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Dry Nonheated Anaerobic Biogas Fermentation Using Aged Beef Cattle Manure

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Abstract. *Biogas production at beef cattle feedlots is hard to justify because of the large amounts of dilution water required and the high cost to design and operate conventional water-based digestion systems. Laboratory and field experiments were conducted to determine the feasibility of producing biogas using "dry" aged beef cattle manure scraped from open-lot feedyards. Biogas production rates were measured at 21°C in the laboratory at four total solids contents using a water displacement technique. Biogas yields were 0.180, 0.210, 0.190 and 0.005 L per gram volatile solids (VS) at solids contents of 20, 30, 40 and 50 percent, respectively. Biogas was produced steadily for 300 days before declining and eventually ceasing after 450 days. The biogas contained 52 to 60* *percent methane. A field demonstration project was conducted to produce biogas using geomembrane-lined digesters. Two 90 m^3 digesters excavated in native soil to a depth of 1.8 m were lined on top and bottom with ethylene propylene diene monomer (EPDM) geomembranes. Digester 1 was loaded with manure (solids content 40 percent) in February, 1999. Biogas was produced during the first summer for 12 weeks beginning August 1, 1999, and during the second summer for 13 weeks beginning July 14, 2000. Digester 1 produced 1,510 m^3 of biogas the first summer and 920 m^3 the second summer, with a typical methane concentration of 52 percent. Total biogas yield over the two summers was 0.16 L/g VS in digester 1. Digester 2 was loaded with manure (solids content 50 percent) in January, 2000, and produced less than 5 m^3 of biogas. This research demonstrates that biogas can be produced in below-ground digesters using aged beef cattle manure if the solids content is less than or equal to 40 percent, but that year-round biogas production is not feasible unless the digesters are heated or insulated.*

Keywords. biogas, manure, methane, energy, beef, solids, solids, landfill

Introduction

More than seven million beef cattle are fed each year in feedyards in the Southern High Plains area (SPS, 1999), producing 1.6×10^{10} kg of as-excreted (fresh) manure annually (Parker et al., 1997). Most of these cattle are fed in feedyards with capacities larger than 20,000 animals. Beef cattle at most large feedyards are raised on earthen-surfaced pens. Unlike many swine and dairy operations that utilize water-based manure collection systems (i.e. flush, scrape, or pull-plug systems), most beef cattle feedyards use a dry manure collection system. At beef feedyards, animals deposit manure directly on the open lot surface, and the manure is scraped and removed every 120 to 365 days. During this period the “aged” manure dries considerably. While the average total solids content of fresh feedyard manure is 24 percent (Auvermann et al., 2000; ASAE, 1999a), manure scraped from open-lot beef cattle feedyards has a total solids content of 55 to 90 percent, much drier than the waste in swine and dairy operations. The dry manure removed from beef feedyards is typically land applied as a source of fertilizer. Manure is sometimes stockpiled for short-term storage prior to land application. Because methane is a greenhouse gas, there has been a concern with potential methane production from manure in the stockpiles. Little data has been collected on the potential methane production from the stockpiled manure.

In a recent evaluation of manure value in the Southern High Plains area, the value of the potential energy from biogas exceeded the value of using the manure for its fertilizer equivalence (Parker et al., 1997). Biogas is produced during the decomposition of organic material under anaerobic conditions. Biogas is comprised of 55-70 percent methane (CH_4) and 30-45 percent carbon dioxide (CO_2) with traces of hydrogen sulfide, nitrogen, hydrogen, and carbon monoxide (Voermans, 1985). Biogas can be used as a substitute for natural gas for heating and producing electricity (Raab, 1985; Voermans, 1985).

The anaerobic breakdown of cattle manure to form biogas is accomplished by three types of bacteria, 1) hydrolytic, 2) transitional, and 3) methanogenic. In the first steps of production, hydrolytic bacteria reduce large macromolecules (proteins, fats, carbohydrates) to smaller molecules such as amino acids, sugars, acids, and alcohols. Transitional bacteria further reduce these molecules into acetic acid, H_2 and CO_2. The final step of breakdown is accomplished by methanogenic bacteria, which reduce the molecules into methane (CH_4) and carbon dioxide (CO_2) (Engler and McFarland, 1997). Hansen et al. (1998) state that acetate-utilizing methanogens are responsible for 70 percent of methane produced in a biogas reactor.

