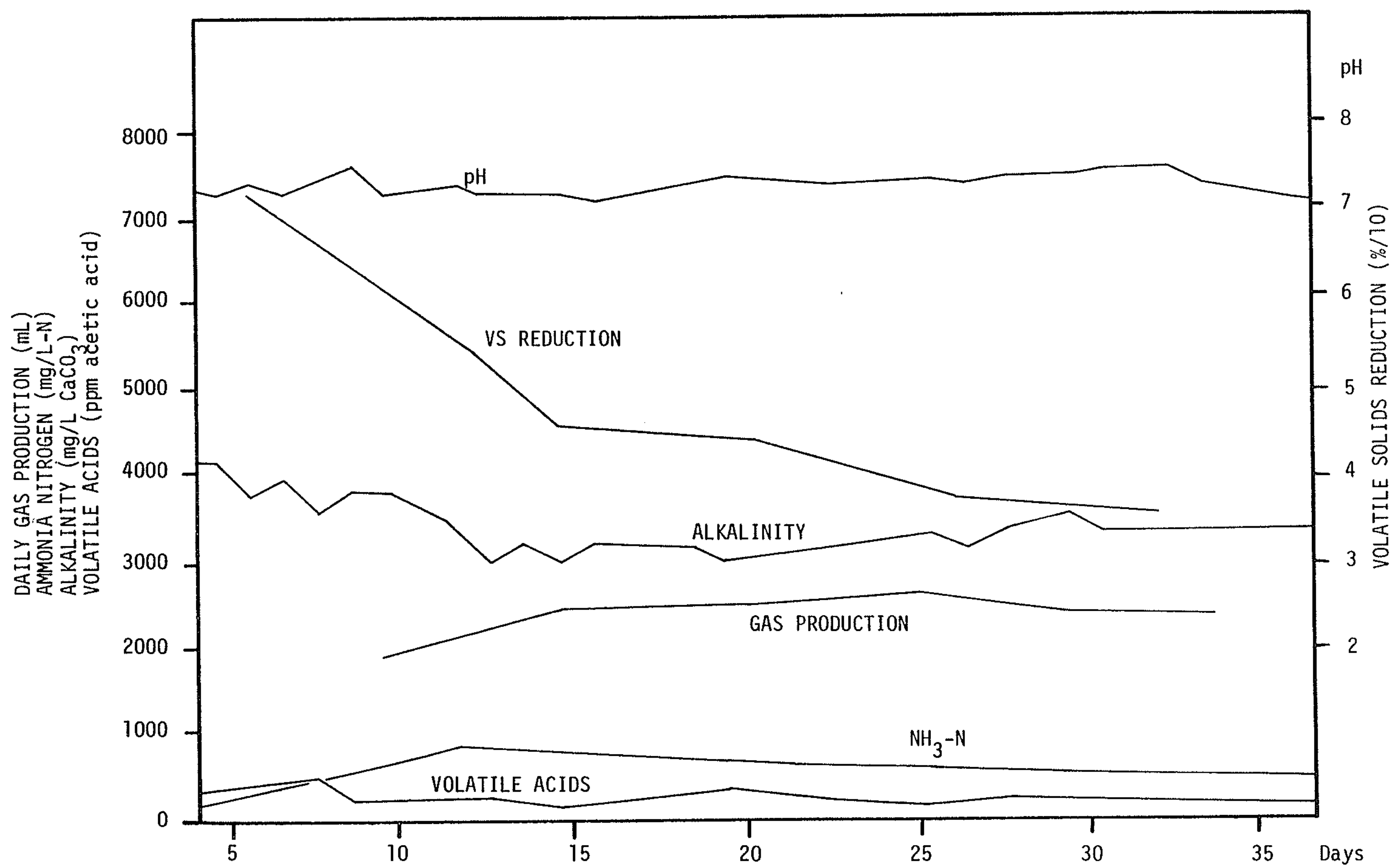

FIGURE 13. DIGESTER UNIT 7a PERFORMANCE vs. TIME
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - feces, Retention 15 days)

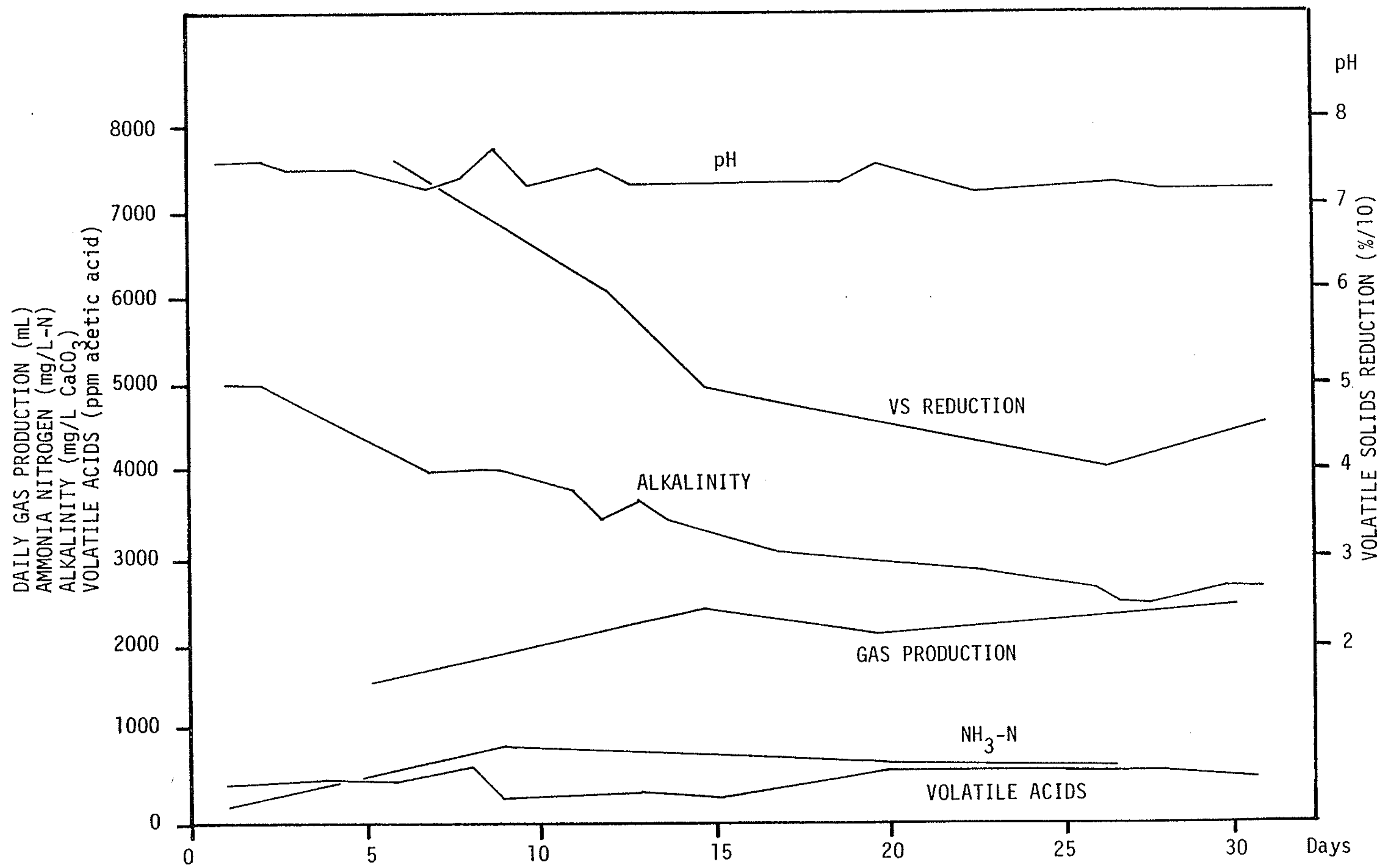

FIGURE 14. DIGESTER UNIT 7b PERFORMANCE vs. TIME
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - feces, Retention 15 days)

