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Pretreatment of food waste with high voltage pulse discharge towards methane production enhancement

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HIGHLIGHTS

- HVPD was firstly used for FW pretreatment to enhance methane production.
- Pretreated by HVPD, 54.3% of solid organics was transferred to soluble organics.
- With HVPD pretreatment, 134% higher methane production was obtained.
- HVPD was better than other reported methods for FW pretreatment.

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ABSTRACT

Anaerobic batch tests were performed to investigate the methane production enhancement and solid transformation rates from food waste (FW) by high voltage pulse discharge (HVPD) pretreatment. The total cumulative methane production with HVPD pretreatment was 134% higher than that of the control. The final volatile solids transformation rates of FW with and without HVPD pretreatment were 54.3% and 32.3%, respectively. Comparison study on HVPD pretreatment with acid, alkali and ultrasonic pretreatments showed that the methane production and COD removal rates of FW pretreated with HVPD were more than 100% higher than the control, but only about 50% higher can be obtained with other pretreatments. HVPD pretreatment could be a promising pretreatment method in the application of energy recovery from FW.

1. Introduction

As a major source of odor emanation, vermin attraction, toxic gas emission and leachate generation, food waste (FW) is becoming a serious environment problem (Iacovidou et al., 2012). In China, the yield amount of FW will reach 1.4×10^8 tons per year in 2020, growing at a rate of about more than ten percent a year due to the population growth and the rising of living standards (Zhang et al., 2016). But if well treated, FW can be a great source of bioenergy due to its high content of organic matters with good biodegradability.

Anaerobic digestion (AD) is considered to be a desirable method and has been widely used for treatment of organic wastes with biogas production (Brown and Li, 2013; Liu et al., 2016). AD process starts with hydrolysis of feedstock, followed by acidogenesis, acetogenesis and methanogenesis steps. In hydrolysis step, insoluble complex organics are transformed into soluble and small molecule organic matters which can be further converted to biogas (Pavlostathis and Giraldo Gomez, 1991). It is well known that, for organic solid wastes (including activated sludge, FW, and so on), hydrolysis is the rate-limiting step in AD, leading to a low methane production (Eastma and Ferguson, 1981; Tatsuya et al., 1985). Thus, different pretreatment technologies were developed to enhance the hydrolysis efficiency (Liu et al., 2015a; Zhen et al., 2014), increasing the transformation rate of solid organics to soluble organics to improve the overall AD process efficiency and methane production (Cesaro and Belgiorno, 2014; Yuan et al., 2014).

Different technologies such as mechanical (e.g., ultrasonic, microwave), chemical (e.g., acid/alkali pretreatment), thermal (e.g., heat pretreatment) and biological (e.g., pretreatment by enzymes) methods were proposed for FW pretreatment to enhance anaerobic digestion and methane production (Kondusamy and Kalamdhad, 2014). For example, microwave was used for FW pretreatment, with the SCOD of the FW leachate and average gas production increases of 35% and 16%, respectively (Marin et al., 2010). Study by Elbeshbishy et al. showed different FW pretreatment

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effects of different methods, including ultrasonic pretreatment (increased the SCOD, soluble carbohydrate, and soluble protein by 25%, 16%, and 17%, respectively), acid pretreatment (increased the SCOD, soluble carbohydrate, and soluble protein by 28%, 18%, and 22%, respectively) and base pretreatment (increased the SCOD, soluble carbohydrate, and soluble protein by 28%, 22%, and 26% respectively) (Elbeshbishy et al., 2011). While another study about ultrasonic pretreatment to FW, the SCOD, carbohydrate and protein increased by 22.1%, 13.6%, 30.3% (Elbeshbishy et al., 2012). These methods can promote the hydrolysis rate of FW somehow, but the efficiency is still not very ideal.

High voltage pulse discharge (HVPD) has been a hot spot of solid organic wastes pretreatment (Lee and Rittmann, 2011; Lee and Chang, 2014). It was found that, with HPVD pretreatment on waste activated sludge (WAS), the soluble chemical oxygen demand (SCOD) of the mixture increased from 20 mg/L to 1000 mg/L or higher, with 100% increase of methane production in biochemical methane potential (BMP) tests (Salerno et al., 2009). Another study showed that, after HPVD pretreatment, the SCOD, soluble sugar, soluble protein and methane production rate increased up to 220%, 300%, 460% and 33%, respectively (Lee and Rittmann, 2011). Compared with other pretreatment methods, HPVD showed an obvious advantage. Acid or alkali pretreatment needn't special equipment requirements, but too high concentrations of Na^+ or K^+ may cause subsequent inhibition of AD (Neves et al., 2006). Furthermore, compared with acid or alkali pretreatment, HPVD pretreatment could greatly shorten the processing time (from 24 h to 30 min) and the operation is more convenient (no need to adjust pH after pretreatment). Ultrasound pretreatment has a good effect to FW due to its disruption of the cell structure and flocs, but the energy needed is high (Kondusamy and Kalamdhad, 2014). HVPD may be able to improve the performance of AD greatly, so that more bioenergy can be recovered.

