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Start-up of a sequential dry anaerobic digestion of paunch under psychrophilic and mesophilic temperatures

Valentine Nkongndem Nkemka, Xiying Hao *

Agriculture and Agri-Food Canada, Lethbridge Research and Development Centre, 5403 1st Ave S., Lethbridge, Canada

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ABSTRACT

The present laboratory study evaluated the sequential leach bed dry anaerobic digestion (DAD) of paunch under psychrophilic (22 °C) and mesophilic (40 °C) temperatures. Three leach bed reactors were operated under the mesophilic temperature in sequence at a solid retention time (SRT) of 40 d with a new batch started 27 d into the run of the previous one. A total of six batches were operated for 135 d. The results showed that the mesophilic DAD of paunch was efficient, reaching methane yields of 126.9–212.1 mL g^{-1} volatile solid (VS) and a VS reduction of 32.9–55.5%. The average daily methane production rate increased from 334.3 mL d^{-1} to 571.4 mL d^{-1} and 825.7 mL d^{-1} when one, two and three leach bed reactors were in operation, respectively. The psychrophilic DAD of paunch was operated under a SRT of 100 d and a total of three batches were performed in sequence for 300 d with each batch starting after completion of the previous one. Improvements in the methane yield from 93.9 to 107.3 and 148.3 mL g^{-1} VS and VS reductions of 24.8, 30.2 and 38.6% were obtained in the consecutive runs, indicating the adaptation of anaerobic microbes from mesophilic to psychrophilic temperatures. In addition, it took three runs for anaerobic microbes to reduce the volatile fatty acid accumulation observed in the first and second trials. This study demonstrates the potential of renewable energy recovery from paunch under psychrophilic and mesophilic temperatures.

1. Introduction

Livestock operations in Canada generate organic waste which, if not treated, will negatively affect the environment. An example of such waste is paunch, partially digested feed recovered when cattle are slaughtered. Currently, paunch is rendered, landfilled or composted but it contains organic compounds, such as fibers (cellulose, hemicellulose), volatile fatty acids (VFA), proteins and lipids, which can be anaerobically converted into biogas (Tritt and Kang, 1991). The estimated biogas potential of paunch with a total solids (TS) content of 22.5–29.6% was 31.1–46.0 GW h (Nkemka et al., 2015) from the 2.1 million cattle slaughtered in 2012 in Alberta, Canada. Anaerobic digestion of paunch is therefore a suitable waste management method, since it produces methane that can in turn reduce the treatment cost. In addition, anaerobic digestion leads to the production of a digestate, which can reduce the application and purchasing costs of mineral fertilizers.

Dry anaerobic digestion (DAD) is fast becoming a process configuration of choice for farm-scale biogas operations due to its simplicity. The DAD of cow manure has been demonstrated at a pilot-scale using three simple steps of fill, react and draw (Massé et al., 2014, 2015). Low maintenance and supervision is another advantage of sequential batch DAD that encourages its deployment by farmers. Treatment of solid wastes at a TS content of 15–50% is categorized under DAD, while for wet processes the TS range is from 2% to 12% (Ahn et al., 2010; Nizami and Murphy, 2010). Dilution of solid wastes prior to anaerobic digestion results in an increase in reactor size, heating and handling demands (Karthikeyan and Visvanathan, 2013). Avoiding the dilution of solid wastes, DAD leads to the production of digestate with high agronomic value due to its high nutrient concentration and less energy is needed to spread it on farmland than the product of wet anaerobic digestion (Ahn et al., 2010; Massé et al., 2015). However, channelling and poor microbial contact with the substrate are two disadvantages of DAD (Nizami and Murphy, 2010).

