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Anaerobic digestion of pre-fermented potato peel wastes for methane production

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ABSTRACT

This study investigated the feasibility of anaerobic digestion (AD) of potato peel waste (PPW) and its lactic acid fermentation residue (PPW-FR) for methane (CH_4) production. The experimental results showed that about 60–70% CH_4 content was obtained. The digester using PPW-FR as feedstock exhibited better performance and produced a highest cumulative CH_4 production of 273 L/kg VS_{fed}, followed by 239 L/kg VS_{fed} using PPW under the same conditions. However, with increasing solid loadings of PPW-FR feedstock from 6.4% to 9.1%, the CH_4 production was inhibited. The generation, accumulation, and degradation of volatile fatty acids (VFAs) in digesters were also investigated in this research.

1. Introduction

Potatoes are a major crop for the United States Pacific Northwest (Idaho, Washington and Oregon), with 12.5 million tons harvested in 2011 (PotatoPRO, 2015), and approximately 50% of the potatoes were processed into fries and other products. Potato peel waste (PPW) is the main co-product of steam peeling generating about 8% waste by weight (Mader et al., 2009), and waste disposal is becoming a major issue. An alternative method has been developed to convert PPW into mainly lactic acid with mixed microbial consortia in batch and sequencing batch fermenters (Liang et al., 2015a, 2014, 2015c). This fermentation process can efficiently utilize easily digestible starch in the PPW and leave the un-reacted cellulosic material in the solids, called "PPW fermentation residue" (PPW-FR), which is still a waste burden for disposal. A comprehensive chemical characterization of PPW-FR reported previously that contained approximate 20% cellulose/hemicellulose, 30% lignin + suberin, 25% protein, and 8% lipids (Liang and McDonald, 2014). Due to its composition, the PPW-FR has been applied to produce other value added bio-based products such as bioplastic composites, pyrolysis crude bio-oil, and bio-char (Liang et al., 2015b; Wei et al., 2015a). In addition, the abundant carbon and nutrients contents also make its good feedstock for biogas production via anaerobic digestion (AD) process (Dreschke et al., 2015; Parawira et al., 2007, 2004).

AD is a biochemical conversion process to decompose organic materials into biogas (50–70% CH_4) by mixed anaerobic microorganisms in the absence of oxygen. The AD system has been widely applied in the environmental management of wastewater sludge, municipal solid waste, and livestock manure, with the primary objective of waste reduction. The produced biogas as renewable energy can also improve the operational profitability, reduce the greenhouse gas (GHG) emission, and mitigate climate change (Coats et al., 2013). It is reported that more than 2000 AD plants are currently operated in the United States to produce biogas, and an additional 11,000 sites could be developed in the future, which in total could provide power supply for over 3 million households and reduce between 4 and 54 million metric tons CH_4 equivalent of GHG emissions by 2030 (USDA et al., 2014). Parawira et al. (2007) compared the biogas production from PPW using two-stage digesters with mesophilic and thermophilic configurations, and results showed that higher CH_4 yield was obtained under mesophilic condition.

In this study, we investigated the feasibility of biogas production using PPW-FR as feedstock with different solid loadings to explore the suitable condition. The raw PPW without lactic acid fermentation was also employed in batch AD process as comparison.

2. Materials and methods

2.1. Feedstock and inoculum

The PPW (*Russet Burbank*) sample was collected over a 2 h period from a potato processing plant (JR Simplot Company, Nampa, ID) in May 2012, mixed thoroughly and stored frozen

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(−20 °C) in plastic containers before use. This PPW feedstock was fermented to produce mainly lactic acid in a 1 L anaerobic sequencing batch reactor under mesophilic (35 °C) conditions as described previously (Liang et al., 2015c). The solid residue was separated from fermentation broth by centrifugation at 5000 rpm for 20 min, and the PPW-FR was obtained and stored in −20 °C freezer prior to use. The AD inoculum was collected freshly from the effluent of a 19 L mesophilic AD located in Department of Civil Engineering, University of Idaho (Moscow, ID) that treated dairy manure to produce biogas (Coats et al., 2012). The characteristics of PPW, PPW-FR, and inoculum used in this experiment are given in Table 1.

2.2. AD set-up

The experimental design of AD in this study is shown in Table 2. Briefly, varying amounts of homogenized PPW and PPW-FR samples were mixed with sodium bicarbonate and water to adjust pH to 7 and total solid (TS) content. After releasing of all the CO_2 bubbles, varying amounts of inoculum was added into each reactor. All tests were conducted in batch mode using 800 mL serum bottles fitted with a rubber septum and incubated in a water bath at 35 °C for 40 days with manually shaking twice a day. The digesters, PPW-1 and PPW-FR-1, have the same TS content of 6.4%, volatile solid (VS) content of 5.2%, and feedstock/inoculum (F/I, the amount of feedstock VS per amount of inoculum VS) ratio of 2.6. Increasing TS, VS, and F/I ratios were conducted in digesters PPW-FR-2 and PPW-FR-3. A blank AD reactor containing inoculum (150 g) and water (150 g) was used as control. Biogas was collected daily in a 1-L Tedlar™ gas sampling bag attached to the outlet of the reactor with syringe needle and plastic tubing, and the produced gas volume was quantified by the water displacement method. An aliquot of liquid sample was withdrawn from the digester every four days using a long needle syringe for analysis, and a solid sample was collected at the beginning and the end of digestion for characterization.

