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Effects of ultrasound pre-treatment on the amount of dissolved organic matter extracted from food waste

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HIGHLIGHTS

- After ultrasonic pretreatment, the total production of VFA increased markedly.
- Ultrasonic significantly increased the COD and protein of supernatant of food waste.
- Ultrasonic increased the amount of reducing sugars dissolved out of food waste.
- Ultrasonic markedly decreased the amount of fat dissolved out of food waste.

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ABSTRACT

This paper describes a series of studies on the effects of food waste disintegration using an ultrasonic generator and the production of volatile fatty acids (VFAs) by anaerobic hydrolysis. The results suggest that ultrasound treatment can significantly increase COD [chemical oxygen demand], proteins and reducing sugars, but decrease that of lipids in food waste supernatant. Ultrasound pre-treatment boosted the production of VFAs dramatically during the fermentation of food waste. At an ultrasonic energy density of 480 W/L, we treated two kinds of food waste (total solids (TS): 40 and 100 g/L, respectively) with ultrasound for 15 min. The amount of COD dissolved from the waste increased by 1.6–1.7-fold, proteins increased by 3.8–4.3-fold, and reducing sugars increased by 4.4–3.6-fold, whereas the lipid content decreased from 2 to 0.1 g/L. Additionally, a higher VFA yield was observed following ultrasonic pre-treatment.

1. Introduction

The total amount of food waste in China reached 40 million tons in 2009. With the growth of the population and the steady and rapid development of the catering industry, the amount of food waste has been increasing at a rate of more than 10% per annum (Xu and Ren, 2010).

Most food waste in China comes from food manufacturers, restaurants, canteens, and family kitchens. Some black market enterprises purchase food waste illegally for the production of waste cooking oil and for breeding at animal farm. Typically, the oil slick floating on food waste after heating has been used to produce waste cooking oil. Statistics show that 2–3 million tons of waste cooking oil has flowed back to China's dining tables annually (Huiming et al., 2012). Not only is waste cooking oil non-nutritious, it is also biologically toxic, chemically toxic, and carcinogenic. In addition, the food waste residue, after skimming the oil slick, is crushed and dried before being delivered to breeding livestock, which causes pollution of protein homology (Jin et al., 2012), posing another grave threat to human health. Therefore, the disposal and reutilisation of food waste is a long-term alarming problem in China.

On the other hand, food waste is a valuable resource because it contains large quantities of organic matter that can be converted into energy (Levis and Barlaz, 2011; Cuellar and Webber, 2010). Hence, the method of food waste disposal should be changed from the conventional food waste processing (incineration for energy recovery, feed or composting) to the sustainable food waste valorisation and recycling strategies so as to produce higher-value and more marketable products (Lin et al., 2013).

The treatment of organic waste using anaerobic digestion technologies has long been an attractive method (Brown and Li, 2013), and has been applied to various complex feedstocks, including municipal wastewater sludge, chemical and agricultural industry wastewaters, and food waste (Lettinga, 1995; Parkin and Owen, 1986). During the processing of food waste using sustainable

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strategies volatile fatty acids (VFAs) can be produced through anaerobic digestion fermentation (Jiang et al., 2013; Lim et al., 2008a,b). VFAs have various applications, such as to achieve higher value biosynthesis of polyhydroxyalkanoates (PHAs) (Chen et al., 2013) as well as increased production of biodegradable thermoplastics (Petkewich, 2003). In addition, VFAs derived from food waste can be used as an alternative carbon source in biological nutrient removal (BNR) (Lim et al., 2008a,b; Min et al., 2002).

However, the low efficiency of VFA production from food waste is a problem, making it unsuitable for industrial purposes. To increase the production of VFAs, the efficiency of anaerobic digestion of food waste must be enhanced. In general, the first steps of solubilisation and hydrolysis are rate-limiting in the anaerobic digestion of food waste. The degree of hydrolysis and the 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). Thus, a pre-treatment stage (e.g. acid hydrolysis, steam explosion, wet oxidation) is needed to soften materials in the food waste, and break down their structures to make them more susceptible to enzymatic attack, thereby enhancing the rate of hydrolysis before fermentation (Xu et al., 2012). Such pre-treatment methods, acid hydrolysis and wet oxidation, require the addition of acid and strong oxide, which increases the risk of environmental pollution; whereas steam explosion requires boilers, and thus a higher demand for equipment, so it is not feasible for processing large quantities of food waste. Therefore, the sustainable food waste pre-treatment methods is critical to achieving higher VFA production efficiency and reducing harm to the environment.

