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Anaerobic digestion of chicken manure by a leach-bed process coupled with side-stream membrane ammonia separation

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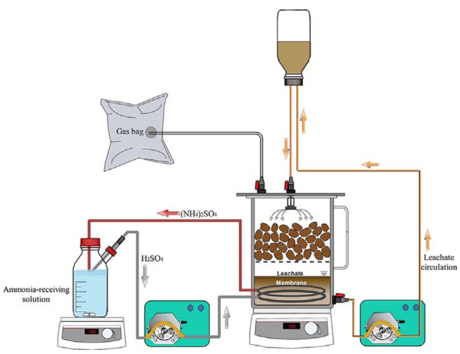
GRAPHICAL ABSTRACT



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ABSTRACT

This study pioneered the use of a single-stage methanogenic leach bed reactor (LBR) for high-solids (total solid content: 14%–16%) anaerobic mono-digestion of chicken manure. Chicken manure was loaded into the LBR in cloth sachets without adding any bulking agents. Ammonia was separated and recovered by placing a hydrophobic gas diffusion membrane in a leachate collection chamber. Methane production in the membrane-integrated LBR was 0.272 m^3/kgVS and 2.3 times higher than that in the control LBR. The results revealed that using membrane-integrated LBR for anaerobic digestion is a simple and cost-efficient technology for the mono-digestion of chicken manure and ammonia removal.

1. Introduction

The increase in the number of chicken farms around the world has resulted in a large production of chicken manure. The Turkish Statistical Institute (2015) has reported that approximately 313 million chickens were raised for egg and meat in Turkey in 2015. With a rough estimation, in 2015, 11 million tons of chicken manure was generated in Turkey. Chicken manure is generally used as fertilizer in the agriculture industry as it contains a high amount of nitrogen and phosphorus. The best way to recycle these nutrients is by applying chicken manure to the soil in a proper way (Bolan et al., 2010). The effective management of the manure is important because excess and inappropriate land application of chicken manure to soils can cause some environmental problems, e.g., greenhouse gas emissions, air pollution, eutrophication, and pathogen contamination (Bayrakdar et al., 2017a).

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Chicken manure is rich in biodegradable organic matter (Abouelenien et al., 2009; Bayrakdar et al., 2017a). Anaerobic digestion is an attractive solution for chicken manure management from the viewpoint of the stabilization of chicken manure and energy recovery. However, ammonia, one of the major inhibitory compounds particularly for methanogens, is released during the anaerobic digestion of chicken manure. The efficiency of the anaerobic digestion process is significantly affected at high ammonia concentrations, which leads to the accumulation of volatile fatty acids (VFAs), thereby causing a failure in the entire system in the digester (Bayrakdar et al., 2017a; Hansen et al., 1998; Niu et al., 2013; Sun et al., 2016; Webb and Hawkes, 1985). Inhibitory concentrations ranging from 1.4 to 14 $g\,L^{-1}$ have been reported to reduce biogas generation up to 50% (Chen et al., 2008). The inhibitory concentrations depend on certain factors, e.g. the concentration of total ammonia nitrogen (TAN), temperature, pH, and microbial acclimation (Yenigün and Demirel, 2013).

To overcome the ammonia inhibition problem and maintain a stable anaerobic digestion performance, wet anaerobic digestion of chicken manure (dry matter < 10%) is usually applied in the lab- and full-scale operations by using a considerable amount of dilution water (Bujoczek et al., 2000; Nie et al., 2015). However, using a considerable amount of dilution water generates a large volume of secondary waste and increases the water consumption; thus, high digester volume is required or low amount of biogas is generated per volume of digester (Nie et al., 2015; Sun et al., 2016). Bayrakdar et al. (2017a) have shown that stable biogas production can be achieved if the TAN concentration is maintained below 4000 $mg\,L^{-1}$ with an organic loading rate of 3.56 kgVS/m^3/day. In other words, if the ammonia concentration is maintained below the inhibitory threshold, chicken manure digesters may be operated at high dry matter contents and high organic loading rates without any process inhibition (Bayrakdar et al., 2017b).

There are some physicochemical ammonia removal methods, e.g., ammonia stripping (Serna-Maza et al., 2017; Sürmeli et al., 2017), ion exchange (Wirthensohn et al., 2009), zeolite adsorption (Fotidis et al., 2014), and struvite precipitation (Uludag-Demirer et al., 2005). However, in continuously operated anaerobic digesters, integration and simultaneous operation of these methods are not applicable.

Previous studies have reported the performance of ammonia removal from wastewater (Liu and Wang, 2016), manure (Garcia-González and Vanotti, 2015), and anaerobic digester effluents (Wäeger-Baumann and Fuchs, 2012) using gas-permeable membranes. Basically, while an acidic receiving solution is recirculated from one side of a membrane, the concentration gradient force helps the ammonia gas to pass through the membrane wall from the ammonia-containing liquid to the receiving solution and ammonia is captured as ammonium ion (Garcia-González and Vanotti, 2015). However, only a few studies have investigated the performance of biogas production from substrates rich in ammonia using a membrane in continuously operated digesters (Bayrakdar et al., 2017b; Lauterböck et al., 2014, 2012).

