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Potential impact of salinity on methane production from food waste anaerobic digestion

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ABSTRACT

Previous studies have demonstrated that the presence of sodium chloride (NaCl) inhibited the production of methane from food waste anaerobic digestion. However, the details of how NaCl affects methane production from food waste remain unknown by now and the efficient approach to mitigate the impact of NaCl on methane production was seldom reported. In this paper, the details of how NaCl affects methane production was first investigated via a series of batch experiments. Experimental results showed the effect of NaCl on methane production was dosage dependent. Low level of NaCl improved the hydrolysis and acidification but inhibited the process of methanogenesis whereas high level of NaCl inhibit both steps of acidification and methanogenesis. Then an efficient approach, i.e. co-digestion of food waste and waste activated sludge, to mitigate the impact of NaCl on methane production was reported. Finally, the mechanisms of how co-digestion mitigates the effect on methane production caused by NaCl in co-digestion system were revealed. These findings obtained in this work might be of great importance for the operation of methane recovery from food waste in the presence of NaCl.

1. Introduction

Food waste is inevitably discharged from domestic and commercial kitchens, cafeterias and restaurants with large amounts. It was estimated that the annual amount of food waste in China was 82.80 million tonnes (Kiran et al., 2014). Food waste has become the main source of odor, toxic gas, and groundwater contamination, which posed great threat to the environment if handled improperly. On the other hand, food waste is composed of high levels of organic substrates such as carbohydrate, protein and lipids, which makes it as ideal renewable resource (Zhao et al., 2015a, 2014; Guo et al., 2014a). Anaerobic digestion is considered as a promising technology for food waste treatment by which pathogen can be killed, the volume of food waste can be reduced, and high-valued products such as short-chain fatty acid (SCFA), methane can be obtained, simultaneously (Wang et al., 2013; Zhao et al., 2015b; Zhao et al., 2016a, 2016b).

Salt (e.g., NaCl), a type of food flavoring agents, is accumulated in food waste with large amounts when the food is processed. The general level of NaCl is in the range of 2% ~ 5% (in term of mass fraction), and the content may show significant difference with different regional eating habits (Wang et al., 2015c). Na^+ is an essential element for the cell synthesis, growth, and metabolism involved in anaerobic digestion system. Appropriate concentration of Na^+ can promote the activity of enzyme reaction, maintain the balance of biofilm and regulate osmotic pressure in the process of microbial growth (Chen et al., 2008). However, high level of Na^+ caused the decrease of biogas production and even resulted in the failure of anaerobic digestion system. It was documented that when the concentration of Na^+ increased form 5.0 g/L to 10.0 g/L, the production of methane decreased from 50% to 10% as compared with that in control (Rinzema et al., 1988). It was also reported that 3.5–5.5 g/L Na^+ caused moderate inhibition on the activities of methanogens, and 8.0 g/L Na^+ seriously inhibited the production of methane (Chen et al., 2008). Kim et al. (2009) investigated the impact of Na^+ on hydrogen production, and found that high level of Na^+ might alter metabolism of microorganisms to promote the production of lactic acid while inhibit the production of butyrate. Short chain fatty acid (SCFA) is an important intermedi-

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ate product during anaerobic digestion of food waste, the presence of salinity also affects SCFA production. Zhao et al. (2016a) demonstrated that with the increase of NaCl level from 0 to 8 g/L SCFA production increased from 367.6 to 638.5 mg chemical oxygen demand (COD)/g of volatile suspended solids (VSS). However, further increase of NaCl caused severe inhibition of SCFA production. Despite these significant progresses, little information of how NaCl affects methane generation from food waste is currently available.

The serious inhibition of NaCl on methane production indeed existed during the practical operation of food waste anaerobic digestion, and previous studies mainly focused on the quantitative relation between NaCl concentration and methane yield. To date, however, the details of how NaCl affects methane production from food waste anaerobic digestion remain unknown. In addition, the efficient approach to mitigate the inhibition caused by NaCl is rarely reported. According to the previous report, the degree of inhibition caused by NaCl is dosage dependant (Zhao et al., 2016a), thus co-digestion of food waste with other easily degradable organic compounds to dilute the content of NaCl in food waste might be an efficient strategy to improve the production of methane (Chen et al., 2013; Wu et al., 2016; Guo et al., 2014b). Waste activated sludge (WAS), generated from wastewater treatment plants (WWTPs) with huge amounts daily, contains high level of organic substrates (e.g., protein, carbohydrate) (Wang et al., 2015a, 2015b; Zhao et al., 2016c; Sun et al., 2016; Wang et al., 2017a, 2017c; Chen et al., 2016; Leng et al., 2015). Although co-digestion of food waste and WAS for methane production has been extensively investigated before, using co-digestion to mitigate the inhibition caused by NaCl on methane production has been seldom reported so far.

The aims of this paper are to understand the details of how NaCl affects methane production and report an efficient approach to mitigate the inhibition caused by NaCl during anaerobic digestion of food waste. First, the productions of methane from food waste with different levels of NaCl addition were compared. Then, the details of how NaCl affects methane production were investigated by analyzing the role of NaCl on the bio-transformation steps of hydrolysis, acidification, and methanogenesis. Finally, an efficient approach e.g., co-digestion of food waste and WAS, to mitigate the inhibition caused by NaCl during anaerobic digestion of food waste was reported. It can be expected that the findings obtained in this work provide further understanding on how NaCl affects food waste anaerobic digestion and might guide engineers to achieve energy recovery from food waste.

