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Anaerobic digestion of poplar processing residues for methane production after alkaline treatment

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HIGHLIGHTS

- ▶ This is the first report of using poplar processing residues for methane production.
- ▶ The residues weren't good material for methane production without NaOH treatment.
- ▶ Enhancement of methane production can be achieved after alkaline treatment.
- ▶ The highest methane production was achieved at 35 g/L with 5.0% alkaline dose.

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ABSTRACT

Poplar processing residues were used for methane production by anaerobic digestion after alkaline treatment and methane production was measured. The highest methane production of 271.9 L/kg volatile solid (VS) was obtained at conditions of 35 g/L and 5.0% NaOH, which was 113.8% higher than non-alkaline treated samples, and 28.9% higher than that of corn straw, which is the conventional anaerobic digestion material in China. The maximal enhancement of 275.5% obtained at conditions of 50 g/L and 7.0% NaOH. Degradation of cellulose, hemicellulose and lignin after treatment increased by 4.0–9.0%, 3.3–6.2%, and 11.1–20.5%, respectively, with NaOH dose ranged from 3.0% to 7.0%. Scanning electron microscopy (SEM), FTIR spectra and Crystallinity measurements showed that the lignocellulosic structures were disrupted by NaOH. The results indicate poplar processing residues might be an efficient substrate for methane production after alkaline treatment.

1. Introduction

In China, fossil fuels are still the main energy sources presently. With increased concerns on energy security, climate change and environmental pollution, developments of renewable energies are becoming more and more important (Zhang et al., 2007). Lignocellulosic biomass, such as agricultural residue, forest waste and municipal solid waste, is abundant and widely available as renewable resources. The estimated annual yield of these biomass materials is more than 0.7 billion tons in China (Zhang et al., 2007).

As one of the ideal energy crops, poplar is widely used for processing of pallets, cheap plywoods, and paper pulp for the characteristics of fast growing, short rotation and richer in cellulose and hemicellulose (Xu, 1988). In China, the areas of natural poplars and artificial poplars are 3 millions square hectometer (hm^2) and 8 millions hm^2, respectively. Both the planting area and the amount of growing stocks are the highest in the world (Jian, 2006). In the northwest of China, poplar is the main species that reproduces trees used for commercial plantation, shelter forests against wind and fixing sand, agricultural protection forest and landscape engineering. The amount of poplar processing residues can be up to 10–15% of the wood volume. Therefore, large amount of poplar processing residues yielded from the wood process, such as wood cuttings, sawdust and sapwood are usually burned or discarded which causes environmental pollution (Jian, 2006). Using poplar processing residues as substrate of anaerobic digestion for bioenergy production will be a viable option, not only for reducing the pollution, but also for producing renewable energy.

As biomass materials, poplar processing residues could be converted to ethanol or biohydrogen (González-García et al., 2010; Cui et al., 2010). However, this method is not economical, mainly due to the high cost of the hydrolysis process and the low yield (Sun and Cheng, 2002). A new alternative is to convert poplar processing residues to biogas by anaerobic digestion. Anaerobic digestion has been widely accepted for great interest from the view of environmental and renewable energy through treatment and recycling of biomass wastes (Amon et al., 2007; Forster-Carneiro et al.,

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2007). However, the complex three dimensional structures formed of polysaccharide and lignin creates recalcitrant, which inhibits the process of hydrolysis of anaerobic digestion. This is the reason that hydrolysis is the rate-limiting phase of anaerobic digestion (Chaudhry, 2000). Also, during the process of Co-digestion, compared with the other substrate, the degradation of the lignocellulosic materials was not significant (Brown and Li, 2013). Pretreatment prior to anaerobic digestion can improve biodegradability of lignocellulosic materials effectively and increase the biogas production (Zhu et al., 2010). Alkaline pretreatment is one of the leading pretreatments, due to several advantages over the other methods, including acid, steam and biological pretreatments. First, alkaline solubilizes lignin (Hendriks and Zeeman, 2009). Second, alkaline neutralizes various acidic productions, and third, alkaline prevents a drop of pH during subsequent acidogenesis process (Pavlostathis and Gossett, 1985). Sodium hydroxide (NaOH) was found to be one of the most effective alkaline reagents for removal of lignin and enhancement of biogas production (Yang et al., 2009). It has been reported that a 72.9% increase in total biogas production was achieved with 2.0% NaOH-treated corn stover for 3 days at 88% of moisture content (Zheng et al., 2009). A 37.0% increase in biogas was obtained by Zhu et al. (2010), with 5.0% NaOH-treated corn stover at 53.0% moisture content for 1 day at ambient temperature. Recently, it has been shown that 24-fold higher of methane production than the untreated samples was achieved with 3.5% NaOH-treated fallen leaves at S/I ratio of 6.2 (Liew et al., 2011).

