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Evaluating Feeding of Organic Waste and Stirring Interval to Optimize Anaerobic Digestion

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Abstract

Purpose: In the process of anaerobic digestion, stirring of the digester and feeding of organic waste into the digester have been considered important factors for digestive efficiency. The objective of this study was to determine the most appropriate conditions for both stirring interval of the digester and organic feeding frequency in order to improve anaerobic digestion performance. **Methods:** A 5-L anaerobic digester was used to conduct continuous batch tests to process swine manure and food waste. Four different stirring intervals of the digester were used: 5 min/h, 10 min/2 h, 15 min/3 h, and 20 min/4 h. **Results:** The application of swine manure to the digester every 5 min/h resulted in the highest production of biogas as well as the highest removal rates of volatile solids (VS) and total chemical oxygen demand. Stirring the digester with a mixture of swine manure and food waste at intervals of 5min/h and 10min/2 h produced the highest biogas yields of 515.3 mL/gVS and 521.1 mL/gVS, respectively. To test different supply frequencies, organic waste was added to the digester in either a 12-hor 24-h cycle. The 24-h cycle produced 1.5-fold greater biogas production than that during the 12-h cycle. **Conclusions:** Thus, from the above results, to optimize anaerobic digestion performance, the ideal stirring condition must be 5min/h for swine manure feeding and 10min/2h for co-digestion of food waste and swine manure in a 24-h cycle.

Keywords: Anaerobic digestion, Food waste, Organic feeding, Stirring interval, Swine manure

Introduction

Livestock manure has higher biochemical oxygen demand (BOD) than sewage (Ministry of Agriculture and Forestry, 2004); therefore, severe environmental pollution results when livestock manure is discharged into river (Kim et al., 2008). Dumping of livestock manure into oceans has been outright banned since 2012 because of the London Convention 1972 and 1996 Protocol. Consequently, appropriate recycling of livestock manure is required (Yoon et al., 2003). Anaerobic digestion has gained attention as an alternative approach to recycling livestock manure because it is environmentally friendly. This technical processes high concentrations of organic wastewater and produces less sludge after treatment. In addition, anaerobic digestion requires little energy and low maintenance costs to produce methane gas (Stafford et al., 1996).

In the process of anaerobic digestion, bacteria are distributed in the slurry by stirring of the digester, which uniformly maintains the temperature and alkalinity inside the digester to control the pH and minimize the concentration of a substance that prevents the microorganism's growth (Kim et al., 2002). Several studies, such as those by Li et al. (2014) and Kim et al. (2011), showed that short stirring time resulted in less biogas production. In both of these studies, the experiments were conducted using, only swine manure (CSTR), which was processed at two stirring intervals:1 min/h and 15min /h. The respective biogas yields obtained were 411mL/g volatile solids(VS) and 389 mL/g VS. In addition, digester overloading because of the high organic load caused a pH drop in the digester, which resulted in decreased digestive efficiency and inhibited the methanogenic reaction (Kim et al., 2006). Therefore,

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frequency of feeding of organic waste into the digester is an important factor for anaerobic digestion. Zhang et al. (1997) conducted experiments by using only swine manure anaerobic sequence batch reactor [ASBR] and determined that feeding of organic waste once or twice per day produced high biogas yields. They used three different cycles (8-h, 12-h, and 24-h), with feeding of organic waste - three, two, and one timesper day, which yield 250, 560 and 500 mL/gVS, respectively. From these studies, the optimal operating conditions for anaerobic digestion can be obtained by altering the stirring intervals of the digester and the frequency of feeding of organic waste. We aimed to derive the operating conditions required for optimal anaerobic digestion performance by changing stirring intervals of the digester and frequency of organic feeding.

Materials and Methods

Experimental device

This study used an anaerobic digester that contained a continuous digester using a batch process to process swine manure and food waste, and the biogas generated from the digester was measured with a gas collector. The stirring of the digester was controlled with motor and a motor controller, and a biogas meter was used to measure carbon dioxide and methane.

Anaerobic digester

The anaerobic digester was 160 mm in diameter, 400 mm in height, and 8 L in total volume. The actual volume for the operation was 5 L, and it was made with 10-mm thick transparent acrylic glass. Each part was fixed with bolts and nuts, and an O-ring was attached onto the upper lid to block the air contact. The biogas generated from the digester was collected in the gas collector, which had 170 mm in diameter and 500 mm in height. Figure 1 shows the anaerobic digestion system.

Biogas meter

A biogas meter, Model Biogas5000, from Geotech was used to measure carbon dioxide, methane, oxygen, and hydrogen sulfide.

pH meter

Model 420A from Orion was used to measure acidity in the digester.

Temperature control device

Model DX4-PMSNR from Hanyoung Nux was used to maintain mesophilic temperatures of the digester. The temperature was measured with a K-type Thermocouple.