2. Materials and methods

2.1. Source of food waste, WAS, and inoculum

Food waste used in this study was withdrawn from a cafeteria in Hunan University (Changsha, China), food waste is mainly composed of rice, noodles, and vegetables. The indigestible substrates (e.g., inorganic particles, bones, and chopsticks) were first removed and then the food waste was crushed into small particles (1–3 mm) for further use. The inherent NaCl and grease involved in food waste were eliminated by washing three times using deionized water. Then, a certain volume of tap water was added into food waste (food waste: tap water = 10/1, V/V) to make the fermentation substrates fluid state. The main characteristics of food waste are as follows: pH 6.5 ± 0.1, total suspended solids (TSS) 24.9 ± 1.2%, VSS 18.8 ± 1.1%, total COD 251.9 ± 7.9 g/L, total carbohydrate 121.8 ± 4.2 g COD/L, total protein 32.5 ± 1.3 g COD/L.

WAS used in this work was taken from the secondary tank of a municipal wastewater treatment plant in Changsha, China. WAS was first filtered with a 1 mm × 1 mm screen and then concentrated in a 4 °C-controlled refrigerator for 24 h before use. The main characteristics of WAS are as follows: pH 6.9 ± 0.1, TSS 13,060 ± 180 mg/L, VSS 10,120 ± 110 mg/L, total COD 13,560 ± 160 mg/L, soluble COD 150 ± 15 mg/L, total protein 8960 ± 140 mg COD/L, total carbohydrate 1380 ± 80 mg COD/L, and SCFA 32.5 ± 0.8 mg COD/L.

The effect of NaCl on methane production from the co-digestion of food waste and WAS was also investigated in this work. Food waste was mixed with WAS at the ratio of 6/1 in terms of mass fraction according to the literature (Zhao et al., 2016a), and the main characteristics of mixture are as follows: pH 6.7 ± 0.1, TSS 21.3 ± 1.2%, VSS 15.3 ± 0.8%, total carbohydrate 65.8 ± 3.4 g COD/L, total protein 17.5 ± 1.1 g COD/L.

Inoculum applied in this work was collected from an anaerobic reactor for WAS treatment, the main characteristics of inoculated sludge are as follows: TSS 12,600 ± 180 mg/L, VSS 9560 ± 210 mg/L, total COD 13,160 ± 160 mg/L, and soluble COD 210 ± 180 mg/L.

2.2. Effect of NaCl on methane production from food waste anaerobic digestion

Five replicate anaerobic reactor with working volume of 1.0 L each were conducted to assess the impact of NaCl on methane production from food waste. First, 4.5 L of food waste and 0.5 L of inoculated sludge mixture were evenly divided into five reactors, respectively. Then, different dosages of NaCl were added into those reactors to obtain the pre-designed level of NaCl of 0, 2.0, 5.0, 10.0, and 15.0 g/L. pH in all anaerobic reactors were maintained at 7.0 ± 0.1 by adding 4.0 M hydrochloric acid or 4.0 M sodium hydroxide, which was beneficial to the activities of methanogenic *Archaea* (Appels et al., 2008; Wang et al., 2015b; Li et al., 2016). Afterwards, those reactors were flushed with high purity nitrogen for 60 s to eliminate oxygen, sealed with rubber stoppers, and fermented in an air-bath shaker (120 rpm) at 35 ± 1 °C for 30 d. All tests were performed in triplicate. During the entire process of food waste anaerobic digestion, the content of methane was determined periodically by releasing the pressure in the serum bottle using a 300 mL glass syringe to equilibrate with the room pressure according to the method documented in the literature (Owen et al., 1979). The cumulative volume of methane was calculated by the following equation:

$$V_{m,i} = V_{m,i-1} + C_{m,i}V_{G,i} - C_{m,i-1}V_{G,i-1} \quad (1)$$

where $V_{m,\,i}$ and $V_{m,\,i-1}$ represent the volume of methane in current (m, i) and previous (m, $i-1$) determination, respectively. $C_{M,i}$ and $C_{M,i-1}$ are the respective percent content of methane measured by gas chromatography in the current and previous time determination, and $V_{G,i}$ and $V_{G,i-1}$ represent respectively the total gas volumes in the current and previous time determination.

2.3. Effect of NaCl on each step involved in food waste anaerobic digestion

Fifteen replicate serum bottles with working volume of 1.0 L each were performed to assess the impact of NaCl on each step involved in food waste anaerobic digestion. The fifteen replicate serum bottles were first divided into three groups (Group-I, Group-II, and Group-III) with five in each. Group-I was carried out to assess the impact of NaCl on the hydrolysis of solubilized organic matter. Whereas, Group-II and Group-III were conducted to evaluate the acidification of hydrolyzed products and methanogenesis of acidification substrates, respectively. Each serum bottle in this group was first received 0.1 L of inoculated sludge and the 0.9 L of synthetic wastewater, and the detail information of synthetic wastewater in each group was shown below. The concentration of NaCl in each group was controlled at 0, 2.0, 5.0, 10.0 and