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Simultaneous pretreatment and acidogenesis of solid food wastes by a rotational drum fermentation system with methanogenic leachate recirculation and andesite porphyry addition

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HIGHLIGHTS

- A simultaneous pretreatment and acidogenesis process for solid wastes was developed.
- The methanogenic leachate considerably enhanced the hydrolysis of solid food wastes.
- The biochemical reactions significantly happened due to the mineral clay addition.

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ABSTRACT

A simultaneous pretreatment and acidogenesis process was developed by recirculating methanogenic leachate and adding andesite porphyry (WRS) powder to a rotational drum fermentation system to enhance the anaerobic digestion of solid food wastes. In the continuous operations, methanogenic leachate recirculation significantly increased hydrolysis rates and volatile solids (VS) degradation. The VS degradation ratio and the hydrolysis rate constant at a higher leachate recirculation ratio (2:1 weight ratio of methanogenic leachate to substrate) were increased by 2.1- and 1.4-fold, respectively, compared to those of the lower ratio (1:1 leachate recirculation ratio). A 10% (weight ratio of WRS to substrate solid content) WRS addition assisted the biochemical reactions in the process at the higher leachate recirculation ratio was employed. The hydrolysis rate constant and VS degradation were elevated by 54.7% and 63.9%, respectively, with the WRS addition. Besides, the WRS addition enhanced the VA formation and its conversion to biogas.

1. Introduction

Bioenergy from solid organic wastes is an excellent alternative to traditional fossil fuels when considering greenhouse gas emission control. Solid food wastes, comprising large fractions of municipal solid wastes, are amenable to bioenergy recovery by anaerobic conversion due to their large biodegradable fractions and moisture. The anaerobic conversion of solid food wastes to the end products CH_4 and CO_2 proceeds in a series of complex biochemical steps due to the lignin content of the solid food wastes (Converti et al., 1999). Hydrolysis is the rate-limiting step in the overall anaerobic conversion of solid substrates (Fdez-Guelfo et al., 2011). The hydrolysis rate mainly depends on the biodegradability of the substrate and the availability of microbes/enzymes (Veeken and Hamelers, 1999), and influenced by many other factors such as rheological properties (Kedziora et al., 2006).

Pretreatments by mechanical, chemical, thermal and combined treatments have been used for decades in the food industry and for biofuel production. Pretreatment contributes to both the reduction of particle size and the rearranging/breaking of some chemical bonds (McIntosh and Vancov, 2011; Seehra et al., 2012). Ball milling is traditionally applied as a mechanical pretreatment for its ability to rapidly reduce particle sizes and does not introduce toxins to subsequent processes. Among the different ball milling pretreatments, wet milling is preferred to dry milling due to the higher pulverization efficiency (Charkhi et al., 2010) and lower energy consumption (Fuerstenau and Abouzeid, 2002) of wet ball milling. In the wet ball milling process, the pulverization is usually enhanced by increasing the moisture of the feedstock or by adding extra water (Fuerstenau and Abouzeid, 2002). Wet ball milling also meets the requirements for pretreating solid food wastes for anaerobic digestion.

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In the anaerobic digestion process, the addition of a methanogenic process leachate instead of extra water during the wet ball milling process is conducive to water conservation (Shahriari et al., 2012). Using leachate recirculation to enhance the anaerobic digestion of solid food wastes (Chen et al., 2008) resulted in a similar VA yield (0.13 g-VA/g-VS) to that (0.11 g-VA/g-VS) of water flushing (Gan et al., 2008). Leachate recirculation improves the rheological properties of substrates and supplies enzymes and microbes to the pretreatment process. The enzymes and microbes also biochemically pretreat the solid substrates. Recycled leachate lowers the acidogenic product concentrations and buffers its inhibition to the hydrolysis and acidogenesis processes as the biochemical pretreatment occurs (Sponza and Agdag, 2004). Pretreatment using leachate recirculation (Zhang et al., 2009) and wet ball milling has been reviewed recently (Chen et al., 2007).

