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Enhancement of hydrolysis and acidification of solid organic waste by a rotational drum fermentation system with methanogenic leachate recirculation

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Abstract

A cascade process of a rotational drum fermentation system with leachate recirculation from a methanogenic to the acidogenic reactor was constructed to enhance the hydrolysis and acidification of solid organic waste. Using fresh soybean meal as substrates, two process configurations, Cascade process 1 and 2, without and with leachate recirculation, respectively were employed to perform the experimental estimation under mesophilic condition and a total HRT of 20 days. An apparent first-order hydrolysis rate constant of 9.0×10^{-3}/d for Cascade process 1 at pH 4.5–4.6, and 15.8×10^{-3}/d for Cascade process 2 at pH 4.6–5.2 were obtained. The apparent VS degradation ratios ranged from 16.5% to 21.1% and total VA (as acetic acid) from 14.5 to 16.7 g/L. Occupying ratios for ionized VA decreased from 40.5% to 35.3% for Cascade process 1 and increased to 68.5% for Cascade process 2. However, occupying ratios of acetic acid decreased from 96.1% to 94.3% for Cascade process 1 and to 72.6% for Cascade process 2, whereas propionic acid and butyric acid ratios increased in acidogenesis of Cascade process 2. The leachate recirculation promoted hydrolysis of substrate in Cascade process 2, where apparent hydrolysis rate constant and VS degradation ratio were higher than that of Cascade process 1.

Keywords: Leachate from methanogenic process; Cascade process; Hydrolysis rate constant; Volatile solid degradation ratio; VA spectrum

1. Introduction

With some superiorities over the conventional one-phase process (Cohen et al., 1979), the two-phase anaerobic digestion process has been widely used in treatment of industrial wastewater (Bull et al., 1984), dairy-industry wastes (Ghosh et al., 1994), municipal solid wastes (Sans et al., 1995; Chugh et al., 1999) and solid food wastes (Argelier et al., 1998; Traverso et al., 2000). This process is carried out in two physically separated reactors for hydrolysis/acidogenesis and methanogenesis. With the aim to accelerate the degradation of complex organic compounds and obtain the maximum concentrations of intermediary products, hydrolysis/acidogenesis is recognized as a rate-limited step where the substrate consists of particles (Eastman et al., 1981). Its performance was significantly affected by environmental and operational parameters such as pH, temperature, substrate, process configuration and concentrations of intermediaries (Veeken and Hamelers, 1999).

In the two-phase anaerobic digestion of solid waste, metabolic intermediary products such as volatile acids (VA) in the acidogenic reactor were prone to accumulate due to the absence of methanogenic microorganisms, which consumed the intermediaries directly (Eastman et al., 1981). According to the surface based kinetics model (Sanders et al., 2000), where it was assumed that the substrate was spherical particles and was degraded from outside, the metabolic intermediaries could easily attach onto the surface of the particles and prevented the microorganisms entrance for

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further reaction. Veeken and Hamelers (2000) observed that the accumulation of metabolic intermediaries such as VA restricted both methanogenesis and acidogenesis. Especially, unionized volatile acid (UVA) would inhibit not only the former (Kroeker et al., 1979), the latter (Garcia et al., 1991) but also the hydrolysis rate of particulate matter (Llabres-Luengo and Mata-Alvarez, 1988). Simultaneously, physical separation of acidogenic and methanogenic phases suppressed the syntrophic acidogenic reactions due to excessive hydrogen-forming where there was a deficiency of methanogenic microorganisms (Fox and Pohland, 1994).