Biogas production is a temperature-dependent process (Misra et al., 1992). Biogas has been produced in psychrophilic (-10 to 30°C), mesophilic (20 to 50°C), and thermophilic (35 to 75°C) temperatures ranges (Chynoweth, 1998; Safley et al., 1992; Tchobanoglous and Burton, 1979). It is difficult to predict biogas production rates in the psychrophilic and lower mesophilic temperature ranges. Based on temperature alone, Hilhorst et al. (2001) predicted a 66 percent reduction in methane emissions whenever the temperature dropped from 20 to 10°C. Safley and Westerman (1992) showed that between the temperature of 8 to 30°C, a 1°C rise in temperature increased methane yield by about 0.009 m^3 per kg of volatile solids.

Most anaerobic digesters are designed to operate in the mesophilic and thermophilic temperature ranges. There are advantages and disadvantages of each temperature range. Mesophilic temperatures are more stable than thermophilic because they inhibit the production of excessive free ammonia, which can destroy the bacteria vital for anaerobic digestion (Fedler and Day, 1985; Hashimoto et al., 1981; Angelidaki & Ahring, 1994). Advantages of thermophilic temperatures include destruction of pathogenic bacteria and higher loading rates. A disadvantage of mesophilic and thermophilic digestion is that an external heat source is required to maintain design operating temperatures.

Traditionally, several types of anaerobic digesters have utilized manure, including complete mix, fixed film, and plug flow (Schulte & Luis, 1983; Rivard et al., 1989; Miner et al., 2000). Most completely mixed and fixed film digesters are designed for 3 to 12 percent total solids (Miner et al., 2000; Moser and Mattocks, 2000). Plug flow digesters are designed to operate at 8 to 12 percent total solids, and are commonly used with dairy waste (Miner et al., 2000; Moser and Mattocks, 2000). Complete mix, fixed film and plug flow digesters are well adapted to water-based manure collection systems, such as scrape, flush and pull-plug systems common in many swine and dairy operations. However, they are not well adapted to dry manure collection systems typical of most open-lot beef cattle feedyards. Jewell (1981) was one of the first to use the term "dry methane fermentation" which refers to digestion with little or no dilution of waste. Schulte and Luis (1983) evaluated biogas production of "dry" beef cattle manure at solids contents of 10, 20, 30 and 40 percent at 35°C in what they called a "tumble mix" system. They were unable to obtain steady state conditions at 40 percent solids. Kitamura et al. (2001) studied biogas production of dry dairy manure at solids content between 9.5 and 14.7 percent in a similar mixing apparatus that they called a "rotational drum system."

During the manure collection process at beef cattle feedyards, foreign solids such as soil and rocks often become mixed with the manure. High quantities of foreign solids cause problems in conventional completely mixed, fixed film, and plug flow digesters. One of the greatest deterrents to the use of biogas as an energy source has been the high cost of building and maintaining digesters (Hills, 1980; Rivard et al., 1989). Of eight biogas digesters installed at beef cattle feedyards, none are operating today (SERI, 1985). The failure of conventional digesters, combined with a limited water supply, leaves an opportunity for exploring other options for producing biogas with beef cattle manure in the arid regions of the United States.

Given an initial solids content of 55 percent, about 6.5 kg of water must be added to each kg of manure to achieve a slurry with 12 percent solids, and 18.2 kg of water to achieve a slurry with 5 percent solids. Water is a precious commodity in most semiarid areas, so the addition of large amounts of water to beef cattle manure for digestion is neither desirable nor economically feasible. Also, the cost for transporting and land applying the spent slurry at digestion completion increases drastically with decreasing solids content.

Biogas generation is of interest because of its energy potential, however, the methane in biogas is a greenhouse gas making biogas an environmental concern (ASAE, 1999). It has been estimated that 6 to 10 percent of all anthropogenic methane emissions are from animal waste (USEPA, 1992). In the U.S., about 36 percent of all agricultural related methane emissions come from anaerobic lagoons, and about 7 percent from dry open-lot feeding operations (USEPA, 1992). Sources of methane emissions from open-lot feeding operations include open-lot pens, runoff storage ponds, and manure stockpiles. These sources are typically aerobic by design, however, after extended precipitation events they may become anaerobic for a short time. Little data exists on methane production from manure associated with open-lot feeding operations, either from the pen surface, the storage pond, or the manure stockpile.

A research project was conducted to evaluate biogas production using aged beef cattle manure scraped from open lots. The specific objectives of this research were to 1) determine the highest solids content at which biogas could be produced, 2) determine the biogas yield at this solids content, 3) determine how temperature and solids content affect biogas production in a field-scale unheated, batch-type anaerobic digester, and 4) determine the potential for methane generation and associated greenhouse gas concerns from manure stockpiled at beef cattle feedyards.

