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Quantifying methane production from psychrophilic anaerobic digestion of separated and unseparated dairy manure

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ABSTRACT

In anaerobic digestion, methane (CH_4) production decreases as temperature decreases, resulting in a lower CH_4 production at psychrophilic (≤25 °C) digestion temperatures. Previous studies at mesophilic temperatures (30–35 °C) have shown that manure separation and digesting only the liquid fraction could result in the reduction of digester volume without sacrificing CH_4 production. In this research, biochemical methane potential (BMP) tests were used to quantify CH_4 production of unseparated and separated manure at two psychrophilic temperatures: 14 and 24 °C.

The results showed that CH_4 production decreased by approximately 70% when the temperature was decreased from 24 °C to 14 °C. Between days 20–216 at 24 °C, higher VS content of the unseparated manure resulted in significantly higher CH_4 production (29–40% more) compared to separated manure, on a volumetric basis, but at digestion times of ≤16 days, faster VS to CH_4 conversion rates in separated manure resulted in no significant differences in CH_4 production between the manure types. Similarly, at 14 °C, the higher VS content of the unseparated manure resulted in significantly higher CH_4 production (56–147% more) throughout most of 216-day experimental period, when normalized by volume. On a VS basis (mL CH_4/g VS), the separated manure at 24 °C produced significantly more CH_4 than the other treatments. The study suggests that at 24 °C, there will be higher CH_4 production, per volume of manure added, from unseparated manure due to the higher VS content, but when operating at a shorter digestion time, the differences could be insignificant.

1. Introduction

During anaerobic digestion (AD), both facultative and obligate anaerobic microorganisms work sequentially to extract energy from organic matter fed into the system, with renewable energy in the form of methane (CH_4)-enriched biogas as a product of this metabolism. AD technology can be used to treat wastewater sources, such as dairy manure, resulting in (1) reduction in detrimental impact of manure waste on water bodies by reducing chemical oxygen demand (COD), total solids (TS), and volatile solids (VS) (Lansing et al., 2010); (2) reduction in odor, which can help to improve relationships between farmers and their neighbors (Powers et al., 1999); (3) use of the CH_4-enriched biogas directly as a source of heat or in an electric generator (Lansing et al., 2008); and (4) capture, combustion, and thus, reduction in the quantity of methane (CH_4) released, a greenhouse gas 21 times more powerful than carbon dioxide, compared to traditional open lagoon storage of manure (AgSTAR, 2011; IPCC, 2007).

High costs, however, impede AD installation in temperate regions, such as the United States. ADs function best at mesophilic (30–35 °C) and thermophilic (50–60 °C) temperatures (Gerardi, 2003), and CH_4 production decreases when temperature decreases. Massé et al. (2003) found that decreasing the temperature of anaerobic swine manure reactors from 20 °C to 10 °C decreased CH_4 production by 70%. In addition, lower-temperature digesters have a longer lag-phase before CH_4 production commences. One study showed that dairy cow manure digested at less than 15 °C did not produce CH_4 for 165 days, while manure digested at 25 °C and 30 °C experienced shorter lag-phases of 66 and 33 days, respectively (Zeeman et al., 1988).

In order to keep biogas production high during colder months, most agricultural ADs in the US are heated and run at mesophilic temperatures, as opposed to psychrophilic (or ambient) temperatures (≤25 °C) (AgSTAR, 2006). To keep digesters in the mesophilic

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range, expensive heating and insulation systems must be installed and maintained. Many heating systems use a portion of the produced biogas to heat the digesters during the colder months, a period when the need for the produced CH_4 is the greatest for other on-farm activities, such as heating barns and buildings. The cost of insulation, installing heat recovery systems from biogas engine generators, and the in-vessel radiant heating mechanisms makes the installation of small-scale ADs in the US largely cost-prohibitive (Klavon et al., 2013), which is one of the reasons AgSTAR (2011) stated that digesters are more economically feasible on dairy farms with more than 500 cows, excluding more than 95% of the US dairy farms (USNASS, 2009). Methods to increase CH_4 production in temperate regions without increasing digester installation costs are thus needed.

This study investigated the effect of manure separation on net CH_4 production from ADs operating at psychrophilic temperature. Manure separation refers to the separation of manure to remove the coarse fractions from the liquid fraction. Separation can reduce clogging in pipes and pumps, and ease manure transportation. While there are several methods for manure separation including the use of mechanical presses, screens, or the addition of flocculants or coagulants to remove the coarse fraction from the liquid filtrate of manure (Pain et al., 1984; Rico et al., 2007), this study concentrated only on the use of a mechanical screw-press separator for solid separation.

