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Biogas production potential from switch grass-animal manure mixture using dry anaerobic digestion

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Abstract. *Anaerobic digestion is a biological method used to convert organic wastes into a stable product for land application without adverse environmental effects. The biogas produced can be used as an alternative renewable energy source. Dry anaerobic digestion (> 15% TS: total solid) has an advantage over wet digestion (<10% TS) because it allows for the use of a smaller volume of reactor and because it reduces wastewater production. In addition, it produces a fertilizer that is easier to transport. Performances of anaerobic digestion of animal manure-switchgrass mixture were evaluated under dry (15% TS) and thermophilic conditions (55^{o}C).Three different mixtures of animal manure (swine manure, poultry manure, and dairy manure) and switchgrass were digested using batch-operated 1-L reactors. Swine manure test unit showed 58% VS removal during 30 day trial while dairy and poultry manure test units showed 24% and 31%, respectively. Over the 30 day digestion, the swine manure test unit yielded the highest amount of methane yield 0.229 L CH_4 /g VS, while, the dairy and poultry manure test units showed very poor methane yield 0.009 L CH_4 /g VS and 0.002 L CH_4 /g VS, respectively. These results indicate that the swine manure test unit has the highest biogas production potential among the three different types of animal manure.*

Keywords. Anaerobic, Digestion, Animal manure, Biogas, Renewable energy

Introduction

Recent increases of fossil fuel prices have raised the demand for biofuel production from crops. The diversion of crops for biofuel production increased food price and food security concern. Therefore, research developing alternative biomass for bioenergy has become recently popular. Animal wastes are good sources of biomass due to an abundance of organic matter and nutrients. Using animal wastes as biomass offers a lot of advantages for livestock operations. It can minimize not only the wastes disposal costs but it also reduces odor and contaminants.

Anaerobic digestion is a biological method used to convert organic wastes into a stable product for application to land without adverse environmental effects, and the biogas produced can be used as an alternative renewable energy source. Dry anaerobic digestion (>15% TS) has benefit over conventional anaerobic liquid digestion (<10% TS) because it reduces the volume of reactor and wastewater as well as produces more easily transportable fertilizer (Schäfer et al., 2006).

In order to develop a suitable dry anaerobic digestion system, appropriate pretreatment and operating strategies need to be employed based on characteristics of feedstock. Biogas production depends on many parameters such as feedstock composition, operating temperature, and organic loading rate. Although dry anaerobic digestion has aforementioned attractive advantages, further investigations have been sparse.

Thus, the aim of this research is to evaluate biogas production potential of animal manure mixtures with switch grass using batch operating dry anaerobic digestion. The purpose was to understand the influence of animal manure type (dairy, swine, and poultry manure) on dry anaerobic digestion performances by investigating the biogas production, composition, substrate removal efficiency, and leachate characteristics.

Materials and methods

Digestive system

Experiments were carried out using laboratory scale digestion bag made of air-impermeable plastic with effective volume of about 1L (Figure 1). Anaerobic digestion bags were placed in 55℃ incubator for maintaining thermophilic condition. The mixtures were completely mixed every other day manually.