Materials and Methods

The research consisted of a laboratory experiment and a field experiment. The laboratory experiment was conducted in the Environmental Agriculture Lab at West Texas A&M University's Killgore Research Center. The field experiment was conducted at the WTAMU Research Feedlot located 10 km east of Canyon, Texas. Manure for both the laboratory and field phases was collected from a large commercial beef cattle feedyard during pen cleaning. Because the manure for the two phases was collected at different times, it had slightly different physical properties. The manure was tested for solids content by oven drying at 100°C for 24 hrs. Volatile solids (VS) content was measured using a muffle furnace at 500°C for one hour (ASAE, 1999b).

Laboratory Experiment

The manure removed from the commercial feedyard had an initial total solids content of 78.3 percent, initial dry basis VS content of 32.0 percent, and initial pH of 8.0. Other characteristics of the manure including nutrient concentrations are shown in Table 1. Manure in amounts of 40.0, 60.9, 81.2 and 86.5 g was placed with 115, 100, 80 and 50 ml of water, respectively, into 125 ml glass Erlenmeyer flasks to obtain total solids contents of 50, 40, 30, and 20 percent. The flasks were equipped with rubber stoppers and plastic tubing (0.6 cm O. D. polyurethane-Cole Parmer Instrument Company). There were three replications at each solids content. The flasks were maintained at 21°C throughout the experiment. Biogas was collected by water displacement in inverted 1 L Nalgene containers (figure 1). The volume of biogas produced in each container was recorded every few days for the duration of the 475 day project. Containers were replaced as they filled with biogas.

In the laboratory, biogas samples were analyzed for methane content using a Hewlett Packard GCD 1800A capillary GC/MS. A 1-ml gastight syringe injection was separated on an HP-PLOT Q (divinyl benzene/styrene) porous polymer capillary column (30 m x 0.32 mm x 20.0 μm). A 5-m uncoated retention gap was used to mate the column to the quadruple mass spectrometer detector. Total ion peak areas were calibrated with standard gas mixtures of methane and carbon dioxide. The GC/MS results closely matched those of the portable methane analyzer.

Field Experiment

Two below ground "landfill-type" digesters were constructed in Fall, 1998. Each digester measured 11 m x 11 m at ground level and was 1.8 m in depth with a 3 m x 3 m base and 2H:1V sideslopes (figure 2). Each digester had a capacity of 90 m^3. The digesters were lined on the bottom with a one-piece black ethylene propylene diene monomer (EPDM) geomembrane liner (Colorado Lining, Parker, CO). The first digester (digester 1) was filled with manure and water (40 percent total solids, initial VS= 32.0 percent), and capped on February 12, 1999. The manure used to fill digester 1 was the same manure that was used in the laboratory experiment (table 1). The second digester (digester 2) was filled with manure and water (50 percent total solids, initial VS= 41.9 percent) and capped on January 4-5, 2000. The manure used to fill digester 2 was from the same feedyard as the manure used in the laboratory experiment and to fill digester 1, however, because it was collected at a different time period it had different properties (table 1).

A grid of perforated PVC pipe was placed at the top of each digester and routed to a common collection point to collect gas samples. The digesters were equipped with a data logger and thermisters (Unidata Starlogger Model 6004, Lake Oswego, OR) to monitor manure temperatures at a depth of 50 cm.

The digesters were capped with a 17 m square black EPDM geomembrane placed loosely over the top. The perimeter of the top membrane was placed in a 60 cm deep trench and covered with compacted soil. Biogas was collected for several days, inflating the geomembrane in a dome shape. The volume of biogas was determined by conventional surveying methods. To periodically collect biogas samples for methane concentration analysis, a tedlar bag was attached to the exit port.

Biogas samples were analyzed in the field using a GT Land Surveyor portable methane meter (Gastech, Newark, CA). The portable methane analyzer was equipped with catalytic compensation to measure combustible gases, and was calibrated against two calibration gases of 2.5 and 95 percent methane concentrations.

A composite manure sample consisting of ten grab samples collected within both digesters at the completion of the experiment and analyzed for TS, VS, and various nutrients and salts.

Statistical Analysis

Statistical analysis was performed using SPSS 10.0 computer software. Analyses included one-way analysis of variance (ANOVA) and LSD comparisons at a significance level of 0.05.

Economic Analysis

An economic analysis was performed to determine the size of digester required to breakeven with construction costs. Benefit to cost (B:C) ratios were calculated using an excavation cost of \$1.00/m^3, installed liner cost of \$4.20/m^2. The biogas was assumed to be composed of 50 percent methane. A range of natural gas prices were used, ranging from a high of \$353/Mm^3 (January 2001) to the current of \$125/Mm^3 (April 2002). A square digester was used because it had the lowest material costs per unit digester volume. A variety of digester sizes were evaluated, all with sideslopes of 2 horizontal to 1 vertical. Digester lifespans of one-time and five-time use were evaluated. Costs for removal and land application of manure from the digester were not included in the analysis.

