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Nitrogen removal from digested slurries using a simplified ammonia stripping technique

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ABSTRACT

This study assessed a novel technique for removing nitrogen from digested organic waste based on a slow release of ammonia that was promoted by continuous mixing of the digestate and delivering a continuous air stream across the surface of the liquid. Three 10-day experiments were conducted using two 50-L reactors. In the first two, nitrogen removal efficiencies were evaluated from identical digestates maintained at different temperatures (30 °C and 40 °C). At the start of the first experiment, the digestates were adjusted to pH 9 using sodium hydroxide, while in the second experiment pH was not adjusted. The highest ammonia removal efficiency (87%) was obtained at 40 °C with pH adjustment. However at 40 °C without pH adjustment, removal efficiencies of 69% for ammonia and 47% for total nitrogen were obtained. In the third experiment two different digestates were tested at 50 °C without pH adjustment. Although the initial chemical characteristics of the digestates were different in this experiment, the ammonia removal efficiencies were very similar (approximately 85%). Despite ammonia removal, the pH increased in all experiments, most likely due to carbon dioxide stripping that was promoted by temperature and mixing. The technique proved to be suitable for removing nitrogen following anaerobic digestion of livestock manure because effective removal was obtained at natural pH (≈8) and 40 °C, common operating conditions at typical biogas plants that process manure. Furthermore, the electrical energy requirement to operate the process is limited (estimated to be 3.8 kW h m^{-3} digestate). Further improvements may increase the efficiency and reduce the processing time of this treatment technique. Even without these advances slow-rate air stripping of ammonia is a viable option for reducing the environmental impact associated with animal manure management.

1. Introduction

Anaerobic digestion of animal manure for biogas production can improve both the characteristics of the manure and the sustainable recycling of nutrients, while simultaneously recovering energy. Frequently, biogas installations do not own the necessary area for the land application of the high-nitrogen digestate at acceptable rates, and this limitation is more severe in nitrate-sensitive regions and in regions where a nitrogen surplus already exists. Thus, digestate must be treated further to reduce the nitrogen content and comply with agro-environmental guidelines and rules for land application. Nitrogen can be removed from digestate biologically through processes such as nitrification and denitrification, but these processes do not facilitate recovery of the nitrogen. Furthermore, the high ammonia, phosphate and solids contents of digestates make biological processing difficult (Lei et al., 2007). Even in areas where there is no nitrogen surplus, the management of digestate may benefit a nitrogen recovery process to produce a mineral fertiliser that is easy to transport and utilize on crops. For this reason physico-chemical nitrogen removal processes such as struvite formation, membrane filtration or NH_3 stripping are more attractive than biological processes.

In particular, NH_3 stripping has been successfully used to remove nitrogen from different wastewaters, e.g. pig slurry, landfill leachate and wastewaters from the production of mineral fertilizers (Gustin and Marinsek-Logar, 2011; Laureni et al., 2012). The efficiency of air stripping depends on four main factors: pH, temperature, ratio of air to liquid volume, and liquid characteristics. Combined stripper/absorber plants operate by heating the influent

Abbreviations: LFSD, liquid fraction of separated digestate; USD, unseparated digestate.

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(to 80 °C) fed to the plant and adding lime or NaOH to increase pH to 10.5–11 and promote NH_3 volatilization. When lime is used, a precipitation tank is normally provided prior to stripping in which phosphates, salts and carbonates can precipitate. Generally in industrial plants, the recommended volumetric gas-to-liquid flow ratio is 600–700:1 (Zarebska et al., 2014) and 95% efficiency of ammonia removal is expected. Unfortunately, temperature and pH modification both require extra effort and often entail added cost. In addition, pH control can require the use of dangerous chemicals that introduce health and safety concerns. Recently another stripping variant that has been proposed is ammonia removal directly in the digestion reactor by biogas stripping. This solution was primarily proposed to cope with the inhibition problem due to ammonia/ammonium accumulation, which is a risk in the digestion of nitrogen-rich materials (e.g. slaughterhouse waste, chicken manure) (Abouelenien et al., 2010; Serna-Maza et al., 2015; Walker et al., 2011). However, although the design of NH_3 stripping technology is well advanced, there exist limitations in its practical application at farm facilities. In this context digested animal manure slurries (i.e., digestates) present important advantages over untreated slurries for NH_3 stripping; the necessary heat to stimulate the stripping process is readily available from the biogas that is generated during digestion, and higher pH resulting from digestion favours un-ionized NH_3 (Gustin and Marinsek-Logar, 2011; Jiang et al., 2014; Serna-Maza et al., 2014). In fact, in the anaerobic conditions of a biogas reactor, the mineral fraction of total nitrogen (as total Kjeldahl nitrogen, TKN) increases owing to conversion of organic nitrogen (Jiang et al., 2014), but remains in the liquid as ammoniacal nitrogen (i.e., NH_4^+ and NH_3). Furthermore, many biogas plants treat the digestate using solid-liquid separation to obtain a solid fraction rich in phosphorus and organic nitrogen, and a low-solids liquid fraction where most of the ammoniacal nitrogen remains. The separated liquid, from a stripping prospective, has even better characteristics than the raw digestate due to the lower solids content. Studies have demonstrated that slurry and digestate characterised by higher solids content exhibit a lower nitrogen removal efficiency than those with low-solids content, probably due to binding of ammonium ions by organic matter in high-solids inputs (Bonmatí and Flotats, 2003; Zarebska et al., 2014).