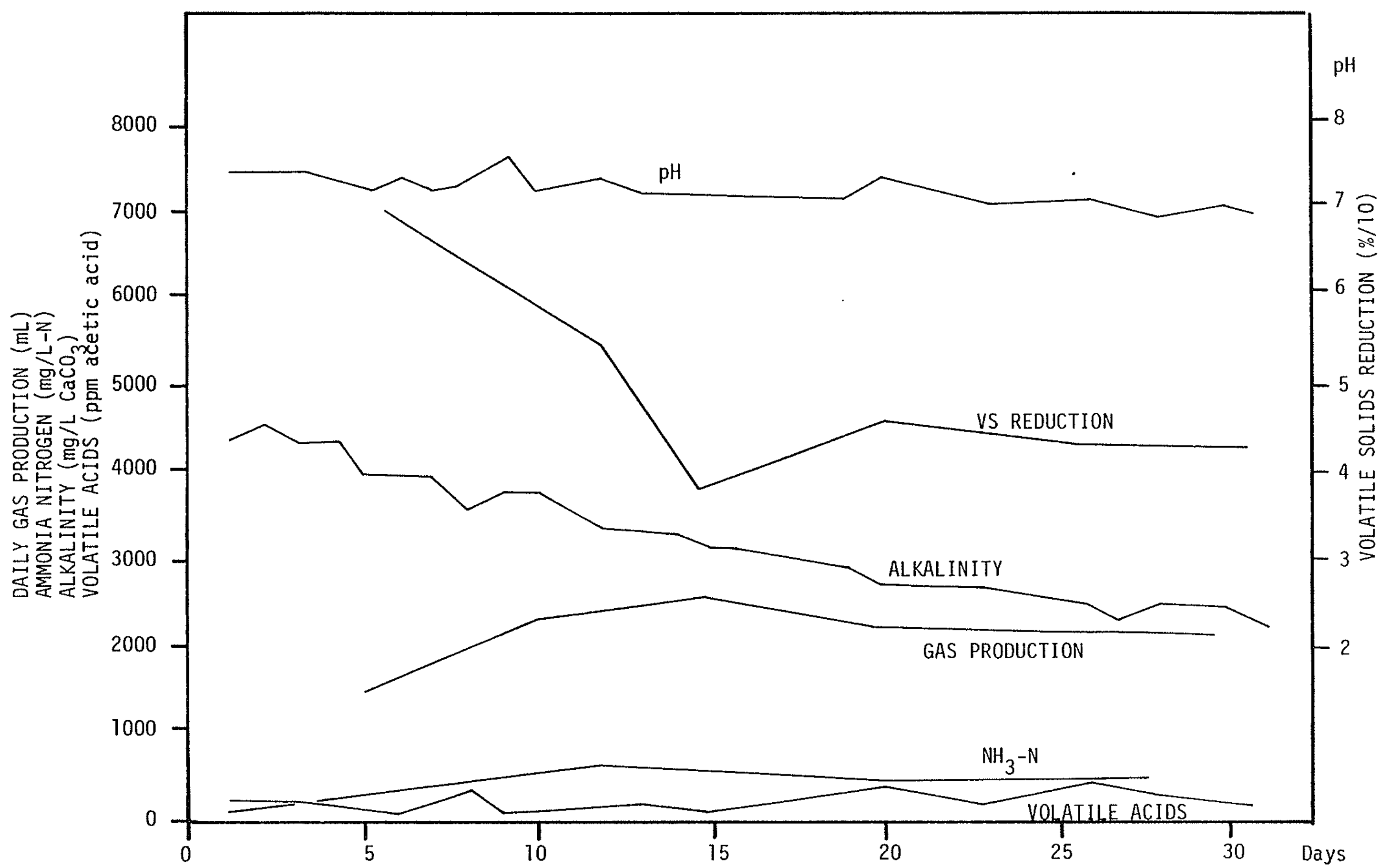

FIGURE 15. DIGESTER UNIT 8a PERFORMANCE vs. TIME
(Loading 0.15 lb VS/cf/d (2.4 g/L/d) - feces, Retention 15 days)

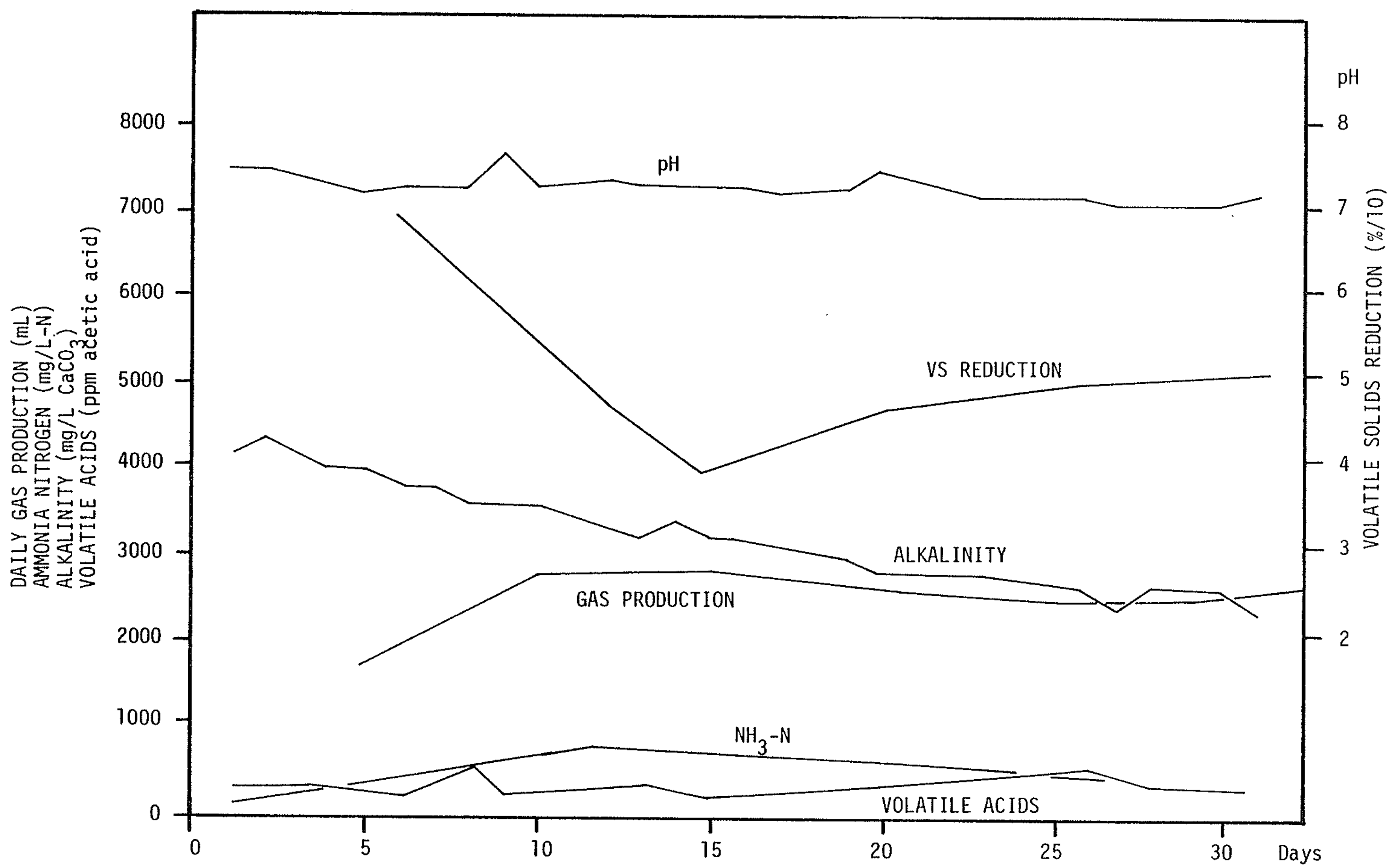

FIGURE 16. DIGESTER UNIT 8b PERFORMANCE vs. TIME
(Loading 0.15 lb VS/cf/d (2.4 g/L/d) - feces, Retention 15 days)

