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Anaerobic Digestion Treatment for the Mixture of Chinese Cabbage Waste Juice and Swine Manure

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Abstract

Purpose: The objective of this study was to investigate the feasibility of anaerobic digestion of Chinese cabbage waste juice (CCWJ) and swine manure(SM). **Methods:** The anaerobic digestion test was conducted under batch and continuous conditions at mesophilic temperature (36-38℃). The batch test was divided into Experiment I and II. In the Experiment I, biogas potential and production rate of CCWJ was evaluated. In Experiment II the effect of F/M ratio (2.0, 3.2, 4.9) at mixture ratio of 25:75(CCWJ: SM, % vol. basis) on biogas yield was studied. **Results:** CCWJ produced biogas and methane yield of 929 and 700 mL/g VS added respectively. The biogas yield from the mixture of CCWJ and SM was almost same at F/M ratio of 2.0 and 3.2 but dropped by 14% when F/M ratio increased from 3.2 to 4.9. In continuous test the mixture of CCWJ and SM (25:75, % vol. basis) produced biogas yield of 352 mL/g VS added which is around 11% higher compared to biogas yield from SM alone. Addition to biogas yield digester performance was also improved with co-digestion of CCWJ with SM. **Conclusions:** The results showed that the anaerobic digestion of CCWJ with SM could be promising for improving both the biogas yield and digester performance at mesophilic temperature.

Keywords: Batch test, Biogas, Chinese cabbage waste juice, Continuous test, Swine manure

Introduction

The waste produced from swine farms in Korea is about 150000 tons/day and approximately 5.7% of the produced swine waste is disposed by ocean dumping (KME, 2005; Shin et al., 2008). It is the major source of odor production, vermin attraction, toxic gas emission and ground water contamination. The vegetable waste has been produced large amount at farm, intermediate market and vegetable processing industries every day in Korea. Especially in Korea, as the forage field is small compared to the required area for animal feed production, most of the forage and grain for animal feed is imported from foreign country. The utilization of agricultural by-product for animal feed can solve the shortage problem on forage supply and was studied by many researchers (De Boer and Brickel, 1988; NRC, 1989; West et al., 1993). The silages method to store vegetable waste can be simple and easy to use at farm without big investments. The low moisture content (50-70% in w.b) materials can produce good silages for feed with low lactic acid and butyric acid (Kim and Shin, 2009). But the vegetable waste has characteristics of high moisture content (more than 90%) which is not suitable for fermentation process (silage making process). Thus, before making silage its moisture content (M.C.) need to be reduced. The M.C. in vegetable waste can be reduced by drying, maceration method etc. The maceration method is cheaper and easier method to reduce the volume of vegetable waste. From the macerated vegetable waste, the juice (vegetable liquid waste) can be extracted easily. In the study conducted by Kim and Shin (2009), the Chinese cabbage waste volume was reduced by 1/6 and its M.C was reduced below 85% from initial M.C of 92.4% through maceration. Thus during volume reduction of vegetable waste large

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amount of juice (liquid waste) will be obtained as byproduct. Everyday large amount of vegetable juice is generated from different vegetable waste treatment industries in Korea. If this vegetable juice is directly disposed to the water sources it will create pollution. Therefore, anaerobic digestion can be good approach for treatment of these vegetable juice and energy production from it.

Although biodegradable organic matter could be used as sole feedstock in anaerobic digestion, the digestion process tends to fail without the addition of external nutrients and buffering agents (Demirel and Scherer, 2008). Co-digestion with substrates having high buffering capacity (alkalinity) like manure can be good alternatives for effective treatment of highly bio-degradable materials. In co-digestion of plant materials and animal manure, animal manures provide buffering capacity and various nutrients, while plant material provides high carbon contents resulting in better C/N ratio balance (Mshandete et al., 2004; Parawira et al., 2004). Therefore, co-digestion of manure and plant materials will decrease the risk of ammonia inhibition (Hills and Roberts, 1981; Hashimoto, 1983) and acidification. So utilizing the vegetable juice with SM for biogas production can be one of the appropriate solutions for its effective treatment and energy production.

In this research, Chinese cabbage waste juice (CCWJ) was digested with SM under batch and continuous conditions. The main objective of this study was to investigate the feasibility of CCWJ for co-digestion with swine manure.

