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Comparison of high-solids to liquid anaerobic co-digestion of food waste and green waste

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HIGHLIGHTS

- High-solids and liquid co-digestion of food waste (FW) and green waste (GW).
- Optimal biogas production was achieved at FW:GW mixing ratio of 40:60.
- Methane yields at 15–20% total solids (TS) were higher than that at 5–10% TS.
- Organic overloading at high TS content (25%) caused inhibition of methanogenesis.
- Volumetric productivity at 15–25% TS was 3.8- to 4.6-fold higher than that at 5% TS.

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ABSTRACT

Co-digestion of food waste and green waste was conducted with six feedstock mixing ratios to evaluate biogas production. Increasing the food waste percentage in the feedstock resulted in an increased methane yield, while shorter retention time was achieved by increasing the green waste percentage. Food waste/green waste ratio of 40:60 was determined as preferred ratio for optimal biogas production. About 90% of methane yield was obtained after 24.5 days of digestion, with total methane yield of 272.1 mL/g VS. Based the preferred ratio, effect of total solids (TS) content on co-digestion of food waste and green waste was evaluated over a TS range of 5–25%. Results showed that methane yields from high-solids anaerobic digestion (15–20% TS) were higher than the output of liquid anaerobic digestion (5–10% TS), while methanogenesis was inhibited by further increasing the TS content to 25%. The inhibition may be caused by organic overloading and excess ammonia.

1. Introduction

Bioenergy recovery and pollution control through anaerobic digestion (AD) of organic wastes is a promising greenhouse gas mitigation option and considered to be a sustainable waste treatment practice (Pantaleo et al., 2013; Rajagopal et al., 2013). Since methane rich biogas is the main end product of AD, methane production must be improved to maximize revenues from energy generation and hence, to make digestion facilities more profitable (Fdez-Güelfo et al., 2012). Driven by a complex and diverse community of microbial organisms, the performance of AD is affected by a variety of operational factors, such as temperature, pre-treatment of substrates, and digester mixing. The total solids (TS) content in association with the organic loading rate is also one of the key factors that affect the performance, cost and stability of AD systems (Alvarez and Liden, 2008; Wu et al., 2009). It has been reported that the TS content affects the following parameters: rheology and viscosity of the digester contents, fluid dynamics, clogging, and solid sedimentation that can directly influence the overall mass transfer rates within the digesters (Karthikeyan and Visvanathan, 2013).

Since the TS content is an important parameter, two main types of AD processes have been developed: liquid and high-solids AD. Liquid AD (L-AD) systems typically operate with 0.5–15% TS, while high-solids AD (HS-AD) refers to a process that generally operates at 15–40% TS (Shi et al., 2013). It has been claimed that HS-AD is advantageous over L-AD for a number of reasons including higher volumetric loading capacity, reduced energy input for heating and mixing, and greater ease in handling the compost-like digestate (Li et al., 2011). However, both HS-AD and L-AD have their own advantages and disadvantages with respect to methane production maximization and process optimization. Even though the HS-AD process is reported to tolerate high organic loadings, low operational stability still hinders wide application of HS-AD technology (Schievano et al., 2010). HS-AD may be particularly sensitive to

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the inhibition caused by overproduction of volatile fatty acids (VFAs) and ammonia, due to organic overloading. However, so far, information is lacking concerning the quantitative threshold of the TS content below which methane production from HS-AD is higher or comparable to the output of L-AD.

There are some studies related to the effect of the TS content on the performance of AD process. Forster-Carneiro et al. (2008) analyzed the AD process of food waste with three different TS levels. The results showed that reactors at 20% TS achieved a higher methane production compared to 25% and 30% TS. In a study conducted by Wu et al. (2009), no significant differences were observed in the methane production ranging from 351 to 381 mL/g $VS_{feedstock}$, applied to four TS contents of 1%, 2%, 5% and 10%. Recently, Brown et al. (2012) evaluated several lignocellulosic feedstocks (switchgrass, corn stover, wheat straw, yard waste, leaves, and maple) for biogas production under L-AD (5% TS) and HS-AD (18–19% TS). The study found no significant difference in methane yield between L-AD and HS-AD. These studies investigated the influence of TS control levels on AD, but the TS contents studied were within a narrow range; studies on a wider range of TS contents affecting performance of anaerobic reactors under both L-AD and HS-AD are limited.