Results and Discussion

Laboratory Experiment

Little biogas was produced at 50 percent total solids content. At 20, 30, and 40 percent total solids contents, biogas production began about 45 days after the manure was placed in the containers, and remained constant until about day 300, when it began to decrease (figures 3 and 4). Biogas production ceased completely after 450 days in all containers. Total biogas yields were 0.18, 0.21 and 0.19 L per gram volatile solids (VS) at solids contents of 20, 30, and 40 percent, respectively. Biogas yields were not statistically different among these volatile solids contents (table 2).

The highest mean biogas yield was 0.21 L/g VS at 30 percent solids content. In comparison, Hills (1980) reported a biogas yield of 0.18 L/g VS for high solids dairy manure, whereas Kottwitz and Schulte (1982) reported a biogas yield of 0.30 L/g VS for beef cattle manure in a high solids digestion process. In optimum conditions and with fresh manure, Safley et al. (1992) reported a maximum methane yield of 0.17 to 0.33 L CH_4/g VS for beef manure. Assuming that biogas is 50 percent methane, then the actual biogas yield would be double these values, or about 0.34 to 0.66 L/g VS for beef manure.

Concentrations of methane and other gases are presented in table 2. Typical methane concentrations were 52.5, 60.2, 58.9 and 6.7 percent for solids contents of 20, 30, 40, and 50 percent, respectively. These methane percentages are typical of those obtained for other manure sources (Safley et al., 1992; Hills, 1980; Hashimoto et al., 1981).

Field Experiment

The manure was warm when it was placed in digester 1 (25°C), a result of aerobic composting while stockpiled for two weeks before loading into the digester. The manure temperature dropped quickly after placement in the digester (figure 5). Digester 1 began biogas production on August 1, 1999, 170 days after it was loaded with manure. At this time, the manure temperature was 22°C and mean weekly air and soil temperatures were both 24°C. Manure temperatures increased during the summer months, a result of warmer ambient temperatures, peaking about August 1 at 22.4°C (figure 5). The lower limit of the thermister was 15.0°C so manure temperatures were not available below this value.

Biogas production ceased abruptly on October 23, 1999, when the manure temperature reached 15°C. During the 12-week period, digester 1 produced 1,510 m^3 of biogas. The pH of the manure in digester 1 was sampled a week after the cessation of biogas production in October, 1999 to determine if a buildup of organic acids could have contributed to the reduction in biogas generation. Three manure samples had a pH ranging from 6.98 to 7.26, indicating that acidity was not the cause of the decline in biogas production.

During the second summer, biogas production began again in digester 1 on July 14, 2000. Because of a malfunction in the datalogger, manure temperatures were not available for June and July. However, mean weekly air and soil temperatures were 27 and 26°C, respectively, in the middle of July, 2000. Biogas production ceased in mid-October, 2000. The manure temperature at this time was 21°C. During the second summer, 920 m^3 of biogas was produced, for a total of 2,430 m^3 of biogas produced in digester 1 over the two summers. No biogas was produced during the third summer. Given the similar rapid onset and cessation of biogas production over both summers, it seems likely that temperature was the controlling factor for biogas production. Biogas was not produced whenever the temperature dropped below 15°C. The methane concentration of the biogas in digester 1 was 40 percent the first time it filled, then ranged from 49 to 52 percent the duration of the experiment.

Less than 5 m^3 of biogas was produced in digester 2, which was loaded with manure at 50 percent total solids. Apparently the solids content was too high, which corresponds with the finding of no significant biogas production at 50 percent solids in the laboratory study.

The total volatile solids content in digester 1 was 1.55×10^7 g. The total volume of biogas produced in digester 1 was 1.51×10^6 L during the first summer and 9.2×10^5 L during the second summer, which equates to a biogas production rate of 0.16 L/g VS. This is slightly less than the average biogas yield of 0.19 L/g VS measured in the laboratory experiment at 40 percent solids content.