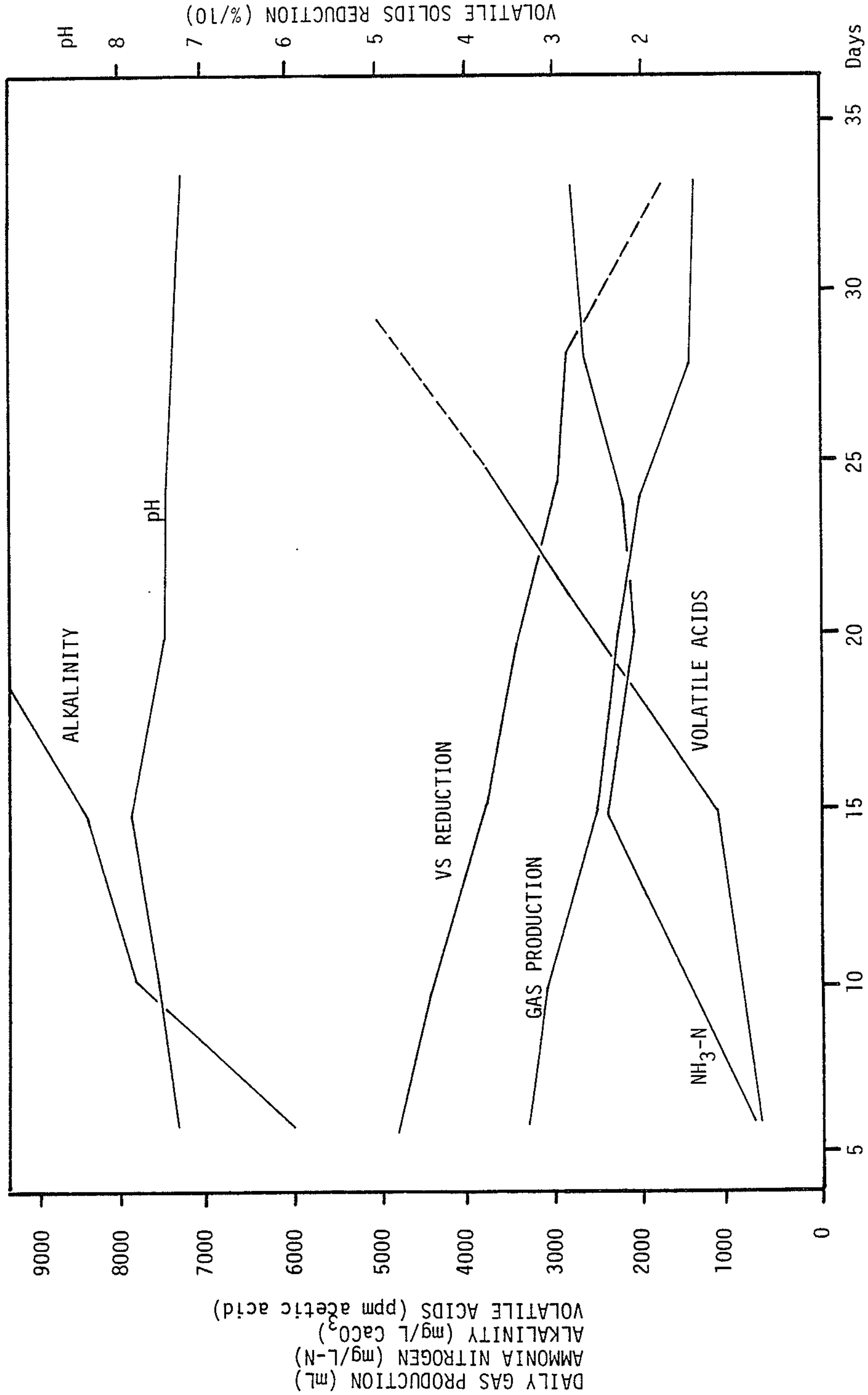

FIGURE 17. DIGESTER UNIT 9a PERFORMANCE vs. TIME
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - urine + feces, Retention 15 days)

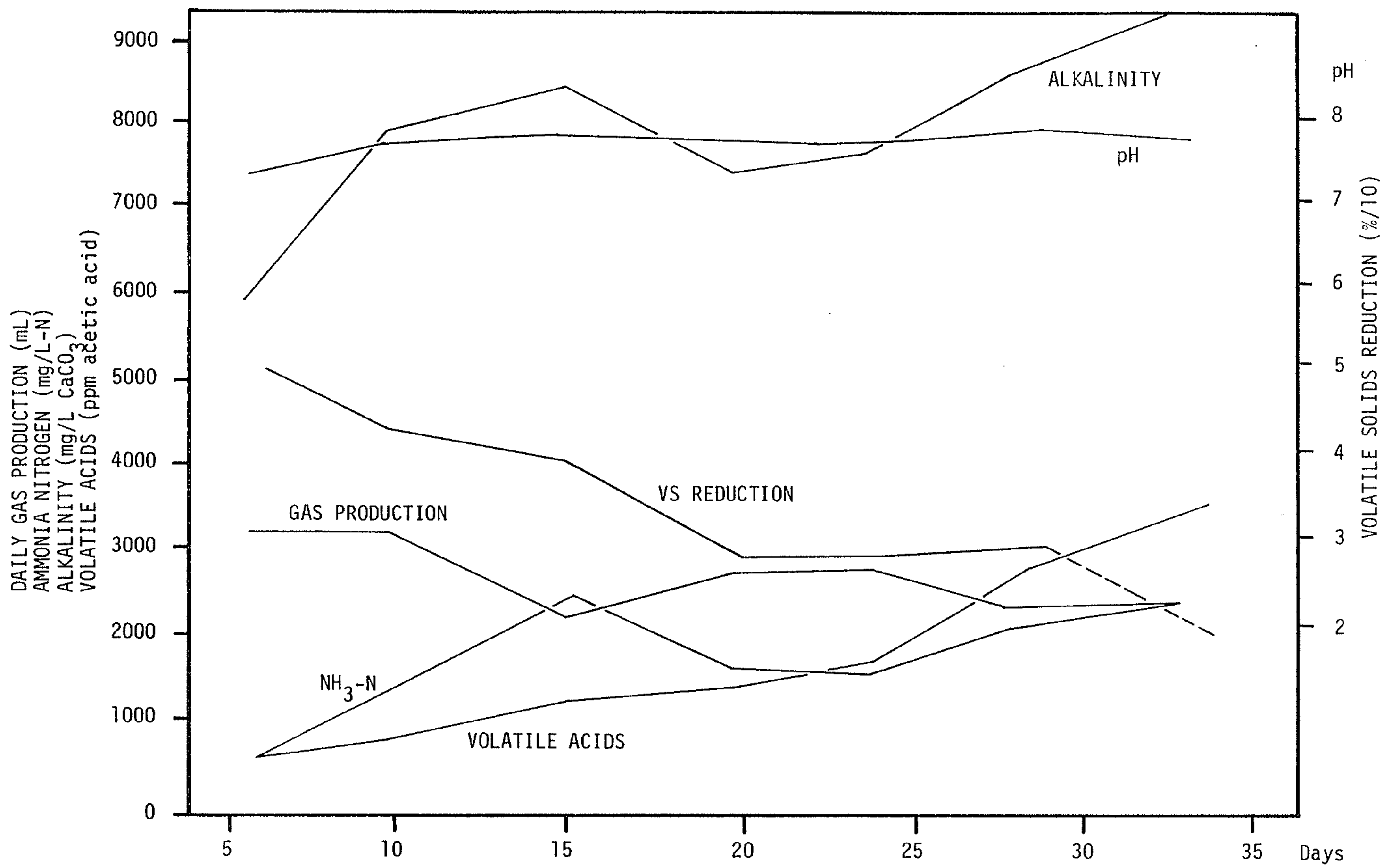

FIGURE 18. DIGESTER UNIT 9b PERFORMANCE vs. TIME
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - urine + feces, Retention 15 days)

