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Control of lactic acid production during hydrolysis and acidogenesis of food waste

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ABSTRACT

Lactate accumulation occurs frequently during the hydrolysis and acidogenesis of food waste and produces an unfavorable substrate for anaerobic digestion. The objective of the present study was to reduce lactic acid production during the hydrolysis and acidogenesis of food waste in leachate bed reactor for establishment of the two-phase anaerobic digestion system. The results showed that the hydrolysis and acidogenesis of food waste in batch feeding mode underwent two consecutive stages, namely lactic acid fermentation and mixed acid fermentation. In the lactic acid fermentation stage, lactate constituted 74.4–96.8% of the total organic acids in the leachate. However in semi-continuous mode the content of lactate in the leachate could be reduced less than 0–2% for leach bed reactors operated at feeding loads of 50–150 g/d although lactate accumulation occurred at a feeding load of 200 g/d. Furthermore the organic acid shifted to acetate and butyrate, providing ideal substrates for anaerobic digestion.

1. Introduction

Food waste (FW) is composed in large part by various organic materials such as starch, protein and lipid that can be easily converted to volatile fatty acid (VFA). This makes FW an ideal substrate for biogas production through anaerobic digestion (AD) (Cho and Park, 1995; Kinnunen et al., 2014; Lee et al., 2016; Zhang et al., 2007b). However, the high solids contents can pose challenges for AD operation. For one-stage system high strength wastes may lead to overloading and excessive acidification when FW is the sole substrate. This may result in failed AD with little methane production and odor generation because the activities of methanogenic archaea would be inhibited when the pH is less than 6.8 whereas acidogenic bacteria are active in slightly acidic conditions (pH 5–6) (Kong et al., 2016; Ngo et al., 2016). To solve this problem two-stage AD system is proposed, in which growth conditions of acidogenic and methanogenic bacteria were optimized in different reactors. Typically the first stage is maintained at low pH (5 − 6) and low hydraulic retention times (HRT) (2–3 days) while the second stage is operated at neutral pH (6.8–7.2) and long HRT of 15–30 days (Grimberg et al., 2015; Kinnunen et al., 2014; Voelklein et al., 2016; Xu et al., 2011). Phase separation has proven to be effective in resolving acidic inhibition in one-stage system.

For facilitating AD of solid waste such as FW leach bed (LB) is usually used as the first phase for hydrolysis and acidogenesis, from which leachate is generated to feed methanogenic reactor (Stabnikova et al., 2008; Voelklein et al., 2016; Wang et al., 2005; Xu et al., 2011). Obviously characteristics of the leachate tend to influence the performance of methanogenic reactor. Although acidic leachate could be neutralized by sodium hydroxide before pumped to the second stage methanogenic reactor, VFA composition of the leachate still influences the efficiency of methanogenesis. For example, lactic acid has been reported to be the main fermentation products for FW (Kim et al., 2016; Li et al., 2015; RedCorn and Engelberth, 2016; Tang et al., 2016; Zhang et al., 2008). It is a really problematic organic acid due to its negative influences on methanogenic process. Firstly, more severe acidification could be resulted from lactic acid accumulation due to its low pKa value (3.86) as compared with other VFAs such as acetic (4.76), propionic (4.87) and butyric acids (4.82). Secondly, lactate is an unfavorable substrate for the anaerobic digestion because it can be easily converted to toxic propionate when feeding methanogenic reactor with lactate as the major carbon source (Zellner et al., 1994). Propionate accumulation has been generally considered as an indicator of failure of methanogenesis due to its toxicity to methanogenesis (Nielsen et al., 2007; Wang et al., 2009; Zhang et al., 2007a). Based on work above, the formation of large amounts of lactic acid in the first stage of AD should be prevented for further improvement of two-stage AD of food waste.

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Therefore the present study was aimed to explore the feasibility of reducing lactic acid production through addition of neutralizing agent and optimizing the loading rate during FW hydrolysis/acidogenesis in leach bed reactors.

2. Materials and methods

2.1. Food waste and inoculum

In order to avoid any possible changes in physicochemical properties, simulated FW was used in this study and it consisted of 11.1% rice, 8.9% steamed bun, 76.1% cabbage and 4.0% boiled pork on wet weight basis. Individual components were crushed using a FW disposer, mixed manually and stored at 4 °C in a refrigerator before experimental use. Total and volatile solids content of the FW were 17.4% and 96.7% of TS, respectively. Dewatered anaerobic digested sludge from a local municipal sewage treatment plant in Nanjing, China was used as the inoculum. The TS and VS/TS of the inoculum were 22.7% and 45.6%, respectively.

2.2. Reactors and operation conditions

Leach bed reactor with total and working volume of 4.5 L and 3 L, respectively was used in this study. The reactor is divided by a perforated plate into two sections. In the top working volume a sand layer (300 g) was placed on a nylon screen to facilitate filtering the leachate. The bottom chamber was used as the leachate holding tank. Two sets of experiments were performed in this study. In the first set of experiment five leach bed reactors (designated as LB1, LB2, LB3, LB4 and LB5, respectively) were operated in batch mode to investigate the effects of neutralizing agent addition on the hydrolysis and acidogenesis of FW. Initially 1772 g of FW, 228 g of inoculum and 40 g of sawdust were mixed thoroughly, loaded to top chamber above the sand bed of each reactor. Then 1000 mL of $NaHCO_3$ solution with salinity of 1, 3, 5, and 7 g/L was added to the working volume of LB2, LB3, LB4 and LB5, respectively. A control reactor or LB1 was set up in the same way except that the neutralizing agent was replaced by 1000 mL of distilled water. Leaching occurred naturally and the leachate was collected in the bottom chamber. The neutralizing agent could be completely percolated within 8 h, allowing recirculation of the leachate to working chamber twice a day. Then the leachate was removed at fixed time everyday for analysis of pH and VFA concentrations before daily addition of freshly prepared neutralizing agent. All the reactors were incubated at 30 °C until the leachate pH rose to slight alkaline condition (pH 8) and TOA concentration decreased to less than 250 mg/L.