Materials

Swine manure was collected from Gwangil farm in Ansung, Gyunggi Province, and food waste was collected from a cafeteria at Kangwon University and Ultra Feed, Ansung. Different materials were used based on experimental method; therefore, the characteristics of the material were described according to each method.

Anaerobic digester performance depending on stirring intervals

Swine manure

The swine manure from Gwangil farm, Ansung had 3.84% of total solids(TS) and 2.36% of volatile solids(VS). Total Kjeldahl Nitrogen(TKN) was 5,848mg/L, and pH was 8.02(Table 1).

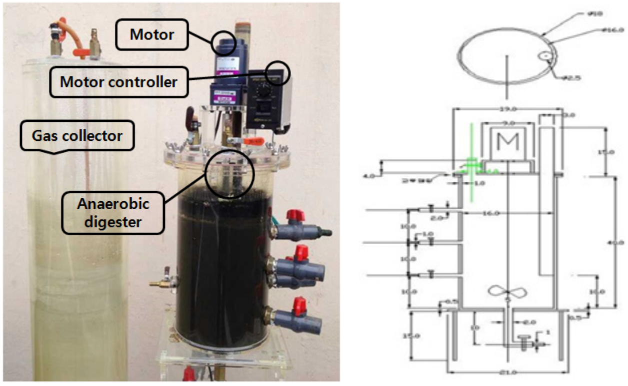

Figure 1. Anaerobic digester.

Table 1. Properties of swine manure

Parameter	units	Value
TS	%	3.84
VS	%	2.36
pH		8.02
VFA	mg/L	7,428.20
TA	mg/L	13,030
VFA/TA		0.57
TCOD	mg/L	36,693.30
NH_3-N	mg/L	4,520
TKN	mg/L	5,848

Table 2. Properties of food waste and swine manure

Parameter	units	Food waste	Swine manure
TS	%	24.96	4.34
VS	%	21.59	2.60
pH		5.15	8.07

Table 3. Food waste components

Waste components	Wet, %
rice	15.50
fish and meat	17.80
vegetable	30.30
other organicmatter	18.20
inorganic matter	18.20

Table 4. Properties of food waste and swine manure mixture

Parameter	units	Food waste + Swine manure
TS	%	3.13
VS	%	2.34
pH		7.78
VFA	mg/L	6,233
TA	mg/L	5,600
VFA/TA		1.11
TCOD	mg/L	40,107
NH_3-N	mg/L	3,820
TKN	mg/L	4,393

Food waste and swine manure

VS of the food waste from Ultra Feed, Ansung was 21.59%, and pH was 5.15. VS of the swine manure was 2.60, and pH was 8.07(Table 2). Vegetable matter (30.30%) was the major component of the food waste (Table 3). VS of the mixture of food waste and swine manure was 2.34%, TKN was 4,393mg/L, and pH was 7.78(Table 4).

Anaerobic digester performance depending on the frequency of organic waste

VS of the food waste from a cafeteria at Kangwon National University was 19.90%, and pH was 4.08 (Table 5). Swine manure VS was 2.40% and pH was 8.11. Cereal (60.56%) was the major component of the food waste (Table 6). VS of the mixture of food waste and swine manure was 3.12%, TKN was 4,447mg/L, and pH was 7.46 (Table 7).

Table 5. Food waste and swine manure properties

Parameter	units	Food waste	Swine manure
TS	%	20.80	3.72
VS	%	19.90	2.40
pH		4.08	8.11

Table 6. Food waste components

Waste component	Wet, %
cereals	60.56
vegetable	28.75
corn	6.85
fish	0.42
sea mustard	2.90

Table 7. Food waste and swine manure mixture properties

Parameter	units	Food waste + Swine manure
TS	%	4.16
VS	%	3.12
pH		7.46
VFA	mg/L	9,885
TA	mg/L	6,800
VFA/TA		1.45
TCOD	mg/L	66,986.70
NH_3-N	mg/L	4,060
TKN	mg/L	4,447

Method

The anaerobic digester was maintained at a mesophilic temperature of 36.50°C, and gas was measured once per day. When gas production increased, it was measured twice a-per day (morning and evening). The frequency of feeding of organi cwaste was determined based on the organic loading rate (OLR) and experimental method, and sampling was conducted twice per day. Every experiment was conducted after stabilizing the digester.

Anaerobic digester performance depending on stirring intervals

Several different stirring intervals of the digester were used: 5 min/h, 10 min/2 h, 15 min/3 h and 20 min/4 h. The average stirring time of 5 min/h and total number of minutes stirred per day were the same for all stirring intervals.