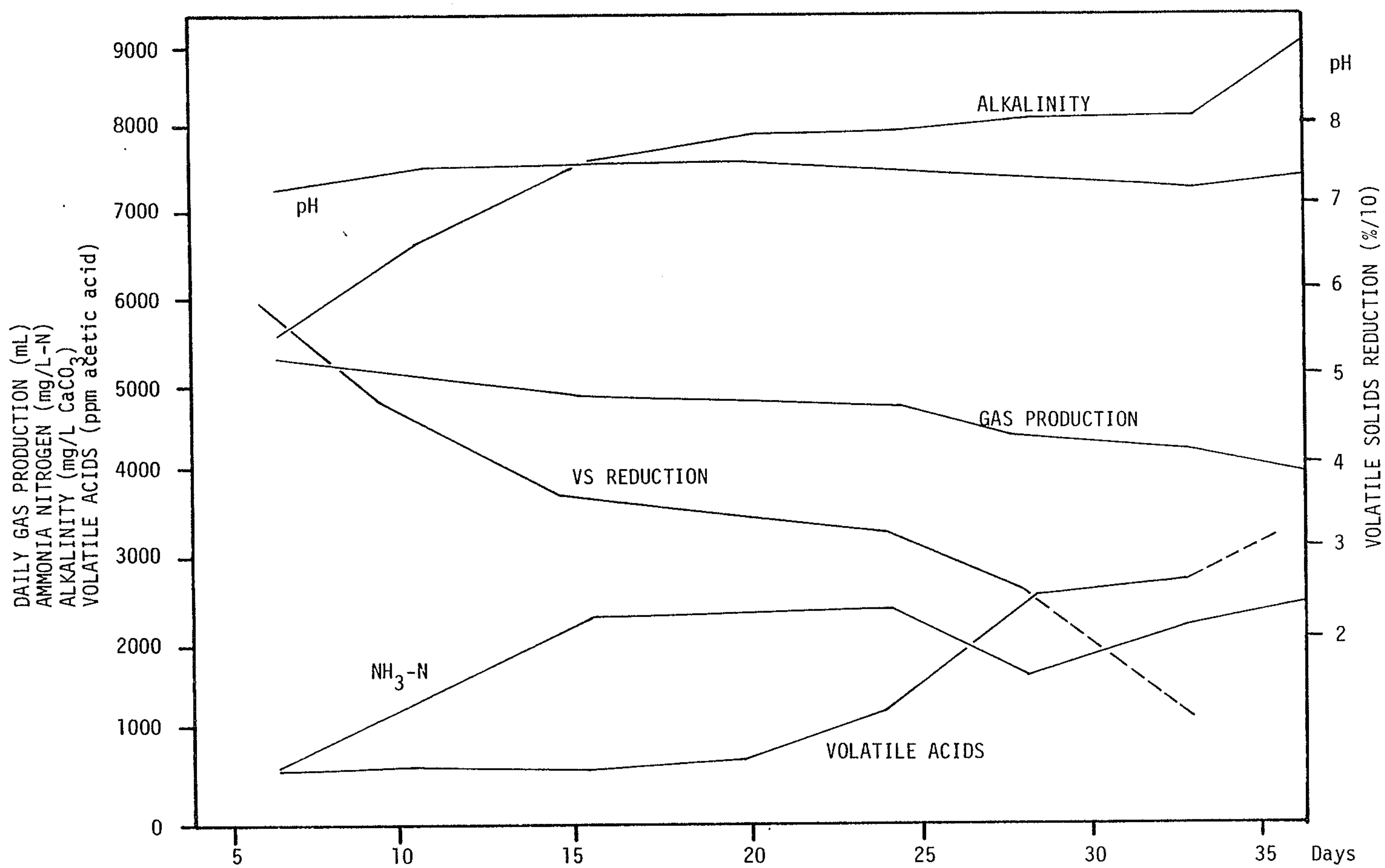

FIGURE 19. DIGESTER UNIT 10a PERFORMANCE vs. TIME
(Loading 0.25 lb VS/cf/d (4.0 g/L/d) - urine + feces, Retention 18 days)

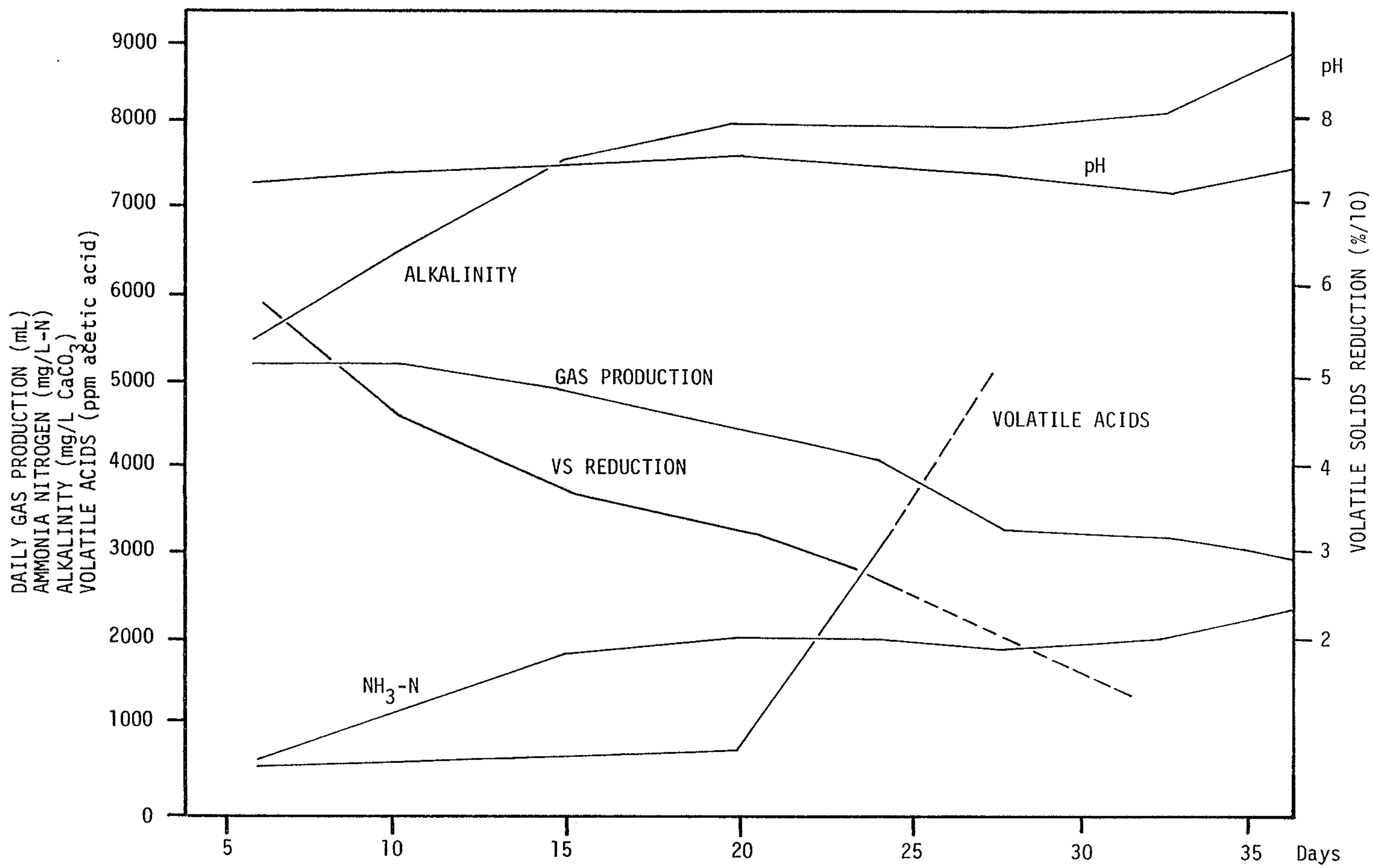

FIGURE 20. DIGESTER UNIT 10b PERFORMANCE vs. TIME
(Loading 0.25 lb VS/cf/d (4.0 g/L/d) - urine + feces, Retention 18 days)

5. DISCUSSION OF RESULTS

5.1 FIRST SERIES

The range of loading rates and retention times for digester units 1, 2 and 3 were as selected to establish more optimum parameters for subsequent digester runs. The manure for these digesters was obtained from barn No. 1 at the Glenlea Research Station which, at the time of the study, was used for raising growing and finishing hogs, and for farrowing pigs. No dilutions of substrate were made prior to feeding. The digester influent characteristics were identical for all three units; alkalinity and volatile acids concentrations were almost equivalent. The performance of all three digesters was similar, with undesirable increases in volatile acids, and corresponding decreases in gas production occurring shortly after digester start-up. The volatile solids reduction varied from 47 to 33%; the percent CH_4 in the gas produced was low and remained below 35%. During the runs, alkalinity levels in the digesters remained well in excess of the volatile acids concentrations which is indicative of good buffering capacity. The increases in alkalinity in the digesters may be attributable to the alkalinity levels in the brackish supply water used in the hog barns. pH values approached pH 8.0 on occasion, particularly in unit 3. This may have been sufficient to inhibit bacterial functions as the generally accepted upper limit for successful anaerobic activity is pH 7.8 (11). No pH adjustments were made for any of the digester runs. The shorter the retention time, the more rapid was the deterioration in digester operation. Although digester unit 3, with a retention time of 40 days, had not been completely displaced at termination, similar signs of digester failure were evident in all units. All three digesters were considered to have failed after 26 days of operation.

5.2 SECOND SERIES

Some thought had been given earlier to the possibility of ammonia in the manure causing toxicity problems in the digesters. To further evaluate this hypothesis, units 4, 5 and 6 were operated on various components of manure from barn No. 1. Representative samples of manure were used as substrate for unit 4, and only separated liquid supernatant and feces fractions were used for substrate in units 5 and 6, respectively. With reference to successful findings of other researchers, loading rates of 0.12 lb VS/cf/d (1.92 g/L/d) and retention times of 10 days were selected for the run but due to the low solids content of the liquid fraction, it was necessary to operate unit 5 on a very short 5 day retention time in order to approximate the common loading rate. The solids fraction used for unit 6 was diluted with tap water to achieve the desired retention time. The ammonia nitrogen content of the solids feed (unit 6) was significantly lower than that contained in the substrates for units 4 and 5; this is to be expected as the liquid fraction of the manure would contain most of the urea.

