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Anaerobic co-digestion of food waste and dairy manure: Effects of food waste particle size and organic loading rate

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ABSTRACT

This study was to comprehensively evaluate the effects of food waste particle size on co-digestion of food waste and dairy manure at organic loading rates increased stepwise from 0.67 to 3 g/L/d of volatile solids (VS). Three anaerobic digesters were fed semi-continuously with equal VS amounts of food waste and dairy manure. Food waste was ground to 2.5 mm (fine), 4 mm (medium), and 8 mm (coarse) for the three digesters, respectively. Methane production rate and specific methane yield were significantly higher in the digester with fine food waste. Digestate dewaterability was improved significantly by reducing food waste particle size. Specific methane yield was highest at the organic loading rate of 2 g VS/L/d, being 0.63, 0.56, and 0.47 L CH_4/g VS with fine, medium, and coarse food waste, respectively. Methane production rate was highest (1.40–1.53 L CH_4/L/d) at the organic loading rate of 3 g VS/L/d. The energy used to grind food waste was minor compared with the heating value of the methane produced.

1. Introduction

In 2011, more than 36 million tons of food waste was generated in the U.S. (U.S. EPA, 2013). Food waste has higher biochemical methane potential. Anaerobic digestion of food waste not only produces methane for energy recovery, but also treats waste for environmental and social benefits (Fuchs and Drosg, 2013; Izumi et al., 2010; Zhang et al., 2013). However, mono-digestion of food waste often leads to digester instability and even failure at higher organic loading rates (OLR), especially under thermophilic conditions, due to accumulation of volatile fatty acids and ammonia (Banks et al., 2012; Banks et al., 2008; Ghanimeh et al., 2012; Nagao et al., 2012; Zhang et al., 2012, 2013).

Animal feeding operations generate significant amounts of animal manure, which is typically applied to cropland (ASABE, 2010; USDA, 2009). Concentrated animal feeding operations often do not have adequate land to absorb all of their manure, having to consider on-farm treatment. Anaerobic digestion is increasingly applied to liquid manure to stabilize organic matter, reduce pathogens, eliminate offensive odors, and recover energy from methane (USDA, 2009; U.S. EPA, 2010). However, cattle manure contains high contents of non-biodegradable substances and has low C/N ratios (Frear et al., 2010; Zhang et al., 2012, 2013), thus having a low methane yield in anaerobic mono-digestion of cattle manure (El-Mashad and Zhang, 2010; Frear et al., 2010; Hartmann and Ahring, 2005). Banks et al. (2011a) recommended on-farm co-digestion of dairy cattle slurry and source-separated domestic food waste as the most effective means of making dairy cattle slurry digestion economically viable. Co-digestion of cattle manure and food waste can increase biogas production and improve process stability (El-Mashad and Zhang, 2010; Zhang et al., 2012, 2013).

Hydrolysis is generally the rate-limiting stage in anaerobic digestion of organic solid waste (Angelidaki and Sanders, 2004; Izumi et al., 2010; Palmowski and Müller, 2000). Good contact between biomass and substrate is a prerequisite for hydrolysis because the organisms secreting hydrolytic enzymes are benefited by adsorption to the surface of particulate substrates (Angelidaki and Sanders, 2004). Methanogens in anaerobic digestion of flushed dairy manure have high affinity to fibrous solids as well (Frear et al., 2010). Reducing substrate particle size through pretreatment such as grinding could increase surface area available for adsorption of hydrolytic enzymes and subsequently produce more biogas (Izumi et al., 2010; Kim et al., 2000; Palmowski and Müller, 2000). However, excessive particle size reduction could overstimulate hydrolysis and acidogenesis, resulting in accumulation of ammonia and volatile fatty acids which could become inhibitory

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to methanogens. The effects of particle size on anaerobic digestion of food waste were investigated in two studies only through short batch tests (Izumi et al., 2010; Kim et al., 2000). The effects of food waste particle size have neither been addressed in continuously fed flow-through anaerobic digesters, nor in co-digestion of food waste and dairy manure. Moreover, the additional energy consumption to produce finer particles and dewaterability of digester effluent has not been reported along with the effect of particle size on methane production. The major objective of this study was to assess the effects of food waste particle size on anaerobic co-digestion of food waste and dairy manure in continuously fed anaerobic digesters at different OLRs. The effects were assessed comprehensively in terms of energy consumption for grinding food waste, biogas production rate, specific methane yield, reduction efficiency for volatile solids (VS), and digestate dewaterability over four periods as OLRs were increased stepwise from 0.67 g VS/L/d to 3 g VS/L/d.

Successful long-term mono-digestion of food waste has been typically limited to OLRs below 2.5 g VS/L/d unless enhancement measures such as supplementation of trace elements, solids return and co-digestion are taken (Banks et al., 2011b, 2012; Ghanimeh et al., 2012; Nagao et al., 2012; Zhang et al., 2012). A number of studies have addressed methane production and ammonia inhibition in co-digestion of food waste and cattle manure at different substrate combination ratios and OLRs (El-Mashad and Zhang, 2010; Hartmann and Ahring, 2005; Marañón et al., 2012; Zhang et al., 2012, 2013). Nevertheless, the combined effect of OLR and food waste particle size in stable co-digestion of food waste and dairy manure is unknown.

