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Combined effect of crude fat content and initial substrate concentration on batch anaerobic digestion characteristics of food waste

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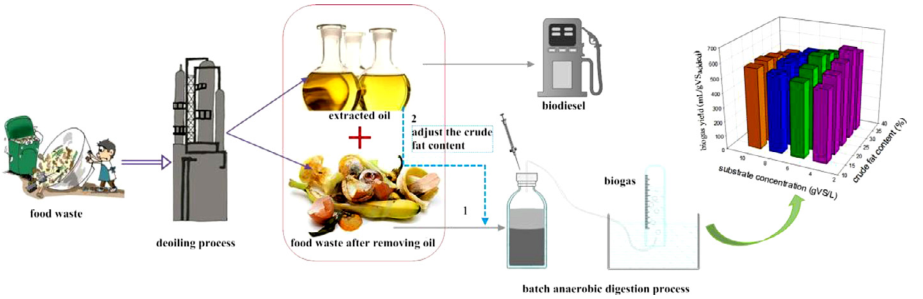
HIGHLIGHTS

- AD character of food waste (FW) with different crude fat contents was evaluated.
- FW with 30% crude fat (CF) with 4 gVS/L achieved the maximum methane yield.
- At loading of 8 and 10 gVS/L, 35% CF content inhibited methane production.
- The λ was extended with the CF contents and substrate concentrations increased.
- 35% CF decreased the first-order degradation constant by approximately 40%.

GRAPHICAL ABSTRACT



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ABSTRACT

The mesophilic anaerobic digestion (AD) characteristics of food waste (FW) with different crude fat (CF) contents and four initial substrate concentrations (4, 6, 8, and 10 gVS/L) were investigated. The maximum methane yields of FW with CF contents of 15%, 20%, 25%, 30%, and 35% were 565.0, 580.2, 606.0, 630.2 and 573.0 mL CH_4/gVS$_{added}$, respectively. An acidification trend with a drop in pH (<6.80) and increase in the volatile fatty acids/total inorganic carbon (VFAs/TIC) ratio (>0.4) were found for CF contents of 30% (10 gVS/L) and 35% (8 and 10 gVS/L). A 35% CF content in FW led to decrease in the first-order degradation constant of approximately by 40%. The modified Gompertz model showed that the lag phase (λ) was prolonged from 0.4 to 7.1 days when the CF content in FW and initial substrate concentration were increased to 35% and 10 gVS/L.

1. Introduction

The management of food waste (FW) has become an important issue in recent years throughout the world. As reported, the annual output of FW in USA, EU-27, and Japan, accounts to around 26, 50, and 20 million tons, respectively (Wu et al., 2011). Especially in China, according to China Statistical Yearbook 2011, 60 million tons of FW was generated per year with the annual increasing rate higher than 10%, and less than 20% of this waste was properly treated (Zhang et al., 2016). Different from the organic fraction of other forms of solid wastes, FW contains a higher level of crude fat (CF), which is defined as fat, oil, and grease (FOG). In addition, CF could

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achieve a higher theoretical methane yield (1000 mL/gVS) than carbohydrates (373 mL/gVS) and proteins (480 mL/gVS) (Cho et al., 2013; Pastor et al., 2013; Wellinger et al., 2013). On the basis of the high biodegradability and biomethane production potential of FW, anaerobic digestion (AD) has become an alternative technology with its dual benefits of stabilizing organic waste and recovering energy from FW (Li et al., 2016; Niu et al., 2013).

Currently, the AD of FW is attracting strong interest, and many studies including adding trace elements, co-digestion, pretreatments on the methane fermentation of FW have been performed recently. However, these studies indicated that high CF content in FW is a main limiting factor for stable operation of full-scale FW biogas plants. During the AD process, CF is initially catalysed to glycerol and long-chain fatty acids (LCFAs) by lipase. Then, the LCFAs are further transformed to hydrogen, CO_2, and acetate (or propionate) viaβ-oxidation pathway, which has been reported as the rate-limiting step of the entire AD process (Angelidaki and Ahring, 1992; Noutsopoulos et al., 2013). On the one hand, appropriate CF could increase the methane yield of anaerobic digester due to its high biomethane production potential. Sompong et al. (2012) reported that co-digestion of oil palm empty fruit bunches (EFB-oil: 1.1%TS) with palm oil mill effluent (POME-oil: 12.5%TS) resulted in a 25–32% higher methane production at mixing ratios of 0.4:1–2.3:1 on a VS basis (based on volatile solids) compared with digesting EFB alone.