Previous research has shown that the VS within separated manure converts to CH_4 more quickly than VS in unseparated manure, likely due to the VS within separated manure having smaller particle sizes leading to quicker degradation (El-Mashad and Zhang, 2010; Lo et al., 1983a,b; Rico et al., 2007). In addition, researchers such as Liao et al. (1984) and Lo et al. (1983a,b) have shown that digester volume could be reduced when digesting separated manure without sacrificing CH_4 production. Therefore, a farmer interested in reducing capital costs for AD construction could build a smaller reactor volume for only the separated manure with shorter retention times and still produce large quantities of CH_4.

Previous experiments that have compared CH_4 production between separated and unseparated manure, however, were conducted at mesophilic conditions (30–35 °C), with no published study investigating the effect of manure separation on CH_4 production at psychrophilic temperatures (≤25 °C). The research objectives for this study were to: (1) quantify differences in CH_4 production at two psychrophilic temperatures, (2) quantify differences in CH_4 production between the separated and unseparated manure fractions at these psychrophilic temperatures, and (3) determine how digestion time affects these differences.

2. Methods

Both unseparated manure and separated manure were collected during one sampling trip to the dairy facility at the USDA Beltsville Agricultural Research Center (BARC) in Beltsville, Maryland, USA and stored at 4 °C before analysis. At the BARC dairy facility, manure and urine, along with some straw bedding from the barn is scraped into a holding pit, which is then pumped into a belt-pressed mechanical screw-press separator (FAN®) that separates the coarse fractions of the manure from the liquid fraction. The liquid fraction is held at a separate holding pit, before being pumped into a continuous-stirred mesophilic digester. The unseparated manure was collected before the screw-press and the separated manure was collected after the screw press. Approximately 70% of the dry weight solids were removed from the manure during the separation process, resulting in the separated manure having approximately 30% of the dry weight solid mass of the unseparated manure (unpublished data).

Inoculum for the experiment was obtained from the BARC mesophilic digester treating the separated dairy manure. The inoculum contains CH_4-producing microorganisms that speed up the digestion process. It was collected on the same day as the manure and stored at 4 °C before analysis.

2.1. Biochemical methane potential (BMP) testing

The biochemical methane potential (BMP) test used in this study was adapted and modified from the procedures conducted by Moody et al. (2011) and Owen et al. (1979). In this study, the BMP tests were not conducted at the standard 35 °C, but conducted in two separate chambers operating at 14 °C and 24 °C to simulate the average temperatures for Fall (14 °C) and Summer (24 °C) in Baltimore, Maryland between 1981 and 2010 (NOAA, 2014).

The BMP test was conducted by monitoring the CH_4 production in 250 mL serum bottles filled with 100 mL of inoculum and 30 mL of either unseparated manure or separated manure. The inoculum volume was kept constant to reduce a potential compounding variable, resulting in an inoculum to substrate VS ratio (ISR) of 1:1 for the unseparated manure, and 2:1 for the separated manure, which are within the ISR range recommended by Moody et al. (2011) and Raposo et al. (2011). The control bottles consisted of 130 mL of inoculum without manure. No nutrient media was added during the BMP test to simulate field conditions.

To create anaerobic condition within the bottles, each bottle was purged with 70% N_2 and 30% CO_2 before being capped with butyl rubber stoppers. The bottles were incubated in two different chambers with temperatures of 14.0 ± 0.0 °C and 24.0 ± 0.0 °C. Triplicate bottles of the different treatments (unseparated manure + inoculum, separated manure + inoculum, and inoculum only) were incubated in each temperature chamber for 216 days. During incubation, no shaking/mixing was conducted to simulate simple, unmixed digestion conditions, such as those for covered lagoon systems.

The quantity of biogas produced in each BMP bottle was measured at least once every week using a graduated, gas-tight, wet-tipped 50 mL glass syringe inserted through the septa and equilibrated to atmospheric pressure. The measured biogas was then vented. After venting, 0.10 mL of biogas was collected from each bottle using a luer-lock, gas tight syringe and injected into an HP 5890 Series II gas chromatograph (GC) to measure percent CH_4. The GC was equipped with a flame ionization detector (FID) and was run with the following parameters: (1) injection temperature of 200 °C; (2) detector temperature of 250 °C; and (3) a flow rate of 300 mL/min for helium, the carrier gas.

In order to take into account the CH_4 produced from the inoculum organic matter, the CH_4 production values (mL CH_4/mL inoculum) from the triplicate inoculum bottles at each temperature were averaged, normalized by inoculum volume, and subtracted from the CH_4 production of each treatment bottle incubated at the same temperature. All CH_4 production volumes were converted using the ideal gas equation to standard temperature and pressure (0 °C and 1 atm). The CH_4 produced by the manure sources were normalized using two different methods: mL CH_4/g VS, which shows the efficiency of VS conversion to CH_4, and mL CH_4/mL manure to show which type of manure would produce higher CH_4 for a given volume of manure digested.

2.2. Substrate characterization

Total solids, VS, pH, and COD analyses were conducted on the two manure types and the inoculum before the BMP experiment