Materials and methods

Feedstock and inoculum

Swine manure was obtained from Anseong swine farm located in Gyeonggi Province, Korea and stored at 4℃. The CCWJ was obtained from Kimchi factory in Korea and stored at 4℃ for 2-3 months. The mesophilic anaerobic sludge was obtained from lab scale completely stirred tank reactor (CSTR) treating swine manure which was installed at Department of Biosystems Engineering, Kangwon National University, Korea. The characteristics of feed stock and inoculum used for batch and continuous tests are shown in Table 1.

Batch test set up and design

Glass bottles with 2 L capacity were used to carry out the tests. The batch test was done at different conditions and altogether two experiments were performed, Experiment I and Experiment II. The design for each experiment is shown in Table 2. In the Experiment I, the biogas potential of CCWJ was measured and in Experiment II the effect of F/M ratio on gas yield from mixture of SM and CCWJ was tested. F/M ratio was calculated based on the initial VS of the substrate and inoculum. In Experiment II the inoculum loading rate varied from 8-12 g VS/L in order to maintain the volume in 1.5 L volume. The digesters were kept at 38℃ in a temperature controlled incubator. Each digester was connected to 2 L plastic gas bag. The gas volume was taken out using a syringe and measured. All the experiments were carried out in duplicate and results were expressed as mean. Each digester was mixed manually for 1 minute once a day.

Continuous test setup and design

Single stage continuous process was carried out in a 5 L reactor with 4.0 L working volume (Figure 1). The reactor was installed inside temperature controlled chamber (36-38℃). The experimental design for the

Table 1. Characteristics of feed stock and inoculum used for the test

Particulars	Batch Test			Continuous test		
	SM	CCWJ	Inoculum	SM	CCWJ	CCWJ: SM (25:75, vol. basis)
TS (%)	11.80	2.04-2.10	3.2-3.50	5.20-9.00	2.20	9.00
VS (%)	8.90	0.60-0.69	1.7-1.90	3.60-6.50	0.84	6.50
VS/TS	0.75	0.29-0.33	0.53-0.54	0.69-0.71	0.38	0.72
TVFA(mg/L)	24039	7362-8026	1897-2874	15630-21634	8424	17085
TA(mg/L)	9000	3640-3790	16612-19420	9920-12100	3180	6935
TVFA/TA ratio	2.67	2.12-3.35	0.11-0.15	1.58-1.70	2.80	2.46
NH_3-N(mg/L)	7800	920	ND	5000-6600	1000	4935
pH	6.90	6.31-6.7	8.00-8.3	7.30-7.50	7.50	7.1

Table 2. Experimental design for batch and continuous test

Description		F/M ratio	Substrate loading rate (gVS/L[a] or gVS/L.d[b])	Feed composition (% vol. basis)
Batch test	Experiment I	0.25	2.5[a]	CCWJ:SM=100:0
	Experiment II	2.0, 3.2, 4.9	25,32,39[a]	CCWJ:SM=25:75
Continuous test		ND	1.1[b]	CCWJ:SM=0:100
		ND	2.0[b]	CCWJ:SM=0:100
		ND	2.0[b]	CCWJ:SM=25:75

F/M ratio- feed to microbe ratio
gVS /L[a]–gramvolatilesolidperliter
gVS /L.d[b]-gramvolatilesolidperliterperday
SM- Swine manure
CCWJ- Chinese cabbage waste juice
ND- not determined

continuous test is shown in Table 2. The digester was fed (influent) once a day using a peristaltic pump and prior to feeding an equivalent volume of digester content (effluent) was discharged. The biogas was collected in gas collector by water displacement method. The reactor was stirred (5 minutes each hour) by circulating biogas stored in the gas collector, using peristaltic pump. The reactor was inoculated on day 0 with 3.75 L of inoculum. Thereafter the digester was fed with SM up to day 49. And in between days 50-92, mixture of SM (75%) and CCWJ (25%) was fed to the reactor. The feed volume was fixed 125 mL/d to maintain the constant HRT of 32 days throughout the test period. During days 1-3 only 50 mL of effluent was discharged in order to maintain 4L volume and thereafter equal amount of feeding and discharging was done regularly. The VS concentration of SM was in the range of 3.6% to 8.9% and CCWJ was 0.84% (Table 1). The substrate concentration(VS %) was maintained 3.6%, 6.5% and 6.5% during days 1-29, 30-49 and 49-92 in

