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Reduction of volatile fatty acids and odor offensiveness by anaerobic digestion and solid separation of dairy manure during manure storage

Laura H. Page [a], Ji-Qin Ni [a, *], Hao Zhang [a], Albert J. Heber [a], Nathan S. Mosier [a], Xingya Liu [a], Hung-Soo Joo [b], Pius M. Ndegwa [b], Joseph H. Harrison [c]

[a] *Department of Agricultural and Biological Engineering, Purdue University, 225 S. University Street, West Lafayette, IN 47907, USA*
[b] *Department of Biological Systems Engineering, Washington State University, PO Box 646120, Pullman, WA 98935, USA*
[c] *Department of Animal Sciences, Washington State University, Research and Extension Center, 2606 West Pioneer, Pulyallup, WA 98371, USA*

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ABSTRACT

Volatile fatty acids (VFA) play an important role in the biodegradation of organic wastes and production of bioenergy under anaerobic digestion, and are related to malodors. However, little is known about the dynamics of VFA during dairy manure storage. This study evaluated the characteristics of VFA in dairy manure before and after anaerobic co-digestion in a laboratory experiment using eight lab-scale reactors. The reactors were loaded with four different types of dairy manure: (1) liquid dairy manure from a freestall barn, (2) mixture of dairy manure and co-digestion food processing wastes at the inlet of an anaerobic digester, (3) effluent from the digester outlet, and (4) the liquid fraction of effluent from a solid separator. Four VFA (acetic, propionic, butyric, and 2-methylbutyric acids) were identified and quantified in weekly manure samples from all reactors. Results showed that the dominant VFA was acetic acid in all four manure sources. The off-farm co-digestion wastes significantly increased the total VFA concentrations and the proportions of individual VFA in the influent. The dairy manure under storage demonstrated high temporal and spatial variations in pH and VFA concentrations. Anaerobic digestion reduced the total VFA by 86%–96%; but solid–liquid separation did not demonstrate a significant reduction in total VFA in this study. Using VFA as an indicator, anaerobic digestion exhibited an effective reduction of dairy manure odor offensiveness.

1. Introduction

Volatile fatty acids (VFA) play a key role as an intermediate product in the conversion of organic matter to biogas in anaerobic digestion (AD) systems. In the past two decades, the number of successful dairy manure-based AD systems has grown tremendously in the United States (USEPA, 2012). The use of non-manure off-farm substrates for co-digestion with manure can enhance biogas yields from dairy manure AD systems thus making them more attractive to producers (Frear et al., 2011). Although co-digestion is a favorable approach to improving biogas production and therefore making biogas plants more economically viable, certain challenges still exist. Selection of co-substrates, the amount of co-substrates added to manure, the organic loading rate, and the digester operating parameters affect the degradation mechanisms of the compounds and ultimately affect methane production (Atandi and Rahman, 2012). Degradation processes of certain substrates can result in the production of compounds (e.g., increased acids and hydrogen sulfide) that have inhibitory effects on methanogen growth (Gerardi, 2003). Many studies have been conducted to test different co-substrates, especially food processing wastes, under different operating conditions (Luostarinen et al., 2009; Frear et al., 2011; Atandi and Rahman, 2012).

Although one of the benefits for AD is the production of bioenergy, odor concerns have been the main motivation for many owners of the existing digesters (Lazarus, 2008). As AD technology continues to change and develop, it will be important to continue evaluating the environmental impact of AD, including the effect on odor generation from stored manure, especially as affected by the addition of different co-digestion substrates. If microorganisms are not able to process all the incoming substrate, there may be undigested material still present in effluent manure. While stored, digester effluent below the liquid surface, where oxygen is

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* Corresponding author.
E-mail address: jiqin@purdue.edu (J.-Q. Ni).

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unavailable, naturally undergoes AD (Lovanh et al., 2009). This leaves potential for incomplete fermentation of those undigested materials by bacteria and results in the production of odorous compounds (Miller and Varel, 2001).

Because they are the compounds most closely correlated with odor from animal manure, VFA may serve as a suitable indicator to quantify odor potential. The use of VFA to monitor odor intensity and the effectiveness of techniques for odor reduction has become accepted by many researchers (e.g., Miller and Varel, 2001; Zhang and Zhu, 2003). In an early study by Bell (1970), a close relationship between VFA and the odor offensiveness of stored poultry manure was established. Barth et al. (1974) late found that VFA correlated to dairy manure odor better than ammonia and hydrogen sulfide. Williams (1984) further determined that pig slurries containing >700 mg L^{-1} VFA could be unacceptably offensive. Sneath (1988) argued that pig slurries containing above 520 mg L^{-1} VFA should release offensive odors. This threshold of unequivocal unacceptability of odor at 520 mg L^{-1} was also used by Ndegwa (2003) to assess the impact that AD had on potential for odor.

Some anaerobic digestion facilities use solid separation in an attempt to further reduce odor from manure because most of the odor-generating organic substances are produced from manure solids (Ndegwa et al., 2002). The separation of manure into solid and liquid fractions has been observed to reduce the potential of odor generation from animal manure storage by removing coarse particles, which normally degrade slowly, and enhancing the oxygen transfer efficiency and therefore improving the stabilization of the liquid manure (Ndegwa, 2004; Hansen et al., 2006). In an experiment conducted by Ndegwa (2003), solid–liquid separation of pig manure resulted in reduction of VFA production in the first 30 days of liquid storage.

