BIOGAS PRODUCTION FROM DAIRY MANURE AND ITS FILTRATE

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The effect of liquid-solid separation pretreatment on methane production from the anaerobic digestion of cattle manure was investigated in the laboratory. Screening out the coarse solid fraction from the waste before digestion had a minimal effect on the rate of biogas production for equal volatile solids loading rates at a 16-day hydraulic retention time. For a 12-day hydraulic retention time, a significant increase was found in the biogas production rate per litre of digester or per gram volatile solids added for the screened manure over the unscreened manure. The results support the concept that a liquid-solid separation pretreatment step could significantly reduce the volume of digester required for a farm with no decrease in biogas production.

INTRODUCTION

In recent years, biogas production through anaerobic digestion of animal manures has received renewed interest. The present state of the art has been reviewed by several researchers (Hashimoto et al. 1980; Smith 1980). Most of the existing on-farm anaerobic digester feed materials are in the range of 8–12% total solids (TS). At these levels, many are having material-handling problems typified by difficulties in manure slurry pumping and solids settling out in the digesters due to inadequate mixing (Abeles et al. 1978). Additional water is sometimes added in an attempt to solve these problems, resulting in an increase in digester volume requirements and hence a higher capital cost.

In the conventional anaerobic digestion process, the volatile solids (VS) breakdown is usually in the range of 15–30% (Hills 1980; National Academy of Sciences-National Research Council 1977). It is logical to assume that the principal organic fraction being metabolized consists of the organic molecules which are already in solution and the very fine particles having a high surface to volume ratio which are readily attacked by bacterial enzymes. If it is hypothesized that a very high percentage of the VS fraction which is destroyed in most digesters is contained in this liquid fraction, then a liquid-solid separation pretreatment of the waste should produce a filtrate which on digestion will still yield a high volume of biogas but which will not have the same material-handling problems. It would also be expected that the size of digester needed to treat the waste from a given number of animals would be smaller with only a small decrease in total biogas production.

The objective of this project was to determine the feasibility of reducing the digester volume per animal unit or per litre of biogas produced by removing a portion of the VS in the waste via screening.

METHODS AND ANALYSIS

Feed Material

Manure from a confined Holstein dairy herd in Aldergrove, B.C. (Blair Farms, 7851 184th St., Aldergrove, B.C.), was used for this study. Manure from the freestall dairy barn is scraped twice daily to the end of the alley. Samples of this manure were collected in plastic pails and stored in the University of British Columbia Bio-Resource Engineering cold storage room at 4°C. The dairy herd was fed with dairy concentrate (16% protein), alfalfa hay, grass and/or corn silage, salt and minerals. No antibiotics were incorporated in the animal feed.

In order to ensure a constant supply and stable feed material, enough dairy manure was taken from the dairy farm to last for the 6-mo duration of the experiment. Before being placed in the cold room, the fresh manure (15% TS wet weight basis) was mixed with an equal volume of water to give a final feed material of 7.5% TS, a level typical of those being recommended in the literature for anaerobic digesters (Lapp et al. 1978). This unscreened manure had a 6% volatile solids (VS) content and was used as feed material (feed D) for digester D. Portions of the thoroughly mixed unscreened manure were then passed through either a No. 10 (2.0-mm) or No. 8 (2.4-mm) vibrating screen to obtain feed materials for digesters A and B, respectively. The No. 8 mesh screen was chosen to match the screen opening of a commercially available rotating-screen liquid-solid separator (Rotostrainer, Hycor Corporation, Lake Bluff, Ill. 60044). The No. 10 mesh was selected based on our preliminary investigation of obtaining an adequate VS level for feed materials. The TS and VS for feed materials A and B were 4.3% TS and 3.3% VS, and 4.7% TS and 3.7% VS, respectively. A portion of the feed material D was further diluted to obtain feed C with a VS content (3.6% VS) similar to that of feed B. The feed materials A, B and C were prepared weekly.

