Evaluation of Biochemical Factors from Mixed Animal Wastes Feedstock in Biogas Production

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***Abstract*—Animal wastes can serve as the feedstock for biogas production that could be used as alternative energy source. The green energy derived from animal wastes is considered to be carbon neutral and offsetting those generated from fossil fuels. In this study, an evaluation of methane production from animal wastes with different nitrogen and carbon sources was carried out. Anaerobic batch reactors containing different mixtures of animal wastes and potential inhibition sources were set up to evaluate methane potential. The results showed that methane productions increased as the solid concentrations, temperature and total carbon increased. However, biogas production decreased substantially when ammonia concentrations in the feedstock were high. The addition of carbon to the feedstock provided a better substrate for methane production during anaerobic digestion of animal wastes. Methane productions were more than several times greater from reactors with feedstock amended with additional source of carbon than the ones with just animal wastes (e.g., swine, poultry or just dairy) or acclimated microbes. Thus, it appears that additional carbon source is necessary to increase methane production from animal waste anaerobic digester. Inhibitor such as ammonia appears to hinder the biomethanation in the anaerobic digestion of animal wastes for optimum methane production.**

***Index Terms*—animal wastes, biochemical factors, biogas, livestock, methanogenesis**

I. Introduction

Millions of tons of animal wastes from livestock operations are generated in the U.S. each year. Animal manure has been traditionally used as natural fertilizer for crop production. However, land application of manure is limited due to problems associated with potential groundwater contamination, air quality, and limited immediate availability of agricultural land. Animal manure is a major source of anthropogenic greenhouse gas (methane, carbon dioxide, and nitrous oxide) emission and offensive odors. Livestock manure emission contributes to roughly 10 to 15% of total greenhouse gas emission. The methane emissions originate mostly from swine (38%), dairy (21%), and poultry (9%) livestock wastes [1], [2].

Thus, alternative waste management and treatment are sought. Anaerobic digestion of animal wastes can serve as an alternative waste treatment practice that could reduce air pollution and generate energy for on-farm use. Animal wastes can serve as the feedstock for biogas production (mainly methane) that could be used as alternative energy source. The green energy derived from animal wastes is considered to be carbon neutral and offsetting those generated from fossil fuels.

Many studies had dealt with biogas production from animal and agricultural wastes [3]-[13]. However, most of these studies only dealt with single substrate for anaerobic digestion to obtain methane for bioenergy (e.g., swine waste, dairy waste, or poultry waste alone). Data on mixed substrate digestion along with biochemical factors of animal wastes for bioenergy production are scarce, especially on mixture of swine, poultry litter, dairy wastes, and food wastes with their potential support and inhibition in anaerobic digestion processes.

Therefore, the types of anaerobic digestion systems and the biochemical conditions could have major effects on the biogas production. Therefore, the objective of this study was to evaluate the effect of different biochemical parameters on the methane potential/production from mixed animal waste anaerobic digestion reactors as an evaluation for a larger scale on-farm anaerobic digestion of livestock wastes.

II. Materials and Methods

A. Experimental Setup and Data Analyses

Anaerobic batch reactors (250 mL; Fig. 1) containing different mixtures of swine and poultry litter (5 to 50% by mass) were set up to evaluate methane potential. In addition, five different scenarios were set up as following to study the significant of substrate sterility and microbial competitive exclusion on methane generation: (1) sterile swine waste and sterile poultry litter; (2) sterile swine waste and non-sterile poultry litter; (3) non-sterile swine waste and sterile poultry litter; (4) non-sterile swine waste and non-sterile poultry litter; and (5) non-sterile swine waste only. Sterilization was carried out by autoclaving and nitrogen gas was used to purge the headspace of the reactors to obtain anaerobic conditions. The reactors were then placed on a shaker (163 rpm) at room temperature. Similar set up was also utilized to examine ammonia inhibition on methanogenesis. A semi-plug flow anaerobic digestion system (9 cubic meter; Fig.

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2) of dairy manure was also set up to study the physico-chemical parameters affecting biogas production. Biogas productions were sampled and monitored by gas chromatography. Volumetric methane production was determined by wet chemistry according to Standard Methods [14]. Fatty acids (acetic, propionic, and butyric acids) were determined by high performance liquid chromatography (Ultimate 3000 HPLC, Dionex Corporation, San Francisco, CA). Table I shows the ranges of important chemical properties of various livestock wastes used in this study.