Quantification of VFA from dairy manure before and after AD treatment facilitates the assessment of digester function and evaluation of the potential for odor generation. However, VFA is still one of the poorly characterized groups of compounds present in animal agriculture (Alanis et al., 2010; Ni et al., 2012). There are only a few published studies on VFA in stored dairy manure. An early study by Barth and Polkowsk (1974) quantified VFA in stored dairy manure and correlated them to odor intensity. Later work by Patni and Jui (1985), El-Mashad et al. (2011), and Moller et al. (2004) investigated VFA characteristics in stored dairy-cattle manure, but the authors only tested raw manure from dairy-cattle. Miller and Varel (2001) studied VFA in fresh and aged (dried) manure from cattle. Frear et al. (2011) conducted a study at a dairy manure-based AD facility on differently treated manure, similar to this study, but they only reported the average concentration of three VFA. Page et al. (2014) characterized the VFA in regard to their temporal and spatial variations in undigested and digested dairy manure under uncovered storage conditions; but the authors did not compare with the VFA under covered (anaerobic) manure storage conditions. Additionally, they only tested limited number of co-digestion substrates.

Results in these publications were obtained under different experimental conditions, from which the variations make it difficult to compare the characteristics of VFA from the different studies. To improve the understanding of the dynamics of VFA, investigations under comparable experimental conditions are needed to characterize the VFA in dairy manure.

The objective of this paper was to (1) gain new insights into the effect of anaerobic digestion and post-AD solid–liquid separation on selected VFA, i.e., acetic, propionic, butyric, and 2-methylbutyric acids, and the dynamic and spatial characteristics of these VFA in four different manure sources from an AD system in a laboratory-scale manure storage experiment; and (2) evaluate the effectiveness of anaerobic digestion and post-AD solid–liquid on malodor reduction.

2. Materials and methods

2.1. Dairy manure and manure preparation

Four sources of dairy manure, two undigested and two digested as designated below, were collected from four different locations at a dairy farm AD system, which had a 16-day hydraulic retention time, in NW Washington State (WSDA, 2011) at the end of March 2012.

1. Raw manure: undigested liquid manure collected from a dairy barn on the farm;
2. Influent: undigested mixture of raw dairy manure and off-farm “pre-consumer, organic waste-derived materials” (WSDA, 2011), or co-digestion substrates, in the influent tank of the AD system;
3. Effluent: digested manure and co-digestion substrates in the effluent tank of the AD system;
4. SS effluent: liquid fraction of digested effluent in the outlet of a solid–liquid separator at the AD system.

Recorded daily inputs into the digester showed that, during the 16 days prior to the effluent manure collection for this study, the digester had been fed a mixture of co-digestion substrates, consisting of 2.7% “Blood” waste from a ruminant slaughter plant; 21.0% “Trap” that was a grease trap waste; 2.7% “Biodiesel” that was a byproduct, mostly glycerin, from crushing seeds for biodiesel production; 8.8% “Bedding” that was soiled bedding at the AD system site; and 64.8% raw dairy manure. During the entire day when manure was collected, a mixture of 6.4% of “Blood”, 21.7% of “Trap”, 4.5% of “Bedding”, and 67.4% of raw dairy manure was fed into the digester.

The collected four manure sources were separately poured into plastic containers that were sealed and frozen. The frozen containers were shipped to Purdue University in Indiana where they were thawed completely before filling eight reactors (R1 to R8). Prior to filling, each container was mixed with a power mixer until the mixture was homogeneous. The manure in the containers was continuously stirred while loading the reactors to ensure uniformity in replicate reactors (Fig. 1).

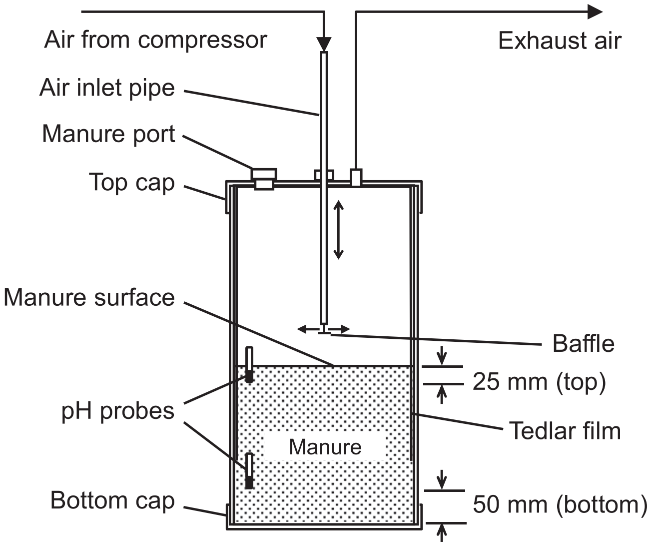

Fig. 1. Cross section of the reactor.