936518

Paper No.

An ASAE Meeting Presentation

THE IMPACT OF VEGETABLE WASTE ON AN ANAEROBIC DIGESTER

by

Eric Wight
Graduate Student
and
E R Huff
Professor

Bio-Resource Engineering
University of Maine
Orono, ME 04468

Written for Presentation at the
1993 ASAE International Winter Meeting
Sponsored by
ASAE

Hyatt Regency Chicago
Chicago, Illinois
December 14-17, 1993

Summary:

This paper investigates the impact of vegetable waste on gas production and stability of a dairy manure digester. Two full-scale and one bench scale experiments show that vegetable waste can produce twice as much biogas as manure per kg of dry weight without significantly affecting digester stability at high vegetable concentrations.

Keywords:

Anaerobic Digestion, Vegetable, Manure, Biogas, Organic Wastes

ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA
Voice: 616.429.0300 FAX: 616.429.3852

THE IMPACT OF VEGETABLE WASTE ON AN ANAEROBIC DIGESTER

Eric Wight and E R Huff

INTRODUCTION:

Because regulatory restrictions on animal waste handling have become more stringent in the past few years, many dairy farmers have been forced to seek new methods for handling animal wastes. Since solid waste disposal costs have also increased sharply due to restrictions on disposal options, supermarkets are actively seeking cheaper and more environmentally compatable ways to dispose of their wastes.

Anaerobic digestion, a waste disposal alternative for dairy farms and supermarkets, has several advantages. First, the closed tank design prevents leaching of nutrients to surrounding surface waters and loss of nitrogen through ammonia volatilization. Second, the retention of the ammonia-nitrogen increases the fertilizer value. Third, digester effluent has been found to have much less of a foul odor than manure allowing it to be spread closer to residential areas. Finally, biogas produced during the process contains approximately 60% methane and 40% carbon dioxide by volume. It can be burned in a gas burner to maintain digester temperature and supply heat to a building, or it can be burned in an engine to run a generator and supply waste heat from the engine.

In 1984 the Witter Dairy Farm at the University of Maine installed a 265 cubic meter anaerobic digester, engine, and 25 kW generator to produce electricity and supply heat to maintain digester temperature and preheat water for washing milking equipment. The biogas is fed to a spark ignition engine which drives a 25 kW gemerator whose average output is presently about 12 kW. Built to accommodate manure from 200 cows, it now receives manure from about 90.

Since 1987, vegetable waste from the University's cafeterias has been added to the manure going into the digester. This has reduced the Universty's waste stream and presumably added to the biogas production. But this addition is too small to determine the effect of vegetable waste on gas production and digester stability. These effects must be determined to understand system performance. This paper addresses the question of how vegetable waste impacts gas yield and stability of a digester.

BACKGROUND:

Gas production from vegetable waste:

Several factors indicate that vegetable waste is an ideal substrate for anaerobic digestion. Vegetable waste is high in soluble sugars, crude protein, and starch, which are readily degradable by the anaerobic bacteria (Ranade 1987) while manure mixed with bedding contains more cellulose, hemicellulose and lignin, which are non-biodegradable. Although the volatile solids in both manure and vegetable waste are 85% to 90% of the total solids, vegetable waste contains more biodegradable volatile solids and results in a higher gas yield. Literature review and evaluation of the Witter Farm digester show that vegetable waste produces about twice as much biogas as manure (Ranade 1987, Mata-Alvarez 1992).

Alkalinity and its Measurement:

Three main groups of bacteria are active in anaerobic digestion. Acidogenic bacteria perform initial degradation on organic material, producing volatile fatty acids (VFAs). Acetogenic bacteria act as an intermediator by transforming larger organic anions such as butyrate and propionate into acetate. Methanogenic bacteria reduce acetate and H_2 into methane, bicarbonate and water (Pauss 1987). Methanogenic bacteria are the most sensitive and slowest growing of them all, requiring a pH range of 6.7 to 7.5. Acidogenic bacteria can also tolerate pH as low as 5.5. Thus, if ample food is present, acidogenic bacteria can grow faster than methanogens, causing an accumulation of acids which disassociate and reduce pH.

To prevent the system from failing, a buffering system is required to maintain pH within a range conducive to methanogen growth. Bicarbonate alkalinity buffers against pH change in an anaerobic digester by absorbing and releasing protons through transformation between carbonate species. VFAs contribute to the total alkalinity but are not a part of the desired buffering system.