2.3. Analytical methods

The TS content was determined by drying at 105 °C for 24 h, and the VS content was based on the weight loss of TS at 550 °C till constant weight was obtained. The C and N contents of solid samples were determined using a CE-440 elemental analyzer (EAI Exeter Analytical). Liquid and solid samples from the digesters were mixed with water (10 × volume) at room temperature for 30 min prior to pH, ammonium nitrogen (NH_4-N), total phosphorous (TP) and volatile fatty acids (VFAs) measurement. The pH value was measured with Orion-3-Star pH meter. The NH_4-N and TP were determined by Nessler method 4500-NH_3 and ascorbic acid method 4500-P, respectively using a Beckman D640 spectrophotometer (Fullerton, CA) (APHA et al., 1998). VFAs were quantified by gas chromatography (GC) using an Agilent 6890 instrument (Palo Alto, CA) with an Alltech-Heliflex-AT™ Wax capillary column (Φ 0.32 mm × 30 m, Deerfield, IL) at 150 °C and flame ionization detection (210 °C). The samples were acidified to pH 2 with HNO_3 prior to injection. The composition of biogas (CH_4 and CO_2) in the gas sampling bags was analyzed using a Gow-Mac 350 thermal conductivity GC (GOW-MAC Instrument, Bound Brook, NJ) equipped with HaySep DB stainless steel packed column (9.1 m × 3 mm) operating at 30 °C with a detector temperature of 200 °C and helium as carrier gas (30 mL/min). Standard curves were prepared from calibration standards of CO_2 and CH_4 in N_2 for quantification.

Table 1
Characteristics of the PPW, PPW-FR and inoculum.

Parameters	PPW	PPW-FR	Inoculum
TS (% wb)[a]	9.2	12.2	3.6
VS (% db)	82.0	79.5	80.1
Carbohydrates	39.3	22.4	–
Lignin	21.3	37.0	–
Lipids	2.0	7.7	–
Carbon (% db)	43.8	47.8	–
Nitrogen (% db)	4.1	4.1	–
C/N	10.7	11.9	–
pH	6.5	4.2	7.5

[a] The TS content is wet basis (wb), and the VS, carbon, and nitrogen contents are dry basis (db). Data are means of three samples (n = 3).

Table 2
Experimental design of anaerobic digestion of PPW and PFR.

Digester	Feedstock (g)[a]	Inoculum (g)	Water (g)	TS (%)	VS (%)	F/I
PPW-1	150	150	0	6.4	5.2	2.6
PPW-FR-1	115	150	35	6.4	5.2	2.6
PPW-FR-2	150	150	0	7.9	6.3	3.4
PPW-FR-3	180	120	0	9.1	7.3	5.0
Control	0	150	150	1.8	1.5	–

[a] The feedstock and inoculum are wet basis, and the F/I ratio = the amount of feedstock VS per amount of inoculum VS.

2.4. Statistical analysis

The AD experiments were conducted in duplicate and the average values reported. The results were analyzed with SAS 9.3 software (SAS Inc., Cary, NC, USA) using a t-test with a threshold p-value of 0.05.

3. Results and discussion

3.1. Methane production

The CH_4 content, CH_4 yield, and cumulative CH_4 production in the four digesters with different substrates and conditions are illustrated in Fig. 1. Among these digesters, the CH_4 content of the biogas increased gradually to 60–70% after 8–10 days, except for digester PPW-FR-3 (having the highest TS content of 9.1% and VS content of 5.0%), which realized a biogas content of 65% on day 14 (Fig. 1A). The slower increase in CH_4 composition was probably due to high organic loadings caused methanogenesis inhibition. The CH_4 contents in all digesters ultimately stabilized around 65%, which was in accordance with previous studies using potato waste as feedstock to produce biogas (Parawira et al., 2004). It is known that the CH_4 production from lignocellulosic biomass by AD usually generates low CH_4 content around 50–60% (Zhu et al., 2010). The relative higher CH_4 contents obtained in this study were probably due to the higher lipids contents of 2–8% in the feedstock PPW and PPW-FR as compared to <1% in woody biomass (Bayr et al., 2014). Lipids have lower oxidation state and higher energy storage than carbohydrates and thereafter tend to generate higher CH_4 content in AD system.

The digester PPW-1 and PPW-FR-1 with identical TS and VS contents shared similar trends of daily CH_4 production (Fig. 1B). A small peak was observed at the beginning of digestion in both PPW-1 and PPW-FR-1, which was due to the quick conversion of available VFAs into biogas, as shown in Fig. 2. After 4–6 days incubation, the CH_4 production increased dramatically and reached the highest daily yield of 16.8 and 20.8 L/kg VS_{fed} on day 10 and 8, respectively, in digester PPW-1 and PPW-FR-1. However, as