Some investigations, such as *in situ* removal of VA and alteration of process configurations, were conducted to alleviate the inhibition of high-concentration VA. Generally, the methods for *in situ* removal, which removed the excess VA physically by extraction, electrodialysis and adsorption (Sun et al., 1999; Aljundi et al., 2005; Hirata et al., 2005), were used to recover VA as products from the fermentation broth. Attempts to alter process configurations, such as leachate recirculation, solid recycle process and cascade process, were made to ease the inhibition by providing a predominant environment for microorganisms. Leachate recirculation, which was operated by recycling the effluent from a methanogenic process to acidogenic or hydrolysis process, not only alleviated the inhibition of excess VA, but also established the balance between each step in the two-phase degradation process. Veeken and Hamelers (2000) designed a batch-wise solid state digestion (BSSD) setup with leachate recirculation to evaluate the effect of leachate recirculation on solid state digestion of biowaste and concluded that the apparent first order hydrolysis rate constant increased from 1.0 to 17.0×10^{-3}/d as the leachate recirculation rates increased from 1 to 100 m^3/m^3/d. Moreover, Jiang et al. (2005) developed a solid recycle (SR) process with leachate recirculation from a methanogenic reactor to acidogenesis using a rotational drum fermentation system (RDFS) to evaluate the effects of leachate on acidogenic performance. The results showed that the leachate recirculation elevated the pH levels and improved acidogenic performance of the solid recycle process such as increasing VA concentration and VS degradation ratio.

Another process configuration, the cascade process, which separated hydrolysis-acidogenesis into detached reactors may be appropriate to suppress inhibitions caused by high-concentration products as well. The separation of the hydrolysis and the acidogenic phase could establish the concentration gradients of pH and reactants for each step, hence upgrading the hydrolysis of solid particles (Jiang et al., 2003). Argelier et al. (1998) established a cascade process for food solid waste to lessen the inhibition of VA on fermentative activities. They succeeded in obtaining effluent with 42 g/L of VA at steady-state conditions at a loading of 12.5 kg-COD/m^3/d and a hydraulic retention time of 12.5 days. Utilizing the rotational drum fermentation system, Jiang et al. (2003) introduced a cascade process and a solid recycle process to achieve a higher TVA concentration and hydrolysis rate. The results indicated that the separation of hydrolysis and acidogenesis strongly affected acidogenic performance in terms of the VA constituents and the distribution of ionized and unionized VA.

The purpose of this work was to enhance the hydrolysis and acidification of solid organic waste in a cascade process with leachate recirculation by a rotational drum fermentation system. The objectives were to: (1) construct a cascade process using a rotational drum fermentation system that recycled the leachate from methanogenic to acidogenic process, and (2) evaluate the effects of leachate on acidogenic performance via parameters such as pH, VA production, hydrolysis rate constant and VS degradation ratio in comparison with a single cascade process.

2. Methods

2.1. Substrate and feeding sludge

Fresh soybean meal or Okara (approximately 20% total solids), a food process by-product from soybean curd (Hisaki Tofu, Shimane, Japan), was used as substrates. The chemical characteristics of the soybean meal were identical to the ones shown previously by Kitamura et al. (1998). Mesophilic anaerobic sludge from a municipal sewage treatment center (Shimane, Japan) was inoculated in the fermentors as the seeding sludge.

2.2. Process configuration

The cascade process configuration is shown in Fig. 1. α represents the recirculation ratio of leachate to feeding rate for fermentors II and IV, respectively. In the case of $\alpha = 0$, the process is named as Cascade process 1 whereas the process is termed Cascade process 2 as $\alpha = 1$. Each process consisted of two fermentors for pseudohydrolysis and pseudoacidogenesis, respectively. Either fermentor I, or II was a component of Cascade process 1. Feedstock was fed to fermentor I, and then the effluent from fermentor I was fed to fermentor II. Finally, sludge from fermentor II was excreted as an effluent of Cascade process 1. Cascade process 2 comprised fermentor III and IV. The same feedstock was fed to fermentor III; its effluent was diluted by leachate from a methanogenic process as feedstock without loss of hydrolytic and acidogenic microorganisms fed to fermentor IV.

The methanogenic fermentor (Jiang et al., 2005) was fed daily with synthetic wastewater (Chang et al., 1982) and operated at mesophilic condition with an HRT of 10 days. CH_4 content in the biogas and the VA concentration in the effluent were 64–72% and 1900 mg/L, respectively, whereas the TS was close to zero. The liquid fraction of the effluent obtained by centrifugation at 3000 rpm for three minutes was recycled to acidogenic process as a "leachate" of methanogenic process.