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Improving production of volatile fatty acids from food waste fermentation by hydrothermal pretreatment

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HIGHLIGHTS

- Hydrothermal pretreatment was applied to enhance VFAs production from food waste.
- Food waste fermentation was inhibited at high hydrothermal temperature.
- 160 °C was found to be the optimal hydrothermal temperature for VFAs production.
- High VFAs recovery was achieved by a liquid–liquid extraction method.

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ABSTRACT

Food waste (FW) was pretreated by a hydrothermal method and then fermented for volatile fatty acid (VFAs) production. The soluble substance in FW increased after hydrothermal pretreatment (⩽200 °C). Higher hydrothermal temperature would lead to mineralization of the organic compounds. The optimal temperature for organic dissolution was 180 °C, at which FW dissolved 42.5% more soluble chemical oxygen demand than the control. VFA production from pretreated FW fermentation was significantly enhanced compared with the control. The optimal hydrothermal temperature was 160 °C with a VFA yield of 0.908 g/g $VS_{removal}$. Butyrate and acetate were the prevalent VFAs followed by propionate and valerate. FW fermentation was inhibited after 200 °C pretreatment. The VFAs were extracted from the fermentation broth by liquid–liquid extraction. The VFA recovery was 50–70%. Thus, 0.294–0.411 g VFAs could be obtained per gram of hydrothermally pretreated FW (in dry weight) by this method.

1. Introduction

One of the greatest challenges of the 21st century is to meet the food demand for the growing population while reducing the adverse effects of the food production system on the environment (Grizzetti et al., 2013). Consequently, large amounts of food waste (FW) will be generated. FW management is a challenging task because of its high moisture content and easy decay under ambient conditions. The treatment and disposal of FW represents a major cost to communities served by landfill plants (Ventour, 2008). Furthermore, methane and carbon dioxide are produced in sanitary landfills. Methane is regarded as a stronger greenhouse gas than carbon dioxide and is also flammable and explosive. Anaerobic digestion (AD) of FW has recently gained attention as a cost-effective and environmentally friendly method for biogas and volatile fatty acid (VFA) production. However, VFAs are generally regarded as a better source than biogas because of their wide application and high yield (Fontanille et al., 2012; Li et al., 2011; Chen et al., 2013a,b; Srikanth et al., 2009).

Three steps are involved in AD: hydrolysis, acidogenesis, and methanogenesis. Hydrolysis is the rate-determining step throughout the fermentation process (Li and Noike, 1992). Thus, improving the efficiency of hydrolysis is a hot topic. Generally, the degree and products of hydrolysis directly affect the fermentation process (He et al., 2012), in which only dissolved organic matter is available for biological degradation (Wang and Zhao, 2009). However, the recalcitrant part of the biomass-like cellulose and hemicelluloses would limit the AD process. Therefore, to reduce the refractory parts and accelerate the hydrolysis of biomass, a suitable pretreatment of biomass prior to AD is a viable strategy to enhance its conversion to biogas and VFAs, such as acid/alkaline, thermal, ozone,

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ultrasonic, and hydrothermal treatments (Bougrier et al., 2006; Jiang et al., 2014). Among these methods, hydrothermal treatment is the most efficient and environmentally friendly method because it does not involve adding chemicals. The hydrothermal process is to increase the ionized products of water at elevated temperatures and high pressure. Macromolecule materials can be hydrolyzed by these ionized products along with organic dissolution. Previous studies have reported that hemicellulose can be hydrolyzed to sugars at temperatures in the range 160–200 °C (Sasaki et al., 2003; Matsunaga et al., 2008).

In the field of biomass utilization, the hydrothermal method is the most used method for obtaining monosaccharides from agricultural wastes (Takata et al., 2013). Its application to FW pretreatment for AD and VFAs production has been seldom studied. Moreover, the components of FW are different depending on the place and time, especially in China. In addition, in different seasons and areas, the proportions of recalcitrant components in FW are quite different. Pretreatment of FW can change the composition for high-efficiency VFAs production. On the other hand, the major barrier in the use of the fermentation process for VFAs production is the technical difficulty associated with their recovery from the fermentation broths (Singhania et al., 2013). Although many studies have focused on how to improve VFAs production (Wang et al., 2014; Jiang et al., 2014; Chen et al., 2013b), VFA extraction from the original fermentation broth has been rarely reported. Therefore, the aim of this work is to investigate the effect of hydrothermal pretreatment on characteristics of FW and its fermentation for VFA production. The VFAs in the fermentation broth were extracted by a chemical method.