Unit 4 followed an operating pattern similar to units 1, 2 and 3, exhibiting progressive increases in alkalinity and volatile acids concentrations and corresponding reductions in gas production. Increasing alkalinity levels may again be attributable to the water supply alkalinity levels and would tend to increase the operating level of the volatile acids in the digester due to the available buffering capacity. Volatile solids reductions in this unit ranged from 45 to 35 percent and the methane content of the gas produced declined steadily from a maximum of about 40%. Ammonia nitrogen concentrations in the digester rose to levels which were considered to be inhibitory (2100 mg/L). At the associated higher pH levels in this digester (7.8, 7.9, which in itself may have been sufficient to inhibit successful anaerobic activity), the ammonia gas form would be prevalent.

Unit 5 exhibited extremely rapid signs of digester failure. Although a larger digester should have been used in this case so as to maintain an equivalent retention time for all units in this series, the results of such a short retention time are evident. Volatile solids reductions in unit 5 were negligible. Alkalinity, volatile acids and ammonia nitrogen levels rose dramatically, exceeding accepted levels within a few days. In this instance it is most likely that the short retention time did not allow the bacteria to become acclimatized sufficiently before being flushed out of the digester, and therefore contributed to the causes of digester failure.

Unit 6, operating on the solids fraction of the manure, operated successfully for 36 days before being terminated. Alkalinity and volatile acids concentrations in the unit were representative of a well-functioning digester; volatile solids reductions ranged from 47 to 66 per cent. Gas production was steady, averaging 2650 mL/day, or about 10 cubic feet/lb VS destroyed per day (624 L/kg), and exhibited a methane content of 55%. Most significantly, and without doubt attributable to the low concentrations in the feed material, ammonia nitrogen levels in this digester averaged only 630 mg/L.

5.3 THIRD SERIES

To confirm the successful operation of a digester being fed the separated solids portion of the manure, four more digesters (7a, 7b, 8a, 8b) were set up to operate on manure solids. Loading rates of 0.12 and 0.15 lb VS/cf/d (1.92 and 2.4 g/L/d) were used, and to allow a more gradual acclimatization to the feed material, a longer retention time of 15 days was selected for all four units. Digester units were run in duplicate. The manure for these digesters was obtained from barn No. 3 at the Glenlea Research Station which, at the time of the study, was used for raising breeding and replacement hogs. The performance of all four digesters was similar to that of unit 6 and after 33 days of operation, all four units were considered successful runs. Alkalinity, volatile acids, pH and NH_3-N were all within typically acceptable limits. Alkalinity exceeded volatile acids within each digester by a factor of about 10, thereby providing good buffering capacity. Ammonia nitrogen levels were compatible with the NH_3-N concentrations in the feed substrate and were well below those levels considered toxic, averaging about 500-600 mg/L. Volatile solids reductions in all four digesters were typical of a well functioning digester, all being around 50%. Gas production was consistent, averaging a high in unit 8b of 9.5 cubic feet/lb VS destroyed/day (593 L/kg/d) and exhibiting a methane content of 68%.

5.4 FOURTH SERIES

Since the successful digester units had all operated on the solids portion of the manure and all failures had occurred in units being fed manure from barn No. 1, tests were run on digesters being fed representative samples of manure (solids plus urine) from barn No. 3. Barn No. 1 at the Glenlea Farm was, at the time of the study, being used in part as a farrowing facility. The wastewater from this barn, unlike the manure from barn No. 3, therefore contained quantities of detergents, soaps, lye, and disinfectants used in the farrowing procedures and subsequent clean-up. The possibility of these compounds being present in such quantities so as to adversely affect the digestion process had been considered. A series of digesters (9a, 9b, 10a, 10b) was therefore set up to run on manure from barn No. 3. The digesters were run in duplicate - two at a loading rate of 0.12 lb VS/cf/d (1.92 g/L/d) and 15 days retention, and two at a loading rate of 0.25 lb VS/cf/d (4.0 g/L/d) and, in conjunction with the higher loading rate, a longer 18 day retention time. Performance in these four digesters was similar to that observed for units 1 to 4, although operational changes were not as rapid. Throughout the operating period, alkalinity levels within the digesters were well above volatile acids levels so good acid buffering capacity was available. The high concentrations of alkalinity in the digester influent may be attributable to the alkalinity levels in the water supply for the farm and are reflected in increasing operating levels in the digesters. Both alkalinity and volatile acids concentrations reached levels which were considered untypical of good digester operation. Volatile solids reductions for the digesters were just over 30% and below those levels considered acceptable for effective digester operation. Gas production was initially very high (4000 to 5300 mL/day) and was likely due to an active sample of municipal sludge used to seed the digesters. Although gas production remained relatively high for all four digesters in this series (relative to units in other series), daily gas production did decrease steadily throughout the run. Ammonia nitrogen in the digester influent exceeded 2000 mg/L and NH_3-N levels in all four digesters increased to levels which were considered inhibitory. None of these digesters actually ceased operating; their performances were typical of digesters which had failed earlier, however, and as digester failure appeared imminent, the units were terminated after 36 days of operation.

6. SUMMARY AND CONCLUSIONS

This study was undertaken as the initial phase in determining the suitability of hog wastes from a Manitoba hog operation as a substrate for anaerobic digestion, and to assess the parameters affecting the digestion process and the gas production capabilities of the system.

The literature survey and laboratory work were conducted at the University of Manitoba during the periods September 1971 to July 1972 and January 1974 to June 1974. The results and comments presented, and the conclusions drawn, are based on the information obtained during this time.

Experiments were conducted using laboratory scale digesters operated at 35°C with once a day feeding and withdrawal at different loading rates and retention times. During the course of the experiments, regular analyses of the digesting material were conducted for various operating parameters, including pH, alkalinity, volatile acids, ammonia nitrogen and volatile solids. The quantity and quality of gas produced were also assessed.

The reader is directed to Section 4, EXPERIMENTAL RESULTS, for a presentation of the findings of this study, and to Section 5, DISCUSSION OF RESULTS, for an explanation of the procedures and tabulated data. General conclusions drawn from the study are as follows:

1. All digesters in the study which were fed wastes containing appreciable quantities of urine (ie. unseparated manure fractions) failed.

2. Digesters operated on substrate from which the majority of the urine fraction had been removed were all successful runs. The

NH_3-N, volatile acids and alkalinity concentrations in the feed material were all considerably lower than those concentrations in the feed material (urine plus feces) for other digesters.

3. NH_3-N concentrations in those units which failed increased to levels which were considered to be inhibitory for effective digester operation. At NH_3-N concentrations exceeding 2000 mg/L and corresponding pH levels of 7.5-7.7, ammonia gas is considered to be the inhibitory form of ammonia.

4. In all digester units, alkalinity levels exceeded volatile acids concentrations, thereby providing buffering capacity at all times. In those units that failed, the volatile acids concentrations progressively approached the alkalinity levels as failure became more imminent. In the successful digestion units, alkalinity exceeded the volatile acids by approximately a factor of 10 throughout the operating period.

5. Soaps and detergents present in the manure from Barn No. 1 were not thought to have contributed to digester failure since units operated on manure from Barn No. 3, which did not contain soaps and detergents, also exhibited signs characteristic of digester failure.

6. Although sufficient data was not accumulated to observe a definite pattern, it was noted that for the successful digesters, a decrease in the retention time appeared to increase the gas production but reduce the percent methane in the gas. Also, an increase in the loading rate appeared to increase the percent methane in the gas. This does not agree completely with the findings of other researchers (6).

7. Gas production from digesters operating on the separated solids portion of the manure averaged 8.8 to 10.4 cubic feet/lb VS

destroyed/day (549 to 649 L/kg/d) and for one digester reached a maximum of 12.1 cubic feet/lb VS destroyed/day (755 L/kg/d). Methane content of the gas averaged 55-68%.

8. Consideration may have to be given to removing the urine fraction of the manure from the waste material in order to allow effective digestion to proceed unless the problem apparently attributable to NH_3-N levels in the urine fraction can be overcome by loading rate and retention time modifications. Other researchers have found that digesters operating on hog wastes containing urine are seldom successful unless loading rates are very low ($\leqslant$.075 lb VS/cf/d (1.2 g/L/d)) and retention times are fairly high ($\geqslant$22 days) (23).