TABLE I. RANGE OF IMPORTANT CHEMICAL CHARACTERISTICS OF LIVESTOCK WASTES USED

	pH	COD (mg/L)	N (%)	C (%)
Liquid Swine	6.5-8.2	1000 - 3000	0.05 – 0.1	0.02-0.4
Rice Hull Poultry Litter	6.2-7.8	5000-8000	1.5-2.8	22-27
Woodchip Poultry Litter	6.5-7.8	4000-6800	0.7-2.0	10-18
Dairy Manure	6.2-9.2	7500-12000	2.2-4.2	25-35

Figure 1. Mixed wastes batch anaerobic digestion.

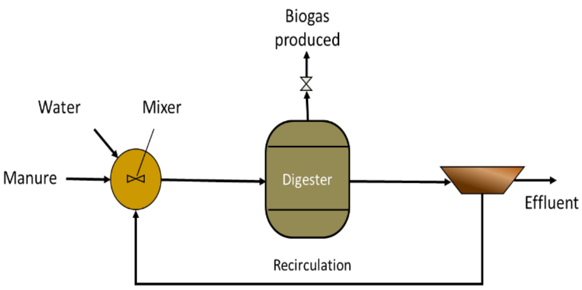

Figure 2. Schematic setup of a plug flow anaerobic digestion.

III. RESULTS AND DISCUSSION

A. Effect of Mixed Feedstocks and Ammonia

In order to delineate the biochemical effects on biomethanation, bench-scale anaerobic digestion study on the sterility of substrates was carried out. Swine slurry (90 ml) was amended with 10% of wood-chip and rice hull poultry litter (by weight) in various sterility conditions. The results showed that reactors with non-sterile swine slurry (reactors 3 and 4; ~180 to 190 cc or mL, respectively) had the most methane production (Fig. 3). The methane productions from reactors 3 and 4 are several times greater than the production from reactor 5 (swine slurry alone) and reactor 2 (sterile swine slurry with non-sterile poultry litter). There were no methane productions from the sterile control (reactor 1). It appeared that microbial strands in swine slurry were necessary for optimum methane generation whereas poultry litter did not provide sufficient microorganisms (methanogens) for optimal methanogenesis.

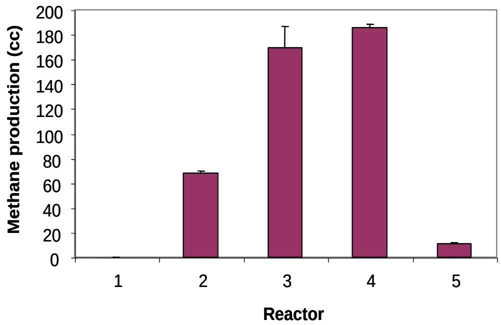

Figure 3. Total methane production after 1080 hours of operation from 10% wood-chip poultry litter in swine slurry. Reactors: 1 = Control (sterile swine and litter); 2 = Sterile Swine and non-sterile litter; 3 = Non-sterile swine and sterile litter; 4 = Non-sterile swine and litter; 5 = Non-sterile swine waste only. Error bars represent standard deviation of triplicate reactors.

In order to delineate the potential rate limiting step in methane production, fatty acid concentrations were monitored by HPLC. Microcosms with rice hull litters appeared to produce higher concentrations of both methane and fatty acids (Fig. 4). The concentrations increased over time. However, fatty acid productions appeared to reach steady state after about 150 hours of incubation. Amount of acetic acid production was much higher than other fatty acids (i.e., propionic and butyric acids). It appeared that methanogenesis from organic compounds is not the terminal step of methane production since the methane concentrations were still increasing whereas fatty acid, especially acetate, production had reached steady state. The rate-limiting step in methanogenesis from these microcosms appeared to consist of steps involved in the production of acetate and hydrogen gas by synthrophs, secondary fermenters which relied on by-products produced from primary fermenters such as fatty acids or alcohols as energy sources for growth [15].

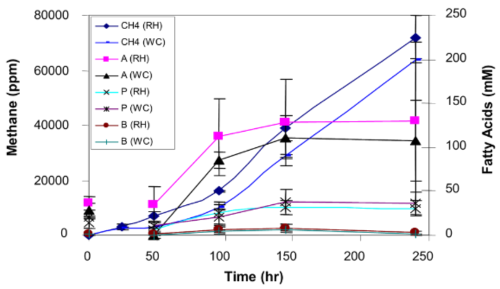

Figure 4. Temporal changes of methane and fatty acid concentrations in non-sterile reactors containing swine slurry and poultry litters (10%). RH = Rice Hull, WC = Wood Chip, A = Acetic acid, P = Propionic acid, B = Butyric acid. The error bars represent standard deviations of triplicate samples.