Leach bed reactor (LBR) is an alternative and promising option for dry anaerobic digestion of high solids containing wastes, e.g., animal manure (Cysneiros et al., 2012; Demirer and Chen, 2008; Dogan et al., 2009). The main advantages of an LBR include its simple and cost-efficient operation, capability of digesting high-solid waste, low water requirement, and nonrequirement of complex stirring equipment and additional solid-liquid separation after anaerobic digestion (Cysneiros et al., 2012; Demirer and Chen, 2008; Riggio et al., 2017; Xu et al., 2011). However, LBRs have few disadvantages. They require bulking agents such as straw, sawdust, and agricultural wastes to eliminate clogging and channeling problems and increase the permeability of leachate, produce unequal and heterogeneous distribution of leachate due to the heterogeneous structure of the waste, and accumulate VFAs in leachate (Riggio et al., 2017; Xu et al., 2011, 2012). Basically, leachate is collected in a leachate collection chamber located at the bottom of an LBR and recirculated to the top of the waste to provide sufficient solid-liquid contact (Demirer and Chen, 2008; Yap et al., 2016). LBRs are usually employed for treating agricultural wastes (Xie et al., 2012), municipal solid waste (Chugh et al., 1999), and food and kitchen wastes (Ghanem et al., 2001; Xu et al., 2012) owing to their porous structure. However, studies investigating the performance of an LBR in the digestion of dairy manure are less (Demirer and Chen, 2008, 2005; Hall et al., 1985). Moreover, to date, there has been no research that investigates the performance of chicken manure digestion in LBR because its high organic nitrogen content complicates the high-solids anaerobic mono-digestion of chicken manure. Alternatively, the design of an LBR and its operation are considerably suitable to place the membrane in the leachate collection chamber to remove excess ammonia from the system.

This study investigates the performance of high-solids anaerobic mono-digestion of chicken manure in an LBR by separating ammonia from the liquid fraction of digestate (leachate) with a hydrophobic gas diffusion membrane integrated into the system.

2. Materials and methods

2.1. Experimental setup

Two identical 4.5-L laboratory-scale LBRs with a leachate collection chamber and a waste chamber of 2.35 and 2.15 L, respectively, were used in this study. The membrane-integrated reactor and the control reactor were labeled as LBR-M and LBR-C, respectively. Both LBRs were operated under mesophilic conditions (Fig. 1). The leachate collection chamber and the chicken manure-loaded chamber were separated by a stainless-steel mesh having pores of 1.5 mm.

For LBR-M, the hydrophobic tubular gas diffusion membrane was placed in the leachate collection chamber and the receiving solution containing 0.25-M H_2SO_4 was recirculated into the membrane at a flow rate of 50 mL/min using a peristaltic pump (Watson Marlow 323) and replenished when it became saturated with ammonia. Since LBR-C was operated as a control reactor, no membrane was integrated, and thus, no ammonia removal was performed.

Preliminary leaching tests were performed beforehand by adding some bulking agents, e.g., wood shavings and straw, to the chicken manure to increase its porosity. However, after several cycles of leachate recirculation, the bulking agents were separated from the chicken

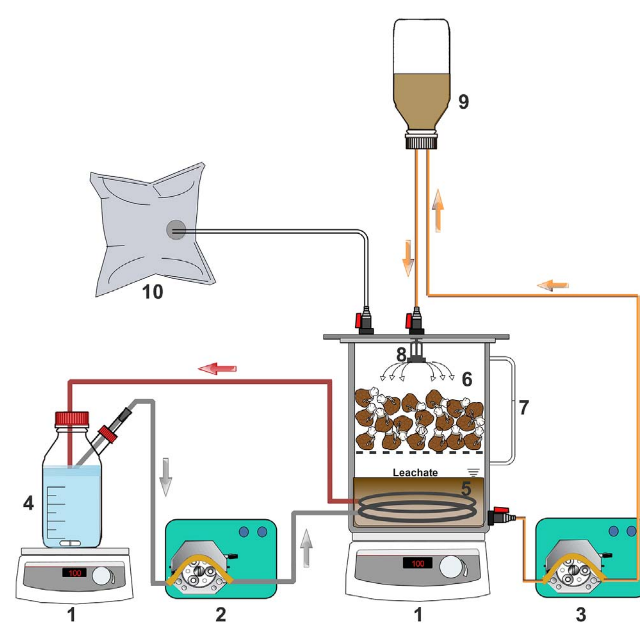

Fig. 1. Experimental set-up of LBR-M; (1) magnetic stirrer, (2) acid circulation pump, (3) leachate circulation pump, (4) receiving solution, (5) membrane, (6) cloth sachets filled with chicken manure, (7) pressure equalization line, (8) sprinkler, (9) reservoir, and (10) gas bag.