Table 8. Experimental design for swine manure based on stirring interval

Reactor No.	OLR	Volume	HRT	Stirring interval	Stirring time	Stirring speed
	g VS·L^{-1}·d	L	d	h	min	rpm
CSTR-1	2	5	25	1	5	90
CSTR-2	2	5	25	2	10	90
CSTR-3	2	5	25	3	15	90
CSTR-4	2	5	25	4	20	90

Table 9. Experimental design to determine microbial concentration variation because of stirring interval

Reactor No.	Volume	Stirring interval	Stirring time	Checking interval	Total time
	L	h	min	h	h
CSTR-1	5	1	5	1	4
CSTR-2	5	2	10	1	4
CSTR-4	5	4	20	1	4

Table 10. Experimental design for the food waste and swine manure mixture based on stirring type

Reactor No.	OLR	Volume	HRT	Stirring interval	Stirring time	Stirring speed
	g VS·L^{-1}·d^{-1}	L	d	h	min	rpm
CSTR-1	2	5	25	1	5	90
CSTR-2	2	5	25	2	10	90
CSTR-3	2	5	25	3	15	90
CSTR-4	2	5	25	4	20	90

Swine manure

Swine manure (TS: 3.84% and VS: 2.36%) was processed with a CSTR (Kim et al., 2001), and the stirring speed was 90 rpm, which is the optimal stirring speed for 3% solid content (Park et al., 2010). At this speed, 120 min of stirring was conducted in a day, and four different stirring intervals (5 min/h, 10 min/2 h, 15 min/3 h, and 20 min/4 h) were used. OLR was 2 g VS·L^{-1}·d^{-1}, and Table 8 shows the experimental design. TS and VS were measured at the upper and lower parts of the digester once per hour for 4 h to identify the changes of microbial concentration in the digester depending on the stirring interval. Additionally, every sampling was conducted with a 5 min pause after stirring (Table 9).

Food waste and swine manure mixture

Jeong et al. (2009) found that a mixture of food waste and swine manure with a 50:50 ratio produced the highest biogas yields and removal efficiency of organic matter. Removal rates of BOD5, COD$_{CR}$, and SS were 23.20%, 24.70%, and 19.70%, respectively. Based on these rates, food waste and swine manure were mixed at a 50:50 ratio, and processed using anaerobic digestion with a CSTR. The stirring speed of the digester was 90 rpm, and total stirring time was 120 min/day. The four different stirring intervals were 5 min/h, 10 min/2 h, 15 min/3 h, and 20 min/4 h. Table 10 shows the experimental design.

Anaerobic digester performance depending on the frequency of feeding of organic waste

Food waste and swine manure were mixed at a 50:50 ratio, and the mixture was processed using an anaerobic digester (ASBR). The minutes of stirring was conducted every 2 h at 90 rpm. Feeding of organic waste was subsequently based on each experimental design.

Food waste and swine manure settling

Organic matter entirely settled during the settle phase of the ASBR process (Hamilton et al., 2012), and a settling experiment was conducted to determine settling efficiency of swine manure, food waste, and the mixture of swine manure and food waste. Three samples were used to measure the initial TS and were placed into a cylindrical plastic tube. The measurements were repeated every 30

Table 11. Settling experiment design

	Initial TS (%)	Checking interval (min)
Swine manure	3.72	30
Food waste	20.80	30
Food waste + Swine manure	4.16	30

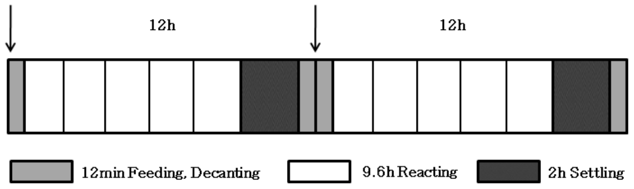

Figure 2. ASBR digester with a 12-h cycle.

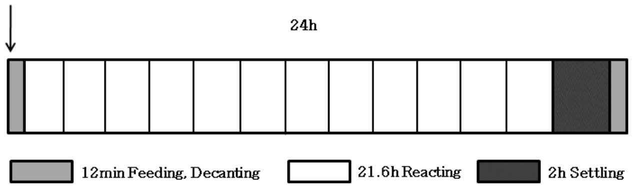

Figure 3. ASBR digester with a 24-h cycle.

Table 12. Experimental design of the 12-h cycle and 24-h cycle

Reactor No.	OLR g $VS \cdot L^{-1} \cdot d^{-1}$	Volume L	HRT day	cycle	Organic waste feeding time
ASBR-2	2	5	25	12	2
ASBR-1	2	5	25	24	1

min at the bottom of the tube, and Table 11 shows the experimental design.

Comparison between the 12-h cycle and 24-h cycle

Feeding of organic waste into the ASBR was conducted following the protocols described by Zhang et al. (1997) because it showed the best efficiency: two feedings per day in a 12-h cycle and one feeding per day in a 24-h cycle. The 12-h cycle had 12 min of the feed phase, 9.6 h of the react phase, 2 h of the settle phase, and 12 min of the decant phase (Figure 2).

The 24-h cycle had 12 min of the feed phase, 21.6 h of the react phase, 2 h of the settle phase, and 12 min of the decant phase (Figure 3). Feeding of organic waste was subsequently based on OLR. Table 12 shows the experimental design.

Analysis

Standard methods (APHA, 1998) were used to measure TS and VS. A closed reflux, titrimetric method was used for total chemical oxygen demand (TCOD).