The total solids concentration in digester 1 increased, indicating a loss of water, while the total solids concentration in digester 2 stayed the same (table 1). The volatile solids concentrations decreased in both digesters. This makes sense for digester 1, which produced a significant amount of biogas, however it does not make sense for digester 2, which produced very little biogas. The nutrient and salt concentrations presented in table 1 are representative of manure conditions in the digesters, but care should be given before using these concentrations for mass balance purposes. While every attempt was made to obtain a representative composite sample of the entire digester, there is no doubt that variations exist between locations in the digester possibly, a result of internal temperature differences and variation in initial manure quality. All concentrations in table 1 are expressed on a wet weight basis, and the mass of the manure changed during digestion because of loss of volatile solids (carbon loss). This might explain why some of the parameters actually increased in concentration. This does not imply that nutrients or salts were produced, only that the concentration increased because of a loss of organic matter (i.e. the total weight decreased).

Economics

The biogas yield in the field experiments was 0.04 L per dry gram of manure. Assuming all manure removed from feedyards in the Southern High Plains had 79 percent solids, then 3.1×10^9 kg of manure would be available annually. The maximum potential biogas production from this manure is therefore 1.2×10^{11} L per year.

Natural gas prices more than quintupled between between January 1999 (\$64/Mm^3) and January, 2001 (\$353/Mm^3). Natural gas prices decreased to about \$125/Mm^3 as of April, 2002. An increase in fuel values usually sparks an increase in anaerobic digestion of beef cattle manure. However, most operations will not consider digesters unless there is a positive return on investment, or if there are some other side benefits such as odor reduction.

Results of the economic analysis show that a small digester like the one used in this research is not economically feasible for one-time use, with a benefit to cost (B:C) ratio ranging from 0.08 (based on natural gas price of \$125/Mm^3) to 0.22 (natural gas price of \$353/Mm^3) (table 3). Economics could be improved by building a larger digester. If the natural gas price of \$353/Mm^3 is used, and the digester is used only once, then several digester sizes are possible to achieve a B:C ratio of 1.0. For example, for a 4 m deep digester, the minimum top width is 45.4 m, and for a 6 m deep digester, the minimum top width is 37 m. If a more recent natural gas price of \$125/Mm^3 is used, then a digester must be at least 14 m deep to achieve a B:C ratio greater than 1.0. A drawback to use of large landfill-type digesters is that special equipment such as draglines or extendable backhoes are required to remove manure.

Economics could also be improved by using the digester more than once. Because the manure is too thick to pump, manual manure removal is necessary, so the entire top liner must be removed. It is difficult to reuse an EPDM liner, so a new top liner must be purchased each time the digester is filled. The bottom liner can be reused if care is taken to avoid damaging it during manure removal. If the digester were used five times, then the B:C ratios would about double (table 3).

An option to using a geosynthetic bottom liner would be to use a clay liner. The clay liner would cost slightly more than the geosynthetic liner, and could be used repeatedly without the risk of damaging the liner, thus improving the long-term economics of the system.

It is apparent that additional engineering solutions must be developed before an unheated, high solids digester will be feasible. These engineering solutions should include development of methods for land application of the digested manure. Most beef feedlot manure is currently surface applied as a solid (80 percent solids, 20 percent moisture) using manure spreaders. A change to a liquid slurry application system would require significant costs in the purchase of new land application equipment. Costs to remove and land apply the digested manure should be evaluated before a high solids digester is constructed.

Conclusions

The following conclusions were drawn from this research:

1. At a constant 21°C in the laboratory, biogas was produced at solids contents of 20, 30, and 40 percent, but not at 50 percent. The maximum solids content for successful anaerobic digestion of aged beef cattle manure was 40 percent.
2. The ultimate biogas yield at 40 percent solids content and 21°C was 0.19 L/g VS under controlled laboratory conditions. There were no significant differences among biogas yields at 20, 30, and 40 percent solids contents.
3. The biogas yield in the field digester was 0.16 L/g VS at 40 percent solids content. Little biogas was produced in the digester with 50 percent solids. No biogas was produced in the field digester during the winter months. Biogas production began in the summer months whenever the manure temperature reached 22°C, and ceased in the fall whenever the manure temperature dropped below 15°C. Biogas production occurred over two consecutive summers.
4. Because most manure is stockpiled in open-lot animal feeding operations at less than 50 percent moisture content, it seems unlikely that methane will be produced from the stockpile.

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DISCLAIMER

The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-ARS or WTAMU.