The Standard Method for measuring alkalinity is to perform an acid titration to a pH endpoint of 4.3, called the total alkalinity endpoint (Standard Methods, 1985). Jenkins et.al.(1983) have suggested using a titration endpoint of 5.75, where approximately 80% of the bicarbonate has been converted to CO_2 while less than 20% of the VFAs will have reacted (Jenkins 1983). Thus, alkalinity at the 5.75 endpoint is approximately equal to bicarbonate alkalinity.

METHODS:

Data for this paper were collected through three experiments; two on the full scale digester and a bench scale study using three 18 L digesters:

a. A single slug shock test on the large digester in 1992 to determine the effect of a large slug of vegetable waste on the stability of the digester.

b. A constant high loading of vegetable waste during the spring of 1993, to determine how the digester would perform with continuous large additions of vegetable waste.

c. A bench scale experiment, currently underway, involves conducting several constant vegetable loadings at much greater waste concentrations and better control than achievable in the big digester.

Shock Test:

A reference datum was first established by operating the manure digester at the Witter Dairy Farm under steady loading conditions for 25 days while monitoring alkalinity and gas production. The gas meter required servicing during this period so data after the shock test was used as the gas production reference datum. The operating parameters are summarized in Table 1.

Alkalinity was measured by Standard Methods (1985) using 0.1N H_2SO_4 as a titrant standardized with 0.2N NaOH, a Chemcadet Model 5986-60 pH meter, and pH endpoints of 6 and 4. Gas production was measured with a direct displacement gas meter. Total solids and volatile solids were measured once a week while gas production and alkalinity were measured daily. Once a steady datum was reached, data were recorded for a week to establish a baseline for the experiment.

Table 1: Digester operating parameters.

Digester Volume	265 m^3 (70,000 gal)
Temperature	35 °C
Organic Loading Rate (OLR)	2.9 kgVS/m^3 day
Hydraulic Retention Time (HRT)	22 days
Total Solids (TS) Influent	7.79 %
Total Volatile Solids (VS)	84 %TS

After establishing the base, 7 1/2 tons of vegetable waste were homogenized using a 3 HP trash disposal and a hammermill and pumped into the digester on days 26 and 27 of the experiment (Table 2). Samples of the influent were analyzed for total and volatile solids, alkalinity, and pH. After loading the vegetable material, the system returned to pre-shock conditions and was maintained for a period after quasi-steady state conditions had resumed.

Table 2: Shock test loading schedule.

Criteria	Day 26	Day 27
Total volume, m^3 (gal)	15.1 (4000)	13.2 (3500)
Manure, kg (lbm) dry matter	829 (1823)	711 (565)
Vegetables, kg (lbm).	350 (771)	322 (709)

Constant Loading:

Vegetable and fruit wastes were collected from five local supermarkets and ground into the manure pit using a hammer mill. Digester vegetable loading on a wet weight basis was determined considering the average retention time in the manure pit and is expressed as a percentage of the total daily loading. Alkalinity was measured using a titration method to 5.75 and 4.00 pH endpoints. Gas volume was measured daily with a direct displacement gas meter and gas composition was measured three times per week using a Fyrite CO_2 analyzer. Digester temperature was controlled and measured by an Omega Process Controller.

Bench Scale Study:

Vegetable waste for the bench scale experiment was collected during the constant loading experiment on the large digester and frozen to be thawed as needed. The waste consisted of 34% vegetable and 64% fruit wastes by weight. By visual inspection, the vegetables consisted mostly of lettuce, cabbage, peppers, green beans, celery and potatoes, and the fruit consisted mostly of watermelon, bananas, apples and honeydew mellon.

Three 18 L digesters were kept in a common constant temperature water bath. Mixing of their contents was aided by pumping gas from the top of each digester up through the liquid. The reactors were started on a mixture of effluent from the farm digester and dairy manure, then changed to dairy manure diluted to a specific gravity of 1.018. The control reactor was maintained on manure substrate while the other two were used to test three different concentrations of vegetable waste by volume according to the schedule in Table 3.

Table 3: Bench Scale Operating Schedule.

Digester	Period A	Period B	Period C
1	Manure	Manure	Manure
2	Manure	Manure	75% Veg.
3	Manure	50% Veg.	100% Veg.

