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Methane Production Potential of Food Waste and Food Waste Mixture with Swine Manure in Anaerobic Digestion

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Abstract

Purpose: Methane production potential in aerobic digestion was assessed according to feed to inoculum (F/I) ratio for food waste only, and mixing ratio of two materials for food waste and swine manure to give a basic data for the design of anaerobic digestion system. **Methods:** Anaerbic digestion test was performed using a lab scale batch reactor at 35°C for six different feed to inoculum (F/I) ratios (0.50, 0.72, 1.14, 1.50, 2.14 and 3.41), three food waste to swine manure ratios (100:0, 60:40 and 40:60) with two different loading concentrations (10g VS/L and 30g VS/L). **Results:** For food waste only, the highest biogas yield of 1008 mL/gVS was obtained at 0.50 of F/I. For the co-digestion of food waste and swine manure mixture, the highest biogas yield of 1148 mL/gVS was obtained at a mixing ratio of 40:60 with loading concentration of 10g VS/L. **Conclusions:** F/I ratio for the food waste only, mixing ratio of food waste and swine manure, and co-substrate loading rate affected the biogas production rate. For the low loading rate, there was not so much difference according to the mixing ratio of food waste and swine manure, but for the high loading rate higher biogas yield was acquired for the co-digestion of food waste and swine manure than for the food waste alone (mixing ratio, 100:0).

Keywords: Food waste, Swine manure, Anaerobic digestion, Biogas yield, Codigestion, Feed to inoculum (F/I) ratio

Introduction

Incineration of Korean food waste is not a desirable method for disposing waste due to the high moisture contents and low heating value of food waste. Consequently, mesophilic anaerobic digestion has been one of the most widely used methods for food waste disposal. Co-digestion has been regarded as another way to improve the production of methane gas (Kim et al., 2010). It offers several advantages including dilution of toxic compounds, improved balance of nutrients and better biogas yield (Sosnowski et al., 2003). Manure has been used as a co-substrate for anaerobic digestion of food waste. The major advantage of using manures as a co-substrate is that it helps to overcome pH issues caused by the volatile fatty acids (VFA) produced from the digestion of food waste (Banks et al., 1998; Kafle et al., 2012). Anaerobic digestion is a biological approach for the treatment of organic waste and the production of biogas, which can be used as a fuel for heating or generating electricity (Zhang et al., 2010). When burned, a cubic foot (0.028 m^3) of biogas yields about 10 Btu (2.52 Kcal) of heat energy per percentage of methane composition (USDE, 2010). For example, biogas composed of 60% methane yields 600 Btu/ft^3 (5400 $kcal/m^3$). In Korea, the amount of food waste generated each day reached 14,452 tons in 2007 (KME, 2008). In addition, the number of swine farms has rapidly grown in Korea due to increasing demand for meat. Swine manure (SM) production is about 150,000 tons/day and approximately 5.7% of the produced swine manure is disposed of by ocean dumping

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(Shin et al., 2008). In addition, it is major source of odor production, vermin attraction, toxic gas emission and ground water contamination. Due to the recent ban on direct disposal of food waste and swine manure into a landfill sites and seawater, waste reduction and recycling has been an issue in Korea. This research was carried out to characterize food waste and swine manure and assess their potential use as a feed stock in a mesophilic anaerobic digester.

Materials and Methods

Feedstock and inoculum

Food waste (FW) and swine manure (SM) samples were collected from the cafeteria and swine farm of Sunchon National University, respectively. The samples were transported immediately to the farm power laboratory at SCNU and stored in a refrigerator at approximately 4°C. The food waste consisted of rice, fish, pork, banana skin, cabbage soup, vegetables and paste. The characteristics of the food waste, swine manure and inoculum are shown in Table 1.

Food waste was crusted using an electric crusher (M-DA 338, Daeseong, Korea) within 2 minutes and the swine manure was sieved (Sieve No. 20, Aperture: 850 m) in order to remove large particles prior to feeding. Inoculum was collected from an anaerobic digester in a local swine manure treating plant.