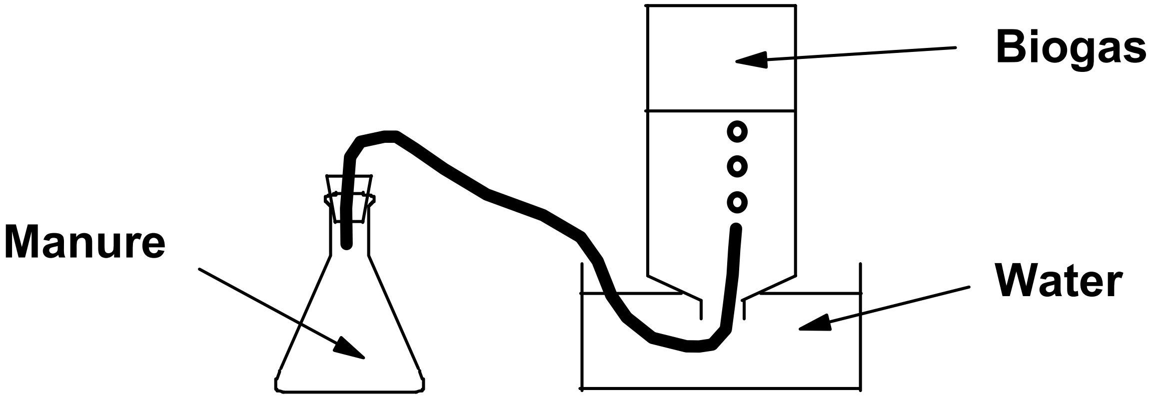

Figure 1. Schematic of small-scale batch type digester and biogas collection apparatus used in the laboratory experiment.

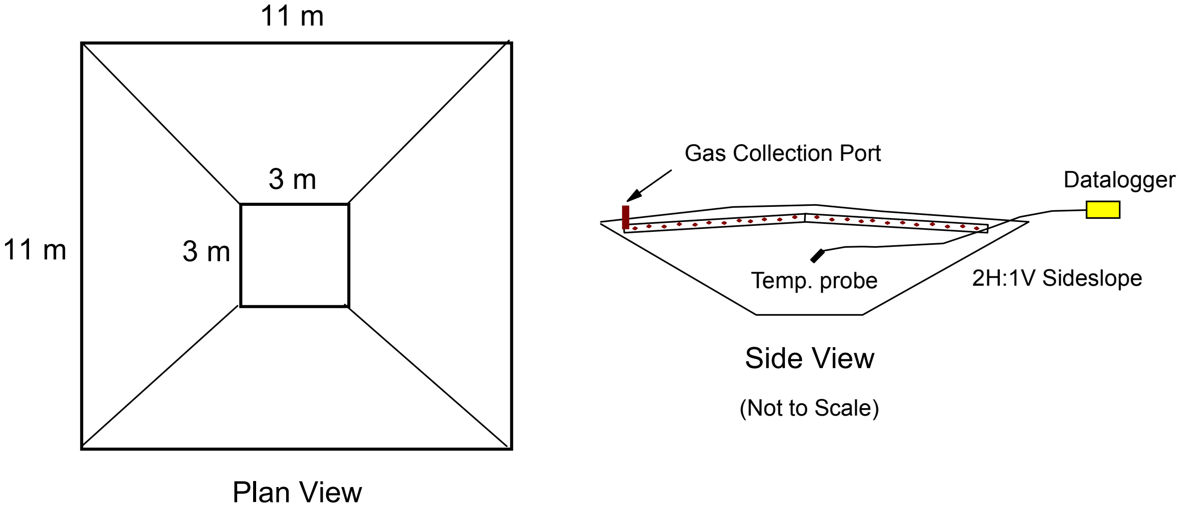

Figure 2. Schematic of unheated, below-ground batch digester used in the field experiment.

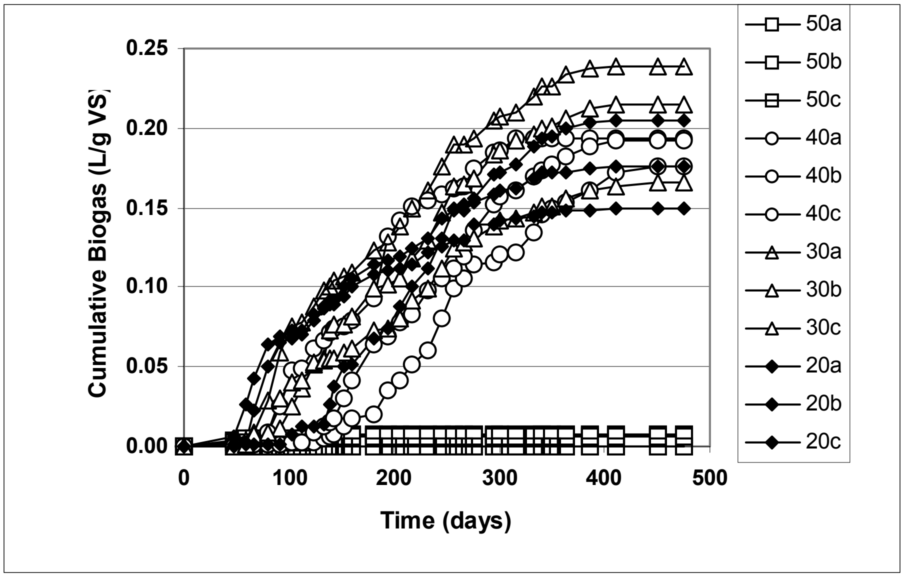

Figure 3. Laboratory biogas production rates at solids contents of 20, 30, 40, and 50 percent. There were 3 replications of each solids content.