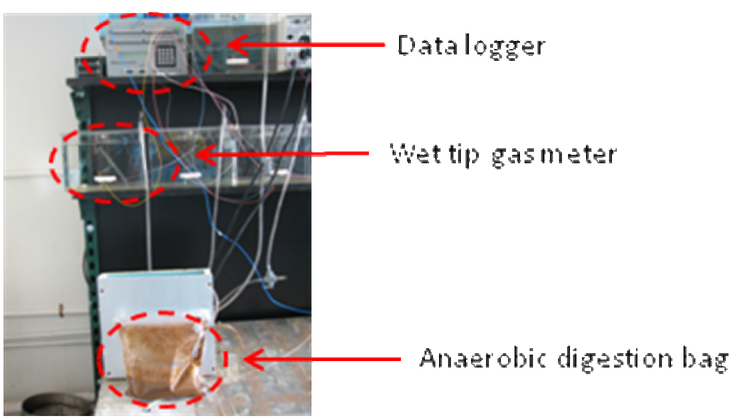

Figure 1. Photo of dry anaerobic digestion system

Feed materials

Three different types of animal manure (dairy, swine, and poultry manure) were tested, each test was replicated three times. The dairy, swine, and poultry manures were collected from USDA-ARS farm at Beltsville Agricultural Research Center (BARC) in Beltsville, MD and stored at 5℃ before use. Switch grass was harvested from USDA-ARS farm at BARC and grounded to average particle size of 2mm. The reactor was inoculated by adding digested dairy manure collected from an anaerobic reactor at USDA-ARS dairy farm. Table 1 shows the characteristics of feed materials. Total solid of animal manure and switch grass mixture was adjusted to about 15% (Table 3). The composition of each mixture is shown in Table 2.

Table 1. Characteristics of animal manure, inoculum, and switch grass (N=3)

	Moisture content (%, w.b.)	Volatile solids (%, d.b.)	Total C (%, w.b.)	Total N (%, w.b.)
Dairy manure	95.5±0.1	79.1±0.5	2.1±0.1	0.2±0.0
Swine manure	97.0±0.4	74.3±1.9	1.2±0.2	0.2±0.0
Poultry manure	57.1±1.6	78.5±0.1	18.1±1.5	2.1±0.4
Inoculum	97.4±0.0	65.4±1.3	1.1±0.1	0.1±0.0
Switch grass	4.8±0.3	97.7±0.1	46.0±0.1	0.4±0.0

Table 2. Composition of animal manure and switch grass mixture

	Manure (g)	Switch grass (g)	Inoculum (ml)	Water (ml)
DM[1]	957	200	239	-
SM [2]	856	200	214	-
PM[3]	94.6	200	230	921

[1] Dairy manure test unit, [2] Swine manure test unit, [3] Poultry manure test unit

Table 3. Characteristics of initial mixture and leachate (N=3)

	DM[1]	SM[2]	PM[3]
Moisture content (%, w.b.)	84.8±0.1	83.5±0.3	84.4±0.6
Volatile solids (%, d.b.)	94.5±0.2	95.3±0.6	92.9±0.2
Total C (%, w.b.)	7.1±0.4	7.9±0.2	6.2±0.5
SCOD (g/L)*	14.7±0.3	9.4±0.9	8.8±0.1
Total N (%, w.b.)	0.2±0.0	0.2±0.0	0.2±0.0
C:N ratio	38.3±3.9	41.2±4.4	32.9±2.5
NH_4-N (mg/L)*	283.1±57.6	801.7±313.3	390.5±58.9
pH*	8.0±0.1	7.8±0.1	6.9±0.1
Alkalinity (g/L as $CaCO_3$)*	7.4±0.4	9.4±0.8	4.6±0.3

[1] Dairy manure test unit, [2] Swine manure test unit, [3] Poultry manure test unit, * leachate

Analytical methods

Moisture content, volatile solids, SCOD, alkalinity, and NH_4-N of leachate samples were analyzed according to Standard Method (APHA, 1998). Total carbon and nitrogen were analyzed by an elemental analyzer (Elementar Vario Max CNS). pH of leachate samples was measured using a pH meter (AR20 pH/conductivity meter, Accument Research). Volatile fatty acids (VFA) were determined by a gas chromatography (Thermo/Finnigan Trace GC Ultra) equipped with a flame ionization detector (FID) and capillary column (Nukol Bonded Free Fatty Acid phase). The column temperature was 250℃ and the injector/detector temperature was 250℃. Helium was used as carrier gas with a flow rate of 20ml/min. Biogas production was measured with wet-tip gas meters. CH_4 was analyzed by a gas chromatography (Thermo/Finnigan Trace GC Ultra) with capillary PLOT column and a thermal conductivity detector (TCD). 20μL volume of sample was injected and analyzed under following condition: inject temperature:180℃; detector temperature:200℃; carrier gas: He (flow rate of 3ml/min).

Results and Discussion

Biogas production

The average daily and cumulative biogas productions are depicted in Figure 2. All three test units showed rapid biogas production for first 2 days, and then a fast decrease in biogas production was observed between days 2 and 4. The rapid biogas production during the first 2 days was due to the preferential digestion of readily biodegradable organic materials like carbohydrates. The dissipation of the readily degradable materials may have caused temporal biogas production decrease between days 2 and 4 (Demirer and Chen, 2008; Lu et al., 2007).