Several DAD technologies have been developed mainly for the treatment of municipal solid waste (MSW), including the single phase continuous digesters marketed by DRANCO, VALORGA, KOMPOGAS, and ITDAT; batch digesters from SEBAC and DiCOM; and multiphase digesters from BTA (Karthikeyan and Visvanathan, 2013; Massé et al., 2015). BEKON and ATF are also market garage-type batch digesters for DAD of agricultural residues and solid wastes (Karthikeyan and Visvanathan, 2013).

* Corresponding author.
E-mail address: xiying.hao@agr.gc.ca (X. Hao).

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The characteristics of MSW and agricultural wastes/residues differ considerably and the use of digesters developed for the treatment of MSW may not be as suitable for agricultural wastes. Continual research is therefore needed to develop simple, affordable and more efficient dry digesters for the treatment of agricultural wastes and energy crops.

Previous research work has been focused on DAD under thermophilic (>45 °C) and mesophilic (25–40 °C) temperatures (Arikan et al., 2015; Li et al., 2014, 2011; Sakar et al., 2009), which are fast but require energy for heating. Operating in the psychrophilic temperature range (<20 °C) saves energy and the adaptation and enrichment of psychrophilic microbes could be more suitable in a temperate region such as Canada. The current study evaluated the sequential leach bed DAD of paunch under psychrophilic and mesophilic temperatures. The effect of the sequential DAD on methane production, total chemical oxygen demand (tCOD) and VFA degradation together with the effect of the initial and final values of water-nitrogen, NH_4^+-N, dissolved organic carbon (DOC), total alkalinity (TA) and C/N ratio were evaluated.

2. Materials and methods

2.1. Feedstock characteristics and anaerobic inoculum

The paunch used in this experiment was collected in March 2014 from Desviar Inc., High River, Alberta, Canada and stored at −20 °C until use. The feedstock characteristics presented in Table 1 are the same as previously reported (Nkemka et al., 2015). The paunch had a TS content of 29.6% and high fiber content as cellulose (33.3% of TS) and hemicellulose (27.6% of TS). Also, the C/N ratio was 21.8, which is within the recommended range of 20–30 reported for efficient anaerobic digestion (Yadvika et al., 2004). The seed sludge used as anaerobic inoculum was collected in January 2015 from the Lethbridge Biogas LP full-scale plant, which digests agro-industrial and food wastes under mesophilic temperature (40 °C). Prior to the start of the experiment, the inoculum was incubated for 5 days at (40 °C) to reduce residual methane production and then stored at room temperature (22 °C) for subsequent use. The inoculum had a pH of 7.98, high water-N concentration of 3797 mg L^{-1} and total alkalinity of 19.3 g L^{-1}. The inoculum therefore provided a starter anaerobic culture together with nutrients and buffer capacity.

2.2. Sequential leach bed operation

Anaerobic digestion of paunch was performed using 4 × 1.3 L (38 cm high and 6.5 cm internal diameter) leach bed reactors. Three of the leach bed reactors (LB1, LB2 and LB3) were used for the sequential digestion of paunch under mesophilic temperature (40 °C) and were each operated twice (e.g., $LB1_{run1}$ and $LB1_{run2}$). The fourth reactor, LB4, was used for the digestion of paunch under the psychrophilic (22 °C) temperature in three successive runs ($LB4_{run1}$ to $LB4_{run3}$). The operation of our sequential leach bed reactors was similar to the schematic representation of the sequential leach bed anaerobic process as reported previously (Nizami and Murphy, 2010). The inoculum and substrate were mixed prior to loading the reactors and liquid content in the reactor was mixed twice a week and during sampling. The sampling was performed by withdrawing 3 mL every 2–3 days (Mondays, Wednesdays and Fridays). Also, the mixing of the reactor content was performed using a peristaltic pump operated at 5 mL min^{-1} for 1 h. Previous research on the anaerobic digestion of manure in a pilot-scale digester had shown it to operate well without affecting reactor performance (Massé et al., 1996).