VFA/Alk is the ratio of volatile fatty acids and alkalinity, and the sample was centrifuged for 30 min and reacted with $0.1NH_2SO_4$.Then, a Model DL15 autotitratorfrom Mettler Toledo (Columbus, OH, USA) was used to measure pH.

NH3-N was measured with a spectrophotometer from Hach (DR/2500). Sample, catalyst, and concentrated sulfuric acid were heated in a digester. Boric acid and distilled water were added, and then the solution was distilled with Model KT 2100 from Kjeltec. TKN was measured after with the solution reacted with HCl.

Results and Discussion

Anaerobic digester performance depending on stirring intervals

This study investigated anaerobic digester performance based on stirring intervals using two types of organic wastes: only swine manure or a mixture of food waste and swine manure. The results obtained are as follows:

Swine manure only

This study included stirring for a total of 120 min per day using four different stirring intervals:5 min/h, 10 min/2 h, 15 min/3 h, and 20 min/4 h. Application of swine manure to the digester every 5 min/h resulted in the highest biogas yield(244.7 mL/g VS), VS removal rate (34.70%), and TCOD removal rate (31.10%). The number of stirring was 24, 12, 8, and 6 at four types of stirring intervals(5 min/h, 10 min/2 h, 15 min/3 h, and 20 min/4 h, respectively) during 24 h. Among them, stirring 24 times per day (i.e., 5 min/h) produced the highest biogas yields and removal rates (Table 14). More frequent stirring produced sufficient organic contact with microbes and maintained a uniform temperature inside the digester. This approach also controlled pH by evenly distributing alkalinity in the digester, and minimized the concentration of the materials that inhibited microbial growth (Kim et al., 2002).

Table 13 shows the changes of TS and VS of swine manure (TS: 3.84%, VS: 2.36%) at the upper and lower parts of the digester over time(1 h, 2 h, and 4 h).The numbers of stirring were 4, 2, and 1 at intervals of 5min/h, 10min/2h, and 20min/4h, respectively. The variations in

Table 13. Changes of TS and VS of swine manure at the upper and lower parts of the digester over time

Stirring method	Sampling	5 min after input	60 min after input	120 min after input	180 min after input	240 min after input
5min/h	Upper part	TS: 3.48% VS: 1.84%	TS: 3.89% VS: 2.23%	TS: 3.94% VS: 2.31%	TS: 3.93% VS: 2.28%	TS: 3.94% VS: 2.30%
	Lower part	TS: 2.98% VS: 1.46%	TS: 3.93% VS: 2.26%	TS: 3.95% VS: 2.33%	TS: 3.92% VS: 2.29%	TS: 3.93% VS: 2.31%
10min/2h	Upper part	TS: 3.56% VS: 1.92%	TS: 3.45% VS: 1.84%	TS: 3.88% VS: 2.24%	TS: 3.49% VS: 1.89%	TS: 3.87% VS: 2.25%
	Lower part	TS: 3.16% VS: 1.61%	TS: 3.32% VS: 1.76%	TS: 3.90% VS: 2.25%	TS: 3.36% VS: 1.81%	TS: 3.88% VS: 2.26%
20min/4hr Stirring	Upper part	TS: 3.51% VS: 1.96%	TS: 3.44% VS: 1.87%	TS: 3.30% VS: 1.72%	TS: 3.19% VS: 1.57%	TS: 4.01% VS: 2.39%
	Lower part	TS: 3.11% VS: 1.58%	TS: 3.20% VS: 1.66%	TS: 3.27% VS: 1.75%	TS: 3.36% VS: 1.87%	TS: 3.98% VS: 2.37%

Table 14. Results based on the stirring intervals (swine manure only)

Parameters	units	CSTR			
Stirring method	min/h	5/1	10/2	15/3	20/4
Biogas yields	mL/gVS	244.70	235.20	230.90	219.20
CH_4 content	%	69.20	66.80	08.70	68.40
CH_4yields	mL/gVS	168.80	155.20	157.0	149.0
VS removal	%	34.20	28.30	27.70	25.40
TCOD removal	%	31.10	24.40	22.40	20.10
pH		7.95	7.97	7.93	7.96
VFA	mg/L	4,328.20	4,499.90	4,689.20	5,167.30
Alk	mg/L	13,030	13,170	13,515	14,938
VFA/Alk		0.33	0.34	0.35	0.35
TS	%	2.42	2.46	2.57	2.68
VS	%	1.55	1.69	1.70	1.76
TCOD	mg/L	25,280	27,733.30	28,480	29,333.30
NH_3-N	mg/L	4,200	4,240	4,020	4,320
TKN	mg/L	5,498	5,669	5,652	5,750