Ultrasound treatment is used typically to break down organic matter. Ultrasonication is used widely in the pre-treatment of excess sludge (Bien and Wolny, 1997; Jung et al., 2011). Ultrasound with a frequency of 20 kHz can generate instantaneous local high temperatures, high pressure, sharp discharging, and super-speed jet flows (Monnier et al., 1999). Microbial cells are broken up and the physical, chemical, and biological characteristics of sludge are altered, thereby enhancing its anaerobic digestion (Harrison, 1991). Few studies have investigated the possibility of using ultrasound to break down food waste to improve the degree of hydrolysis. Elbeshbishy investigated the effects of ultrasonication on the anaerobic biodegradability of food waste in single- and two-stage systems, but focused on ultrasonication for biohydrogen production from food waste (Elbeshbishy et al., 2011a,b).

The main objectives of the current study were to investigate the effects of ultrasonic pre-treatment on the characteristics of food waste disintegration, and to quantify the effects of both ultrasonic energy density and ultrasonic exposure time, as well as the yields of soluble organic matter (proteins, reducing sugars and lipids). The concentration of VFAs was also determined following acidification.

Notations	
COD	Chemical oxygen demand
SCOD	Soluble chemical oxygen demand (g/L)
BNR	Biological nutrient removal
C:N ratio	Carbon-to-nitrogen ratio
FID	Flame ionisation detector
HRT	Hydraulic retention time (h)
TKN	Total Kjeldahl nitrogen (g/L)
TS	Total solids (g/L)
VS	Volatile solids (g/L)
VFAs	Volatile fatty acids (g COD/L)
PHAs	Polyhydroxyalkanoates

2. Methods

2.1. Substrates and inoculum

Simulated food waste was used in this study. This was composed of rice (35%), cabbage (45%), pork (16%), and tofu (4%). The four components came from the same vendor at a market and were crushed using a food-waste disposer. The simulated waste was then stored in a refrigerator at 4 °C. Tap water was added to the food to attain TS of 40–100 g/L. Characteristics of the food waste before and after ultrasound pre-treatment and after anaerobic hydrolysis acidification are presented in Table 1.

Mesophilic anaerobic sludge, obtained from the Gaobeidian Wastewater Treatment Plant in Beijing, China, was used as an inoculum after natural sedimentation for 3 days.

The pH of the inoculum was 6.81 ± 0.2, and the concentration of SCOD, TS and VS were 120 ± 0.6, 11.4 ± 0.1 and 8.3 ± 0.1 g/L, respectively.

2.2. Experimental set-up

Food waste (1000 ml) with TS of 40 and 100 g/L was treated with 480 W ultrasound for 3, 6, 9, 12, 15, 18, 21, 24, 27 and 30 min; the COD content of the food waste supernatant was then determined. Two portions of food waste (1000 ml) with TS of 40 and 100 g/L were treated at 20 kHz for 15 min at powers of 240, 480, 600, 720, 840, and 960 W, providing ultrasonic energy densities of 240–960 W/L. Next, 1 L of inoculum and 3 L of food waste that had undergone ultrasound pre-treatment were placed in a reactor. For comparison, identical quantities of inoculum and food waste without ultrasound pre-treatment were placed in another reactor. An agitator, at a constant speed of 250 rpm, was mechanically fixed to the reactor. The temperature was maintained at 35 ± 1 °C using a temperature sensor. The pH of the reactors was maintained automatically at 6.0 using a pH controller, via the addition of hydrochloric acid (HCl) or sodium hydroxide (NaOH). At the start of the experiment, nitrogen gas was flushed through the system to create anaerobic conditions. Samples were taken using a peristaltic pump at sampling times of 15, 24, 36, 50, 60, 72, 88, or 100 h.

The ultrasonic cell breaker used (model FS1200, Shanghai Sonxi Ultrasonic Instrument Co., Ltd.) has adjustable power under 1200 kW and an ultrasonic frequency of 20 kHz.

Table 1
Characteristics of food waste analysed in this study.

	TS 40	TS 100
Initial properties		
TS (g/L)	40.6 ± 4.3	103.8 ± 6.6
VS (g/L)	35.9 ± 2.1	98.8 ± 6.8
SCOD (g/L)	34.6 ± 5.6	40.6 ± 7.0
pH	4.6 ± 0.2	5.0 ± 0.2
After ultrasound pre-treatment		
TS (g/L)	40.2 ± 4.3	103.2 ± 6.6
VS (g/L)	38.2 ± 1.7	99.7 ± 1.7
SCOD (g/L)	96.5 ± 5.7	125.5 ± 6.9
pH	5.0 ± 0.1	5.0 ± 0.2
After anaerobic hydrolysis acidification with ultrasound		
TS (g/L)	35.6 ± 3.6	84.6 ± 2.1
VS (g/L)	20.6 ± 2.4	51.0 ± 0.8
SCOD (g/L)	116.9 ± 4.7	134.7 ± 7.0
After anaerobic hydrolysis acidification without ultrasound		
TS (g/L)	36.4 ± 2.8	85.6 ± 2.3
VS (g/L)	22.6 ± 2.3	52.9 ± 1.7
SCOD (g/L)	110.5 ± 4.8	128.7 ± 6.7