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The effect of temperature variation on biomethanation at high altitude

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Abstract

The aim of the current study was to examine effects of daily temperature variations on the performance of anaerobic digestion. Forced square-wave temperature variations (between 11 and 25, 15 and 28, and 19 and 32 °C) were imposed on a bench-scale digester using a mixture of llama–cow–sheep manure in a semi-continuous process. The volumetric biogas production rate, methane yield, and the volatile solid reductions were compared with the results obtained from anaerobic digestion (AD) at constant temperatures.

The forced cyclic variations of temperature caused large cyclic variations in the rate of gas production and the methane content. As much as 94–97% of the daily biogas was obtained in the 12 h half-cycle at high temperature. The values for volumetric biogas production rate and methane yield increased at higher temperatures. The average volumetric biogas production rate for cyclic operation between 11 and 25 °C was 0.22 L d^{-1} L^{-1} with a yield of 0.07 m^3 CH_4 kg^{-1} VS added (VSadd), whereas for operation between 15 and 29 °C the volumetric biogas production rate increased by 25% (to 0.27 L d^{-1} L^{-1} with a yield of 0.08 m^3 CH_4 kg^{-1} VSadd). In the highest temperature region a further increase of 7% in biogas production was found and the methane yield was 0.089 m^3 CH_4 kg^{-1} VSadd.

The employed digester showed an immediate response when the temperature was elevated, which indicates a well-maintained metabolic capacity of the methanogenic bacteria during the period of low temperature. Overall, periodic temperature variations appear to give less decrease in process performance than *a priori* anticipated.

Keywords: Anaerobic digestion; Temperature; Periodic operation; Manure

1. Introduction

Anaerobic digestion (AD) that utilises manure for biogas production is one of the most promising uses of biomass wastes because it provides a source of energy while simultaneously resolving ecological and agrochemical issues. The anaerobic fermentation of manure for biogas production does not reduce its value as a fertilizer supplement, as available nitrogen and other substances remain in the treated sludge (Robertson et al., 1975). The use of AD is widely demonstrated in Asia with several million small-scale biogas plants in China and India (Khoiyangbam et al., 2004; Nazir, 1991).

Anaerobic digestion is a temperature dependent process, which is normally operated at defined and constant temperatures. Nevertheless, situations exist in which reactors are subject to repeated sudden and abrupt changes of temperature. On farms, bioreactors may be subjected to temperature fluctuations due to large variations in outdoor temperature, especially in highland and northern climates (Alvarez et al., 2006; Massé et al., 2003). The anaerobic digestion process is normally classified into three different temperature ranges, namely psychrophilic (<20 °C), mesophilic (20–40 °C) and thermophilic (>40 °C) (El-Mashad et al., 2004). The microorganisms involved in anaerobic digestion are characterized by an optimal temperature as well as by an upper limit that would cause immediate death of the considered group of bacteria (Chen, 1983).

The anaerobic digestion of manure in conventional treatment tends to have high process stability. However,

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sudden environmental changes, e.g. dramatic increases or drops in temperature, may cause severe disturbance in all parameters of the process, and the overall adaptation to new stable operation requires a long period of time (Bouskova et al., 2005; Cha et al., 1997). The extent of the disturbance has been related to the magnitude of the temperature variation (El-Mashad et al., 2004). The effect of increasing or decreasing temperatures followed by re-establishment of the initial temperature has been assessed in some previous studies. These studies show that a decrease in temperature typically causes lower chemical oxygen demand (COD) removal efficiencies, lower biogas production, and the accumulation of volatile fatty acids (VFA). Anaerobic digestors were in one previous study reported to recover their efficiencies fully after the temperature had been readjusted (Ahn and Forster, 2002). In another study, different recovery methods were tested after the temperature in digesters operating at steady state had been lowered. Raising the temperature in a single day gave only a transient effect and steady state was re-established within eight days. However, a slow increase in temperature led to more deleterious effect on the digester stability (Peck et al., 1985).

