Evaluation of Methane Production and Biomass Degradation in Anaerobic Co-digestion of Organic Residuals

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***Abstract*—**The objective of this study is to characterize two different types of municipal organic waste sources; septage and primary sludge (PS) in order to evaluate potential methane production and co-digestability. The highest specific biogas yields of PS and septage and were 629.6 and 568.3 mL-biogas/g-VS at biological methane potential test, respectively. The results revealed that there was a significant difference in chemical composition and carbon to nitrogen ratio between primary sludge and septage. Co-dgestion of mixed substrate enhanced the digestion performance in terms of biogas production and composition.

***Keywords*—**Biological methane potential; Food waste; Septage; Methane; Co-digestion; Biogas

I. Introduction

ANAEROBIC digestion has been proven to be an efficient and green technology in treating organic waste such as wastewater sludge, industrial wastewater, waste biomass, food waste, septage and animal manure [1, 2]. Advantages of anaerobic digestion are the production of renewable energy in the form of biogas and the possibility to recycle by-product as a valuable fertilizer and soil conditioner [3]. Anaerobic digestion is broadly applied for the stabilization of municipal wastewater sludge.

In Korea, application of anaerobic digestion has been limited, although lots of large wastewater treatment plant adopts anaerobic digestion as sludge treatment methods [4]. Septage is produced from septic tanks treating the night soil. Most of the septage has been aerobically and has been dumped in ocean, causing pollution problems. In recent years, the need for renewable energy generation [5] and the law to divert biodegradable waste from landfill or ocean have been promoted anaerobic digestion for the treatment of various biodegradable wastes.

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Out of the biodegradable fraction of septage are the most challenging feed of anaerobic digester because they contain biodegradable fraction but low carbon to nitrogen C/N ratio. However, anaerobic co-digestion has attracted more attentions, since septage has not so much experiences in anaerobic digestion [6]. Co-digestion involves the digestion of two substrates together as a way to improve digestion efficiency and increase the energy output [7]. In Korea, the co-digestion of sewage sludge with other waste does not well-established.

Therefore, the objective of this study was to evaluate the technical feasibility of anaerobic co-digestion of primary sludge and septage.

II. Materials and Methods

A. Experimental procedure

Food waste and septage was provided by a food waste and septage treatment facility in Anyang, Korea. Feed and seed sludge were taken from anaerobic digester in the Anyang wastewater treatment plant.

TABLE I
CHARACTERISTICS OF FEED ORGANIC WASTES

	TS (%)	VS (%)	TCOD (mg/L)	SCOD (mg/L)	T-N (mg/L)	NH_4-N (mg/L)
PS	2.0	1.31	22,200	1,283	480	249
Septage	0.69	0.57	10,200	1,027	380	219

Biological methane potential (BMP) test was carried out to determine the anaerobic digestibility by comparing methane production for different co-digestion conditions applied [8]. The 160 ml of serum bottles were used for BMP test. The ratio of inoculum and substrate used was 1:1 by mass of volatile solids. In BMP test, serum bottles capped with butyl rubber stoppers. All the serum bottles were sealed and headspace was also purged with oxygen free nitrogen gas. Serum bottles were kept in 35°C incubator until they stop producing biogas. Daily biogas was measured by inserting needle attached to a syringe

B. BMP Data Analysis

Using methane content measurement and the Gompertz equation [9], the biochemical methane potential was calculated. All gases were measured at 35°C. The gas volume was corrected for background gas production as well as standard temperature and pressure (STP) conditions using the following equation (1).

$$V = (V_s - V_b)\frac{273}{(273+35)} \cdot \frac{29.2}{P} \quad (1)$$

where V= net gas produced at STP, V_s = gas produced by sample at 35 °C, V_b = Gas produced by blank at 35 °C, P = atmospheric pressure.

Graph fitting was performed to investigate the BMP. In this study, we proposed to use the Gompertz equation [9] as shown in equation (2).

$$M = P \times \exp\left\{-\exp\left[\frac{R_m \cdot e}{P}(\lambda - t) + 1\right]\right\} \quad (2)$$

where M = cumulative methane production, λ = lag-phase time, P = methane production potential, R_m = methane production rate, and *e= exp(1)*.

C. Calculation of the theoretical methane potential

The composition of the considered organic wastes was studied in order to obtain their chemical formula, since, the maximum theoretical methane potential might be foreseen based on the organic matter elemental composition. The proposed an equation derived from the stoichiometries balance between the chemical formula $C_aH_bO_cN_d$) and the biogas products expected from its anaerobic digestion [10, 11]. However, this theoretical calculation does not take into account needs for cell maintenance and anabolism:

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow \left(\frac{4a+b-2c+3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{4}\right)CO_2 + dNH_3 \quad (3)$$

In equation (3), the considered organic wastes is stoichiometrically converted to methane, carbon dioxide and ammonia. The specific methane potential applied to the considered sample can thus be calculated as Sialve *et al*. [2]:

$$\text{Methane Potentia1} = \frac{4a+b-2c-3d}{12a+b+16c+14d} \times V_{CH_4} \quad (4)$$

Where V_{CH4} is the normal molar volume of methane.

Gas production was measured daily by inserting a needle that was attached to a frictionless syringe through the septum and allowing the headspace to equilibrate with atmospheric pressure. The compositions of the headspaces were analyzed via gas chromatography (HP 5890, PA, USA) by a thermal conductivity detector (TCD) and helium as the carrier gas. The oven, injector, and detector temperatures were 70 ^oC, 150 ^oC, and 180 ^oC, respectively.