At start-up, 220 g of paunch (60 g VS), 220 g water and 300 g inoculum were placed in the reactors for the first batches, while 50% of the digestate replaced the inoculum in the second run digesting paunch under the mesophilic and psychrophilic temperatures. The inoculum to substrate ratio (ISR) was 0.1 based on g VS and 0.2–0.8 v/v inoculation has been reported previously for faster start-up of mesophilic leach bed processes (Dearman and Bentham, 2007).

For mesophilic digestion, the solid retention time (SRT) was set at 40 d and new batches were started 27 d into a previous batch. The start time of 27 d for a new batch was based on the operation of the first leach bed reactor, which resulted in a methane yield of 162.6 mL g^{-1} VS after 27 d or 54% of the batch methane yield of 299 mL g^{-1} VS (Nkemka et al., 2015). Also, the exchange of the leachate between a mature leach bed reactor and a new batch was performed for 3 d to further increase the chance of VFA degradation and a faster start-up as previously reported (Nizami and Murphy, 2010). This was achieved with the aid of a peristaltic pump, which operated at a flow rate of 5 mL min^{-1} for 40 min, exchanging 200 mL of leachate. $LB2_{run2}$ was allowed to operate until day 100.

The psychrophilic anaerobic leach bed digestion was operated for a long SRT of 100 d, since it was slow to degrade. Approximately, 100 mL of extra inoculum was added on day 39 in $LB4_{run1}$, on day 108 (8 d in $LB4_{run2}$) and on day 208 (8 d in $LB4_{run3}$) to adjust the pH to neutral. A higher ISR of 0.2 based on g VS was therefore used due to the addition of the extra inoculum.

During the experiment, samples were analyzed for pH, VFA, tCOD, biogas composition and volume. Also, the initial and end samples of water-N, NH_4^+-N, DOC, C/N and TA were analyzed.

Table 1
Initial characteristics of paunch used in the sequential leach bed anaerobic digestion.

Feedstock characteristics	Inoculum	Paunch
TS (%)	3.3 ± 0.3	29.6 ± 2.5
VS (% of TS)	60.9 ± 1.2	93.0 ± 0.3
C (% of TS)	36.86 ± 0.33	41.5 ± 0.2
N (% of TS)	2.36 ± 0.04	1.9 ± 0.1
C/N	15.6 ± 0.3	21.8 ± 0.6
Cellulose (% of TS)	–	33.3 ± 0.9
Hemicellulose (% of TS)	–	27.6 ± 0.6
AD lignin (% of TS)	–	6.5 ± 0.8
CP (% of TS)	14.7 ± 0.2	11.6 ± 0.3
NH_4^+-N (mg L^{-1})	2997	217 ± 8
Water-N (g L^{-1})	3797	701 ± 28
DOC (g L^{-1})	1895	2607 ± 202
pH	7.98 ± 0.16	7.32
TA (g L^{-1})	19.3 ± 0.7	–
Reference		Nkemka et al. (2015)

AD lignin: Acid detergent lignin, DOC: Dissolved organic carbon, CP: crude protein, TA: Total alkalinity, TS: total solids, VS: volatile solids.

2.3. Analytical methods

Analyses of total solids (TS) and volatile solids (VS) were performed in accordance with standard methods (APHA, 1998). Measurements of pH, tCOD, VFA, TA, DOC, water-N, NH_4^+-N, C and N (using freeze-dried samples) and biogas volume and composition were performed as reported previously (Nkemka et al., 2015). The methane yield was calculated by dividing the normalized (273.15 K and 1 atm) methane volume produced by the amount of organic matter in g VS added at the start of the leach bed process. The VS of the pre-incubated inoculum was not included in the methane yield and OLR calculations in the first batch. However, the methane yield of a pre-incubated inoculum after 27 days of the methane potential batch test of paunch was 31.4 mL g^{-1} VS. The amount (g VS) carried forward as inoculation for the next batch was also included when calculating the methane yield and the organic loading rate (OLR) of subsequent runs (Table 2).

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