Although wet ball milling with leachate recirculation enforces the stabilization of food waste, the acidogenic products are prone to accumulation when low recirculation ratios are used. The accumulated acidogenic products caused the pH decrease and the increase of unionized volatile acid (UVA). The extremely low pH and UVA inhibited the activity of methanogens and acidogens and may even lead to a failure of the entire anaerobic process (Wang et al., 1999). Many experimental efforts have aimed to alleviate this inhibition, including lowering the product concentrations (Gan et al., 2008), electrodialysis (Yi et al., 2008), pervaporation (Cui et al., 2004) and removal of the products in situ (Cheng et al., 2010). Adsorptions by porous media such as zeolite (Wang et al., 2011), activated carbon (Pyrzynska and Bystrzejewski, 2010) and resin (Lin and Juang, 2009) are an interesting method for in situ removal. In recent years, andesite porphyry (known as wheat-rice-stone, WRS, in Asia), a kind of natural clay mineral, has been applied as a candidate to remove the acidogenic products in situ and thereby assist hydrolysis and acidogenesis (Cheng et al., 2010). WRS not only adsorbs the accumulated acidogenic products due to its unique tetrahedral structure with micro- and nano-channels, but also dissociates and releases cations, including Ca^{2+}, Mg^{2+} and Na^{+}, during the acidogenesis of solid food wastes (Li et al., 2009; Cheng et al., 2010). The dissociated cations provide nutrition required by the microbes (Cheng et al., 2010). The acidogenic product adsorption and cation dissociation contribute positively to the anaerobic digestion of solid food wastes.

In this study, a rotational drum fermentation (RDF) system with methanogenic leachate recirculation has been developed. The objectives of the work were to (1) pretreat and simultaneously acidify solid food wastes as part of anaerobic digestion by an RDF system with methanogenic leachate recirculation and (2) enhance pretreatment and acidogenesis of solid food wastes by methanogenic leachate recirculation and WRS addition.

2. Methods

2.1. Materials

2.1.1. Substrate and seeding sludge

Fresh soybean meal (approximately 24.1% total solids, TS) was collected from a dining hall of the China Agricultural University (Beijing, China) to be used as the substrate. The composition of the dry soybean meal was as follows: protein (22.6%), lipid (19.6%), sugar (37.0%), cellulose (14.5%), ash (6.1%) and other constituents (0.2%). The initial mean particle size of the raw material was 673 μm.

Anaerobic digestion sludge was taken from a municipal wastewater treatment plant (Beijing, China) for use as the seeding sludge. The TS, VS and of the sludge were 2.6%, 1.4% and 7.8, respectively. The initial volatile fatty acids of the substrate and the sludge were 0 and 0.04 g/L, respectively.

2.1.2. Andesite porphyry

Andesite porphyry (WRS) was collected from the Changping Mine (Beijing, China) for use as an additive during the hydrolysis and acidogenesis of the solid food wastes. The chemical composition of the WRS used was as in Li et al. (2009). The WRS was washed 2–3 times with distilled water and then dried in an oven at 105 °C to constant weight.

2.1.3. Methanogenic leachate

The methanogenic leachate was obtained from a sound mesophilic (35–37 °C) methanogenic process. The methanogenic process was fed daily with acetic acid and synthetic wastewater (Chang et al., 1982) and run well for over 2 years. The methanogenic effluent was centrifuged at 3000 rpm for 3 min, and the supernatant was recycled into the acidogenic process as the methanogenic leachate. The average pH of the leachate was 7.2.

2.2. Experimental apparatus

The RDF system developed by Jiang et al. (2005) was employed to perform the simultaneous pretreatment and acidogenesis of the solid food wastes. The RDF system consisted of six drum fermentors, and each fermentor's working volume was 3.6 L. The mechanical pretreatment was mainly performed by rotating the fermentor with 26 aluminum oxide milling balls (diameter = 30 mm), taking up 10% of each fermentor (in volume). Each fermentor was rotated automatically for 15 min every 45 min at 12 rpm and 35 ± 1 °C during the experimental period.

2.3. Experimental procedure

2.3.1. Batch operation

In batch operation, two fermentors, LB1 and LB2, were used to evaluate the effect of leachate recirculation on the simultaneous pretreatment and acidogenesis of solid food wastes, while the other four fermentors, B11, B12, B21 and B22, were used to evaluate the effect of leachate recirculation with the addition of WRS. The seeding sludge was considered as the methanogenic leachate in the batch operation. The leachate recirculation ratio (the weight ratio of methanogenic leachate to substrate) was 1:1 for LB1, B11 and B12 and 2:1 for LB2, B21 and B22. Five percent WRS (the weight ratio of WRS to substrate solid content) was added to B11 and B21, and 10% to B12 and B22. The detailed feeding conditions were shown in Table 1.

The batch operations lasted for 10 days. Samples were withdrawn for the analysis of pH, TS (total solids), TDS (total dissolved solids), VS (volatile solids), TVA (total volatile acids), volatile acids (VA) spectra, mean diameter (MD), cation concentration (CC) and ATP concentration on alternate days.

2.3.2. Continuous operation

Fermentors LC1, LC2, C11, C12, C21 and C22 were used for continuous operation. Their detailed feeding conditions are shown in Table 2.

The hydraulic retention time (HRT) of the continuous operation was 10 days. The continuous operation was maintained with daily feedings and withdrawals for at least three HRTs before reaching pseudo-steady state. The pH was tested every day, while other parameters were measured on alternate days during the pseudo-steady state as for the batch operation.