The potential applicability of the stripping process to digestate has been widely reported (Bonmatí and Flotats, 2003; Gustin and Marinsek-Logar, 2011; Jiang et al., 2010; Jiang et al., 2014; Laureni et al., 2012; Lei et al., 2007; Limoli et al., 2016; Morales et al., 2013; Quan et al., 2010; Zeng et al., 2006). However, most of these studies achieved good removal efficiencies in a short time by combining a high air-to-liquid feed ratio (from 5:1 to 850:1) with pH corrections and/or high temperature (up to 80 °C). Bonmatí and Flotats (2003) obtained complete NH_3 removal from digested pig slurry at 80 °C without pH modifications; however, the difficulty and expense of operating at this temperature was recognized as an obstacle to the practical application of this approach. Gustin and Marinsek-Logar (2011) investigated the effect of pH, temperature and airflow on the continuous stripping of NH_3 from the effluent of an anaerobic wastewater treatment plant (treating pig slurry and other organic materials) and showed that pH had the most relevant effect on NH_3 stripping. At the beginning of the stripping process pH may increase. García-González et al. (2015) and Zhu et al. (2001) showed that when manure was mixed and aerated, pH would increase due to CO_2 stripping, and good nitrogen removal efficiencies could be obtained without using chemicals. Particularly interesting was the study of Lei et al. (2007), which showed that the pH of an anaerobic digestate can be increased from 7.5 to 9.1 by CO_2 stripping in only one day at 15 °C.

These studies suggest the possibility of developing a slow-release stripping process that is easy to implement and manage at farm facilities and overcomes the limitations typical of this technology, which are mainly related to the large demand for thermal energy and the need for additives. In fact, although the principle of the stripping process is well known, its application to digested slurry has not yet been fully successful due mainly to (a) the need to remove solids prior to the stripping columns, (b) the large energy (thermal and electrical) demand and (c) the requirement for chemicals. Therefore, there is the need to develop new solutions based on simplified technologies that are able to achieve adequate nitrogen removal and have only limited pre-treatment and energy requirements. Recent studies (Garcia-González and Vanotti, 2015; Garcia-González et al., 2015; Starmans and Timmerman, 2013; Vanotti et al., 2017) have examined some alternative systems that might meet these design criteria; however, none of the techniques evaluated were able to satisfy all constraints, especially the one related to the high solids content of the slurry processed.

The study here presented investigated the performance of a stripping process based on a new concept of installation in which slow-rate NH_3 volatilization was promoted in a closed reactor containing continuously mixed digestate. The volatilized ammonia was removed by an air stream through the headspace of the reactor. The objectives of the study were to assess the effect on nitrogen removal efficiency of temperature, pH correction and type of digestate.

2. Material and methods

2.1. Experimental apparatus

The pilot plant used in the study (Fig. 1) consisted of two Poly (methyl methacrylate) containers (reactors), each with a volume of 50 L (40-cm diameter and 40-cm height) and a tight-fitting polyvinylchloride lid with ports for sampling and inserting probes. Each container had an (ambient) air inlet regulated by a flow meter (2–30 L min^{-1}, Key Instruments, Trevose, PA, USA) and an outlet for the NH_3-charged air. The air flow was generated by a membrane pump (EVO30 series, ELECTRO A.D., Barcelona, Spain) and was set at 10 L min^{-1} to ensure one air exchange of the headspace every minute and enhance the slow release of NH_3. This flowrate

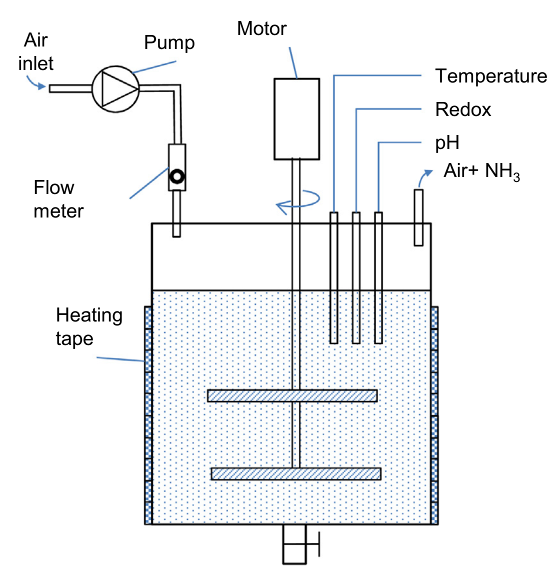

Fig. 1. Reactor used to assess nitrogen removal from digestate using a slow-rate stripping technique.