Gas production was measured using a brine (Standard Methods 1985) displacement device which counted constant volume displacements using a photocell and relay counter. Gas composition was measured daily using a Fyrite CO_2 analyzer. Total and volatile solids of reactor influent and effluent were measured weekly using Standard Methods procedures. Alkalinity was measured using a titration method to 5.75 and 4.00 pH endpoints.

RESULTS:

Shock Loading:

The effect of vegetable waste on gas production during the shock test is shown by Figure 1. Unfortunately, an extra loading of manure and a temperature supression masked this effect. Vegetable waste gas production was determined by subtracting the manure gas yield from the total measured gas production. Manure gas yield was calculated by multiplying the amount of manure volatile solids loaded by the specific gas production (SGP, m^3/kg VS) previously established from the constant loading data at the normal operating temperature. Gas production values are only an estimate since true production from each component was not known and only data from four days of a 22 day retention time could be used. Calculations assume that the specific gas production rate from the manure was constant.

Considering these assumptions, gas produced from the vegetable waste was 245 m^3 (8645 ft^3), resulting in a SGP of 0.405 m^3/kg (6.48 ft^3/lbm) of volatile solids (VS). This is a 21% increase in gas production over the manure SGP of 0.334 (5.35). This SGP is much lower than the literature value, perhaps because their results were for constant loading while shock test results were produced during bacteria stress.

The alkalinity results show a quick recovery from vegetable waste induced stress (Figure 2). While the influent alkalinity shows the shock duration of four days, the digester alkalinity was suppressed for less than 18 hours. The fast response demonstrates that the acidogenic bacteria can quickly adapt to vegetable waste while the short duration of the stress period shows that the methanogenic bacteria had little trouble acclimating.

Two factors decrease the certainty of these results. First, 6.8 Mg of vegetable waste is only 2.5% of the liquid mass in the digester. Second, the high initial bicarbonate alkalinity of over 6000 mg/l as $CaCO_3$ could have buffered the system against acidification of the vegetable waste, decreasing the disturbance. Nevertheless, the experiment demonstrates that the system can withstand moderate shock loadings.