Anaerobic Digesters

Four laboratory-scale completely mixed 4-L digesters (Fig. 1) were fabricated. For each digester, mixing was accomplished using an impeller driven by a DC motor for 15 min every hour. The digester temperature was maintained at 30°C using a thermostatically controlled electric heater. Gas produced was held in a collector filled with saline water which was connected to a reservoir. The gas volume was measured by reading the liquid level in the collector when the gas reached equilibrium with the atmospheric pressure as indicated by a mercury manometer.

The feed material preparation and characteristics (TS, VS, total Kjeldal nitrogen (TKN), ammonia nitrogen (NH₃-N)), and the loading rate and hydraulic retention time (HRT) for the digesters are presented in Table I. Digester D, using the unscreened manure, was set up as a control. Digesters A and B were fed with liquid filtrates (feeds A and B) to compare the effect of screen size on filtrate VS content and subsequent biogas production rate. Digester C was fed with diluted feed material D to compare directly with digester B. While the VS loading rates in both digesters C and B were about the same, a portion of the VS in feed C was made up of a coarse solid fraction which had been removed from B by the screen.
At start up, 2L of the thoroughly mixed effluents from the anaerobic digesters from our preliminary studies and 2L of the prepared feed materials were added to each digester. After a 1-wk period, daily feeding began and the loading rates were gradually increased to the desired level within a 4-wk period. Prior to daily feeding, each digester was thoroughly mixed for 15 min. A fixed volume of effluent was then withdrawn and the prepared feed material of equal volume added. The study was carried out from July to December 1981. The HRT was set at 16 days for a period of four HRTs and then changed to 12 days for a period of four HRTs.

**Chemical Analysis**

Chemical analyses were performed weekly for the feeds and the effluents of all digesters. Analyses for TS, VS, and pH were carried out according to standard methods (American Public Health Association 1971). Total Kjeldahl nitrogen (TKN) and ammonia-N were determined using a block digester and a Technicon AutoAnalyser II according to the method of Schumann et al. (1973). The biogas production was monitored daily and the methane content was analyzed every 2 wk with a Fisher-Hamilton (model 29) gas partitioner. All gas measurements were expressed at 0°C and standard pressure 760 mm of Hg).

**RESULTS AND DISCUSSION**

The composition of the dairy manure remained very stable during the 6-mo storage period at 4°C. The averaged values and the ranges of the chemical compositions of the feed materials are presented in Table I.

### Table I. Feed and Operating Characteristics of Anaerobic Digesters

<table>
<thead>
<tr>
<th>Digester</th>
<th>Dilution (manure: water)</th>
<th>Screen mesh no. (mm)</th>
<th>HRT (days)</th>
<th>TS (%) In</th>
<th>TS (%) Out</th>
<th>VS (%) In</th>
<th>VS (%) Out</th>
<th>Loading rate (g VS/L-day) In</th>
<th>TKN (mg/L) In</th>
<th>NH$_3$-N (mg/L) In</th>
<th>Methane production (L CH$_4$/L CH$_4$ added)</th>
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<tbody>
<tr>
<td>A</td>
<td>1:1</td>
<td>No. 10</td>
<td>16</td>
<td>4.3</td>
<td>3.7</td>
<td>3.3</td>
<td>2.8</td>
<td>2790</td>
<td>2805</td>
<td>281</td>
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<td>B</td>
<td>1:1</td>
<td>No. 8</td>
<td>16</td>
<td>4.4</td>
<td>3.7</td>
<td>3.4</td>
<td>2.7</td>
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<td>2980</td>
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<td>C</td>
<td>1:2.3</td>
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<td>16</td>
<td>4.6</td>
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<td>3.2</td>
<td>2890</td>
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<td>D</td>
<td>1:1</td>
<td>NA</td>
<td>16</td>
<td>4.6</td>
<td>3.9</td>
<td>3.7</td>
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<td>1914</td>
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†Numbers in parentheses indicate the range obtained.
‡NA = not applicable.
The fresh manure had about 15% TS. While some researchers have used dairy manure with about 12% TS or more in their anaerobic digestion studies, our own experience and personal communications with other investigators involved in on-farm biogas production operations indicated that operating a full-scale digester at a TS level above 10% is often associated with material-handling problems and a certain degree of dilution is deemed necessary. Also, our preliminary study found that fresh dairy manure with 15% TS could not be separated readily on the vibrating screens. Therefore, in this study dairy manure with a TS of 7.5% (feed D) was used as a control and is used as a basis for the following discussion.