Food waste and green waste are available year round and account for a significant portion of municipal solid waste (MSW) (Brown and Li, 2013). The use of food waste and green waste may improve the overall economic benefits of AD process due to the low or zero cost associated with collecting these two feedstocks (Brown et al., 2012; Brown and Li, 2013). However, due to the high biodegradability and relatively low carbon to nitrogen (C/N) ratio, mono-digestion of food waste may encounter various potential inhibitors, including fast VFAs production from starch and free ammonia from protein (Brown and Li, 2013; Xu and Li, 2012). Mono-digestion of lignocellulosic green waste also faces challenges, including its poor nutrient content, slow start-up and long retention time (Pohl et al., 2013). Better methane production performance is expected in co-digestion systems. Co-digestion is a well-accepted process that enhances organic matter degradation and biogas production by synergistic and complementary effects, which improve the balance of nutrients and dilute inhibitory compounds (Kim and Oh, 2011; Wan et al., 2011). Consequently, anaerobic co-digestion may be a promising solution for centralized treatment of food waste and green waste.

The objective of this study was to investigate the effect of TS control levels on anaerobic co-digestion of food waste and green waste. Anaerobic batch tests were conducted under L-AD and HS-AD, with TS contents ranging from 5% to 25%. A preferred food waste to green waste (FW/GW) mixing ratio was also needed to optimize biogas production for co-digestion. Hence, the effect of FW/GW mixing ratio on the performance of co-digestion was assessed first. Then, a comparison of high-solids to liquid anaerobic co-digestion of food waste and green waste was evaluated based on the pre-determined preferred FW/GW ratio.

2. Methods

2.1. Feedstock and inoculum

The food waste was collected from one student canteen in Zhejiang University, Hangzhou, China. Impurities contained in the food waste, such as bones, eggshell, wastepaper and plastics were removed manually after sampling. Then the food waste was ground up using a blender (CPEL-23, Shanghai Guosheng, China). The ground food waste slurry was sealed in plastic bags and stored in a freezer at −20 °C. The food waste was thawed overnight under ambient conditions before usage.

Green waste was collected on the campus of Zhejiang University and mainly contained grass clippings and fallen leaves. The green waste was air-dried at room temperature for 48 h, and then ground with a grinder (DYQ-188, Ruian Huanqiu, China). Then the ground green waste was screened through a 5-mm sieve, and stored at 4 °C until used.

The anaerobic sludge taken from the bottom settlement of a mesophilic anaerobic digester in Hangzhou, China was used as inoculum. The digester was a 300 m^3 tank fed with livestock manure. Before sampling, the digester stirring was stopped for 1 day. The sludge was kept in air-tight buckets under ambient conditions (about 25 °C) after sampling.

2.2. Batch anaerobic digestion system

Each batch AD system consisted of a 500-mL digestion glass bottle, a 2-L gas collection glass bottle and a 500-mL liquid collection beaker. The digestion bottle was loaded with feedstock and inoculum. Once biogas was produced in the digestion bottle, it was automatically distributed into the gas collection bottle which was filled with diluted hydrochloric acid solution (pH < 3), and then an equivalent volume of acid solution to the produced biogas was displaced to the liquid collection beaker. Thus, the biogas production volume could be measured periodically by means of the water displacement method.

2.3. Experimental design and set-up

Two sets of experiments were carried out in the batch AD system. The first set of experiments studied the effect of FW/GW mixing ratios on biogas production via anaerobic co-digestion. Six feedstock mixing ratios (FW/GW: 100:0, 80:20, 60:40, 40:60, 20:80, and 0:100, based on VS) were studied. Based on the initial TS contents of the food waste, green waste and inoculum, a sufficient amount of deionized water was added in each condition to adjust the TS content of the mixture inside the batch system to 15%.

After completing the first set of experiments, a preferred FW/GW mixing ratio for optimal biogas production was determined: 40:60. Based on this ratio, the second set of experiments investigated the effect of TS content on co-digestion of food waste and green waste. Food waste and green waste (40% food waste and 60% green waste, based on VS) were digested at five TS levels: 5%, 10%, 15%, 20% and 25%. Based on the initial TS contents of the feedstock and inoculum, a sufficient amount of deionized water was added in each digestion test to adjust the corresponding TS content. For the digestion tests with higher TS contents (i.e. 20% and 25%), the inoculum sludge was centrifuged (Centrifuge 5810R, Eppendorf, Germany) at 3000 rpm for 30 min. After removing the decanted liquid from the solid, the solid portion was collected, and then its TS and volatile solids (VS) contents were measured again for the digestion tests.

In all the digestion tests, the feedstock and inoculum were loaded into the batch system at a feedstock/inoculum ratio of 1.0 (5.0 g VS of feedstock and 5.0 g VS of inoculum were added). The feedstock/inoculum ratio was calculated based on the amount of feedstock to the amount of inoculum on a VS basis. Blank trials containing inoculum only were performed to correct for the biogas produced from the inoculum. All the tests were carried out in duplicate. After adding the feedstock and inoculum, the anaerobic reactor was tightly closed with a rubber stopper and a screw cap, and then flashed with argon gas for 5 min. Thereafter, the AD systems were incubated at 37 ± 1 °C.