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Research article

Effect of temperature on continuous dry fermentation of swine manure

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ABSTRACT

Laboratory-scale experiments were performed on the dry digestion of solid swine manure in a semi-continuous mode using 4.5 L down plug-flow anaerobic reactors with an organic loading rate of 3.46 kg volatile solids (VS) m^{-3} d^{-1} to evaluate the effects of temperature (15, 25 and 35 °C). At 15 °C, biogas production was the poorest due to organic overload and acidification, with a methane yield of 0.036 L CH_4 g^{-1} VS added and a volumetric methane production rate of 0.125 L CH_4 L^{-1} d^{-1}. The methane yield and volumetric methane production rate at 25 °C (0.226 L CH_4 g^{-1} VS added and 0.783 L CH_4 L^{-1} d^{-1}, respectively) were 6.24 times higher than those at 15 °C. However, the methane yield (0.237 L CH_4 g^{-1} VS added) and the volumetric methane production rate (0.821 L CH_4 L^{-1} d^{-1}) at 35 °C were only 4.86% higher than those at 25 °C, which indicated similar results were obtained at 25 °C and 35 °C. The lower biogas production at 35 °C in dry digestion compared with that in wet digestion could be attributed to ammonia inhibition. For a single pig farm, digestion of solid manure is accomplished in small-scale domestic or small-farm bioreactors, for which operating temperatures of 35 °C are sometimes difficult to achieve. Considering biogas production, ammonia inhibition and net energy recovery, an optimum temperature for dry digestion of solid swine manure is 25 °C.

1. Introduction

Common collection methods for swine manure in production houses utilize a slatted floor with liquid storage under the slats (slurry system) or a flush system, both of which cause difficulty for the treatment of slurry to a degree that meets a typical discharge standard. Manual manure collection and the V-shaped pit floor system fitted with a scraper are popular in large-scale pig farms (Schuchardt et al., 2011); however, these collection methods produce a considerable quantity of solid manure that must be disposed of. Anaerobic digestion is an attractive treatment strategy for swine manure and has been considered as the main commercial option for both treating and recycling biomass wastes (De Baere, 2000; Pham et al., 2014; Terradas-Ill et al., 2014; Bergland et al., 2015). On the basis of total solids (TS) concentration in the feedstock, the anaerobic digestion process can be classified as a wet process (<10% TS in the feed), a semi-dry process (10–20% TS in the feed) or a dry process (>20% TS in the feed) (Bolzonella et al., 2003; Kusch et al., 2008). When treating solid manure in the wet process, fresh and recycled water must be added to increase the water content of the feedstock. Conversely, in the dry process, the quantity of added water is minimal or no water is added, which minimizes energy consumption for digester heating and feed slurry pumping (Pavan et al., 2000). Moreover, the dry process generates much less digestate than the wet process, and the resulting digestate can be easily managed through a composting process or utilization as fertilizer (ten Brummeler, 2000). However, due to their high solid contents, these solid substrates are difficult to handle, pump and mix (Vandevivere et al., 2003). Therefore, the dry digestion process suffers from numerous inhibition problems (Liu et al., 2006).

One of the most important factors affecting anaerobic digestion is temperature (Cheunbarn and Pagilla, 2000). There are three possible ranges of temperature in which the process can be conducted: ambient temperature (10–25 °C), mesophilic temperature (35–37 °C) and thermophilic temperature (50–60 °C) (Mata-Alvarez et al., 2000). Considering the potential biogas yield and

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heating requirement, the optimum digester temperature is one of the most critical operating parameters influencing the economic viability of digester operation. Thermophilic digestion can effectively kill infectious germs and enhance the degradability of complex organic matter (Forster-Carneiro et al., 2008). However, with substrates having a high level of nitrogen (such as swine manure), ammonia inhibition can hinder thermophilic digestion (Hansen et al., 1998, 1999). Although anaerobic digestion at ambient temperature offers the advantages of simple operation and low energy consumption, low temperature gives rise to a low efficiency. Dhaked et al. (2010) suggested that the temperature of anaerobic digestion should not be lower than 10–11 °C. Considerable studies have shown that mesophilic anaerobic digestion has good potential for energy production and economic benefits (Chae et al., 2008; Guo et al., 2011).

The effect of temperature on anaerobic digestion of swine manure has been studied widely, but only for the wet process treating relatively “weak” feedstocks, such as those with chemical oxygen demand (COD) in the range of 3310–19,480 mg L^{-1} (Chae et al., 2008), TS of 2.17–8.5% (Safley and Westerman, 1994; El-Mashad et al., 2004; Alvarez and Lidén, 2009), volatile solids (VS) of 4.2–4.5% (Angelidaki and Ahring, 1994; Ahring et al., 2001). Little is known about the effect of temperature on the dry anaerobic digestion process.

In our previous study (Chen et al., 2015), swine manure was treated in a semi-continuous dry anaerobic digestion process in a down plug-flow anaerobic reactor (DPAR). However, the optimal temperature for this dry process was not determined. The aim of this study was to investigate the effect of temperature on dry anaerobic digestion, and to determine a clearly optimal temperature for the anaerobic digestion of swine manure.