As shown in Table I, there was no major loss of nitrogen through volatilization of ammonia during the experiments. No significant change was observed when the concentrations of the TKN in the influent and the effluent were compared. The concentrations of ammonia nitrogen were similar in all digesters. The ammonia nitrogen concentration rose during the experiments but stabilized at about 500 and 900 ppm NH₃-N and never approached the levels where toxicity is considered a potential problem (Loehr 1974).

All digesters reached a relatively constant biogas production rate within 40 days of start up. A new constant rate of biogas production was reached within 10 days when the HRT was decreased from 16 to 12 days. The biogas production rates reported for the digesters (Table I) are the arithmetic mean of the daily values for a time equal to four HRTs of stable operation. The pH values for the feed materials and the digester substrates were 7.2 and 6.9, respectively.

The biogas composition from all digesters was 63.5±1.5% CH₄ with the balance being CO₂ and trace impurities. The methane production rate is presented in two ways: litres of CH₄ per litre of digester per day and litres of CH₄ per g VS added per day. For the 16-day HRT, the rate of methane production from digesters A, B, and C was about the same at 0.18 L CH₄/L.d, while digester D had a higher production at 0.24 L CH₄/L.d. This shows that for a 16-day retention time and a similar VS loading rate (digesters A, B, C), the methane production rate was not affected by the presence of the coarse solids (digesters A and B vs. C). At the higher VS loading rate of 3.75 g VS/L.d (Digester D), the higher gas production rate indicated that it should be possible to increase the VS loading rate further or decrease the HRT without affecting the gas production rate. In terms of litres of methane produced per gram VS added, the biogas production for digesters A, B, and C was much more efficient than that in Digester D. The screening out of the coarse solids did have an impact when the HRT was reduced to 12 days. The methane production in both digesters A and B nearly doubled to 0.35 and 0.39 L CH₄/L.d, while the production in digester C increased only 15% and the production in digester D even decreased slightly. The effect of this coarse solids fraction became more obvious in terms of L CH₄/g VS added. The methane productions from both digesters A and B are nearly 1.8 times that from digester C and 3.2 times that from digester D. Apparently the anaerobic digestion process was much more active in digesters A and B than that in digesters C and D. It appears that at a shorter HRT, anaerobic digestion using liquid filtrate (feeds A and B) has a definite advantage over that of unscreened liquid manure (feeds C and D). The data are comparable to those reported by Chen et al. (1980).

The results obtained in this study could have a significant impact on the design of on-farm biogas production systems for dairy manure. In our liquid-solid separation pretreatment, about 50% of the manure sample (by volume or mass) was retained by the screen with the balance forming the filtrate fraction. Thus, for any given quantity of dairy manure, if the filtrate from a liquid-solid separation pretreatment step is used as the feed to an anaerobic digester, it is possible to cut the volume of manure being fed to the digesters in half and still produce the same amount of biogas as obtained from unscreened manure. Using the liquid filtrate alone (feed A or B, HRT 12 days) would require only 3/8 the digester volume that would be required for the unscreened liquid manure (feed D, HRT 16 days).

This represents more than a 60% reduction in digester volume and would certainly result in a reduction in the capital cost of the digester. We believe that this is an important concept in both animal manure management and biogas production. Further study is currently underway investigating the effects of VS loading rate, HRT, and particle size on the rate of biogas production. The impact of the liquid-solid separation pretreatment on the economics of the whole system remains to be investigated.

It should be noted that the results presented are for individual digesters and not the mean of two or more replicates as would be desirable. Limitations on space, labor and equipment did not permit carrying out replicates during this study, but based on the relative stability of the digesters during constant loading and on the rapid change in biogas production rates in response to changes in the loading, we feel it is unlikely that the observed differences in biogas production are random variations in the experiments.

ACKNOWLEDGMENT

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REFERENCES