APPENDIX A

PROCEDURE FOR DETERMINING VOLATILE ACIDS

USING A HACH DR COLORIMETER

PROCEDURE FOR DETERMINING VOLATILE ACIDS

USING A HACH DR COLORIMETER

1. A sample is clarified by centrifugation.
2. Pipet exactly 0.5 mL of sample, or an aliquot diluted to 0.5 mL with demineralized water, into a clean test tube.
3. Into another clean test tube pipet exactly 0.5 mL of demineralized water.
4. Add 1.5 mL Ethylene Glycol (analytical reagent) to each tube.
5. Add 0.2 mL of 19.2 N H_2SO_4 to each tube. Mix well by swirling.
6. Heat in a boiling water bath for exactly three minutes.
7. Immediately cool in cold water.
8. Add 0.5 mL Hydroxylamine Hydrochloride solution (HACH Chemical Co.) to each tube.
9. Add 2.0 mL 4.5 N NaOH to each tube. Mix well by swirling.
10. To each of two clean colorimeter bottles (supplied with unit) add 10 mL Ferric Chloride Solution (HACH Chemical Co.).
11. Pour the contents of the sample tube into one colorimeter bottle and the prepared demineralized water blank into the other.
12. Add 10 mL water to each bottle. Swirl to mix.
13. Allow to stand 5 minutes for color development.
14. Place the prepared demineralized water blank in the light cell. Insert the volatile acids meter scale and use the 4445 Color Filter (both supplied with unit). Adjust the light control for a meter reading of 0 ppm.
15. Place the prepared sample in the light cell. Read the volatile acids as ppm acetic acid.

Volatile acids in the range 0 to 3000 ppm as acetic acid can be determined directly using the above method. Higher values can be determined using standard dilution procedures.

APPENDIX B

TABULATED EXPERIMENTAL RESULTS

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.7	3400	340	-	-	-	-	-
2	7.6	3600	-	-	-	-	-	800
3	7.6	4300	-	-	-	-	-	-
4	7.5	5200	-	3.04	61.3	47	-	800
5	7.5	6600	2900	-	-	-	-	-
6	7.4	6800	3000	-	-	-	-	-
7	-	-	-	-	-	-	-	-
8	7.2	7400	>3000	-	-	-	-	1150
9	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-
11	7.4	8400	>3000	-	-	-	-	1100
12	7.4	8500	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
14	7.7	8600	>6000	4.75	67.6	33	-	700
15	7.7	8700	>6000	-	-	-	-	-
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	425
19	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	250
23	7.5	9000	>6000	3.67	61.6	47	-	-
24	7.5	9000	-	-	-	-	-	-
25	7.4	9000	-	-	-	-	-	-
26	7.6	9200	>8000	-	-	-	-	200
27								

TABLE B1 DIGESTER UNIT 1 ANALYSES DATA
(Loading 0.5 lb VS/cf/d (8.0 g/L/d) - urine + feces, Retention 8 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.7	3400	340	-	-	-	-	-
2	7.7	3600	-	-	-	-	-	625
3	7.8	4000	-	-	-	-	-	-
4	7.8	4600	-	2.68	62.4	45	-	750
5	7.7	5200	-	-	-	-	-	-
6	7.6	5800	2800	-	-	-	-	-
7	-	-	-	-	-	-	-	1325
8	7.4	6800	>3000	3.38	62.9	44	-	-
9	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	1775
11	7.6	7200	>3000	-	-	-	-	-
12	7.6	7400	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
14	7.8	7200	3400	3.77	65.8	37	-	1225
15	7.8	7200	3600	-	-	-	-	-
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	925
19	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	450
23	7.8	7600	>3000	3.44	63.1	44	-	-
24	7.8	7600	-	-	-	-	-	-
25	7.7	7000	-	-	-	-	-	-
26	7.6	6600	4800	-	-	-	-	275
27								

TABLE B2 DIGESTER UNIT 2 ANALYSES DATA
(Loading 0.25 lb VS/cf/d (4.0 g/L/d) - urine + feces, Retention 16 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.7	3400	340	-	-	-	-	-
2	7.7	3800	-	-	-	-	-	550
3	7.8	4200	-	-	-	-	-	-
4	7.8	4800	-	2.98	63.4	43	-	550
5	7.9	4600	-	-	-	-	-	-
6	7.7	4800	2200	-	-	-	-	-
7	-	-	-	-	-	-	-	950
8	7.8	5200	2000	2.74	-	-	-	-
9	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	1430
11	7.9	6000	2300	-	-	-	-	-
12	7.9	6200	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
14	-	5000	1800	2.80	60.9	51	-	1300
15	-	5000	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	950
19	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	400
23	8.0	5200	1700	2.63	58.9	52	-	-
24	7.9	5200	-	-	-	-	-	-
25	7.8	5400	-	-	-	-	-	-
26	7.8	4600	1800	-	-	-	-	350
27								

TABLE B3 DIGESTER UNIT 3 ANALYSES DATA
(Loading 0.10 lb VS/cf/d (1.6 g/L/d) - urine + feces, Retention 40 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.6	3000	375	-	-	-	150	-
2	7.7	3600	350	-	-	-	-	1825
3	7.7	4000	-	3.88	45.3	-	-	-
4	7.8	4400	-	-	-	-	-	-
5	7.9	4800	470	-	-	-	-	4000
6	7.9	5400	-	-	-	-	-	-
7	7.9	5800	340	3.28	48.9	45	725	-
8	7.9	6000	-	-	-	-	-	3630
9	7.8	6400	-	-	-	-	-	-
10	7.6	6600	-	-	-	-	-	-
11	7.9	6800	1850	-	-	-	-	2150
12	7.9	7600	-	-	-	-	1740	-
13	7.7	7200	-	3.00	54.8	35	-	1300
14	7.6	7400	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-
16	7.2	7800	-	-	-	-	-	-
17	7.4	7800	5200	2.65	50.5	42	1860	-
18	-	-	-	-	-	-	-	800
19	7.7	8000	>6000	-	-	-	-	-
20	-	-	-	-	-	-	-	-
21	7.3	8200	-	-	-	-	-	-
22	7.3	8000	-	-	-	-	-	375
23	7.4	7800	-	-	-	-	-	-
24	7.4	7200	>6000	-	-	-	2100	-
25								

TABLE B4 DIGESTER UNIT 4 ANALYSES DATA
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - urine + feces, Retention 10 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.6	3000	275	3.85	42.0	Negligible.	150	-
2	7.8	4200	780	-	-	Rapid Failure	-	1850
3	7.8	5800	-	3.05	41.2	of Digester	-	-
4	7.9	6400	-	-	-	Within a Few	-	3375
5	7.9	7400	>3000	-	-	Days	-	-
6	7.8	7800	-	-	-		-	1825
7	7.6	6800	>3000	3.29	44.1		850	-
8	7.6	6000	-	-	-		-	1125
9	7.5	7000	-	-	-		-	-
10	7.4	7000	-	-	-		-	625
11	7.7	7600	>5000	-	-		-	-
12	7.6	7800	-	-	-		1790	420
13	7.6	7800	-	-	-		-	-
14								

TABLE B5 DIGESTER UNIT 5 ANALYSES DATA
(Loading 0.10 lb VS/cf/d (1.6 g/L/d) - liquid, Retention 5 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.6	3000	350	-	-	-	150	-
2	7.8	3000	180	-	-	-	-	-
3	7.6	3000	-	3.15	50.0	-	-	-
4	7.9	3000	-	-	-	-	-	2375
5	7.9	3000	200	-	-	-	-	-
6	7.6	3000	-	-	-	-	-	-
7	7.8	3200	150	3.81	54.6	66	-	-
8	7.8	3200	-	-	-	-	-	2140
9	7.5	3200	-	-	-	-	-	-
10	7.6	3000	-	-	-	-	-	-
11	7.7	3200	160	-	-	-	-	-
12	7.5	3000	-	-	-	-	196	2450
13	7.8	3200	-	2.01	56.8	63	-	-
14	7.6	3200	-	-	-	-	-	-
15	-	-	-	-	-	-	-	2400
16	7.6	3400	-	-	-	-	-	-
17	7.7	3200	100	1.95	60.4	57	795	-
18	-	-	-	-	-	-	-	3230
19	7.7	4600	240	-	-	-	-	-
20	-	-	-	-	-	-	-	-
21	7.7	3600	-	-	-	-	-	-
22	7.7	3600	-	-	-	-	-	3200
23	7.8	3600	-	-	-	-	-	-
24	7.8	3800	300	-	-	-	1100	-
25	-	-	-	-	-	-	-	3200
26	7.4	3400	-	1.93	64.7	48	-	-
27	7.3	3400	-	-	-	-	-	-
28	7.1	3600	850	-	-	-	-	-
29	7.2	3800	-	-	-	-	-	2600
30	-	-	-	-	-	-	-	-
31	7.1	3800	-	2.05	65.6	47	-	-
32	-	-	-	-	-	-	-	-
33	7.1	3800	720	-	-	-	900	2950

