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Solid state anaerobic co-digestion of yard waste and food waste for biogas production

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HIGHLIGHTS

- ▶ Solid state anaerobic digestion (SS-AD) of food waste and yard waste.
- ▶ The highest methane yields were obtained at feedstock/effluent (*F*/*E*) ratio 1.
- ▶ Increasing *F*/*E* ratio from 1 to 2 and 3 caused decreases in methane yield.
- ▶ The AD was upset at *F*/*E* ratio 3 except yard waste only.

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ABSTRACT

Food and yard wastes are available year round at low cost and have the potential to complement each other for SS-AD. The goal of this study was to determine optimal feedstock/effluent (*F*/*E*) and food waste/yard waste mixing ratios for optimal biogas production. Co-digestion of yard and food waste was carried out at *F*/*E* ratios of 1, 2, and 3. For each *F*/*E* ratio, food waste percentages of 0%, 10%, and 20%, based on dry volatile solids, were evaluated. Results showed increased methane yields and volumetric productivities as the percentage of food waste was increased to 10% and 20% of the substrate at *F*/*E* ratios of 2 and 1, respectively. This study showed that co-digestion of food waste with yard waste at specific ratios can improve digester operating characteristics and end performance metrics over SS-AD of yard waste alone.

1. Introduction

Solid-state anaerobic digestion (SS-AD) has been successfully used to convert various lignocellulosic biomass feedstocks to biogas (Li et al., 2011a). SS-AD has been the dominant AD system installed in Europe since the early 1990s for the treatment of municipal solid waste (MSW), and typically operates at 15–50% total solids (TS) content (Li et al., 2011b; Baere and Mattheeuws, 2008; Guendouz et al., 2010). SS-AD provides many benefits over liquid AD in digesting lignocellulosic biomass such as treating more organic solids in the same size digester and producing a compost-like finished organic material that is easier to handle and can be applied to agricultural land for fertilizer (Martin et al., 2003a; Li et al., 2011b). The SS-AD system also features fewer moving parts and lower energy inputs needed for heating and mixing (Li et al., 2011a), and it has a greater acceptance of inputs containing glass, plastics, and grit. Furthermore, SS-AD can overcome other common problems existing in the liquid AD process such as floating and stratification of fats, fibers, and plastics (Chanakya et al., 1999).

The start-up period of an SS-AD system is considered the most critical phase in batch digestion. The feedstock/effluent (*F*/*E*) ratio, an operating parameter that measures the amount of substrate to the amount of inoculum on a dry volatile solids (VS) basis, has been shown to be a critical factor affecting the performance of SS-AD (Li et al., 2011b). SS-AD may require up to 50% of digested residue for a rapid startup, which decreases reactor utilization efficiency (Martin et al., 2003b; Rapport et al., 2008; Li et al., 2011b). A highly concentrated and active inoculum source is important to reduce digestion time, improve digester efficacy, and increase TS in the finished product (Forster-Carneiro et al., 2008).

Co-digestion of mixed substrates offers many advantages, including ecological, technological, and economic benefits, compared to digesting a single substrate (Rughoonundun et al., 2012). However, combining two or more different types of feedstocks requires careful selection to improve the efficiency of

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anaerobic digestion (Álvarez et al., 2010). The purpose of co-digestion is to balance nutrients (C/N ratio and macro- and micronutrients) and dilute inhibitors/toxic compounds to enhance methane production (Hartmann et al., 2004; Sosnowski et al., 2003).

Xu and Li (2012) found that an *F*/*E* ratio of 2 achieved higher accumulative methane yields than at higher *F*/*E* ratios of 4 and 6 for the same dog food to corn stover ratio. The study also found that co-digestion improved methane yield compared with using corn stover or dog food as the sole substrate due to improvements in reactor characteristics. The study also concluded that co-digestion of dog food with corn stover reduced start-up time and volatile fatty acid (VFA) accumulation in SS-AD. A study by El-Mashad and Zhang (2010) found that inclusion of food waste, at rates of up to 60% of feedstock VS, with dairy manure resulted in higher biogas yields and production rates as compared to the digestion of dairy manure alone. Panichnumsin et al. (2010) examined the potential of co-digestion of cassava pulp with pig manure using a semi-continuously fed, stirred tank reactor. The study found a maximum methane yield and VS removal of 306 L/kg VS_{added} and 61%, respectfully, when the cassava pulp accounted for 60% of the feedstock VS. However, at higher (>*X*%) cassava pulp ratios, the reactor failed due to rapid VFA accumulation and insufficient buffering capacity.