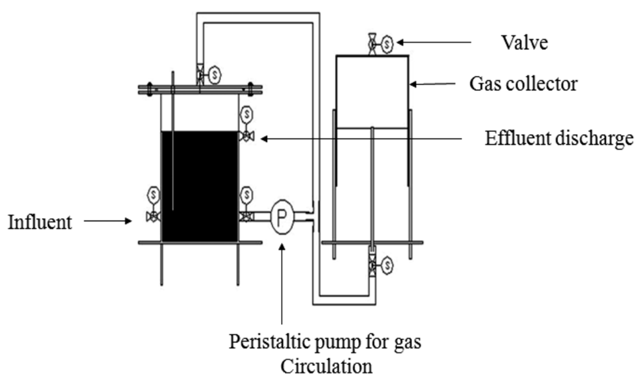

Figure 1. Single stage CSTR used for continuous test.

order to maintain designed OLR and HRT(Table 5).

Analytical analysis methods

Total solids (TS) and Volatile solids (VS) were determined in the well mixed samples in triplicates according to standard methods (APHA, 1998). pH value was determined using a pH meter (YK-2001 PH, Taiwan) at same temperature as digester(36-38℃) and measurement of ammonia nitrogen (NH_3-N) was made by using the Nessler method and was determined using a spectrophotometer DR 2500, Hach, USA(Kim and Zhang, 2003). Methane (%) and H_2S (ppm) concentration in biogas was analyzed by using gas analyzer (BioGas Check- Geotechnical Instruments (UK) Ltd.). The gas analyzer was calibrated using certified gas, Methane (50.13, 15.01, 5.01, %), Carbon Dioxide (49.87, 15.01, 5.00, %) and Oxygen (20.93%). Biogas and methane yields were calculated by dividing the cumulative biogas and methane volume by the amount of substrate (feed) VS initially added to each digester in the case of batch test and in continuous test the daily gas yield was divided by daily VS input to the digester.

TVFA (total volatile fatty acids), TA (Total alkalinity) and TVFA/TA ratio were determined using Nordmann-titration method (Rieger and Weiland, 2006; Lossie and Pütz, 2008; Koch et al., 2009; Kim and Kafle, 2010; Kafle and Kim, 2011). The TVFA/TA ratio (German: FOS/TAC) was developed at the Federal Research Institute for Agriculture (FAL) in Braunschweig, Germany. The sample was centrifuged (3000 RPM for 30 minutes) and titrated by Titrator DL15 (Mettler Toledo). A 5-ml sample was diluted with 50 ml deionized water and then titrated with a standard H_2SO_4 (0.1 Normal (N)). The TVFA and TA were calculated by using empirical equations (1) and (2) respectively (Nordmann, 1977).

$$TVFA = [((Con\ B - Con\ A) \times 20ml / EF \times 1.66) - 0.15] \times 500\ [mg/L\ acetate] \quad (1)$$

$$TA = Con\ A \times 250 \times 20\ ml / EF\ [mg/L\ CaCO_3] \quad (2)$$

Where,

Con A= mL of 0.1 N H_2SO_4 consumed by sample to reach 5.0 pH value.

Con B= mL of 0.1 N H_2SO_4 consumed by sample to reach 4.4 pH value.

EF = extracted fluid volume (sample volume)(mL)

Results and Discussion

Gas yield and biogas production rate of CCWJ (Experiment I)

The biogas yield, methane yield (mL/g VS added), biogas production rate (mL/g VS.d) and methane content for CCWJ during Experiment I are shown in Figure 2. Biogas production started immediately from the first day. The biogas production rate continuously increased until day 12 and then started to decline. The peak value of daily biogas production rates was calculated to be 94 mL/g VS.d in twelve days of digestion.