Swine manure test unit showed a steady increase in biogas production starting on day 5. Its biogas production level peaked (3.8L/day) after 11 days of digestion and then gradually decreased to 1L/day on day 30. Dairy and poultry manure test units showed slight biogas production increase up to 0.3L/day on day 6 and 8, respectively, after which the biogas production started to decrease and finally ceased on day 14.

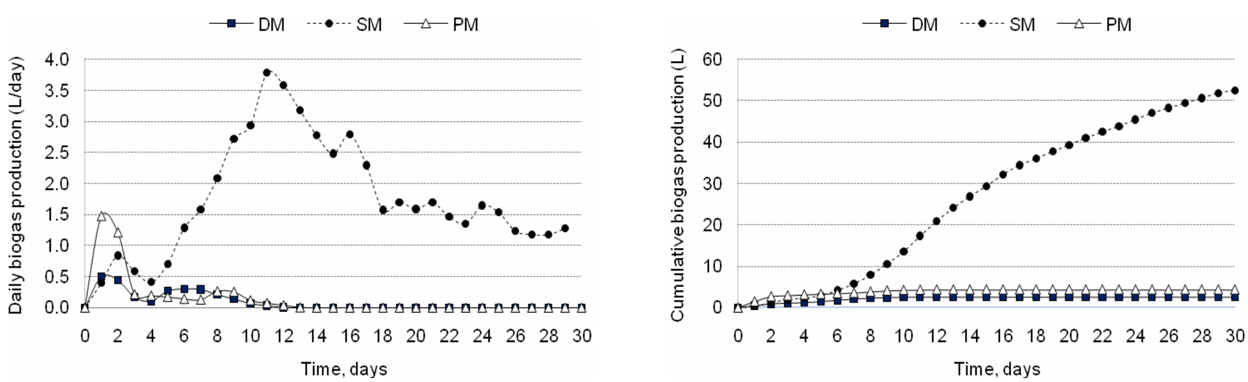

Figure 2. Average daily and cumulative biogas production.

Figure 3. shows that methane percentage and cumulative methane production. Although rapid biogas production was observed from all three test units during the first 2 days, there was not much methane produced during those 2 days. The maximum methane percentages obtained in dairy, swine, and poultry test units during first 2 days were about 5%, 5%, and 0%, respectively. Due to the oxygen that dissolved in wastewater and also remained in the pore spaces of the biosolid, the most of biogas production during the first 2 days came not through anaerobic digestion but aerobic or anoxic degradation.

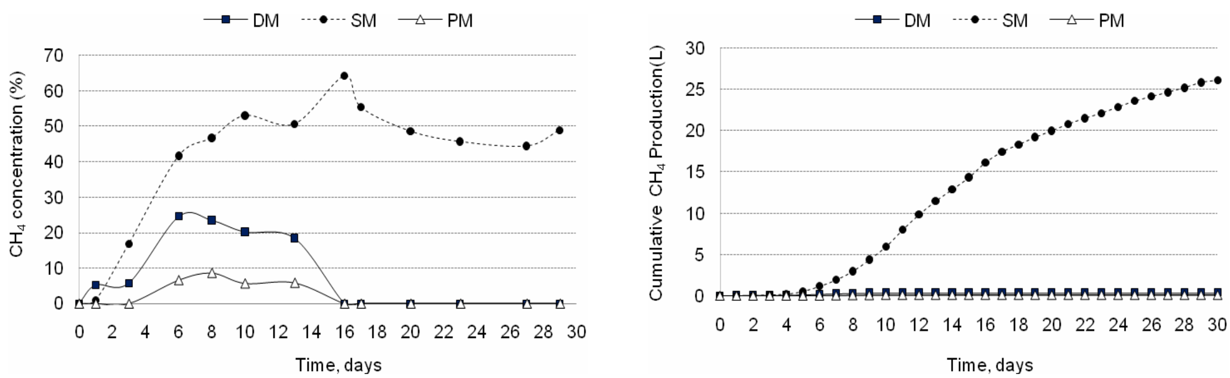

Figure 3. Methane composition and cumulative methane production.