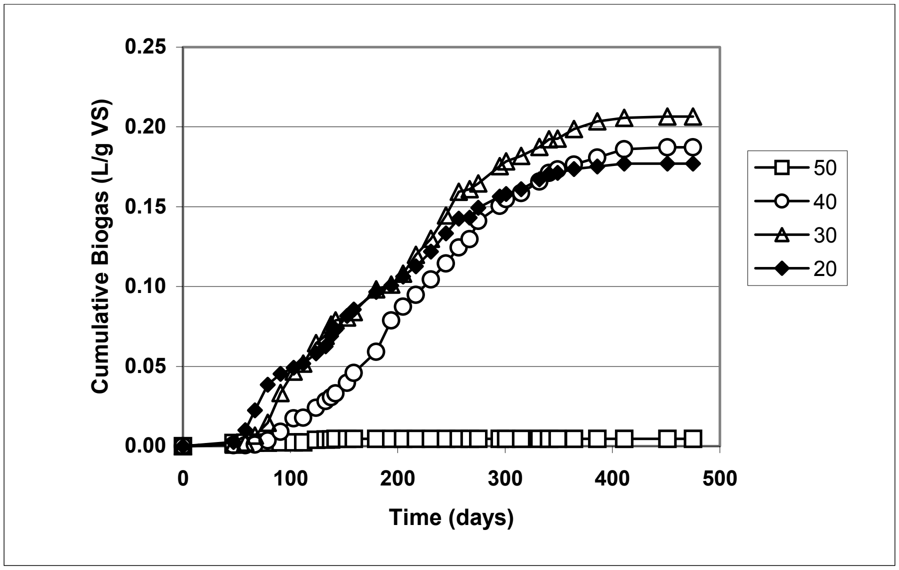

Figure 4. Mean laboratory biogas production rates at solids contents of 20, 30, 40, and 50 percent. Each point is the average of 3 replications.