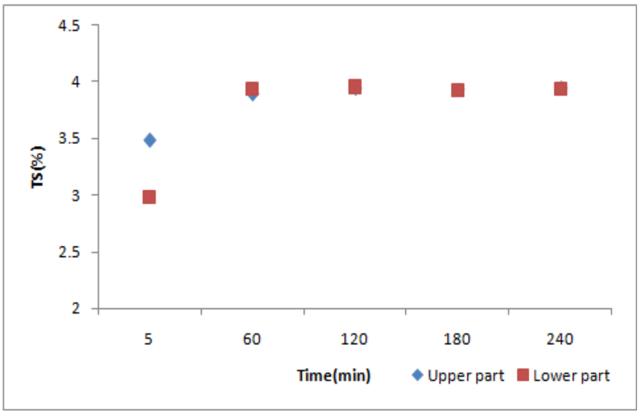

Figure 4. Changes of total solids (TS) with stirring at an interval of 5 min/h (stirring every 60, 120, 180, and 240 min).

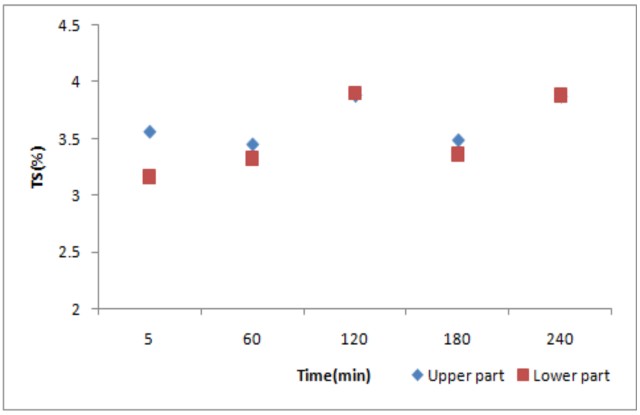

Figure 5. Changes of total solids (TS) with stirring at an interval of 10 min/2 h (stirring every 120 and 240 min).

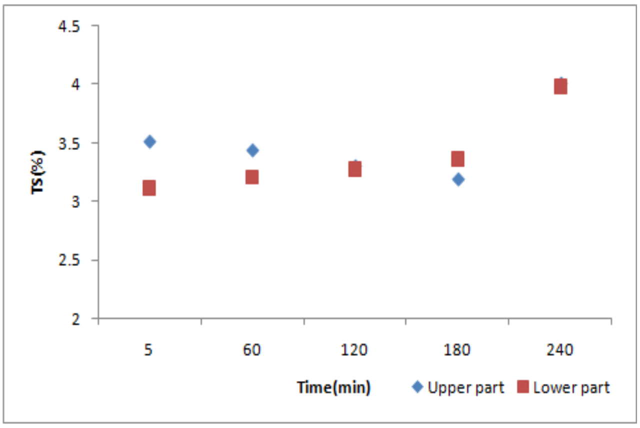

Figure 6. Changes of total solids (TS) with stirring at an interval of 20 min/4 h (stirring every 240 min).

TS in both parts of the digester were homogeneous by stirring at an interval of 5min/h (Figure 4), but the difference of TS between the upper and lower parts was 0.13% at a stirring interval of 10 min/2 h (Figure 5). In addition, maximum difference of TS between upper and lower parts was 0.24%, with a stirring interval of 20 min/4 h (Figure 6). Therefore, a stirring interval of 5 min/h produced sufficient organic contact with microbes and maintained a homogeneous microbial concentration.

Mixture of food waste and swine manure

The mixture of food waste and swine manure was supplied to the digester, and stirring intervals were 5 min/h, 10 min/2 h, 15 min/3 h, and 20 min/4 h (for a total of 120 min/day). Two types of intervals, 5 min/h and 10 min/2 h, produced high biogas yields (515.3 mL/g VS and 521.1 mL/g VS, respectively) that showed no significant difference. In addition, VS removal rates at these two types of intervals were as high as 38.50–41.00%, and TCOD removal rates were as high as 58.10–58.90% (Table 15). More frequent stirring produced sufficient organic contact with microbes and produced higher biogas yields and removal of organic matter.

While swine manure was relatively low in protein and fat but rich in organic carbohydrate up to approximately 60–70% (Jeong et al., 2004), food waste was high in protein and fat (Islam et al., 2012).

Nam et al. (2012) investigated microbial community changes of bacteria and archaea in the anaerobic digestion process when using a mixture of food waste and livestock wastewater. They presented a three-step methane production process of livestock wastewater based on acetogenesis, but the process of using food waste was based on hydrogenotrophic methanogen. Biogas produced by acetogenesis in the anaerobic digestion process with swine manure was 72%, and biogas produced by hydrogenotrophic methanogen was 28% (Lee et al., 2005). However, biogas produced by acetogenesis in the anaerobic digestion process with a mixture of food waste and swine manure was 4%, and biogas produced by hydrogenotrophic methanogen was 96% (Nam et al., 2012). Kafle and Kim et al. (2013) reported similar results: they processed a mixture of swine manure and silage that was made with saury and rice

Table 15. Results based on stirring intervals (food waste and swine manure)