After day 6, the swine manure test unit maintained methane content between 40% and 65% until day 30. Dairy manure and poultry manure test units reached their peak methane percentage 24.5% and 8.6% on day 6 and 8, respectively, and then subsequently produced no biogas after 2 additional weeks of digestion.

Substrate removal in the leachate

The temporal variations of the soluble COD concentrations of the leachate are shown in Figure 4. The soluble COD of swine manure test unit increased rapidly up to 29 g/l on day 1, and then decreased to 15g/l until day 30. The soluble COD of dairy and poultry manure test units increased steeply for the first 6 days and subsequently remained stable.

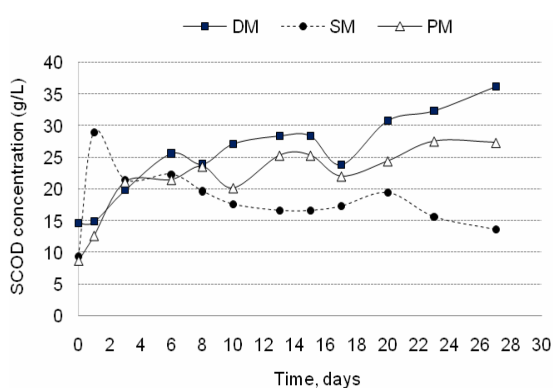

Figure 4. Temporal variation of soluble chemical oxygen demand (SCOD).

Due to the transformation of readily degradable organic materials into their soluble form through hydrolysis, a rapid increase of soluble COD was observed during the early stage of digestion. The swine manure test unit maintained a 53% reduction in soluble COD during 30 days of digestion, while the dairy and poultry manure test units showed no soluble COD reduction because of reactor failure. This disparity can be attributed to stable and active anaerobic microbial performances observed in the swine manure (Kim et al., 2002; Lu et al., 2007).

pH, alkalinity, and ammonium nitrogen variations in the leachate

The temporal variation of pH, alkalinity and NH_4-N are presented in Figure 5. All three test units showed pH increase during the first 2 days digestion due to the degradation of urea to ammonia. Further pH decreases were a resultant of VFA production by acetogenic bacteria (MØller et al, 2004; Paul and Beauchamp, 1989). Swine manure test unit showed a minimum pH value (6.5) on day 6, after which started to increase again. It kept the pH levels between 7.5 and 8.5 for the remainder of experiment. However, dairy and poultry manure test units showed rapid pH drops to below 6 until day 8. Their pH remained between 5.0 and 5.5, which is not favorable to methanogens. The pH of a normal and healthy anaerobic digestion system is generally in the range of 6.5-8.5 (Mshandete et al., 2006).

In general, pH increment accompanies the rise of biogas because methanogens consume VFAs and generate alkalinity (Kime et al., 2002). The pH and alkalinity levels imply that the swine manure test unit had a higher buffering capability than either the dairy or poultry manure. The alkalinity of swine manure test unit maintained the highest levels among the three test units until day 20, at which point it reversed. The abrupt alkalinity drop of swine manure test unit after day 20 can be attributed to the consumption of alkalinity when methane production started to slightly decrease.

Rapid NH_4-N increases were observed from all three test units for the first day. The NH_4-N of poultry and dairy manure test units constantly maintained 1500mg/L and 1000mg/L, respectively. The NH_4-N of swine manure increased to 2300mg/L on day 1 and it decreased to 830mg/L after 30 days of digestion. All three test units showed appropriate NH_4-N levels to maintain stable anaerobic digestion performance. In general, there is a possible inhibitory effect of the ammonium ion if NH_4-N concentration is between 1500mg/L to 3000mg/L and the pH is above 7.5. If the NH_4-N concentration is above 3000mg/L, anaerobic digestion is inhibited regardless pH level.

