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Effect of pretreatment and anaerobic co-digestion of food waste and waste activated sludge on stabilization and methane production

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ABSTRACT

The effect of pretreatment and anaerobic co-digestion of food waste (FW) and waste activated sludge (WAS) was assessed by the reductions of total suspended solids (TSS), volatile suspended solids (VSS), COD removal and methane production. Thermal treatment and anaerobic digestion reduced VSS up to 43.4% (FW) and 43.1% (FW + WAS) by increasing the solubilization of the feedstock. Methane yields of ultrasonic treatment reached 206.4 (FW) and 326.3 (FW + WAS) mL CH_4 g^{-1} VSS removed which were 50.5 and 56.2% higher than that of the control. Results showed that each pretreatment gave distinctive effect on different feedstocks due to dissimilar composition. Co-digestion conferred superior result than mono digestion with FW or WAS. Estimated parameters (methane production potential and the rate) with Gompertz equation also inferred that co-digestion increased methane production significantly.

1. Introduction

Food waste (FW) is becoming a serious concern of the developed countries due to its environmental impacts. About 5 million tons of FW is produced every year in South Korea alone and it contributed 23% of the total municipal solid waste in year 2010 (Callaghan et al., 1999; Zhang et al., 2014). It has also been assessed that fossil fuels are rapidly decreasing and will be depleted in near future. Therefore, alternative source of renewable energy is required, such as biomass energy. Renewable energy source from biomass has gained research interest due to less environmental concern, especially less greenhouse gas emissions (Buendía et al., 2009; Kim et al., 2003). With the rising demand of renewable energy and the increasing cost of waste disposal increased the research interest on the conversion of FWs into bio-energy by anaerobic treatment. It could also provide an economically viable option due to the advancement of technology and public concerns on environmental sustainability.

Anaerobic digestion (AD) has been widely used for waste and wastewater treatment for the disposal of organic pollutants and the production of methane (Kim and Lee, 2012; Valo et al., 2004). AD process depends upon the activity of different groups of microorganism in order to convert organic matter into CO_2 and CH_4 (Appels et al., 2008). It starts with hydrolysis of feedstock, and then followed by acidogenesis, acetogenesis and methanogenesis steps. In hydrolysis step the insoluble complex organic material transforms into soluble organic material and these are further converted to CH_4. (Appels et al., 2008; Zhang et al., 2014).

AD is slower than aerobic biological processes and requires much longer time for the stabilization of the organics. Hydrolysis is regarded as the rate-limiting step of the AD as hydrolytic enzymes adsorbed on the surface of the substrate and convert it into smaller molecules for further degradation into volatile fatty acids along with other byproducts (Kim and Lee, 2012; Veeken and Hamelers, 1999; Zhang et al., 2014). To enhance the hydrolysis pretreatments have been carried out to improve the digestive efficiency of waste by solubilizing decomposable organic substances and also reduce the overall process time for AD (Kim, 2013; Wang et al., 1997). Several pretreatments have been reported previously such as thermal pretreatment (Ma et al., 2011), thermo-chemical pretreatment for increasing solubilization (Vavouraki et al., 2013), ultrasonic pretreatment for enhancing sludge solubilization (Kim and Youn, 2011; Zhang et al., 2013) and chemical pretreatment for increasing methane production (Lin et al., 2009). Many studies used various pretreatments for enhancing biogas and solubilization by using either specific FW or sludge (Kim et al., 2003; Seng et al., 2010; Zhang et al., 2014).

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Furthermore, it was also found in literature survey that mostly single or combined pretreatment has been used such as ultrasonic, chemical or combined ultrasonic with chemical/thermal on WAS and other wastes (pulp and paper waste) that is difficult to compare the efficacy of the pretreatments (Lin et al., 2009; Valo et al., 2004; Wonglertarak and Wichitsathian, 2014; Zhang et al., 2013), and few studies reported multiple pretreatments on WAS (Kim et al., 2003; Seng et al., 2010). Moreover, pretreatment enhanced not only AD but also electricity generation in microbial fuel cell (Oh et al., 2014) which used heat/alkali pretreatments on various wastewater sludge. Similarly Ma et al. (2011) and Menon et al. (2016) used various pretreatments on food waste for AD. However, combined effect of various pretreatments and co-digestion on FW and WAS has not reported to the best of our knowledge, although several studies showed enhanced AD efficiency using different combination of either FW with different wastewater sludge and *vice versa* (Bouallagui et al., 2009; Brown and Li, 2013; Callaghan et al., 1999; El-Mashad and Zhang, 2010). It has reported that co-digestion has several advantages upon mono digestion including ecological, technological and economic perspectives (Brown and Li, 2013). Co-digestion helps in nutrient balance and enhance methane production by diluting the inhibitors and toxic compound (Brown and Li, 2013; Hartmann et al., 2004), and it also has been reported in semi-continuous digestion (Zhang et al., 2013).

The objective of this study was to investigate the effects of various pretreatments on anaerobic digestion using FW, WAS and the mixture of both FW and WAS. This study will also provide a comparison among the mono substrate anaerobic digestion (FW, WAS) and co-digestion of FW and WAS in terms of solids reduction, COD removal and methane production and the yields. Methane production potentials and the rates with various pretreatments were also compared by the regression of Gompertz model.