Batch digester and experimental procedure

A triangle glass flask of 200 mL was used to carry out the anaerobic digestion tests. The working volume of the digester was 120 mL. The batch tests were conducted using food waste only and mixtures of food waste and swine manure as the substrate for anaerobic digestion. In the food waste test (R1-R6), the inoculum was supplied at different feed to inoculum (F/I) ratios. In experiments that examined the mixture of food waste and swine manure (R7-R12), each digester contained the same amount of inoculum (20 mL). The F/I ratio of the reactor was expressed as the amount of feedstock (food waste) VS per amount of inoculum VS (Liu et al., 2009). The experimental design is shown in Table 2. At mesophilic temperature, food waste was digested at six F/I ratios: 0.50, 0.72, 1.14, 1.50, 2.14 and 3.41. Food waste and

Table 1. Basic characteristics of feed materials (average value)

Parameters	Food waste	Swine manure	Inoculum
tCOD (g/L)	371.29	23.55	49.50
sCOD (g/L)	90.54	9.80	15.60
NH_3-N (g/L)	2.07	0.03	12.63
VFA (CH_3COOH) (g/L)	25.42	17.70	2.40
Alkalinity ($CaCO_3$) (g/L)	41.70	26.40	15.90
TS (%)	17.94	1.32	45.32
VS (%)	13.41	0.53	7.94
MC (%)	82.06	98.68	54.68

Remark: Analysis was repeated with duplicate samples.

Table 2. Experimental design and biogas production performance

Reactor	Initial loading (g VS/L)	F/I ratio	Biogas yield (mL/gVS)	Reactor	Initial loading (g VS/L)	Ratio of FW to SM (% volume basis)	Biogas yield (mL/gVS)
R1	10	0.50	1008	R7	10	100:0	925
R2	10	0.72	952	R8	10	60:40	1113
R3	10	1.14	720	R9	10	40:60	1148
R4	30	1.50	127	R10	30	100:0	110
R5	30	2.14	111	R11	30	60:40	814
R6	30	3.41	151	R12	30	40:60	586

mixtures of food waste and swine manure (100:0, 60:40, 40:60, % volume basis) were digested at two initial volatile solids (VS) loading concentrations: 10 and 30 g VS/L.

After adding the required amount of substrates, the digester was purged with nitrogen gas for 2 min to assure an anaerobic condition before it was tightly closed with a rubber stopper. The reactors were kept on a laboratory shaking incubator (VS-8480SF, Vision Scientific Co. Ltd, Korea) at a temperature of 35°C, which was within the optimal temperature for the mesophilic bacteria (Henstra et al., 2007). Continuous and homogeneous mixing was achieved using an automatic stirring laboratory shaker at 120 rpm. Each batch digester was connected to the needle blocked by a rubber stopper to stop the leakage of gas and liquid as shown in Figure 1. The produced biogas forced to move the piston of medical syringe through the needle by the pressure difference when opening the gate valve.

Biogas measurement and analytical methods

Biogas was removed from the digester by pressing the needle into the rubber stopper. After connecting the needle, biogas produced inside the digester was moved into the syringe by expanding the volume (piston moves). The volume of the produced biogas was recorded by reading the scale on the syringe twice a day. Analysis of food waste and swine manure samples was conducted before digestion and after 30 days of digestion. Total chemical oxygen demand (tCOD), total solids (TS) and VS of the mixed samples were determined according to standard methods (APHA, 2005). Soluble COD (sCOD), VFA (as CH_3COOH) and NH_3-N were analyzed after centrifugation at 4000 rpm for 10 minutes. Alkalinity (as $CaCO_3$) was determined by the close reflux, titrimetric method according to standard methods (APHA, 2005). The pH value was measured using a pH meter (EGA 133/BNC, Sechang Instruments, Korea).

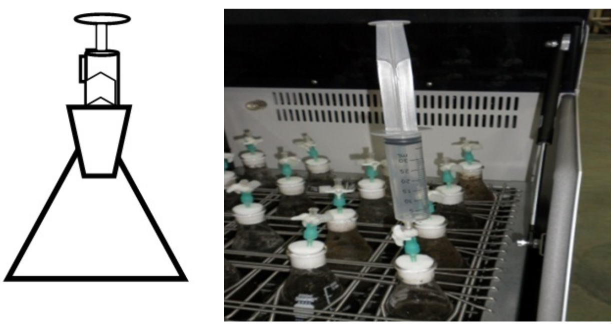

Figure 1. Schematic diagram and picture of the laboratory experimental batch test.

Results and Discussion

The average daily biogas production and cumulative biogas production during the digestion of food waste at six different F/Is are shown in Figure 2. Daily biogas production ranged from 20 mL/gVS-day to 80 mL/gVS-day at low F/I ratios (F/I: 0.50, 0.72 and 1.14), whereas, biogas production gradually decreased at the higher F/Is. The peak value of daily biogas production rates was calculated to be 83 mL/g VS-day after the 9th day of digestion at a F/I ratio of 0.5.