Parameters	units	CSTR			
Stirring method	min/h	5/1	10/2	15/3	20/4
Biogas yields	mL/gVS	515.30	521.10	435.70	395.00
CH$_4$ content	%	67.70	69.20	65.80	66.90
CH$_4$yields	mL/gVS	345.30	359.60	283.20	260.70
VS removal	%	38.50	41.00	31.20	23.50
TCOD removal	%	58.10	58.90	54.50	51.20
pH		7.85	7.82	7.89	7.86
VFA	mg/L	2,215.20	2,126.40	2,528.60	2,750.60
Alk	mg/L	11,289	10,048	11,359	12,789
VFA/Alk		0.21	0.21	0.22	0.22
TS	%	2.61	2.55	2.89	3.10
VS	%	1.44	1.38	1.61	1.79
TCOD	mg/L	16,800	16,483	18,267	19,573
NH$_3$-N	mg/L	1,927	1,837	2,114	2,034
TKN	mg/L	2,481	2,349	2,572	2,506

bran to supplement protein and fat and obtained 801 mL/g VS of biogas, which was 6% higher than when only swine manure was used (711 mL/g VS).

When swine manure was processed, a stirring interval of 5 min/h produced the highest biogas yield (244.7 mL/g VS). However, when the mixture of food waste and swine manure was processed, stirring intervals of 5 min/h and 10 min/2 h showed similar biogas yields (515.3 mL/g VSand 521.1 mL/g VS, respectively), which was 35.60% higher than when only using swine manure. The change in microbial community resulted from the main component of organic waste, and thus, caused these differences. Jeong et al. (1996) suggested that stirring was essential for anaerobic digestion to increase the contact between microbial and organic matter, but they revealed that excessive stirring might cause the destruction or dispersion of the microbial community. A stirring interval of 5 min/h resulted in the solution being stirred 24 times in 24 h, which was excessive, and the results from this study were consistent with the results of Jeong et al (1996). Thus, biogas production with a stirring interval of 5 min/h produced similar yields with the stirring interval of 10 min/2 h, because excessive stirring destroyed or dispersed the microbial community in the anaerobic digestion of the food waste and swine manure mixture.

Anaerobic digester performance depending on the frequency of feeding of organic waste

Two organic feedings in the 12-h cycle and one organic feeding in the 24-h cycle were provided. The results are as follows:

Settling of food waste and swine manure

ASBR uniformly maintained the concentration and processed the waste at a short hydraulic retention time. At the same time, it maintained solids for a longer retention time. The settle phase among ASBR's four-step treatment process made these dynamics possible (Kim et al., 2002). Performance test results of the mixture of food waste and swine manure are as follows: swine manure was not settled out even after 2 h, but the mixture was completely settled out within 2 h. Thus, the optimal settle phase for ASBR was determined to be 2 h (Table 16).

Table 16. Settling of food waste and swine manure

Time	food waste	swine manure	food waste + swine manure
	TS (%)	TS (%)	TS (%)
5 min	15.81	1.22	3.58
30 min	16.76	1.38	3.82
60 min	16.85	1.41	3.90
90 min	16.85 (complete settling)	1.45	3.91
120 min		1.48	3.91 (complete settling)

Table 17. Results based on the number of feeding of organic waste

Parameters	units	ASBR-2	ASBR-1
Cycle		12-h	24-h
Feeding times of organic waste		2	1
Biogas yields	mL/g VS	503.30	746.90
CH_4 content	%	65.70	64.80
CH_4 yields	mL/g VS	327.10	478.00
VS removal	%	49.80	56.50
TCOD removal	%	61.20	63.80
VFA reduction	%	9.80	17.40
pH		7.86	7.89
VFA	mg/L	4,391.20	3,836.10
Alk	mg/L	12,468	11,377
VFA/Alk		0.35	0.34
TS	%	4.16	3.94
VS	%	2.50	2.29
TCOD	mg/L	25,952.20	24,273.30
NH_3-N	mg/L	3,600	3,500
TKN	mg/L	4,867	4,881

Comparison of 12-h and 24-h cycles

We used two feedings (12-h cycle) and one feeding (24-h cycle) of an organic mixture of food waste and swine manure into the ASBR per day. The single feeding cycle produced 1.5-times higher biogas yield (746.9 mL/g VS) than that during the two feeding cycle (Figure 7). Removal rates of VS and TCOD were as high as 56.50% and 63.80%, respectively (Figure 8).