2. Materials and methods

2.1. Substrate collection and sample preparation

FW and WAS were collected from the FW treatment plant and municipal wastewater treatment plant (WWTP) in Chuncheon, Korea. Seed sludge for anaerobic digestion was taken from an anaerobic sludge digester at the same WWTP. The detailed characteristics of the FW, WAS, and the anaerobic seed sludge were given in Table 1. Blended FW were screened out by passing through a 2 mm sieve in order to remove large particles.

2.2. Pretreatment of FW and WAS

Hydrolysis of the substrate and the performance of anaerobic digestion were compared with four different pretreatment methods. The schemes of these pretreatments are discussed in the following sections:

Table 1
Characteristics of the FW, WAS, and the seed sludge used in the batch anaerobic digestion. (Average value, n = 3).

Contents	FW	WAS	Seed sludge
TSS (g/l)	49.4 ± 3.7	7.5 ± 0.2	4.6 ± 0.1
VSS (g/l)	41.2 ± 3.7	5.5 ± 0.2	3.4 ± 0.1
T-N (mg/l)	1996 ± 64	472 ± 63	264 ± 57
T-P (mg/l)	1588 ± 38	844 ± 53	655 ± 70
TCOD (g/l)	121.2 ± 14.2	8.0 ± 0.4	4.5 ± 0.1
SCOD (g/l)	41.3 ± 4.5	0.13 ± 0.02	0.06 ± 0.01
COD/N	60.7	17.0	17.2
COD/P	76.3	9.5	7.1
NH_3N (mg/l)	453 ± 20	37 ± 8	43 ± 5

Alkali treatment: Alkali pretreatment was carried out at ambient temperature with 0.4 N NaOH (Kim, 2013). The FW and the WAS were placed into a batch mixed reactor with 0.4 N NaOH for 1 h. The pH reached about 12.7 after the treatment.

Alkali-thermal treatment: NaOH was added to the reactor to make 0.2 N which was feasible reported in the previous study with WAS (Kim et al., 2003). The feeds were heated up in an autoclave at 120 °C for 30 min. After the treatment, the feed was cooled down to room temperature before the anaerobic digestion.

Thermal treatment: The feeds were heated in an autoclave at 120 °C for 60 min. After the thermal treatment, the feed was cooled down to room temperature (Jeong et al., 2007).

Ultrasonic treatment: Ultrasonic homogenizer (VCX 750, Sonics & Materials Inc., U.S.) was used and treated the sample for 30 min at the energy intensity of 360 kJ/L (Kim and Youn, 2011).

2.3. Anaerobic digestion of pretreated FW and WAS

For the anaerobic batch reaction, 3 different types of samples were prepared containing: 1) FW (50 mL) and seed sludge (10 mL) for FW digestion, 2) WAS (50 mL) and seed sludge (10 mL) for WAS digestion, and 3) FW (35 mL) with WAS (15 mL) and seed sludge (10 mL) for anaerobic co-digestion. The volume ratio of FW to WAS for co-digestion was 70:30, and the ratio based on the volatile suspended solid was 100:5.7. The pH was adjusted to 7.0 before the anaerobic seed sludge inoculation. For the pH adjustment 1 M $NaHCO_3$ and 1 M HCl solutions were used.

A serum bottle having a capacity of 120 mL with butyl rubber stopper and aluminum cap was used for the anaerobic batch experiment. All the bottles were degassed by purging nitrogen gas before fixing the rubber stopper and the cap to the serum bottle. The serum bottles were incubated in a temperature controlled shaking water bath at 35 ± 1 °C for 20 days at 80 rpm. All the batch experiments were carried out in triplicates and the average values were used for the data analysis.

2.4. Chemical analysis

The characteristics of the FW, WAS, and the seed sludge were determined by the Standard Methods (APHA, 2005). Total suspended solids (TSS) and volatile suspended solids (VSS) were analyzed for the measurement of solids reduction. Total chemical oxygen demand (TCOD) and soluble COD (SCOD) were analyzed by $K_2Cr_2O_7$ closed reflux method. Diluted sample (2 mL) was added into a vial (Hach, U.S.) containing digestion solution and analyzed by a spectrophotometer (Think-HS3300, Humas, Korea). For SCOD measurement, the sample was filtered with GF/C filter (47 mm) for screening out suspended particles and used for the analysis.

Biogas produced during the anaerobic batch reaction was measured using an interchangeable syringe. The composition of the biogas was measured by a gas chromatograph (6890, Agilent, U.S.) with a molecular sieve column (60/80 Molecular Sieve 5A, 6 ft * 1/8″t * 8/8 Sieve U) equipped with a thermal conductivity detector. The gas chromatograph was operated at the oven temperature of 50 °C, inlet temperature 125 °C and detector temperature of 200 °C. Helium was used as the carrier gas and the reference flow and make up flow was 45.0 mL/min and 3.0 mL/min, respectively. Gas sample volume was 0.1 mL. For standardization of the produced gas from the anaerobic reactor, a standard gas (Cat no. 501697, Scotty, U.S.) was used for the analysis. A gas tight syringe (Hamilton, U.S.) was used to inject gas sample into gas chromatograph.

2.5. Data analysis

The modified Gompertz equation (Nielfa et al., 2015) was used