The specific biogas yield increased until about day 17 and thereafter gradually biogas yield leveled off. The average biogas yield and methane yield after 30 days of digestion was approximately 929 and 700 mL/g VS added (Table 3), respectively. Almost 90% of total biogas yield was achieved within 15 days of digestion and gas production was almost ceased after 20days of digestion (Figure 2(a)). The TVFA removal was calculated to be 78% after 30 days of digestion. There was no lag phase and continuous biogas production was observed with

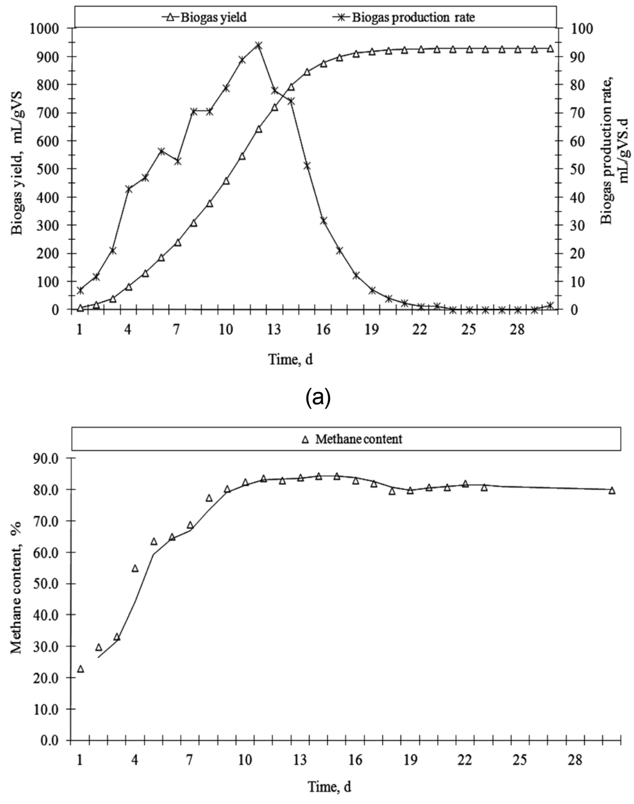

Figure 2. (a) Cumulative biogas yield and biogas production rate; (b) methane content from CCWJ.

CCWJ. The final pH was 8.36 (Table 3) which reflects that there was no inhibition in gas production with CCWJ at OLR of 2.5 g VS/L. Thus this result showed that CCWJ can be anaerobically digested as mono-substrate at HRT of 15 to 20 days in continuous digester.

Effect of F/M ratio on gas yield from mixture of CCWJ and SM (Experiment II)

The biogas and methane yield (mL/g VS added) from mixture of CCWJ and SM at different digestion time are shown in Table 4. The average biogas yields from the

Table 3. Performance results of CCWJ under batch condition (Experiment I)

Feed ratio Vol. basis (%)		Substrate g VS/L	Inoculum g VS/ L	Gas yield mL/g VS added		Initial				Final				Removal (%)
SM	CCWJ			Biogas	Methane	pH	TVFA[a]	TA[a]	TVFA/TA	pH	TVFA[a]	TA[a]	TVFA/TA	TVFA
0	100	2.5	10.0	929	700	ND	4573	10604	0.43	8.36	996	12706	0.08	78

[a]Units in mg/L

digesters operated at F/M of 2.0, 3.2 and 4.9 were 277, 272 and 233 mL/g VS added respectively, after 30 days of digestion (Table 4). Fairly similar final biogas yields were found at F/Ms of 2.0 and 3.2 but biogas yield was decreased by 16% at F/M ratio of 4.9. Liu, et al. (2009) reported similar biogas yield for F/M ratio between 1.6 to 4.0 but the biogas yield was greatly reduced when the F/M ratio increased to 5.0. The methane yield was almost constant at F/M ratio of 2.0 and 3.2 but it decreased by 11% when F/M ratio increased from 3.2 to 4.9 during 30 days digestion time (Table 4). However, the methane yield was decreased with increase of F/M ratio from 0.67 to 4.00 in the study conducted by Parawira et al. (2004). About 95%, 71% and 72% of total biogas yield were achieved after first 20 days of digestion for F/M of 2.0, 3.2 and 4.9, respectively. Thus the results showed that for the higher F/M ratio (> 2.0), the digestion time should be greater than 20 days.