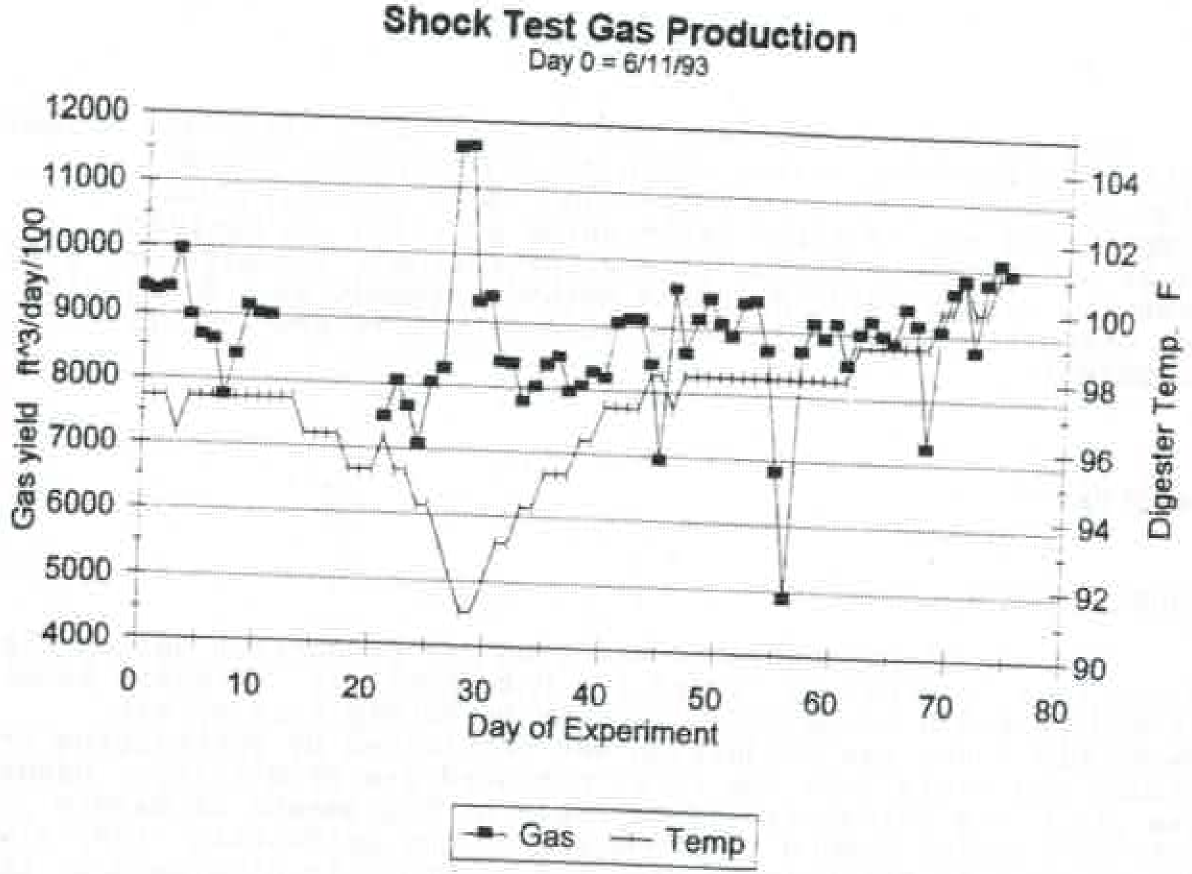

Figure 1: Shock Test Gas Production.

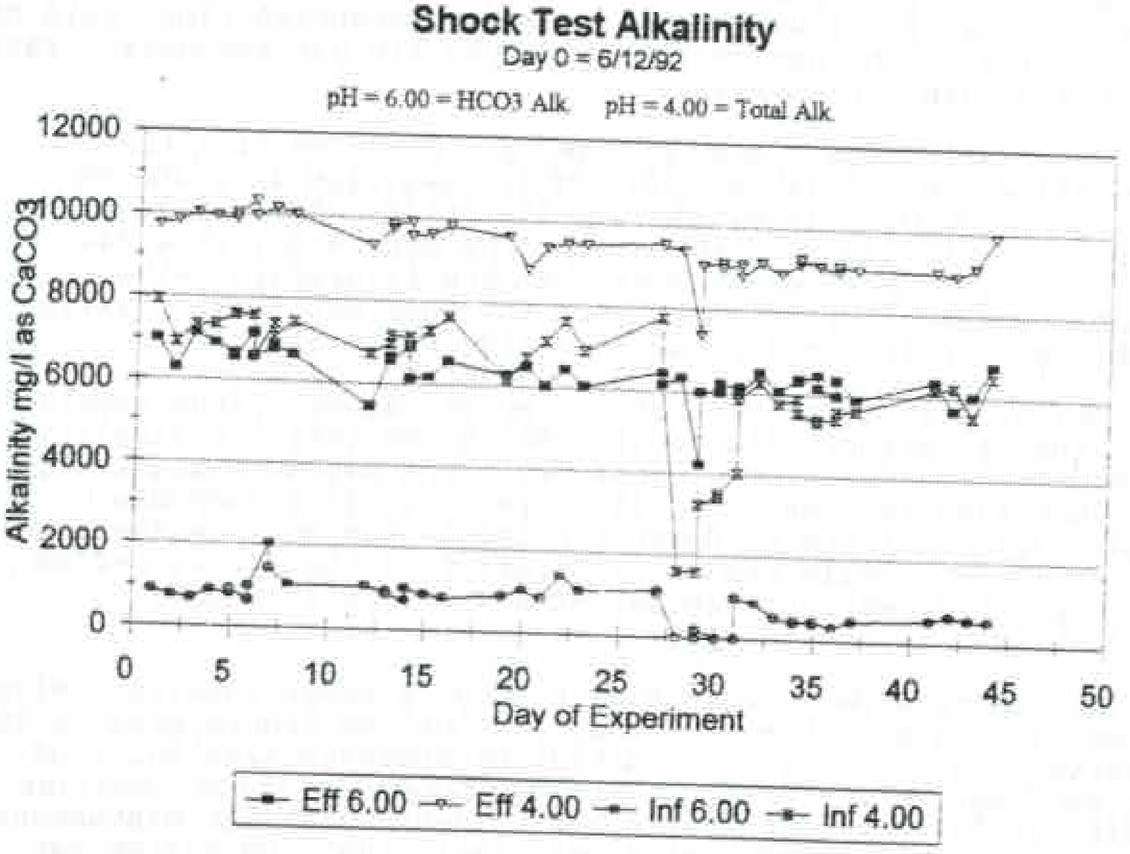

Figure 2: Shock Test Alkalinty.