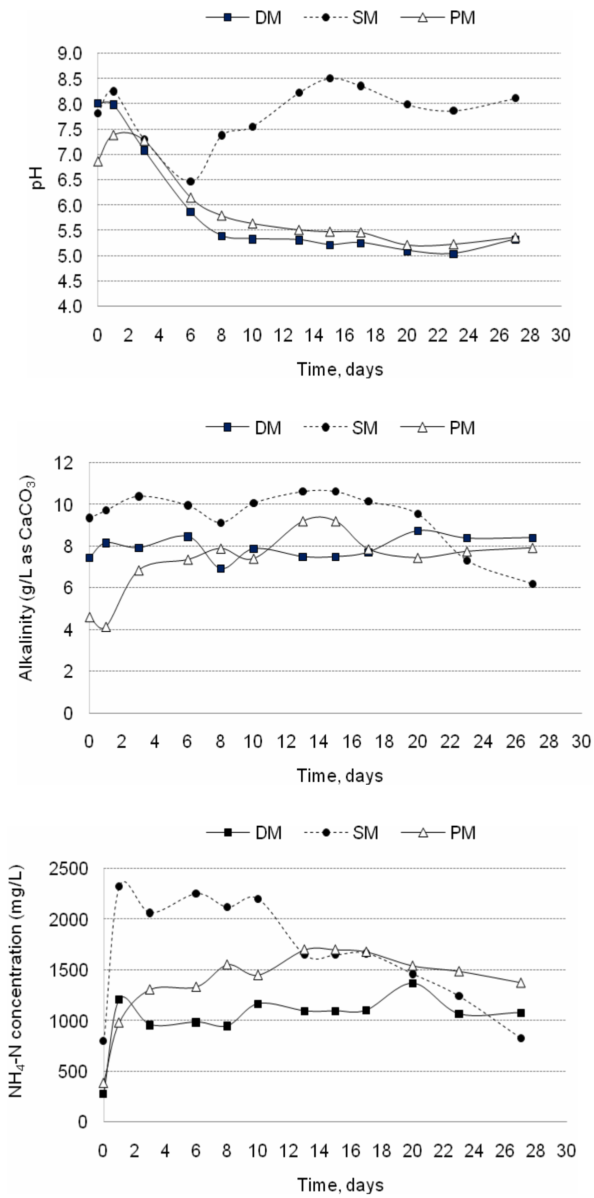

Figure 5. Temporal variations of pH, alkalinity, and NH_4-N.

VFA variations in the leachate

VFAs are the intermediary compound produced through anaerobic conversion of organic materials. Acetic acid, propionic acid, and butyric acid are the major VFAs produced during anaerobic digestion. Acetic acid is generated via syntrophic metabolism of propionic and butyric acids. Finally, methanogens convert acetic acid to CO_2 and CH_4. VFAs are one of the important indicators to measure anaerobic digestion performance with because they are closely related to the change of pH, alkalinity, and the activity of methanogens (MØller et al, 2004; Buyukkamaci and Filibeli, 2004).

Temporal variations of VFAs are depicted in Figure 6. Swine manure test unit showed maximum VFAs concentration (acetic acid: 13g/L) after 6 days and decreased to 2g/L on day 10. It showed minimum pH value (6.5) when VFAs concentration reached maximum concentration and increased to above 7.5 as VFAs concentration decreased to 2g/L on day 10. Most of VFAs seemed to be consumed by methanogens completely after 17 days. In contrast to swine manure test unit, dairy and poultry manure slowly reached maximum VFA concentration (dairy manure: 12g/L, poultry manure: 9.4g/L) after 10 days. Dairy and poultry test units remained at their maximum VFA concentrations for the rest of the experiment. It indicates that there was not much conversion of VFAs to CH_4 by methanogens.