CSTR performance with SM only and mixture of CCWJ and SM

The result of Experiment I showed that CCWJ can be anaerobically well treated and it has good potential for biogas production. Similarly, the results of Experiment II showed that there is no inhibition with the mixture of CCWJ and SM. Thus based on the batch test results, the mixture of CCWJ and SM was treated with single stage CSTR under continuous fed condition.

The operation and performance parameters of the continuous feeding reactor are illustrated in Figure 3. Table 5 summarizes the steady state data for reactor processes. After inoculating digester, manure alone was fed up to day 29 at OLR of 1.1 g VS/L.d and HRT of 32 days. The average biogas yield was 486 mL/g VS added methane content was 72%. After the biogas production was stable the OLR was increased from 1.1 to 2.0 g VS/L.d keeping constant HRT. The biogas yield dropped from 486 to 318 mL/g VS added and the pH decreased from 8.1 to 8.0 with increased in OLR. Similarly, the TVFA concentration increased from 7390 to 8520 mg/L and TVFA/alkalinity ratio increased from 0.40 to 0.51(Table 5). On observing normal digester performance during days 30-49, the co-digestion of CCWJ with SM with mixture ratio 25:75(CCWJ: SM) was started from day 49 at same OLR and HRT. The biogas production increased (by 11%) from 318 to 352 mL/g VS added and the methane content was increased from 69 to 71% with this mixture fed. The TVFA/TA ratio dropped from 0.50 to 0.45 reflecting more stable digester condition compared to manure alone fed. The lower VFA accumulation (Table 5) during mixture fed compared to manure alone also reflects the higher methanogens activity during mixture fed compared to

Table 4. Gas yield from mixture of CCWJ and SM at different F/M ratios (Experiment II)

F/M ratio	Substrate g VS/ L	Biogas yield mL/g VS added		Methane yield mL/g VS added	
		20 d	30 d	20 d	30 d
2.0	25	262	277	200	215
3.2	32	194	272	154	213
4.9	39	168	233	133	189

d-days

Table 5. Performance of single stage CSTR under continuous fed mode

Feed ratio (%, vol. basis)		OLR g VS/ L.d	Subatrate Concentration VS (%)	HRT (d)	Days	Biogas mL/g VS	Gas composition		pH	TVFA[a]	TA[a]	TVFA/TA ratio
SM	CCWJ						Methane (%)	H_2S (ppm)				
100	0	1.1	3.6	32	1-29	486(30)	72(2.0)	ND	8.10(0.07)	7390(415)	15544(240)	0.40(0.03)
100	0	2.0	6.5	32	30-49	318(30)	69(0.8)	ND	8.00(0.02)	8520(173)	16640(164)	0.51(0.01)
75	25	2.0	6.5	32	49-92	352(20)	71(1.6)	1741(420)	7.90(0.03)	7450(1138)	16607(647)	0.45(0.02)