Before operating the digester, VFAs of the mixture for both cycles were the same at 9,885 mg/L (Table 7), and initial VFAs in the digester were 4,868.50 (12-h cycle) and 4,646 mg/L (24 cycle). After the operation, VFAs were 4,391.20 (12-h cycle) and 3,836.10 mg/L (24-h cycle), indicating that reduction rates of VFA were 7.60% higher in the 24-h cycle (17.40%) than in the 12-h cycle (9.80%) (Table 17). The reason for this increase was that

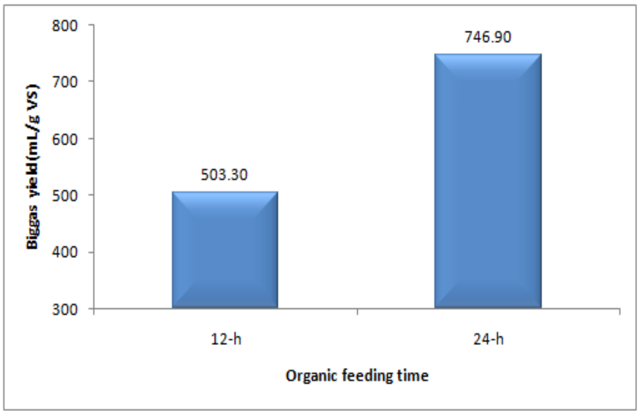

Figure 7. Biogas yields based on cycle.

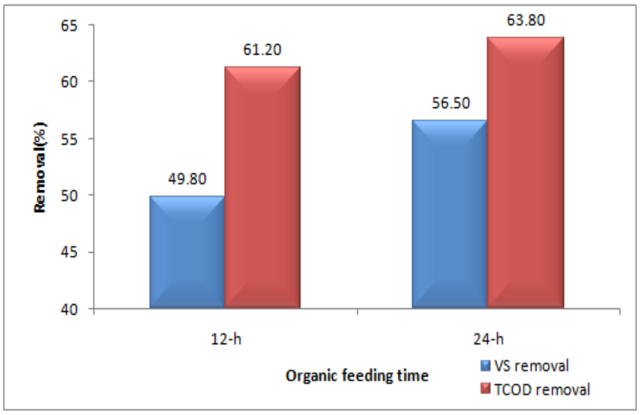

Figure 8. VS and TCOD removal based on cycle.

the VFA produced during acidogenesis was used as a nutrient source of methanogenic bacteria (Lee et al., 2005). Less feeding of organic waste reduced the inflow and outflow of the digester during the cycle, which increased the duration that the organic matter was in contact with the microbes (Kim et al., 2009). Therefore, one organic feeding per day showed the highest biogas yields and removal rate.

Conclusions

This study examined anaerobic digestion performance in order to determine the optimal operating conditions for stirring interval and feeding of organic wastes.

(1) When only using swine manure, stirring once per hour is better than stirring every 2 h and 4 h, even if using the same total stirring times for the reactor operation. Only applying swine manure to the digester 5 min/h resulted in the highest biogas yields (244.7 mL/g VS), VS removal rate (34.70%), and TCOD removal rate (31.10%). This was caused by the fact that more frequent stirring produced sufficient contact of the organic matter with the microbes inside of the digester (Kim et al., 2002).TS at the upper and lower parts of the digester can show appropriate trace for microbial concentration changes based on stirring.

(2) Stirring interval for the application of the mixture of food waste and swine manure could be different because of the characteristics of more complex feed. Two types of stirring intervals, 5 min/h and 10 min/2 h, produced high biogas yields (515.3 mL/g VS and 521.1 mL/g VS, respectively) and there was no significant difference in these yields. In addition, VS removal rates at these two types of stirring intervals were as high as 38.50%–41.00%, and TCOD removal rates were as high as 58.10%–58.90%. A stirring interval of 5 min/h meant that the solution was stirred 24 times over 24 h, which was excessive and caused the destruction or dispersion of the microbial community (Jeong et al., 1996). Even if the biogas production with a stirring interval of 5 min/h produced similar yields as a stirring interval of 10 min/2 h, considering the excessive stirring of food waste and swine manure, the stirring interval of 10 min/2 h should be selected.

(3) Feeding of organic wastes once per day produced the highest biogas yield that was 1.5-times higher (746.9 mL/g VS) than that produced during two feedings. In addition, the removal rates of VS and TCOD were as high as 56.50% and 63.80%, respectively. In addition, reduction rates of VFA were 7.60% higher in the 24-h cycle (17.40%) than that in the 12-h cycle (9.80%). The reason for this increase was that the VFA produced during acidogenesis was used as a nutrient source of methanogenic bacteria. Less feeding of organic wastes reduced the inflow and outflow of the digester during the cycle, which subsequently increased the time that the organic matter was in contact with the microbes.

(4) To improve anaerobic digestion performance, the most appropriate stirring interval for swine manure and a mixture of organic waste and swine manure is 5 min/h and 10 min/2 h, with once feeding in a 24-h cycle.

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Conflict of Interest

“The authors have no conflicting financial or other interests.”

References

APHA, 1998. Standard Methods for the Examination of Water and Wastewater. 20th ed. American Public Health Assoc.

Douglas W. Hamilton, Matthew T. Steele, Pius M. Ndgewa. 2012. The anaerobic sequencing batch reactor(ASBR), an advanced anaerobic digester for dilute live swine production by products. m. cigr. ageng 2012. org.