The SGP was greatest during period C at a value of 0.85 L/gVS (13.6 ft^3/lbVS) fed, which is similar to a value published by Mata-Alvarez (1992) of 0.762 L/gVS (12.2 ft^3/lbVS) fed. The methane content decreased slightly from 67% to 63% after vegetable waste was added.

Alkalinity measurement during period A was lost due to pH probe failure so a reference datum was not established prior to period B. However, the bicarbonate alkalinity in digester 3 remained above 5500 mg/l as CaCO$_3$ throughout the 50 percent vegetable waste loading period, demonstrating the system remained well buffered. During period C, bicarbonate alkalinity in digesters 2 and 3 remained above 5000 mg/L as CaCO$_3$ with the largest decrease, 700 mg/L as CaCO$_3$, occurring in digester 2. Therefore the anaerobic system remained well buffered at 100 percent vegetable waste feed and was capable of withstanding a sudden substrate conversion from zero to 75 percent vegetable waste.

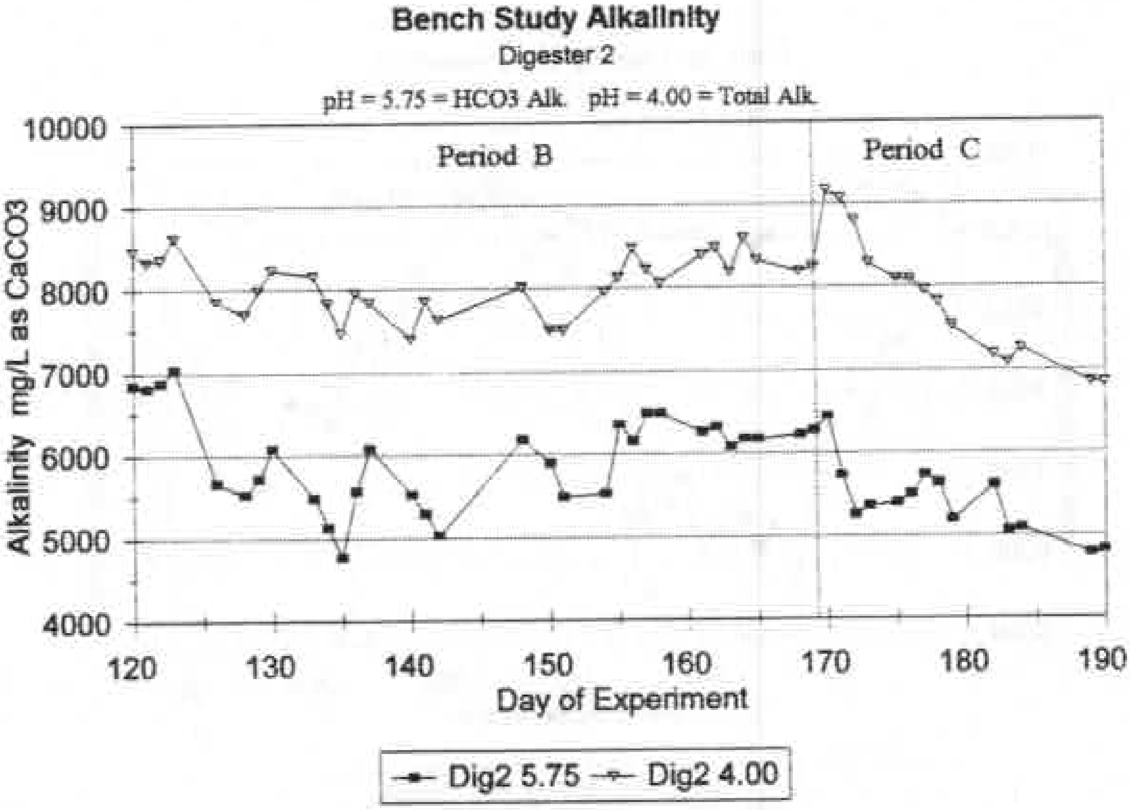

Figure 6: Bench Scale Alkalinity for Digester 2.