Treatment and disposal of digestate account for a great portion of the operational cost of pilot- and full-scale anaerobic digestion projects (Fuchs and Drosg, 2013). Digestate processing can become a bottleneck to scaled-up applications (Gebrezgabhera et al., 2010). Typically, digestate is separated into liquid and solids by filtration, screw pressing, or centrifugation. However, dewaterability of digestate has rarely been addressed. This paper evaluates digestate dewaterability along with methane production and solid removal.

2. Materials and methods

2.1. Setup and operation of anaerobic digesters

Three 2-L complete-mix anaerobic digesters were set up in a laboratory. Each digester as shown in Fig. 1 was built with a modified Duran GLS80 glass reactor with a magnetic impeller. A Thermo scientific hotplate/stirrer was used to heat each digester and drive its impeller at 140 rpm. The digestate temperature was targeted at 36 °C. The digesters were initially filled with bacterial inoculum to a working volume of 1.8 L. The inoculum was made from anaerobically digested sludge from a municipal wastewater treatment plant and anaerobically digested dairy manure with coarse materials (>2.06 mm) sieved out. The inoculum had a VS concentration of 1.33%, with one half (by mass) from the digested sludge and the other half from the digested manure. Compared with food waste and dairy manure separately, it had a slightly basic pH and generally balanced concentrations of macro- and micro-nutrients (Table 1).

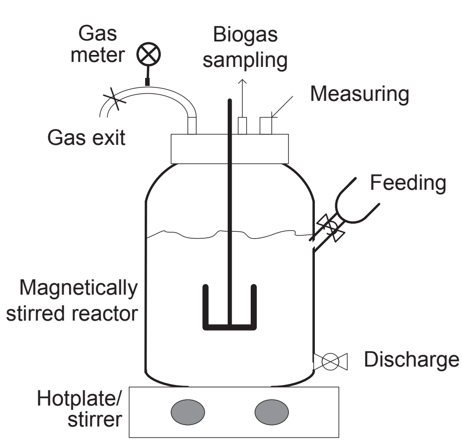

Fig. 1. Sketch of a bench-scale, semi-continuously fed anaerobic digester.

Based on earlier studies (El-Mashad and Zhang, 2010; Zhang et al., 2012, 2013), it appears that a VS ratio of manure to food waste around 1 is the optimum combination for co-digestion of cattle manure and food waste. The feedstock used in this study was prepared by combining domestic food waste and dairy manure at a VS ratio of 1 and stored frozen at −21 °C in plastic tubes. Table 1 summarizes the characteristics of the feedstock and its two components. The food waste was collected from a Sheraton Hotel's restaurant over five days and ground through a MG800 Waring Pro Professional meat grinder with three cutting plates having different aperture diameters (2.5, 4, and 8 mm) for the three digesters, called fine, medium and coarse food waste, respectively. Energy consumption to grind food waste was recorded with a Watts up? PRO electricity watt meter (Electronic Educational Devices, Inc., Denver, CO, USA). Dairy manure was taken from a storage vessel of liquid manure which was scraped from concrete lots of a large-size dairy farm at Cayuga County of New York, USA.

The digesters were operated in a semi-continuous mode. The feedstock was thawed in a refrigerator at 4 °C and fed to the digesters every 2 d. OLR was increased from 0.67 g VS/L/d to 1, 2, and 3 g VS/L/d stepwise over 178 d of operation. Digestate (67–90 mL) was discharged every 6 d at the OLRs of 0.67 and 1 g VS/L/d, 4 d at 2 g VS/L/d, and 2 d at 3 g VS/L/d. This study aimed at dry digestion. Only 25–45 mL of tap water was used to wash the feedstock storage tubes and maintain the working volume after discharge. Hydraulic retention time or solids retention time was 160 d at the OLRs of 0.67 and 1 g VS/L/d, 80 d at 2 g VS/L/d, and 54 d at 3 g VS/L/d.

Table 1
Characteristics of inoculum and feedstock made from dairy manure and food waste.

	Dairy manure	Food waste	Feedstock	Inoculum
pH	6.6	4.4	6.6	7.7
Total volatile solids, %	9.68	29.3	14.6	1.33
Total dissolved solids, g/L	16.9	16.9	16.8	7.52
Crude protein, g/kg VS	167	266	273	335
Fat, g/kg VS	40	350	231	90
Non-fiber carbohydrate, g/kg VS	623	325	380	543
Neutral detergent fiber, g/kg VS	616	196	291	543
Total N, %TS	1.9	3.8	3.6	3.0
Total C, %TS	39.9	48.4	46.3	32.4
Orthophosphate, g P/L	0.78	No data	No data	0.33
Total ammonia, g N/L	1.71	No data	No data	1.68
Sulfur, g/kg TS	6.1	3.4	4.8	11.9
Total Ca, g/kg TS	20.6	1.7	13.3	26.0
Total Mg, g/kg TS	8.5	0.7	5.2	12.2
Total K, g/kg TS	23.8	9.6	18.0	20.3
Total Na, g/kg TS	7.25	10.1	8.9	12.1
Total Fe, mg/kg TS	705	41	374	18300
Total Zn, mg/kg TS	233	32	136	900
Total Cu, mg/kg TS	123	5	46	569
Mn, mg/kg TS	176	8	98	269
Mo, mg/kg TS	1.6	0.3	1.2	11.3