It is concluded that the good effects of HPVD pretreatment are due to the accompanied roles by high energy electron radiation, ultrasonic oxidation, blast hole oxidation, wet oxidation, photochemical catalytic oxidation and a series of advanced oxidation reactor (Salerno et al., 2009). It was also put forward that the discharge action can break up cellular membrane, make complex organic solids and macromolecules transferred to soluble and biodegradable organic matters (Lee and Rittmann, 2011; Vorobiev and Lebovka, 2010). Meanwhile, HVPD could destroy the crystalline structure of lignocellulosic and cellulose (about 7% in FW), make cellulose structure become loose and easier to be degraded (Bundhoo et al., 2012). So it is expected that, using HPVD pretreatment, the hydrolysis rate of FW could be higher than those using other existing pretreatment methods, with higher SCOD, soluble protein and soluble sugar and methane production being expected.

Thus, the objectives of this study were: (1) to explore the effects of HPVD conditions (including pulse peak voltage, electrode distance, pulse frequency and pretreatment time) on FW pretreatment; (2) to investigate how much can HPVD enhance the methane production by batch anaerobic tests; (3) to compare the pretreatment efficiencies of HPVD with acid, alkali and ultrasonic pretreatment. The results of this study could have a guiding role for the future application of HVPD pretreatment for getting more renewable energy from FW.

2. Materials and methods

2.1. FW and inoculum

The raw FW, mainly containing leftovers of cooked foods, such as meats, rice, breads, noodles and vegetables, was collected from the canteen of Shanghai University, Shanghai, China. After plastic bags and bones being removed, the FW was crushed to a particle size of less than 5 mm by an electrical grinder. The FW was then diluted with tap water to 30 g/L on a chemical oxygen demand (COD) basis, collected and stored at 4 °C.

Anaerobic sludge with good methanogenesis ability was used as inoculum, which was collected from a full-scale anaerobic reactor treating wastewater plant in Shanghai, China, stored in a refrigerator at 4 °C before use. The characteristics of the FW and inoculum are shown in Table 1.

2.2. HVPD pretreatment

The HVPD pretreatment system consists of a pulsed high-voltage power supplier and a multi-needle-to-plate reactor. High-voltage pulses were generated by the combination of a 0–50 kV adjustable direct current power supplier, a storage capacitor, an adjustable trim capacitance and a rotating spark-gap switch. The multi-needle-to-plate electrode, which produced positive streamer corona discharge at its needle tips, was located in the cylinder. The ground plate electrode is a stainless-steel disc (with diameter of 90 mm and thickness of 1.5 mm). The electrode distance was adjustable. The pulse peak voltage amplitude, pulse frequency and storage capacitance (Cp) were 50 kV, 400 Hz and 2 nF, respectively. When the pulse peak voltage was more than 40 kV and the electrode distance was less than 5 mm, the discharge was more intense and unstable and the discharge electrode was loss faster. This could make the current or voltage become too large and damage the reactor. So the pulse peak voltage was set at 22, 28, 34, 40 kV, with the electrode distance of 5, 7, 9, 12 mm (Sugiarto and Sato, 2001). Then the pulse frequency was set at 100, 200, 300, and 400 Hz, with different pretreatment time (5, 10, 15, 20, 30 min), while the control sample was stored in a refrigerator at 4 °C before use. In this experiment process, a total of 20 samples to treat, each sample has a parallel. Energy usage efficiency was calculated as follows (Jiang et al., 2014; Zhang et al., 2013b):

$$\mathrm{G} = \frac{(C_0 - C_t) \times V}{\int_0^T UIdt \times f \times t}$$

$$\mathrm{G} = \frac{V'}{\int_0^T UIdt \times f \times t}$$

C_0, C_t-initial and final COD concentration, mg/L; U-discharge voltage, kV; f-discharge frequency, Hz; V-solution volume, Ml; V′-CH_4, L; t-reaction time, h; T-the discharge period.

2.3. Anaerobic digestion tests

The batch anaerobic tests were performed using serum bottles (with total volume of 1500 mL and effective volume of 1000 mL). The stored FW was pretreated under optimized HPVD conditions, with pulse voltage of 40 kV, electrode distance of 5 mm, pulse frequency of 400 Hz and pretreatment time of 30 min. The stored FW and inoculum were added into the bottles with mixing ratio of 1:2

Table 1
Characteristics of the raw FW and inoculum.

Parameters	FW	Inoculum
pH	4.68–4.81	7.43
TCOD (g/L)	157.0–177.6	/
SCOD (g/L)	59.4–68.2	0.9
Total solids (%)	12.3–15.8	8.4
Volatile solids (%)	10.7–14.5	4.0
VS/TS (%)	87.3–91.6	47.6