Constant Loading:

Gas production during the constant loading experiment is shown in Figure 3. The results are somewhat obscured by a temperature suppression before the vegetable waste additions. Some of the gas yield increase could have resulted from the increasing temperature during the experiment, but the gas yield at the normal operating temperature of 34°C (93°F) was the same after the experiment as before the temperature suppression. The gas yield increase from the vegetable waste was determined by assuming an average value of 229 m^3 (8100 ft^3) per day for manure at the normal operating temperature. Gas production above this averaged 45.3 m^3 (1600 ft^3) per day at a maximum of 7% vegetable waste in the digester influent. Gas composition stabilized during the vegetable waste additions at 55 percent methane.

Anaerobic systems are generally considered stable if the bicarbonate alkalinity is above 2500 mg/l as $CaCO_3$ (Chynoweth 1987, Mosey 1984). This digester was extremely well buffered before vegetable additions began, with a bicarbonate alkalinity over 6000 mg/l as $CaCO_3$ and a total alkalinity close to 10,000 mg/l as $CaCO_3$ (Figure 4). During the experiment the bicarbonate alkalinity dropped approximately 600 mg/l as $CaCO_3$ and the total alkalinity dropped about 1300 mg/l as $CaCO_3$. The changes in the buffering capacity are negligible considering the high alkalinity.

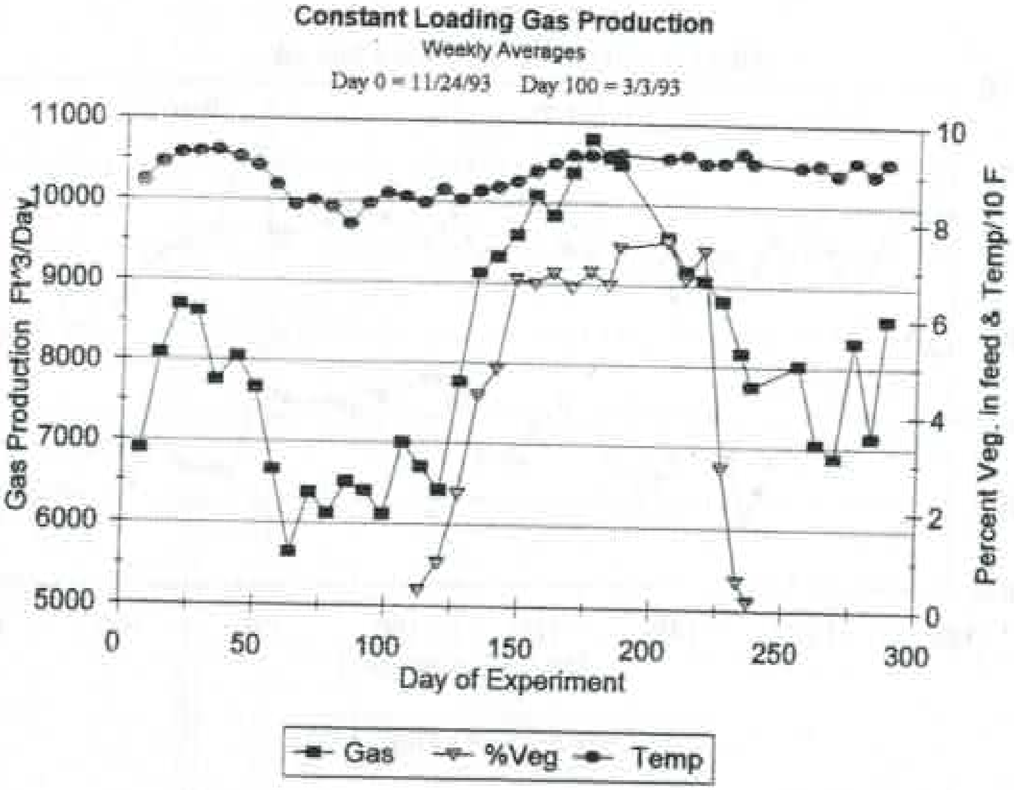

Figure 3: Constant Loading Gas Production.