On the other hand, LCFAs produced by CF were toxic to the microorganisms, such as hydrogen-producing acetogenic bacteria and acetotrophic and hydrogenotrophic methanogens, even at low concentrations (Cho et al., 2013; Kafle and Kim, 2013; Kim et al., 2004). Furthermore, the adsorption of LCFAs onto biomass also caused various operational problems such as biological bulking, foaming, flotation, oxygen mass-transfer difficulties, odours, and increased effluent concentrations of organic matter, as well as clogging of the gas and effluent lines (Cirne et al., 2007; Noutsopoulos et al., 2013). Many methods have been evaluated in attempts to minimize the negative effects caused by LCFAs. These strategies include the co-digestion of fat-rich matter with other organic matter (Pastor et al., 2013; Sompong et al., 2012), addition of absorbents (bentonite powder and fibers) (Palatsi et al., 2009), use of the novel anaerobic flotation reactors, and removal of CF prior to AD operation (Cho et al., 2013; Gumisiriza et al., 2009). Gumisiriza et al. (2009) found that the removal of CF prior to AD enhanced the production of methane by 52% from fish processing wastewater.

Actually, CF is a good material for producing biodiesel (Zhang et al., 2003). Thus, in order to improve the economic feasibility and the operation stability of the AD process for treating FW, part of the CF prior to AD could be extracted from collected domestic FW. In addition, for a practical biogas plant using FW as the main material, the hydraulic retention time (HRT) could be shortened after the CF was extracted. Besides the CF content, consideration of the variable seasonal FW output, the substrate concentration is another important factor that influences the efficiency of AD (Dhar et al., 2015; Raheman and Mondal, 2012; Zhang et al., 2014). On the basis of methanogens' metabolic activity, certain studies have been performed on how CF enhances or inhibits methane production. However, one side, in the site of FW biogas plants, how much CF should be kept in raw FW for biogas production is not clear. On the other side, the available information on the AD of FW with different CF contents is quite limited in terms of the effect of the initial substrate concentrations.

This study aimed to investigate the AD characteristics of FW with various CF contents and initial substrate concentrations. The methane yields of FW with different CF contents at four substrate concentrations were evaluated. Furthermore, the first-order kinetic model and modified Gompertz model were introduced to fit the experimental results and predict the methane yields of each FW sample in AD. Moreover, linear and non-linear regression curves were developed to assist in the interpretation of the results. The results obtained from this study will provide valuable fundamental information for future research and acquiring renewable energy from FW.

2. Methods

2.1. Substrates and inoculum

The FW used in this study was collected from a restaurant in Beijing, China. Firstly, the non-biodegradable contaminants in the FW were removed by hand, then the FW was crushed using an electrical kitchen blender (JYL-A100, Jinan, China). The CF (oil, fat, and grease) in FW was extracted using the method described by Lalman and Bargely (Lalman and Bagley, 2004). The fat extracted FW was frozen at −20 °C to prevent biological decomposition, and the frozen substrates were thawed in a refrigerator at 4 °C for 1 day before they were used. The inoculum (seed sludge) was collected from an anaerobic digester in the Xiaohongmen municipal wastewater treatment plant located in Beijing, China. The characteristics of the original and CF extracted FW and inoculum are listed in Table 1. Simultaneously, the characteristics of FW used in this study were compared with that taken from other regions of the world (Banks and Zhang, 2010; Qiang et al., 2012).

2.2. Batch digester start-up and experimental design

The batch digestion test was performed in 250 mL serum bottles capped with natural rubber sleeve stoppers. The working volume of the bottle was 180 mL. In order to keep the physicochemical properties constant, fat-extracted FW was used as the basic substrate, and the CF contents of the fermentation substrate were adjusted to 15%, 20%, 25%, 30%, and 35% using the extracted CF according to the Eq. (1). Different VS (volatile solids) concentrations of the substrates were required to determine the degradation characteristics of FW samples with different concentration of CF. The initial fermentation concentration was 4.0%, 6.0%, 8.0% and 10.0% of VS (corresponding to initial substrate concentrations of 4, 6, 8 and 10 gVS/L, respectively), respectively, in this test. Firstly, according to the substrate concentrations, different amounts of FW samples were added to each bottle. The feed to inoculum (F/I) ratio was maintained at 0.5 according to the suggested value (F/I = 0.5–2.0) by Kafle et al. (2014). Then, appropriate volume distilled water was added to the bottle for a final volume of 180 mL. Subsequently, the initial pH of the mixed liquor in each digester was adjusted to 7.0 ± 0.1 by using 1 mol/L HCl or 1 mol/L NaOH (Zhang et al., 2014). The headspace of the bottles were flushed with 100% pure nitrogen for approximately 2 min to ensure anaerobic conditions (Kafle et al., 2013). The anaerobic digesters were maintained at 37 ± 1 °C in a temperature-controlled chamber. Assays with inoculum alone were also used as control samples. Biogas produced from the inoculum were subtracted from the sample assays. The cumulative methane yield (CMY) of FW was calculated by dividing the cumulative volume of methane produced after complete AD by the total mass of VS initially added. All of the batch experiments were performed in triplicate. After methane production stopped, the digestates were finally sampled for determination of total solids (TS), VS, pH, total ammonia nitrogen (TAN), total volatile fatty acids (TVFA) and total inorganic carbon (TIC). All the results were expressed as means ± standard deviation in this test.