TABLE B6 DIGESTER UNIT 6 ANALYSES DATA
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - feces, Retention 10 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.5	4600	350	-	-	-	180	-
2	7.5	4600	-	-	-	-	-	-
3	7.4	4200	350	-	-	-	-	-
4	7.4	4200	-	-	-	-	-	-
5	7.3	4200	-	-	-	-	-	-
6	7.4	3800	-	2.9	62.6	71	-	-
7	7.3	4000	-	-	-	-	-	-
8	7.4	3600	560	-	-	-	-	-
9	7.6	3800	240	-	-	-	-	-
10	7.3	3800	-	-	-	-	-	1920
11	-	-	-	-	-	-	-	-
12	7.4	3400	-	3.06	71.4	56	963	-
13	7.3	3000	275	-	-	-	-	-
14	7.3	3200	-	-	-	-	-	-
15	7.3	3000	200	3.38	75.8	45	-	2440
16	7.2	3200	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	7.4	3200	-	-	-	-	-	-
20	7.5	3000	400	3.39	76	44	627	2480
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23	7.4	3200	150	-	-	-	-	-
24	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	2540
26	7.5	3400	200	3.76	78	38	-	-
27	7.4	3200	-	-	-	-	660	-
28	7.5	3400	325	-	-	-	-	-
29	-	-	-	-	-	-	-	-
30	7.5	3600	-	-	-	-	-	2400
31	7.6	3400	300	4.37	80.3	35	-	-
32	-	-	-	-	-	-	-	-
33	7.6	3400	300	-	-	-	-	-
34	7.4	3400	-	-	-	-	-	-
35	-	-	-	-	-	-	-	2400
36	7.3	3400	300	-	-	-	599	-

TABLE B7 DIGESTER UNIT 7a ANALYSES DATA
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - feces, Retention 15 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.6	5200	400	-	-	-	180	-
2	7.6	5000	-	-	-	-	-	-
3	7.5	5000	450	-	-	-	-	-
4	7.5	4800	-	-	-	-	-	-
5	7.5	4600	-	-	-	-	-	-
6	7.4	4400	400	2.75	58.7	75	-	-
7	7.3	4200	-	-	-	-	-	-
8	7.4	4000	600	-	-	-	-	-
9	7.7	4000	200	-	-	-	-	-
10	7.3	4000	-	-	-	-	-	2010
11	-	-	-	-	-	-	-	-
12	7.5	3800	-	3.05	69.5	59	902	-
13	7.3	3400	300	-	-	-	-	-
14	7.3	3600	-	-	-	-	-	-
15	7.3	3400	200	3.24	74.5	49	-	2480
16	7.3	3400	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	7.3	3000	-	-	-	-	-	-
20	7.5	3000	580	3.61	76.0	44	593	2280
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23	7.2	2800	500	-	-	-	-	-
24	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	2360
26	7.3	2600	500	2.54	77.0	40	-	-
27	7.3	2400	-	-	-	-	510	-
28	7.2	2400	500	-	-	-	-	-
29	-	-	-	-	-	-	-	-
30	7.2	2600	-	-	-	-	-	2460
31	7.2	2600	400	3.58	75.6	45	-	-
32	-	-	-	-	-	-	-	-
33	7.2	2600	420	-	-	-	550	2500

TABLE B8 DIGESTER UNIT 7b ANALYSES DATA
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - feces, Retention 15 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.5	4400	350	-	-	-	180	-
2	7.5	4600	-	-	-	-	-	-
3	7.5	4400	350	-	-	-	-	-
4	7.4	4400	-	-	-	-	-	-
5	7.3	4000	-	-	-	-	-	-
6	7.4	4000	175	3.10	63.0	70	-	-
7	7.3	4000	-	-	-	-	-	-
8	7.4	3600	410	-	-	-	-	-
9	7.4	3800	150	-	-	-	-	-
10	7.3	3800	-	-	-	-	-	2400
11	-	-	-	-	-	-	-	-
12	7.5	3400	-	3.45	73.2	52	851	-
13	7.3	3400	250	-	-	-	-	-
14	7.3	3400	-	-	-	-	-	-
15	7.3	3200	175	4.22	78.0	38	-	2760
16	7.3	3200	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	7.3	3000	-	-	-	-	-	-
20	7.5	2800	500	4.14	75.7	45	593	2540
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23	7.2	2800	325	-	-	-	-	-
24	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	2540
26	7.3	2600	475	3.90	76.2	42	-	-
27	7.2	2400	-	-	-	-	493	-
28	7.1	2600	400	-	-	-	-	-
29	-	-	-	-	-	-	-	-
30	7.2	2600	-	-	-	-	-	2500
31	7.1	2400	350	4.20	75.9	42	-	-
32	-	-	-	-	-	-	-	-
33	7.1	2400	380	-	-	.-	500	2620

TABLE B9 DIGESTER UNIT 8a ANALYSES DATA
(Loading 0.15 lb VS/cf/d (2.4 g/L/d) - feces, Retention 15 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	7.5	4200	275	-	-	-	180	-
2	7.5	4400	-	-	-	-	-	-
3	7.4	4200	300	-	-	-	-	-
4	7.3	4000	-	-	-	-	-	-
5	7.2	4000	-	-	-	-	-	-
6	7.3	3800	200	2.88	64.0	68	-	-
7	7.3	3800	-	-	-	-	-	-
8	7.3	3600	540	-	-	-	-	-
9	7.7	3600	110	-	-	-	-	-
10	7.3	3600	-	-	-	-	-	2820
11	-	-	-	-	-	-	-	-
12	7.4	3400	-	3.58	75.0	45	823	-
13	7.3	3200	350	-	-	-	-	-
14	7.3	3400	-	-	-	-	-	-
15	7.3	3200	175	3.99	78.5	37	-	2960
16	7.3	3200	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	7.3	3000	-	-	-	-	-	-
20	7.5	2800	350	4.90	75.7	45	588	2740
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23	7.2	2800	400	-	-	-	-	-
24	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	2560
26	7.2	2600	575	4.60	74.6	48	-	-
27	7.1	2400	-	-	-	-	482	-
28	7.1	2600	300	-	-	-	-	-
29	-	-	-	-	-	-	-	-
30	7.1	2600	-	-	-	-	-	2780
31	7.2	2400	275	4.43	74.0	50	-	-
32	-	-	-	-	-	-	-	-
33	7.2	2400	280	-	-	-	500	2880

TABLE B10 DIGESTER UNIT 8b ANALYSES DATA
(Loading 0.15 lb VS/cf/d (2.4 g/L/d) - feces, Retention 15 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	-	-	-	-	-	-	-	4000
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	7.4	6000	500	3.90	45.2	48	550	3350
7	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	7.7	7800	720	3.94	47.5	42	-	3150
11	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
15	7.8	8400	1100	3.94	50.1	38	2280	2300
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-
20	7.7	9400	2350	3.88	51.5	35	1930	2100
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-
24	7.7	9600	3600	3.89	53.1	30	2160	2000
25	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-
28	7.6	10000	>5000	3.91	53.5	29	2660	1600
29	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-
33	7.5	9600	>5000	4.35	58.5	<20	2860	1600
34								

TABLE B11 DIGESTER UNIT 9a ANALYSES DATA
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - urine + feces, Retention 15 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	-	-	-	-	-	-	-	4000
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	7.4	6000	500	3.82	45.2	48	500	3150
7	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	7.7	7800	720	3.80	47.7	42	-	3150
11	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
15	7.8	8400	1200	3.84	49.6	39	2470	2200
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-
20	7.7	7200	1350	3.54	54.5	27	1420	2800
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-
24	7.7	7600	1800	3.56	54.6	27	1600	2800
25	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-
28	7.8	8600	2700	3.59	53.9	29	2160	2400
29	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-
33	7.7	9200	3300	4.07	58.0	<20	2400	2400
34								