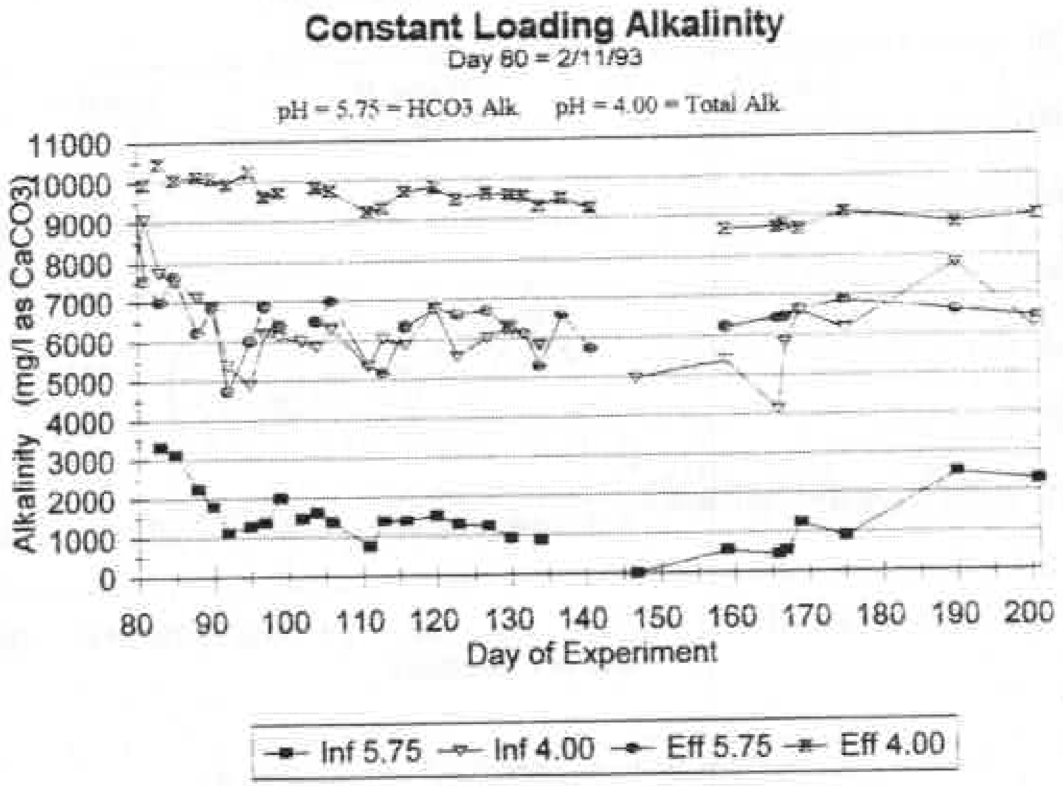

Figure 4: Constant Loading Alkalinity.

The alkalinity results demonstrate with greater confidence that the digester stability was not significantly impacted. However, the presence of a buffering capacity in the influent suggests that the vegetable loadings were still relatively small compared with the manure. Further experimentation is required to insure that vegetable waste will not adversely affect the system even under extremely high loadings.

<u>Bench Scale Study</u>:

Figure 5 reveals dramatic gas increase from the addition of vegetable waste. However, some of this gas increase is a result of a slightly higher organic loading during periods of vegetable waste addition as shown by Table 3. The organic loading of digester 3 increased 9.6 gVS/L during period B which would account for an increase of 3.3 L/Day if the SGP was the same while the actual increase during this period was 15 L/Day. Similarly, the organic loading increased during period C accounts for only a 8.3 L/Day increase in reactor 2 and a 6.4 L/Day increase in reactor 3. The majority of the gas increase is a result of greater substrate utilization. Table 3 shows an increase in the percent reduction of volatile solids for digesters 2 and 3 during periods B and C. The increase in VS reduction is a result of a the higher biodegradability of the vegetable waste which is further illustrated by the increase in specific gas production rate.