Digesters working with imposed daily cyclic temperature fluctuation have been the subject of only a few studies – with different purposes: Man-chang et al., 2006 simulated the heating failure of a thermophilic anaerobic digester fed with municipal organic solid wastes by rapidly decreasing the temperature and then re-establishing the optimal temperature. The effect of temperature fluctuations between 10 and 20 °C on a psychrophilic anaerobic sequencing batch reactor treating swine manure has also been evaluated. Results suggest that the performance of anaerobic sequencing batch reactors (ASBRs) will deteriorate significantly if the operating temperature is decreased from 20 to 10 °C. However, the ASBRs will remain stable and it will recover at 20 °C (Massé et al., 2003). In another study, the gas production dynamics was investigated using a laboratory scale digester fed daily with dairy manure that was operated at a constant temperature, as well as with a programmed temperature fluctuation of 3.3 °C about a mean of 35.8 °C. The data suggested that it would be possible to manipulate gas production by heating and cooling the content of the digester. Thus it may be possible to reduce gas storage volume by matching the production to a varying energy demand (Chayovan et al., 1988).

In highlands, such as the Bolivian Altiplano, where the livestock is composed mainly of llamas, cows and sheep (currently more than 1.8, 0.6, and 6.2 million animals, respectively), the use of the manure from these animals in anaerobic digestion could satisfy the energy demands for cooking and lighting (especially in remote rural areas) and reduce the use of firewood and the deforestation that goes with it. However, the extreme environmental conditions constitute a limiting factor for the biomethanation process. The Bolivian Altiplano has an average elevation of nearly 4000 m, it is swept by strong, cold winds, and has an arid, chilly climate, with large differences in temperature. The average highs during the day range from 15 to 20 °C and the average lows range from −15 to 3 °C with an atmospheric pressure around 460–500 mm Hg. The large variation in ambient temperature is likely to affect – to some extent – the operating temperature of low-cost simple anaerobic digestors. This effect of daily temperature fluctuations on the anaerobic digestion process has rarely been investigated.

The aim of the current work was to assess the effect of daily temperature variations on the semi-continuous anaerobic digestion of manures from the Bolivian Altiplano using an experimental model system with forced temperature variation. The daily temperature variations were simulated by a forced square-wave oscillation of the reactor temperature of an anaerobic digester, which used a mixture of llama, cow and sheep manure as feedstock. The performance of the digester was analysed with respect to volumetric biogas production rate, methane yield and volatile solid reduction in the substrate.

2. Methods

2.1. Feedstock and preparation

Llama, sheep and cow manure were collected from farms in the Bolivian Altiplano (19° S latitude, 68° W longitude). The manures were separately minced and pulverized with a semi-industrial cutter (CUT-3, Metvisa, Brazil). The samples were packed into 500 g polyethylene bags and stored at −10 °C in a freezer. The characteristics of the various manures are given in Table 1.

Batches of equal volumes of the three manures (33.3% (VS/VS) each) were prepared with llama manure (5.7% by weight), cow manure (13.4% by weight), and sheep manure (4.2% by weight). Each batch was diluted with tap water (76.6%) to obtain the desired solid content (6% of VS w/w). The slurry was homogenized in a domestic electric blender (Hamilton Beach 908, Hamilton Beach Commercial, USA) and fractionated (with a volume defined by the value of the desired hydraulic residence time, HRT = 30 days). The samples were packed into polyethylene bags and stored in a freezer. The samples for each day were withdrawn from the freezer and allowed to thaw overnight.

Table 1
Characteristics of fresh undiluted manure used in experiments at 18, 25, 35 °C and temperature fluctuation

Analysis	Llama manure	Cow manure	Sheep manure
Total solids (% w.w)	49.5 (3.2)	19.8 (1.1)	77.6 (2.2)
Volatile solids (% of TS)	70.3 (2.2)	74.9 (1.6)	61.3 (5.6)
Total nitrogen (% of TS)	1.7 (0.1)	1.6 (0.2)	1.1 (0.3)
Total organic carbon (% of TS)	29.5 (2.3)	26.5 (5.7)	18.9 (4.1)
Total phosphorous (% of TS)	0.4 (0.1)	0.4 (0.1)	0.5 (0.1)
Total potassium (% of TS)	1.5 (0.2)	0.7 (0.3)	1.8 (0.5)

Standard deviation from five samples in parentheses.