In the second set of experiment four leach bed reactors were operated in semi-continuous mode to investigate the effects of feeding loads on the leachate VFA composition during the hydrolysis and acidogenesis of FW. Operational conditions were similar to the first set of experiments, except that 500 mL of $NaHCO_3$ solution containing salinity of 5 g/L was used as neutralizing agent and that FW was added every day at feeding loads of 50, 100, 150 and 200 g/d, respectively. Hydrolysis and acidogenesis was initiated by addition of all those materials to the working volume and incubation of the reactors at 30 °C. During the semi-continuous operation period the leachate collected in the bottom chamber was also recirculated to the working volume twice a day. The leachate was removed at fixed time everyday for analysis of pH and VFA concentrations before daily addition of FW and freshly prepared neutralizing agent. Gentle mixing was performed to allow organic materials evenly contact to hydrolytic and acidogenic bacteria. Semi-continuous operation lasted for 24 days for each of the reactors.

2.3. Analytical methods

Total solids of the FW were determined by drying the mixture at 105 °C to a constant weight. Volatile solids were determined by igniting the dried sample at 550 °C for 16 h in a muffle furnace. The pH values of the leachates were determined with a pH meter (Leici PHST-4A). Organic acids present in the leachate samples were measured by high-performance liquid chromatography (Prominence LC-20A) equipped with reversed phase C18 column (Phecda, 5 μm × 25 cm × 4.6 mm) and detected at the wavelength of 210 nm. A mixture of methanol and 10 mmol/L phosphate buffered solution (PBS) (pH 2.5) at 15:85 (v/v) was used as mobile phase at a flow rate of 0.5 mL/min. Leachate samples were filtered through 0.22 μm cellulose acetate membrane with an injection volume of 10 μL for HPLC analysis.

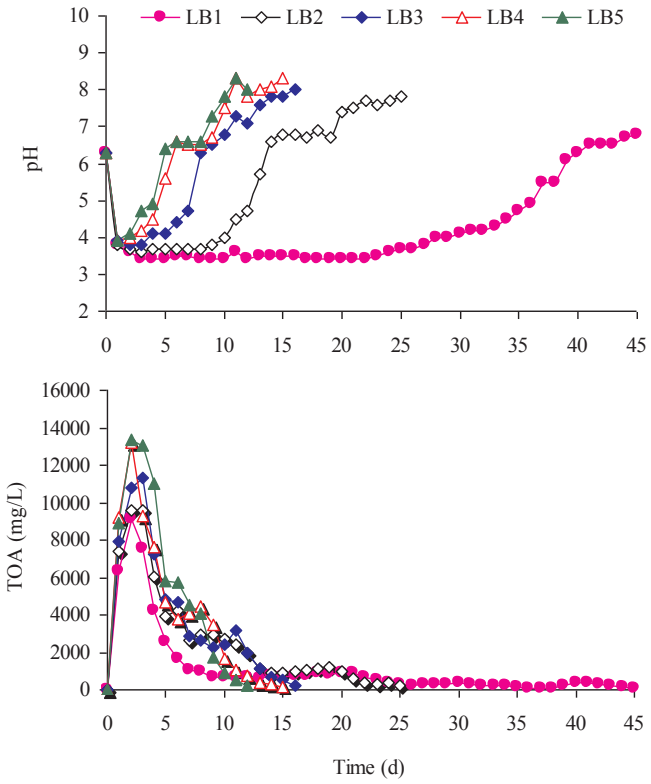

Fig. 1. pH and TOA concentration of the leachates from hydrolytic and acidogenic reactors as affected by addition of neutralizing agent. Note: LB1-LB5 was daily leached by $NaHCO_3$ solutions with salinity of 0, 1, 3, 5 and 7 g/L, respectively.

3. Results and discussion

3.1. Effects of neutralizing agent on acidogenesis of FW in batch culture mode

Rapid hydrolysis and acidogensis of FW occurred in all leach bed reactors as indicated by a rapid decline in the leachate pH values from 6.3 to 3.8 on the first day of operation and a rapid increase in the total organic acid (TOA) concentration to their peak values on day 2 (Fig. 1), confirming the effectiveness of anaerobic digested sludge as an inoculum for hydrolytic and acidogenic reactors (Grimberg et al., 2015; Kinnunen et al., 2014; Voelklein et al., 2016; Xu et al., 2011). Both hydrolytic and acidogenic bacteria were fully activated during the first two days of operation. After that leachate pH value showed an increasing trend till slightly alkaline condition (pH 8) was reached while TOA concentration decreased continuously till the end of operation. A long incubation time period of 45 d was required before the pH of leachate rose to alkaline condition and TOA concentration decreased to less than 250 mg/L in the control that did not receive the neutralizing agent, and it was shortened to 25, 16, 15 and 12 d, respectively when the reactor was daily added with $NaHCO_3$ solution with salinity of 1, 3, 5 and 7 g/L. Furthermore, TOA concentrations in the leachate from