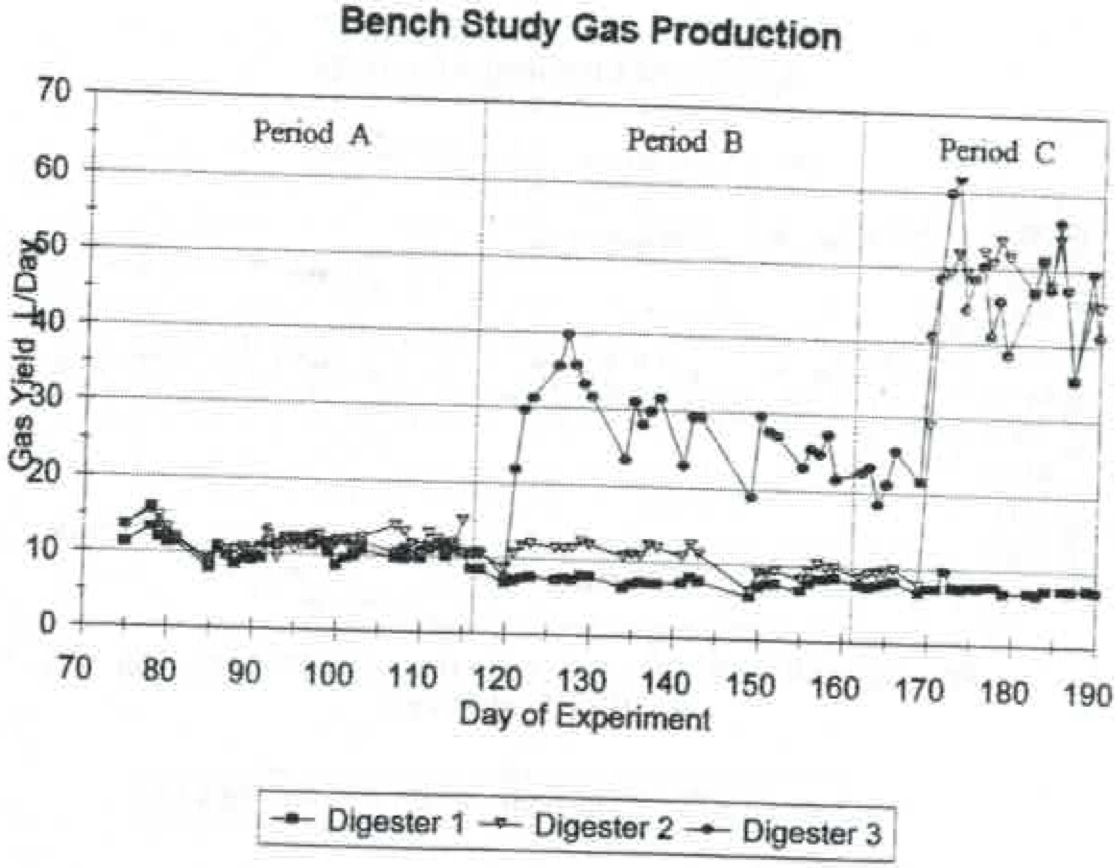

Figure 5: Bench Scale Gas Production.

Table 3: Solids Analysis.

	Inf D1	Eff D1	INF D2	Eff D2	Inf D3	Eff D3
Period A						
TS (%)	4.44	2.68	4.79	2.59	4.79	2.90
VS (%)	3.40	1.83	3.39	1.76	3.39	2.03
%VS of TS	76.55	67.70	74.03	66.24	74.03	67.44
VS Red. (%) (g/l)	46.09	15.66	47.98	16.24	39.96	13.53
SGP L/gVS fed	0.30		0.35		0.34	
Period B						
TS (%)	3.88	2.94	3.88	2.52	5.08	2.88
VS (%)	3.01	2.07	3.01	1.75	4.35	2.00
%VS of TS	77.42	68.09	77.42	68.40	85.89	68.83
VS Red. (%) (g/l)	31.12	8.36	41.92	12.60	54.03	23.51
SGP L/gVS fed	0.25		0.35		0.61	
Period C						
TS (%)	3.31	2.26	6.17	2.47	6.01	1.32
VS (%)	2.61	1.56	5.38	1.71	5.40	0.71
%VS of TS	78.68	67.96	87.23	65.77	89.89	52.89
VS Red. (%) (g/l)	40.29	10.50	68.27	36.76	86.76	46.84
SGP L/gVS fed	0.29		0.84		0.85	

CONCLUSION:

Adding vegetable waste to a dairy manure digester increased the gas production without significantly impacting the system stability. Gas yields on a full scale manure digester could be increased as much as 20 percent through the addition of seven percent vegetable and fruit waste in the influent. Bicarbonate alkalinity dropped slightly but remained well above critical limits. Experimentation using bench scale digesters showed that specific gas production rates nearly twice that of manure are achievable with a vegetable/fruit waste substrate. Alkalinity results demonstrate that the anaerobic process is capable of swiftly converting from manure to vegetable waste substrate while maintaining a stability through a strong bicarbonate buffer.

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