Dugba, P. N. and Zhang, R. 1999. Treatment of dairy wastewater with two-stage anaerobic sequencing batch reactor systems —thermophilic versus mesophilicoperations. Bioresource Technology 68(3):225-233.

Islam, M. N., Park, K. and Yoon, H. 2012. Methane production potential of food waste and food waste mixture with swine manure in anaerobic digestion 37(2):100-105.

Jeong, B.G., H.M. Li, J.H. Yun, H.S. Jeong and B.S. Yang. 1996. Mixing effect on organic removal efficiency in treating low-strength wastewater using a modified anaerobic filter reactor. Korea Environmental Science and Technology Conference.

Jeoung, U.Y., J.W. Kim, J.Y. Lee and S.J. Ohh. 2004. Evaluation of physic chemical properties of swine manure for either recycle or waste treatment.Annals of animal resource 15:8-15.

Jeong, S.I. and S.H. Kim. 2009. Design of anaerobic sequencing batch reactor(ASBR) application to the swine farm. Department of Biosystems Engineering Kangwon National University, Dissertations.

Jeong, D.Y., M.H. Jeong and Y.K. Kim. 2009. Optimal mixing ratio of wastewater from food waste and cattle manure and hygienic aspect in batch type anaerobic digestion. Organics Recycling 17-2:93-100 (8page).

Kafle, G. K. and Kim, S. H. 2013. Anaerobic treatment of apple waste with swine manure for biogas production: Batch and continuous operation. Applied Energy 103: 61-72.

Kafle and Kim. (2013). Development of evaluation methods for anaerobic digestion of agricultural and food processing by-products silage with swine manure.Department of Biosystems Engineering Kangwon National University, Dissertations.

Kim, B.G. and J.M. Im. 2001. The effect of hydraulic retention time on the anaerobic digestion of swine wastes. Environmental Engineering Society paper 23(2):233-241.

Kim, J.S. and S.I. Kim. 2002. Organic waste anaerobic digestion technology trends and future prospects. Today and tomorrow's waste recycling, pp. 217-223.

Kim, S.H. and R.H. Zhang. 2002. Biological treatment of kitchen food waste with sequencing batch reactors. The society fir engineering in agricultural, food and biological systems. ASAE paper number, 026054.

Kim, S.H., G.J. Park, J.H. Kim. (2006). Biological wastewater treatment processes and engineering, pp. 280-285, 291-292.

Kim, S.H. and H.S. Shin. 2009. Acidogenesis of lipids-containing wastewater in anaerobic sequencing batch reactor. Journal of Korean society of environmental engineers paper, original paper 1075-1080.

Kim, W.G., I.H. Oh, S.Y. Yang, K.M. Lee and S.I. Lee. 2011. Biogas production from anaerobic co-digestion using the swine manure and organic byproduct. Livestock Housing and Environment 17(1):49-54.

Lee, J.H. and I.H. Seong. 2014. Mixing effects of anaerobic digestion efficiency on livestock wastewater treatment. Industrial cooperation Society 15(1):585-592.

Li, S.W. Waste Treatment Articles, pp. 2-17.

Li, B., Sun, Y. and Li, Y. 2005. Pretreatment of coking wastewater using anaerobic sequencing batch reactor (ASBR).Journal of Zhejiang University. Science. B, 6(11): 1115-1123.

Li, Y., Zhang, R., He, Y., Zhang, C., Liu, X., Chen, C. and Liu, G. 2014. Anaerobic co-digestion of chicken manure and corn stover in batch and continuously stirred tank reactor (CSTR). Bioresource technology 156:342-347.

Ministry of Agriculture and Forestry 2004.

Nam, J.H., S.W. Kim and D.H. Lee. 2012. Microbial diversity in three-stage methane production process using food waste. Korean Journal of Microbiology 48(2):125-133.

Ndegwa, P. M., Hamilton, D. W., Lalman, J. A. and Cumba,

H. J. 2008. Effects of cycle-frequency and temperature on the performance of anaerobic sequencing batch reactors (ASBRs) treating swine waste. Bioresource Technology 99(6):1972-1980.

Park, W.K., H.B. Jun, S.I. Kwon, K.J. Chae and N.B. Park. 2010. Optimum recovery of biogas from pig slurry with different compositions. Korea Journal of Environmental Agriculture 29(2):197.

Stephenson, D. 1943. Water and wastewater systems analysis.

Yun, S.S. and S.H. Kim. 2003. Study on leachate treatment using the ASBR. Department of Biosystems Engineering Kangwon National University, Dissertations.

Zhang, R., Yang, P., Pan, Z., Wolf, T. and Turnbull, J. 2004. Treatment of swine wastewater with biological conversion, filtration, and reverse osmosis: A laboratory study. Transactions of the ASAE 47(1):243-250.

Zhang, R., Yin, Y., Sung, S. and Dague, R. 1997. Anaerobic treatment of swine waste by the anaerobic sequencing batch reactor. Transactions of the ASAE 40(3):761-767.