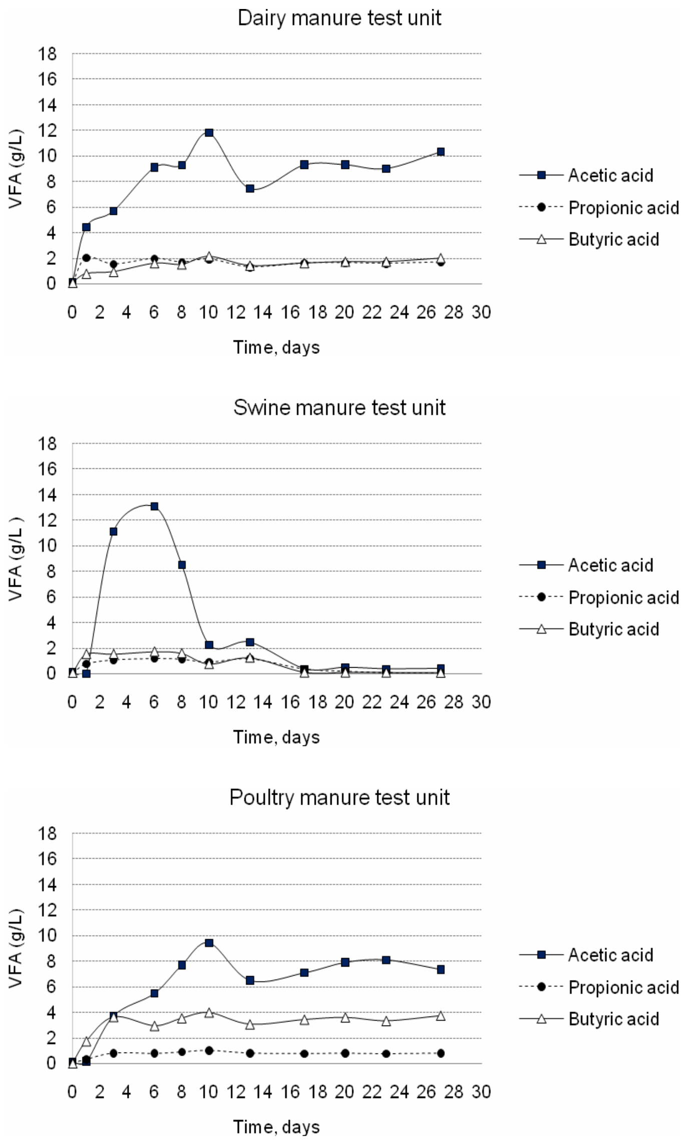

Figure 6. Temporal variations of VFAs (acetic, propionic, and butyric acids).

Comparative anaerobic digestion performance

The swine manure test unit showed superior biogas production (52.5L) compared to dairy and poultry test units (dairy manure: 2.5L, poultry manure: 4.3L). The average methane production of swine manure test unit was 26.1L while the rest test units produced less than 1L throughout the 30 days digestion (Table 4). Assuming that the weight loss in the digested material was primarily caused by organic material degradation, VS removal was estimated based on material weight difference between the first and last day of the experiment. The swine manure test unit showed 58 % VS removal over 30 days while dairy and poultry manure test units showed 24% and 31%, respectively. Over the 30 day digestion, the swine manure test unit yielded the highest amount of methane (0.229 L CH_4 /g VS), while, the dairy and poultry manure test units showed very poor methane yield 0.009 L CH_4 /g VS and 0.002 L CH_4 /g VS, respectively.

Table 4. Methane yield of each test unit for 30 days of digestion (N=3)

	Total biogas production (L)	Total CH_4 production (L)	VS removal* (%)	VS removal* (g)	CH_4 yield (L/g VS)
DM[1]	2.5±0.4	0.39±0.16	24.4±7.0	48.7±13.9	0.009±0.005
SM [2]	52.5±10.3	26.09±5.11	58.0±9.1	115.5±18.6	0.229±0.053
PM[3]	4.3±0.4	0.90±0.83	30.5±9.5	59.6±18.4	0.002±0.002

[1] Dairy manure test unit, [2] Swine manure test unit, [3] Poultry manure test unit, * Total weight loss assumed as VS removal

Conclusion

Considering the overall results of anaerobic digestion of animal manure- switch grass mixture under dry and thermophilic condition, the swine manure test unit maintained well balanced conditions while the dairy and poultry manure test units showed poor performances. Swine manure test unit proved its high biogas production potential (0.229 L CH_4 /g VS).

Although dairy and poultry manure showed failure performances in this study, they still have high potential as biomass for dry anaerobic digestion if the appropriate design applied to prevent significant VFA accumulation and pH drop.

In further research, feasible operational conditions in order to improve biogas production of dairy and poultry manure needs to be determined. Eventually, a suitable design to minimize energy required to maintain reactor temperature should be developed. The energy required for heating may be reduced by changing the temperature at which digestion is carried out or by creating an economical complementary heat source such as a composting system.

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