TABLE B12 DIGESTER UNIT 9b ANALYSES DATA
(Loading 0.12 lb VS/cf/d (1.92 g/L/d) - urine + feces, Retention 15 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	-	-	-	-	-	-	-	4000
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	7.3	5600	400	5.66	53.5	57	420	5300
7	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	7.5	6600	470	6.23	58.5	46	-	5100
11	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
15	7.6	7600	460	6.85	63.0	36	2120	4850
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-
20	7.6	7900	716	7.25	65.6	33	2210	4800
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-
24	7.5	7900	1200	7.40	66.2	31	2200	4750
25	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-
28	7.4	8000	2500	7.77	67.4	25	1820	4400
29	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-
33	7.4	8000	2700	7.64	68.0	<20	2260	4300
34	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-
36	7.5	9000	>3000	7.81	68.2	<20	2400	4000

TABLE B13 DIGESTER UNIT 10a ANALYSES DATA
(Loading 0.25 lb VS/cf/d (4.0 g/L/d) - urine + feces, Retention 18 days)

Day	pH	Alkalinity (mg/L $CaCO_3$)	VA (ppm acetic)	TS (%)	VS (%)	VS Red'n (%)	NH_3-N (mg/L)	Daily Gas Prod'n (mL)
1	-	-	-	-	-	-	-	4000
2	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-
6	7.3	5600	400	5.88	54.2	55	450	5350
7	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-
10	7.5	6600	450	6.40	59.0	45	-	5300
11	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-
15	7.6	7600	460	6.97	63.3	35	1930	4900
16	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-
20	7.7	8100	600	7.75	66.0	31	2020	4600
21	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-
24	7.6	8000	3000	8.2	67.6	25	2000	4050
25	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-
28	7.4	8000	>5000	8.4	68.3	<20	1960	3300
29	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-
33	7.2	8200	>5000	8.18	69.8	<20	2000	3200
34	-	-	-	-	-	-	-	-
35	-	-	-	-	-	-	-	-
36	7.4	8500	>5000	8.30	69.6	<20	2260	3000

TABLE B14 DIGESTER UNIT 10b ANALYSES DATA
(Loading 0.25 lb VS/cf/d (4.0 g/L/d) - urine + feces, Retention 18 days)

APPENDIX C

GLENLEA HOG BARN INFORMATION

BARN No. 1 INFORMATION

Type of hog: Growing and Finishing

Residence: Approximately 600 hogs

Feed Ration: High protein concentrate (16-20%) composed of

1. alfalfa, OR
2. barley and wheat, OR
3. only barley, PLUS
4. protein supplements of potassium, calcium, limestone, bonemeal and multimineral salts (copper, cobalt, zinc, iodine).

Feed-Rite (Feed-Rite Mills Ltd.) ratio exhibits the following guaranteed analysis:

	FINISHER	GROWER
Crude Protein (min.)	14.00%	16.00%
Crude Fat (min.)	3.00%	3.00%
Crude Fibre (max.)	10.00%	8.00%
Salt NaCl (actual)	0.35%	0.25%
Calcium Ca (actual)	0.65%	0.75%
Phosphorus P (actual)	0.45%	0.60%
Zinc Zn (actual)	0.0054%	0.014%
Vitamin A (min. I.U./lb.)	1000	3000
Vitamin D (min. I.U./lb.)	300	1000
Arsanilic Acid (g/ton)	-	90

Trace mineralized salt analysis in feed ration (0.35% - 0.25%):

Salt (NaCl)	96.500%
Iodine (I)	.010%
Cobalt (Co)	.004%
Iron (Fe)	.160%
Copper (Cu)	.033%
Managanese (Mn)	.120%
Zinc (Zn)	.400%

Farrowing is practiced in this barn therefore the waste contains washwater and detergents from the wash room.

Detergent use:	15-20 gallons used per year
Detergent type:	Wood's Pine Disinfectant
	Wood's Concentrated Soap
	Gillett's Lye
	Canada Packers Sterling Soap
Wash water:	Contains Calgon water softener

BARN No. 3 INFORMATION

Type of hog:	Breeding and Replacement
Residence:	Approximately 250 hogs
Feed Ration:	Low-medium protein concentrate (10-12%) composed of

1. grain screenings, OR
2. alfalfa hay, OR
3. oats and barley, OR
4. a combination of the above.

Feed-Rite (Feed-Rite Mills Ltd.) ration exhibits the following guaranteed analysis:

	GESTATION	LACTATION
Crude Protein (min.)	14.00%	16.00%
Crude Fat (min.)	3.00%	3.00%
Crude Fibre (max.)	10.00%	8.00%
Salt NaCl (actual)	0.30%	0.25%
Calcium Ca (actual)	0.80%	0.75%
Phosphorus P (actual)	0.60%	0.60%
Zinc Zn (actual)	0.0076%	0.0076%
Vitamin A (min. I.U./lb.)	2500	2500
Vitamin D (min. I.U./lb.)	600	600

Trace mineralized salt analysis in feed ration (0.35% - 0.25%):

Salt (NaCl)	96.500%
Iodine (I)	.010%
Cobalt (Co)	.004%
Iron (Fe)	.160%
Copper (Cu)	.033%
Managanese (Mn)	.120%
Zinc (Zn)	.400%

Waste from this barn contains no detergents.

APPENDIX D

SUPPLY WATER CHARACTERISTICS

SUPPLY WATER CHARACTERISTICS

Characteristics of the well water supply to the Glenlea hog barns, as provided by the Manitoba Department of Health (August 4, 1965) samples, are as follows. The Winnipeg city water characteristics are also provided for comparative purposes.

	Source of Water	
Analysis	Glenlea Well	Winnipeg City
Nitrate	Nil	Nil
Total Hardness Calcium Carbonate (ppm)	620	96.3
Total Alkalinity Actual calcium carbonate (ppm)	208	87.5
Bicarbonate (ppm)	254	107.0
Carbonate (ppm)	Nil	Nil
pH	7.6	6.9
Conductivity Dissolved solids (ppm)	4500	125
Calcium	144	25.2
Magnesium	63.2	8.1

APPENDIX E

FEED RATE CALCULATION EXAMPLE

FEED RATE CALCULATION

Following is an example of how the feed rates were determined. Although the numbers are representative, they do not pertain to any one specific digester in this project.

Assumptions

Digester volume	4 litres
Loading Rate	0.12 lb VS/cf/d (1.9 g/L/d)
Retention Time	12 days
Residue Analyses of manure	
Total Solids	4.0% = 40 000 mg/L
Volatile Solids	80% = 32 000 mg/L
	= 32 g/L

Loading Rate = 1.9 g VS/L/d
= 7.6 g VS/4-L digester/d

Substrate required = $\frac{7.6}{32} = \underline{237 \text{ mL}}$

Hydraulic Retention Time (12 days) = $\frac{\text{Digester volume (4000 mL)}}{\text{Feed volume}}$

Feed volume = $\underline{333 \text{ mL/d}}$

So daily feed addition requires 237 mL manure substrate
plus 96 mL water.

APPENDIX F

ENERGY POTENTIAL OF HOG WASTES

ENERGY POTENTIAL OF HOG WASTES

An important end product of anaerobic digestion is methane gas (CH_4). Methane, a highly combustible gas, can be adapted for heating, domestic uses, and as an energy source for internal combustion engines.

The results of the work done indicate that an average of approximately 1400 cubic feet of gas can be produced for every ton of hog manure processed (43 500 litres/metric tonne). Sludge gas has a heating value of 600 to 750 B.t.u. per cubic foot (22 300 to 28 000 Joules/litre) (25). The sludge gas produced from one ton of manure contains heat energy equivalent to 18 pounds of gasoline or 13 pounds of coal (9 kg or 6.5 kg/metric tonne, respectively) (25, 26, 27, 28). The hog manure being produced in Canada therefore has an approximate potential equivalent of some 90,000 gallons (400 000 litres) of gasoline per day.

Similarly, the results of the laboratory testing have shown that approximately 5 cubic feet of digester gas can be produced for every pound of volatile solids fed to the digester per day (310 litres/kg/d), or roughly 5 cubic feet (140 litres) of gas per hog. At a methane content in the gas of 68%, a 1000 head hog operation could produce about 3400 cubic feet (95 000 litres) of methane gas per day. The heating value of one cubic foot of pure methane is 1000 B.t.u. (37 250 Joules/litre) (29). Therefore, the potential heat value of the methane from a 1000 head hog operation is about 3,400,000 B.t.u. (3.6×10^9 Joules). If this is compared to heating oil with a heat value of about 140,000 B.t.u./gallon (3.25×10^7 Joules/litre) (27), the daily heat production from a 1000 head hog operation would be equivalent to about 24 gallons (110 litres) of heating oil.

These figures are of course based on laboratory experience and in actual practise a portion of this potential energy would be used to maintain an effective operating temperature in the digester and for operating pumps, mixing facilities and other related equipment.

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