All the other analyses were performed basically following standard methods [12].

III. Results and Discussion

A. Biological Methane potential

Anaerobic co-digestion experiment carried out and compared with single substrate digestion. The modified Gompertz model was also used to predict methane yield. A modified Gompertz model fit well with the experimental results. Anaerobic digestion of primary sludge only resulted in calculated biogas yield of 629.6 mL-biogas/g-VS added and 56% of VS reduction without significant volatile fatty acid accumulation. For septage as a single substrate, generated methane yield was calculated to be 541.6 mL/g-VS, whereas 568.3 mL/g-VS of biogas yield was obtained in BMP test using a mixed substrate.

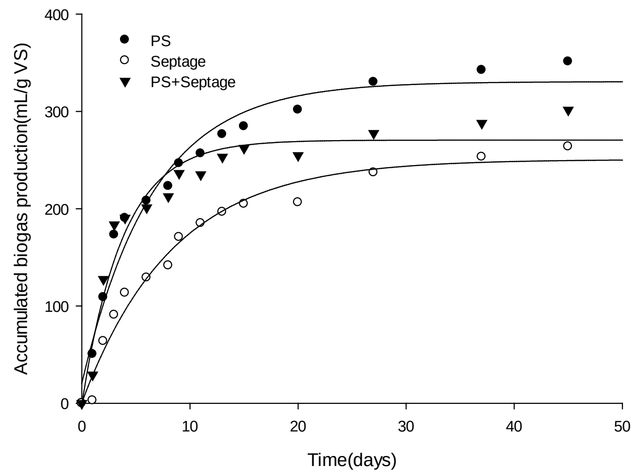

Fig. 1 Accumulated biogas production profile with different feed orgaics

In the curve fitting R^2 was higher than 0.9 and P was below 0.0001. The kinetic parameters for PS were calculated as being P = 629.6, R_m = 24.3, and λ <0.01, respectively. Septage had lower P and R_m. Co-digestion of two substrates has enhanced 4 to 6 % of methane yield in comparison with single digestion.

TABLE II
Parameters Calculated from Gompertz Equation

	P	R_m	λ	R^2
PS	629.6	24.3	<0.01	0.96
Septage	541.6	20.8	<0.01	0.94
PS+Septage	568.3	22.9	<0.01	0.93

B. Theoretical biogas production

The elemental analysis confirmed that the matrices are very rich in carbon, which represents around the 50% of the whole weight for PS. Septage represent about 30% of carbon content, because of the high moisture value that increases the total weight of the matter. Septage has showed lower C/N ratio which means difficult to anaerobic digestion.

TABLE III
ELEMENTAL ANALYSIS OF SELECTED ORGANIC WASTES

	C (%)	H (%)	O (%)	N (%)	C/N Ratio
PS	49.9	3.3	29.3	3.3	15.1
Septage	32.7	6.3	50.7	6.3	5.2
PS+Septage	44.224	4.29	36.362	4.29	11.833

The elemental analysis results allowed the estimation of the chemical formula that describes each selected organic waste samples. Since the substrates have all organic origins, we can postulate that their general chemical formula is $C_aH_bO_cN_d$, depending on C, H, O and N content defined by the employed instrument. Therefore, we calculated theoretical biogas generation using equation (3) and compared with experimental data as shown in Fig. 2. Experimental biogas production of PS reached around over than 83% of theoretical biogas. However, septage showed less than 68% of theoretical biogas.

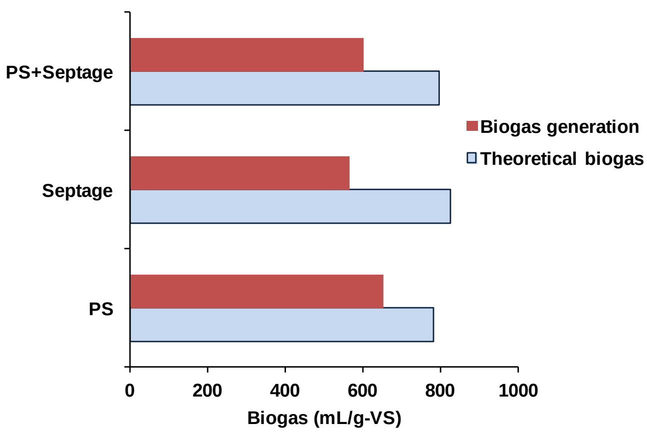

Fig. 2 Comparison of biogas generation in experiment with theoretical biogas production calculated from chemical formula

Table IV shows gas composition from BMP test of selected organic wastes. PS resulted in a very high methane contents with 25.5% of carbon dioxide and 465 ppm of hydrogen sulfide. Compared with PS, for septage, methane contents were low but carbon dioxide and hydrogen sulfide were high.

TABLE IV
GAS COMPOSITION FROM BMP TEST OF SELECTED ORGANIC WASTES

	PS	Septage	PS+Septage
CH_4 (%)	70.2	68.3	73.3
CO_2 (%)	25.5	26.9	23.4
N_2 (%)	1.6	1.6	1.4
H_2S (ppm)	465	500	545

IV. CONCLUSION

The better quality of biogas composition was also obtained from BMP test using a mixture of substrate indicating co-digestion. The results of co-digestion of wastewater sludge with the different organic wastes suggested that a mixed substrate enhanced the co-digestion performance in terms of biogas production and composition.

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