2. Methods

2.1. Food waste and seeding sludge

FW contained mainly rice, meat, vegetables and tofu was collected from a canteen on the campus of Zhejiang Gongshang University. Before use, the hard objects in the FW were picked out. The FW was then cut into small particles by hand-breaking. Anaerobic activated sludge was collected from an up-flow anaerobic sludge bed of the Xihu Brewery, which was set as the seeding sludge. Prior to inoculation, the seeding sludge was re-activated under its culture conditions.

2.2. Hydrothermal pretreatment

The hydrothermal pretreatment of FW was carried out in air-tight pressure digestion vessels with volumes of 80 mL. About 30 g crushed FW was placed in the vessel without water adding. The reactor was operated at 100–220 °C for 30 min in an air dry oven without any other chemicals. The time was measured from when the air dry oven reached the set temperature. The reactor was cooled to ambient temperature after 30 min pretreatment.

2.3. Fermentation experiments for VFA production

The 140, 160, 180, and 200 °C pretreated FWs were fermented in brown wide-mouth bottles with working volumes of 500 mL. FW without hydrothermal pretreatment was used as a control. The total solid (TS) content in each reactor was adjusted to 7% and the substrate was composed of 80% pretreated FW and 20% inoculum (dry weight). The pH was controlled at 6.0 by adding 4.5 M HCl or NaOH. Experiments were conducted in a greenhouse maintained at 30 ± 2 °C, and all reactors were mechanically stirred at 120 rpm using a magnetic stirrer throughout the experiments. Each reactor was duplicated and the redox potential was controlled between −200 and −100 mV by operating under a non-strict anaerobic condition. The fermentation tests ran for 15 days.

2.4. VFA extraction from fermentation broths

After fermentation, the broths were taken out of the bottles and centrifuged at 13000 rpm. The supernatant pH was adjusted to be $\leqslant$1.0 with high concentration sulfuric or hydrochloric acid. The centrifuged fermentation broths were then distilled to remove nonvolatile matter, and the distillates were collected. Isometric ethyl acetate was used to extract the VFAs from the distillates five times. Finally, the extracted liquor was concentrated by a rotary evaporator.

2.5. Analytical methods

Soluble and solid indexes, including soluble chemical oxygen demand (SCOD), VFAs, soluble protein, carbohydrate, ammonia nitrogen (NH_4^+–N), lipid, volatile solid (VS), TS, hemicellulose, and cellulose, were measured during the hydrothermal pretreatment process. All of these indexes except hemicellulose and cellulose were measured throughout the whole fermentation process. The pretreated FW was immediately used for analysis of the solid indexes. A part of the pretreated FW was diluted with distilled water. The diluents were filtrated through a filtration membrane with a pore size of 0.45 μm. The filtrate was used for soluble indexes assay. The fermented broth was separated from the residue by centrifuging at 10,000 rpm for 10 min. The soluble and solid index determinations were the same as those mentioned above. The SCOD, TS, VS, and NH_4^+–N were analyzed in accordance with the Standard Methods (APHA, 1998). The soluble protein, carbohydrate, VFAs, and lactate were determined as previously described (Wang et al., 2014). Hemicellulose and cellulose were assayed using the Van Soest detergent method (Luo et al., 2011). Lipids were extracted by Soxhlet extraction (Liu, 1994). The final experimental data are the average of duplicate reactor tests.

The conversion factors used for determination of the chemical oxygen demand (COD) of the soluble organic materials were 1.07 g COD/g acetic acid, 1.51 g COD/g propionic acid, 1.82 g COD/g butyric acid, and 2.04 g COD/g valeric acid. The carbon contents of the VS, carbohydrate, and protein were determined as previously described (Wang et al., 2014).

3. Results and discussion

3.1. Effect of hydrothermal pretreatment on FW

FW was pretreated under high pressure for 30 min at 100, 120, 140, 160, 180, 200, and 220 °C. The solid characteristics of the pretreated FW are shown in Table 1. The pretreated solid had a darker brown color than the untreated FW. In addition, the color became increasingly dark with increasing pretreatment temperature. The TS of the pretreated FW was nearly constant below 200 °C. However, the VS obviously decreased at temperatures $\geqslant$120 °C. 29.1% and 31.2% of the TS and VS were lost at 220 °C, respectively. This indicated that the VS, mainly hemicellulose and cellulose, was decomposed to lower molecular organics, such as monosaccharides, furans, and organic acids, at high temperatures (Takata et al., 2013). From Table 1, hemicellulose degradation occurred at 160 °C followed by cellulose hydrolyzation at 200 °C. Only 11.13 g/kg hemicellulose and 4.56 g/kg cellulose remained in the residue after 200 °C hydrothermal pretreatment. Ando et al. (2000) also reported that cellulose was difficult to degrade below 200 °C. On the other hand, hydrothermal pretreatment could contribute to lipids (crude fat) dissolving from the FW. 160 °C was the