2. Materials and methods

2.1. Experimental reactor

A DPAR was designed consisting of a double-layer cylinder made of plexiglas with a height of 375 mm and an internal diameter of 125 mm. The total volume and effective volume of the DPAR were 4.6 L and 4.5 L, respectively. The top of the reactor was fitted with a feeding inlet with an internal diameter of 20 mm. The bottom of the reactor had a digestate outlet with an internal diameter of 20 mm (Chen et al., 2015). The temperature of each reactor was controlled by means of circulating hot water in a thermostatically controlled water-bath.

2.2. Swine manure and inoculation sludge

Swine manure used as the feedstock in this experiment was a mixture of feces from sows, piglets and growing-fattening pigs on a swine farm in central Sichuan Province, China, 35 km from the laboratory. After collection, the swine manure was transported to the laboratory and stored at 0 °C until used. The average value of TS of manure was 27.4% (wet basis), and VS was 77.8% of TS, total Kjeldahl-N (TKN) was 2.28% of TS. The average value of ammonia nitrogen (NH_4^+-N) was 0.4 g L^{-1}.

The inoculation sludge was the digestate from an experimental digester treating solid swine manure (Chen et al., 2015). The TS of the inoculant was 11.4% (wet basis), and VS was 67.0% of TS, total Kjeldahl-N (TKN) was 2.37% of TS. The average value of ammonia nitrogen (NH_4^+-N) was 1.52 g L^{-1}.

2.3. Experimental methods

Three DPARs were operated simultaneously in a semi-continuous mode, one each at a digestion temperature of 15, 25 and 35 °C. At the beginning of the experiment, 4.5 L of inoculation sludge was added to each DPAR. Then, the mixed swine manure was loaded into each DPAR daily. Sufficient digestate was removed daily to maintain a constant working volume throughout the experiment. The organic loading rate for each DPAR was 3.46 g VS L^{-1} d^{-1} and the corresponding retention time of the reactors was 61.7 day.

2.4. Analytical methods

During the experiment, reactor biogas output and the pH of both feedstock and digestate were recorded daily. Concentrations of TS and ammonia nitrogen (NH_3-N) were measured every 2 days. Once the gas collection bag was filled, the biogas composition was measured. The biogas output was measured using a wet-type gas flow meter (LML-1, Changchun, China), and the biogas volumes were corrected for reporting at standard temperature and pressure (0 °C, 101.325 kPa). The composition of biogas was determined using a biogas component analyzer (Biogas 401, ADOS GmbH, Germany). The pH was analyzed using an acidometer (PHS-3C, DAPU, China). The analyses of COD, TS, VS and NH_3-N were carried out according to standard methods (APHA 2012).

3. Results

3.1. Biogas production at different temperatures

The daily biogas production measured at standard conditions is demonstrated in Fig. 1. As shown in Fig. 1, temperature had an obviously significant effect on the dry fermentation of swine manure. At 35 °C, the biogas production rate peaked on the 13th day, with a value of approximately 9.0 L d^{-1}. On the 26th and 55th days, the biogas production rate decreased until Day 62, after which the rate tended to be stable at approximately 6.5 L d^{-1}. When the temperature was 25 °C, the biogas production rate reached a maximum value of approximately 7.5 L d^{-1} on the 26th day. After the 31st day, the biogas production rate decreased; however, it began to increase again and remained at 6.0–7.0 L d^{-1} after the 52nd day. Before the 51st day and after the 64th day, the biogas production rate at 35 °C was higher than that at 25 °C. Between the 52nd and 63rd days, the biogas production rate was lower at 35 °C than that at 25 °C. At 15 °C, the biogas production rate was very low (approximately 1.0 L d^{-1}), which was 85% lower than that at 25 and

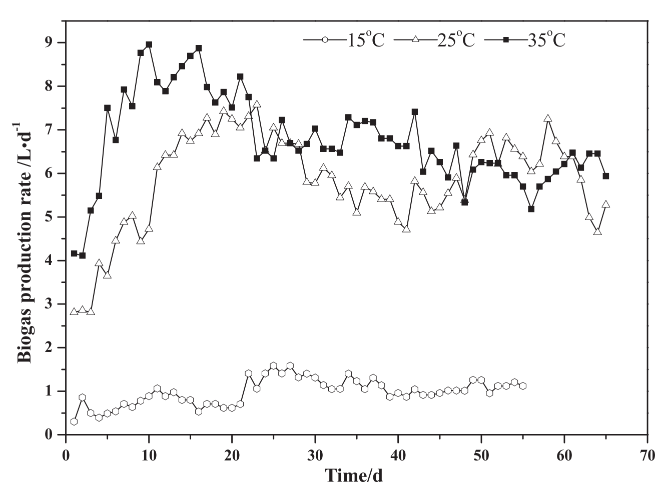

Fig. 1. Biogas production during dry digestion of swine manure at temperatures of 15, 25 and 35 °C.