In this study, the effect of NaOH pretreatment on anaerobic digestion with poplar processing residues as sole feedstock was conducted. The objective of the study was: (1) to test whether the poplar processing residues are good substrate of anaerobic digestion for methane production after NaOH pretreatment; (2) to investigate the effect of NaOH pretreatment on the daily and total methane production, and determine the optimal condition of pretreatment and anaerobic digestion; (3) to test the effect of methane production with poplar processing residues as substrate of anaerobic digestion, compared to the abundant lignocellulosic biomass of corn straw; (4) to study the structure changes of poplar processing residues by Scanning electron microscopy (SEM), FT-IR spectra and X-ray diffraction analysis during pretreatment.

2. Methods

2.1. Feedstock and inoculum

Poplar processing residues were collected from a wood processing factory located in the suburb of Jiuquan City, Gansu province, China. The poplar processing residues were cut and grounded into 6–12 mm particles by a hammer mill (RT-34, BeijingWeiBoChuang, China). The resultant poplar processing residues were stored at −20 °C prior to use. Effluent from a biogas plant digesting manure in Linxia city, Gansu province, China, was used as inoculum of anaerobic digestion. The characteristics of poplar processing residues and inoculum are shown in Table 1.

2.2. Pretreatment

Three NaOH doses of 3.0%, 5.0% and 7.0% based on dry matter of poplar processing residues were used in this study. The moisture contents (MC) was 88%, similar to that in the report of Zheng et al. (2009). No NaOH addition treatment was used as control. All the prepared samples were kept at ambient temperature (20 ± 1 °C) for 4 days. A few pretreated samples were dried in an electronic oven at 60 °C for 48 h and then kept in a refrigerator for chemical composition analyses (Pang et al., 2008).

Table 1
Characteristics of poplar processing residues and inoculum.

Parameter	Poplar processing residues	Inoculum
Total solid (%)	84.8 ± 0.1	9.9 ± 0.3
Volatile solid (%)	77.3 ± 0.4	5.0 ± 0.1
Total carbon (%)	48.1 ± 0.1	27.5 ± 0.0
Total nitrogen (%)	0.2 ± 0.0	1.4 ± 0.0
H (%)	5.6 ± 0.1	3.2 ± 0.0
pH value	6.9 ± 0.1	7.5 ± 0.0
Cellulose (%)	47.7 ± 1.7	41.0 ± 1.1
Hemicellulose (%)	25.6 ± 0.4	29.5 ± 0.8
Lignin (%)	23.6 ± 0.3	ND
Crystallinity index (CrI)	23.7 ± 0.0	ND

ND: not determined.

2.3. Anaerobic digestion

Different amount of the untreated and the NaOH-treated poplar processing residues were digested in batch anaerobic digesters at laboratory scale. The volume of each digester was 2 L, with a 1.5 L working volume. Amount of inoculum seeded into each digester was 15 g/L, based on the research result by Zhang and Zhang (1999), and the untreated, 3.0%, 5.0% and 7.0% NaOH treated poplar processing residues placed into each digester are included to final concentrations of 35, 50, 65 and 80 g/L for anaerobic digestion, respectively. The VS concentrations were 25.9, 39.5, 53.2 and 66.9 g/L for the four concentrations, respectively. Ammonia chloride (NH_4Cl), as nitrogen source, was added to each digester and the carbon/nitrogen ratio (C/N) was 25 after solved in deionized water (Zhang and Zhang, 1999). The amount of ammonia chloride added into digesters of 35, 50, 65 and 80 g/L were 1.8, 3.4, 4.8 and 6.4 g, respectively. Deionized water was then added to each digester to complete the working volume (or active volume) of 1.5 L. The prepared digesters were incubated at 35 °C (mesophilic temperature) without shaking. The digestion experiment for each condition was duplicated. The characteristics of digestion mixtures are shown in Table 2.

2.4. Analytical methods

2.4.1. Chemical composition analyses

TS and VS were measured according to the APHA standard methods (1998). Total carbon (TC), total nitrogen (TN) and total hydrogen (TH) were determined by an elemental analyzer (varioEL cube, Elementar Analysensysteme GmbH). The samples were prepared by suspending 5 g wet digestate into 50 ml distilled water prior to pH determination by pH meter (PB-21, Sartorius, Germany) (Zhu et al., 2010). The contents of cellulose, hemicellulose and lignin were determined according to the procedure of Van Soest et al. (1991).

2.4.2. Biogas analyses

Biogas production was recorded every 2 days by the method of water displacement, and the total biogas volume calculated after

Table 2
Characteristics of digestion mixtures.

Concentration (g/L)	Total solid (g)	Volatile solid (%)	Cellulose (%)	Hemicellulose (%)
35	52.5 ± 1.0	73.9 ± 0.9	44.8 ± 0.7	27.2 ± 1.1
50	75.0 ± 1.2	79.1 ± 0.6	45.6 ± 1.4	26.7 ± 3.8
65	97.5 ± 0.1	81.8 ± 2.6	46.2 ± 0.4	26.5 ± 0.8
80	120.0 ± 3.4	83.6 ± 0.3	46.4 ± 0.8	26.3 ± 6.1

Note: Volatile solid (%), cellulose (%) and hemicellulose (%) were calculated based on total solid.