ppm- Parts per million
[a] -mg/L
Values in parentheses are standard deviation

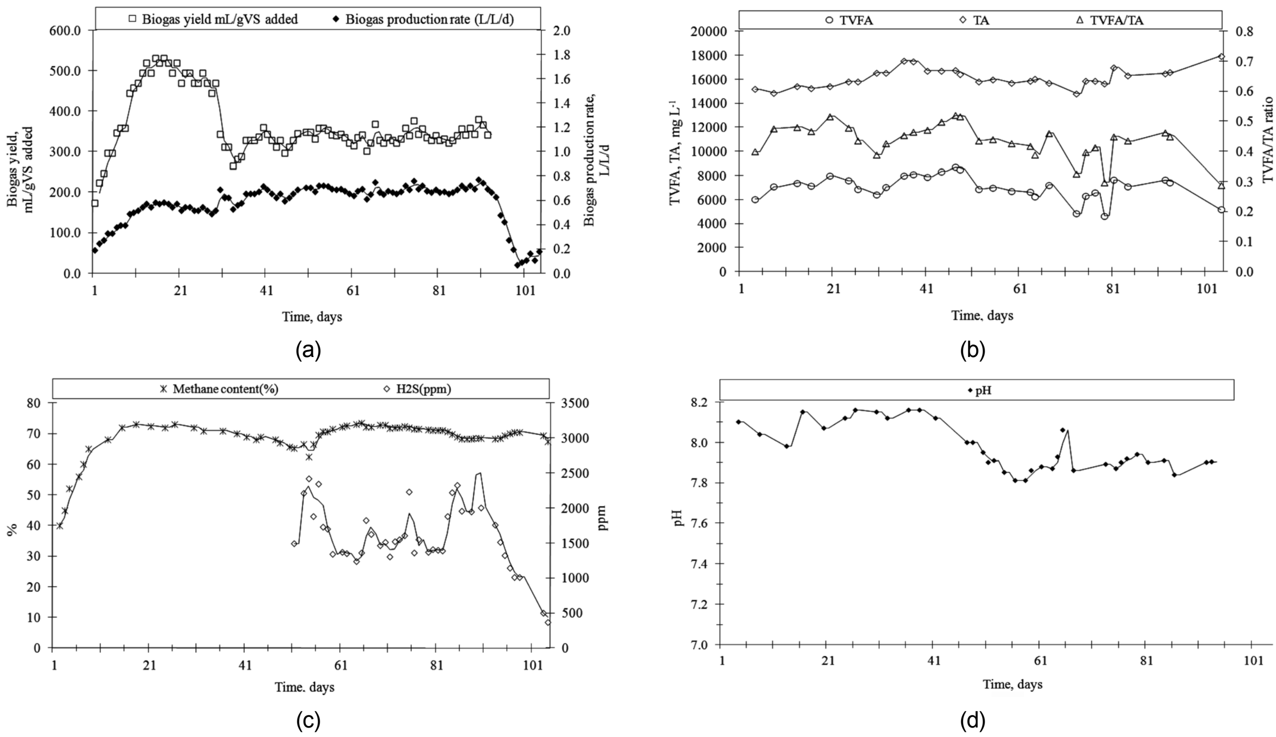

Figure 3. Process performance of single stage CSTR under continuous fed mode: (a) biogas yield; (b) TVFA, alkalinity (TA) and TVFA/TA ratio; (c) methane content and H_2S concentration; (d) pH.

manure alone. Kaparaju and Rintala (2005) reported that mixture of potato waste (20%) and swine manure (80%) increased methane yield up to 30% compared to swine manure alone at OLR of 2.0 g VS/L.d. Similarly, specific methane yield was increased by 19.2% when herbal extraction residues (25%) was co-digested with SM (75%) compared to SM alone (Li et al., 2011). The average H_2S concentration in biogas was 1741 ppm during mixture fed (Table 5).

From day 93 to 104 the feeding was stopped to study the effect of post-storage. There was regular gas production until the end of the test and it was continued even after end of the test as shown in Figure 3(a). In 10 days post digestion period the TVFA reduced from 7630 to 5000 mg/L and the TVFA/alkalinity ratio dropped from 0.46 to 0.29. The TVFA of the digested sludge need to be reduced to very low level before it is used as manure or discharged to the water sources. Also, the gas production during post digestion (10 days) indicated that the digested material still contained some degradable material and have potential for further gas production. The VFA concentration in the digested sludge could be reduced by serial digestion (Kim and Kafle, 2010) and at the same time biogas yield can also be optimized. Also if we need to store the digested slurry for several months before using to agricultural field, then slurry storage anaerobic digester can be used. The sludge storage anaerobic digester can provide the additional biogas by preventing the release of methane gas to atmosphere (supports on aims of Kyoto protocol) and at the same time more stabilized sludge can be obtained.

Conclusions

The results showed that Chinese cabbage waste juice (CCWJ) has good potential for biogas production and it can be successfully anaerobically treated as mono-substrate at mesophilic temperature. The biogas yield as well as digester performance was improved, when CCWJ was co-digested with swine manure(SM) compared to SM alone. For the mixture of CCWJ: SM (25:75,% vol. basis) no effect of F/M ratio on biogas and methane yield was observed for F/M ratio up to 3.2; however, biogas and methane yield was decreased when F/M ratio was increased from 3.2 to 4.9. The data obtained from this study could be used as a basis for designing large scale anaerobic digesters for the treatment of CCWJ discharged from the Kimchi factories and other vegetable waste treatment industries with SM. Our future study will be continued with different mixture ratios of CCWJ and SM under batch and continuous conditions.

Conflict of Interest

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

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