In the United States, MSW such as yard and food wastes, which are available year round, are often landfilled, incinerated, or composted. Food waste is the largest waste stream in MSW, except for recyclables, and accounted for 14.3% (34.7 million tons) of the total MSW in 2009 (USEPA, 2011). Collection of food waste from restaurants, grocery stores, and processing plants, which are single large sources, can ease logistical issues and reduce collection costs compared to household pick up. Yard waste, which includes grass, leaves, and various wood chips, had a total annual availability in the United States of 30.9 million metric tons (28 million tons) (Milbrandt, 2005). Collection of yard waste from cities and town's collection service and tree trimming businesses can provide a large amount of yard waste at low cost. Grass, leaves, and maple wood chips were determined to have C/N ratios of 17, 11, and 567, respectively (Michel et al., 1993; Wong et al., 2001; Zagury et al., 2006). Food waste collected from restaurants, which was found to have a C/N ratio of 15 (Zhang et al., 2007), could be added to balance the C/N ratio of yard waste. The final mixture of liquid AD effluent, yard waste, and food waste should have a C/N ratio in the range of 20–30 for optimum microbial performance. In order to maximize biogas production, the volumetric loading of food waste should be maximized . Increasing the volumetric loading of food waste can be accomplished by: (1) increasing the F/E ratio with a constant substrate composition that includes a certain percentage of food waste, (2) increasing the percentage of food waste in the feedstock while keeping the F/E ratio constant, or (3) combining these two approaches.

Currently, there are no reported studies on solid-state co-digestion of food waste with yard waste. This study could provide baseline data for the adoption of SS-AD in the United States using inexpensive and available feedstocks that complement each other. Therefore, the major objective of this study was to determine methane yields and volumetric productivities for solid state co-digestion of different food waste to yard waste ratios at different *F*/*E* ratios.

2. Methods

2.1. Feedstock and inoculum

Yard waste was obtained in June 2011 from the OARDC Wooster campus and contained leaves and tree branches. The feedstock was oven dried at 40 °C for 48 h in a convection oven (Precision Thelco Model 18, Waltham, MA) to obtain a moisture content of less than 10%, and then ground with a hammer mill (Mackisik, Parker Ford, PA) to pass through a 5 mm screen, and stored in air tight containers until used. Food waste was collected in August 2011 from the feeding hopper of quasar energy group's liquid anaerobic digester in Wooster, Ohio, USA. The food waste originated from several Wal-Mart grocery stores nearby. The food waste collected was cut and ground up using a standard kitchen blender. Food waste was stored in air-tight buckets at 4 °C in a walk-in cooler until used.

Effluent from a mesophilic liquid AD system fed with food wastes, fats, oils and greases (FOG), and sewage sludge (operated by quasar energy group in Columbus, OH, USA) was used as inoculum. Due to the low TS content (7.7%), the effluent was centrifuged (Thermo Scientific Sorvall Legend T+) at 3500 rpm (2634*g*) for 30 min to obtain the required TS content of 15%. The decanted liquids were removed from the solids by turning the plastic containers (600 ml for each) upside down and letting the liquid portion run out. The solids attached at the bottom of the container were collected to be used as inoculum for SS-AD. Effluent was kept in air-tight buckets at 4 °C in a walk-in cooler. Prior to use, the inoculum was starved for 1 week and incubated at 37 °C to reactivate microbiological activity and remove the easily degradable VS.

2.2. Solid-state anaerobic digestion

The effect of *F*/*E* ratios (1, 2 and 3) and percentage of food waste (0%, 10%, 20%, based on dry VS) in the feedstocks on the performance of SS-AD was studied. A wide range of volumetric loading rates of food waste (0.0–166 g/L) was studied in the digesters. The inoculum, food waste, and yard waste were mixed by a hand-mixer (Black & Decker, 250 watt mixer, Towson, MD, USA) for 10 min. Well-mixed materials were loaded into a 1 L glass reactor and incubated in a walk-in incubation room for up to 30 days at 36 ± 1 °C. Duplicate reactors were run for each condition. Inoculum without any feedstock addition was used as a control. Biogas generated was collected in a 5 L Tedlar gas bag (CEL Scientific, Santa Fe Springs, CA, USA). The composition and volume of biogas were measured every 1–3 days during the 30 day SS-AD.

2.3. Analytical methods

The Standard Methods for the Examination of Water and Wastewater were used to analyze the TS and VS contents of feedstocks, inoculum, and material taken at the beginning and end of the AD process (Eaton et al., 2005). Samples were taken and prepared to determine total carbon and nitrogen contents by an elemental analyzer (Elementar Vario Max CNS, Elementar Americas, Mt. Laurel, NJ, USA). Total volatile fatty acids (TVFA) and alkalinity (total inorganic carbon) were measured using a two-step titration method (McGhee, 1968). Samples for pH, TVFA, and alkalinity measurements were prepared by diluting a 5 g sample with 50 ml of deionized water. The dilution was then analyzed using an autotitrator (Mettler Toledo, DL22 Food & Beverage Analyzer, Columbus, OH, USA). The TVFA/alkalinity ratio was calculated using the empirical formula to determine the risk of acidification, a measure of the process stability (Anderson and Yang, 1992). The extractive content of feedstocks was measured according to the NREL Laboratory Analytical Procedure (Sluiter et al., 2008b). Extractive-free solid and solid fractions before and after digestion were further fractionated using a two-step hydrolysis method based on the NREL Laboratory Analytical Procedure (Sluiter et al., 2008a). Monomeric sugars (glucose, xylose, galactose, arabinose, and mannose) and cellobiose in the acid hydrolysate were measured by HPLC (Shimadzu LC-20AB, MD, USA) equipped with a Biorad Aminex (Biorad, CA, USA) HPX-87P column and a refractive index detector