Ammonia, on the other hand, seems to have inhibitory effect on biogas production. With similar set up as above, biogas production decreased as the concentrations of ammonium increased in the feedstock (Fig. 5). High concentrations of ammonia will have detrimental effect on methanogens since it can freely penetrate cellular membranes to change the intracellular pH, requiring cells more energy for regulation and reducing the effectiveness of cellular enzymes [16]-[19]. Several studies [20]-[23] have shown that high concentrations of ammonia reduced the amount of biogas produced which corroborated well with the results of our study.

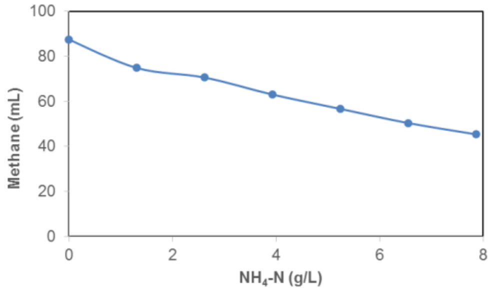

Figure 5. The effect of initial ammonium concentrations on total methane production. Duplicate reactors were utilized and the average values were used to form the standard curve.

B. *Effects from Physico-Chemical Parameters*

A plug flow anaerobic digestion system was set up to examine the effect of physico-chemical factors on biogas production. Using dairy manure as feedstock, it was found that temperature and pH had major effect on biogas production as well as the flowrates (i.e., retention time of feedstock in the digestion system). It appeared that the optimum production of biogas was observed in the temperature range from 25 to 35℃ (mesophilic conditions; Fig. 6) and pH in the neutrality zone (Fig. 7). However, the pH of the feedstock (influent) appeared to have a major effect on the biogas production. The high pH of the feedstock appeared to reduce gas production substantially (Fig. 7). Our results corroborated well with previous study where pH and temperature affect the growth of microorganisms, especially methanogenic and acidogenic microorganisms [18], [23]-[26]. Optimum biogas production was observed when the pH of the feedstock near neutrality. Optimum biogas production was also obtained with long retention time: biogas production decreased as flowrates increased (data not shown).

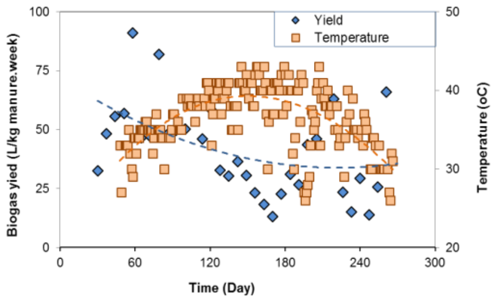

Figure 6. Relation among biogas yield and temperature of a plug flow anaerobic digester.

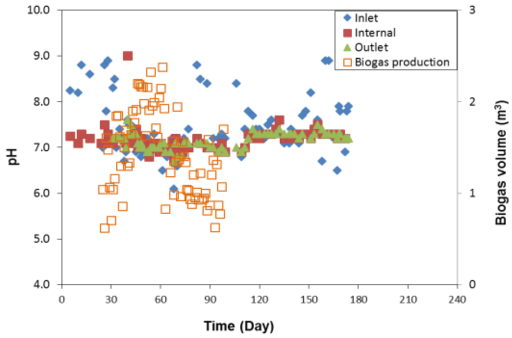

Figure 7. Relation among biogas production and pH of a plug flow anaerobic digester.

IV. Conclusions

Biochemical factors play major roles in biogas production from livestock wastes. This study was carried out to determine the effects from various parameters relating to the operation and the nature of different feedstocks on methanogenesis. From the results, it was shown that acclimated culture of methanogens (seeds) is needed for optimal biogas production. Furthermore, additional carbon source, whether by mixing different feedstocks, along with the correct ranges of pH and temperature help improve the biomethanation of mixed livestock wastes. Biological inhibitor such as ammonia can also have a profound effect on methanogenesis as well. Likewise for a flow through system, hydraulic retention time is very critical in achieving optimal biogas production. Thus, it is very important to consider various biochemical factors when designing and operating an anaerobic digester for optimizing biogas production, especially from non-traditional feedstocks such as mixed livestock wastes.

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