The accumulated biogas yields were measured to be 1008, 952, 720, 127, 111, and 151 mL/g VS at F/I ratios of 0.50, 0.72, 1.14, 1.50, 2.14, and 3.41, respectively, indicating that the yields decreased with an increase in F/I ratio. The highest biogas yield obtained was 1008 mL/g VS at a F/I ratio of 0.50. A fairly similar biogas yield (952 mL/g VS) was obtained at a F/I ratio of 0.72. At higher F/I ratios (1.50, 2.14 and 3.41), a total biogas yield of about 90% was achieved during the first five days of digestion. These results indicate that the lower F/I ratio (0.50, 0.72 and 1.14) is desirable for effective digestion of food

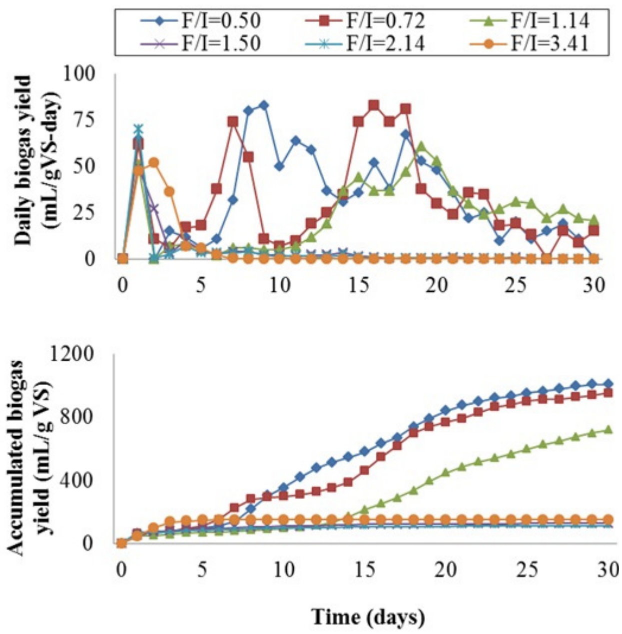

Figure 2. Daily and accumulated biogas yield from mesophilic anaerobic digestion of food waste at six different F/Is.

waste.

The accumulated biogas yield were measured to be 925, 1113.5, and 1148.5 mL/g VS when the organic load concentration was 10 g VS/L at mixing ratios of 100:0, 60:40 and 40:60 (FW: SM), respectively (Figure 3). At a organic loading concentration of 30 g VS/L, the biogas yield was 110, 814, and 584.6 mL/g VS at mixing ratios of 100:0, 60:40 and 40:60, respectively, after 30 days of digestion (Figure 4 and Table 2). The highest biogas yield obtained was 1148.5 mL/g VS at a mixing ratio of 40:60 and organic load concentration of 10 g VS/L.

These results demonstrate that biogas yields after 30 days of digestion of food waste are influenced by the mixing ratio of food waste and swine manutre and the F/I ratio. In this study, a higher biogas yield was achieved (1008 mL/g VS) at a lower F/I of 0.5 and lower biogas yields were observed at higher F/I ratios. This inverse relation might be due to the low methanogenic activity

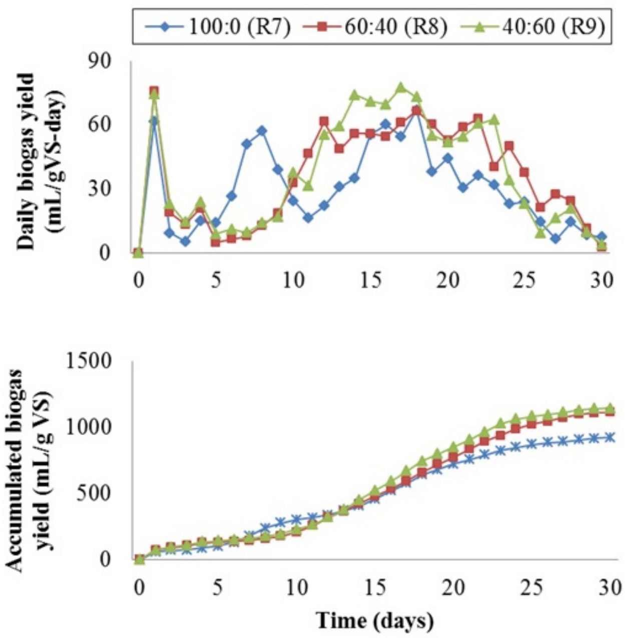

Figure 3. Daily and accumulated biogas yield from mesophilic anaerobic digestion of food waste at three different mixing ratios for initial organic loading of 10 g VS/L.