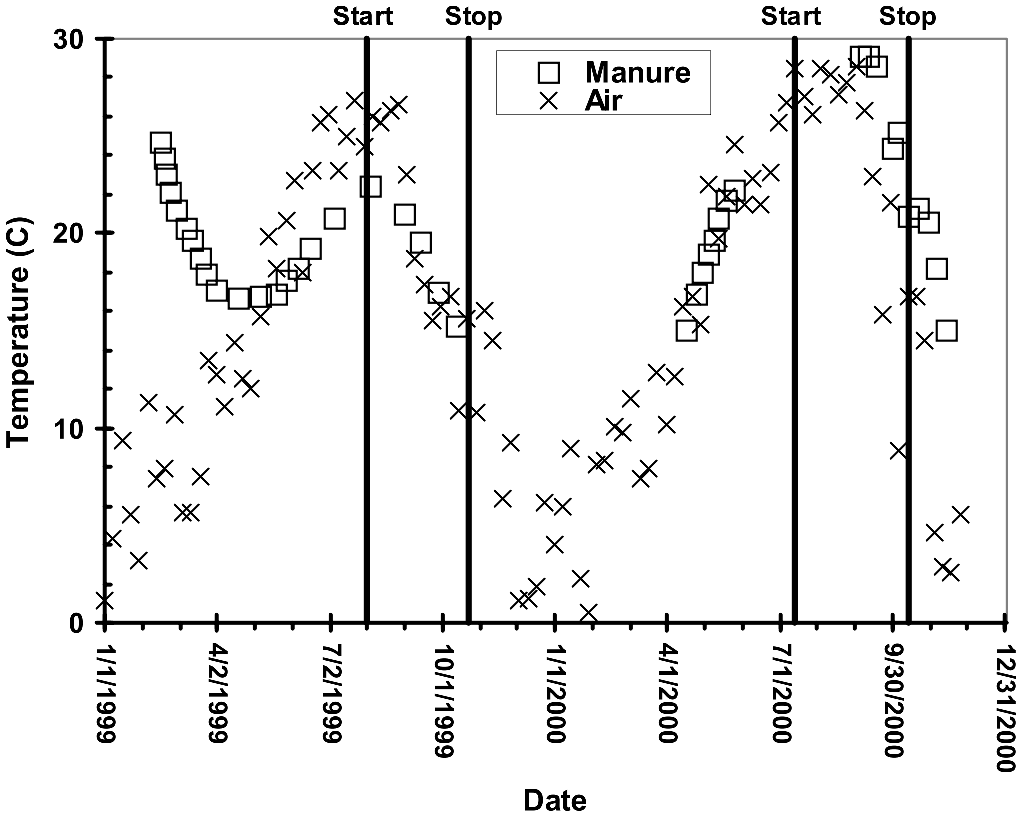

Figure 5. Temperature of manure in digester 1 compared to average weekly ambient air temperature. Vertical lines are start and stop dates for biogas production. The lower limit of the manure thermister was 15°C.

Table 1. Manure characteristics before and after anaerobic digestion in the field digesters. The initial manure used in digester 1 was the same as used in the laboratory experiment.

	Digester 1		Digester 2	
	Initial	Final	Initial	Final
TS (%)	40.0	47.7	50.0	50.3
VS (%)	32	25.2	41.9	23.2
Organic N (%)	1.32	2.21	na	1.11
NH_4-N (mg/kg)	836	3125	na	2164
NO_3-N (mg/kg)	19.9	3.4	na	3.2
Total N (%)	1.41	2.53	na	1.33
P (%)	0.51	0.91	na	0.54
K (%)	1.37	3.21	na	1.45
S (%)	0.52	0.68	na	0.5
Ca (%)	3.95	2.88	na	2.56
Mg (%)	0.88	1.03	na	0.67
Na (%)	0.31	0.84	na	0.34
VFAs (mg/kg)	8131	7493	na	8959
pH	8.0	8.4	na	8.4

na=not analyzed

Table 2. Biogas production rates and other gas concentrations.

Solids Content (%)	Biogas Production Rate		Typical Gas Concentrations (%)			
	Mean (L/g VS)	St. Dev.	Methane	Carbon Dioxide	Water	Other Gases
20	0.18 b	0.028	52.5	32.8	3.0	11.7
30	0.21 b	0.037	60.2	27.0	2.1	10.7
40	0.19 b	0.010	58.9	28.4	5.0	7.7
50	0.005 a	0.004	6.7	23.6	2.5	67.2

Using LSD comparisons, mean biogas production rates with same letters are not significantly different (α=0.05).

Table 3. Economic analysis showing benefit to cost (B:C) ratios for a variety of digester sizes at two natural gas prices and one-time or five-time use lifespan.

Top Width (m)	Depth (m)	Volume (m^3)	Natural Gas Price ($\$/Mm^3$)	Biogas Value ($)	Liner Cost ($)	Excavation Cost ($)	B:C Ratio
10.4 [ab]	1.8	90	125	152	1840	90	0.08
10.4[ab]	1.8	90	353	430	1840	90	0.22
10.4[ac]	1.8	90	125	760	5304	90	0.14
10.4[ac]	1.8	90	353	2,145	5304	90	0.40
45.4[b]	4.0	5,680	125	9,554	21,298	5,680	0.35
45.4[b]	4.0	5,680	353	26,980	21,298	5,680	1.00
45.4[c]	4.0	5,680	125	47,769	62,296	5,680	0.70
45.4[c]	4.0	5,680	353	134,899	62,296	5,680	1.98
37.0[b]	6.0	4,038	125	6,791	15,130	4,038	0.35
37.0[b]	6.0	4,038	353	19,179	15,130	4,038	1.00
37.0[c]	6.0	4,038	125	33,957	43,371	4,038	0.72
37.0[c]	6.0	4,038	353	95,896	43,371	4,038	2.02
36.4 [b]	8.0	4,012	125	6,748	15,052	4,012	0.35
36.4 [b]	8.0	4,012	353	19,055	15,052	4,012	1.00
36.4 [c]	8.0	4,012	125	33,738	42,472	4,012	0.73
36.4 [c]	8.0	4,012	353	95,277	42,472	4,012	2.05
555.0 [b]	14.0	3,891,865	125	6,545,703	2,656,061	3,891,865	1.00
555.0 [b]	14.0	3,891,865	353	18,485,064	2,656,061	3,891,865	2.82
555.0 [c]	14.0	3,891,865	125	32,728,513	7,905,742	3,891,865	2.77
555.0 [c]	14.0	3,891,865	353	92,425,321	7,905,742	3,891,865	7.83

[a] Research digester.

[b] Digester used one time.

[c] Digester used five times.

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