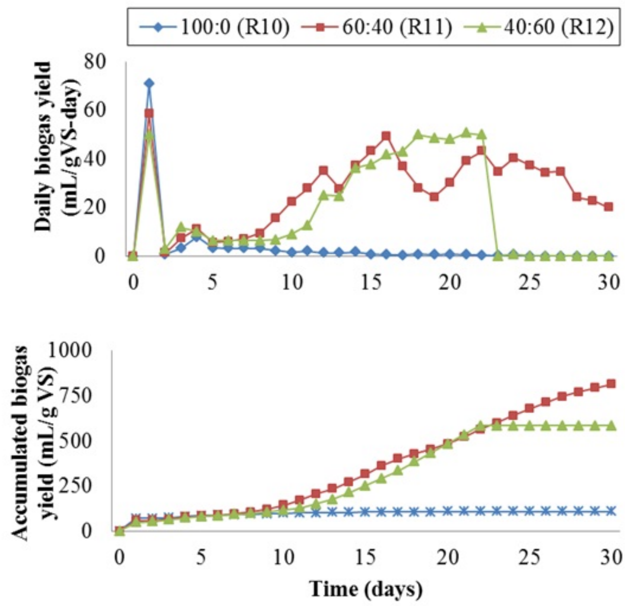

Figure 4. Daily and accumulated biogas yield from mesophilic anaerobic digestion of food waste at three different mixing ratios for initial organic loading of 30 g VS/L.

Table 3. Characteristics of digested waste (after 30 days of digestion)

Reactor	pH	Alkalinity (as $CaCO_3$) mg/L	NH_3-N mg/L	sCOD mg/L	VFA (as CH_3COOH) mg/L	VFA/alkalinity ratio
R1	7.90	12000	1640	3070	850	0.11
R2	7.87	7900	1690	3520	1300	0.11
R3	7.74	8500	695	2190	6450	0.82
R4	6.45	9900	1680	20430	8500	1.00
R5	6.80	6900	1900	20410	8300	0.84
R6	5.57	6900	885	20210	9250	1.34
R7	7.90	12000	690	3520	1300	0.11
R8	8.09	11900	1335	6000	1300	0.11
R9	7.15	14100	1785	7080	1150	0.08
R10	6.80	9900	900	20410	6800	0.69
R11	7.09	15100	2310	8750	1100	0.07
R12	7.86	12300	2705	20350	2000	0.16

and/or number of methogens in the digesters, which produce excess VFA during the acidogenic step. High concentrations of VFA could inhibit methanogenesis (Liu et al., 2009).

Generally, FW is thought of as being highly degradable, but a adequately high alkalinity is required for sucessful digestion. Callaghan et al. (2002) reported that, for balanced digestion of FW alone or with co-substrates, the alkalinity should not be less than 1500 mg/L. The toxic and inhibitory inorganic compounds of NH_3-N can be problematic to the anaerobic process should be and should be within the range of 50-500 mg/L for normal digestion (Tchobanoglous et al., 2003). Throughout this study using food waste, the alkalinity was always greater than 5000 mg/L.

The stability of the digestion system depends on a number of factors, such as pH, VFA, NH_3-N and alkalinity, etc. The result of alkalinity, NH_3-N, sCOD, VFA, and VFA:alkalinity ratio of each reactor are presented in Table 3. One of the most important criteria to digester stability is the VFA:alkalinity ratio. Callaghan et al. (2002) reported that the VFA:alkalinity ratio should be less than 0.7.

As shown in Table 2, some of reactor's (R4, R5, R6, R10) biogas yields were very low, which may have been due to digester instability because of the high VFA concentrations and VFA:alkalinity ratios (Table 3).

Conclusions

The effects of different substrate loading rates, feed to inoculum (F/I) ratios and mixing ratios of food waste and swine manure on biogas yield from food waste and their mixture were studied using batch anaerobic digester under mesophilic conditions. In the food waste test (based on different F/Is), higher biogas yields were obtained at comparatively lower F/I ratios for the six different F/Is. The highest biogas yield obtained was 1008 mL/g VS at a F/I ratio of 0.50 as shown in Table 2 and Figure 2. In the food waste and swine manure test (based on mixing ratio), the highest biogas yield obtained was 1148.5 mL/g VS at a mixing ratio of 40:60 (FW: SM) and organic loading concentration of 10g VS/L as shown Table 2 and Figures 3 and 4. Results from this study suggest that food waste and swine manure are potential substrates for anaerobic digestion for the production of biogas. As a result, anaerobic co-digestion of food waste and swine manure was more effective in terms of biogas production than single digestion of food waste. The data obtained in this study could be used as a basis for designing large scale anaerobic digesters for the treatment of food waste and mixtures of food waste and swine manure.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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