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Ammonia stripping for enhanced biomethanization of piggery wastewater

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ABSTRACT

In this study, the effects of ammonia removal by air stripping as a pretreatment on the anaerobic digestion of piggery wastewater were investigated. Ammonia stripping results indicated that ammonia removal was strongly dependent on pH and aeration rate, and the ammonia removal rate followed the pseudo-first-order kinetics. A significant enhancement of biomethanization was observed for wastewaters of which ammonia was air-stripped at pH 9.5 and pH 10.0. The methane productivity increased from 0.23 ± 0.08 L CH_4/L d of the control (raw piggery wastewater) to 0.75 ± 0.11 L CH_4/L d (ammonia-stripped at pH 9.5) and 0.57 ± 0.04 L CH_4/L d (ammonia-stripped at pH 10.0). However, the improvement of methane production from the piggery wastewater pretreated at pH 11.0 was negligible compared to the control, which was thought to be due to the high concentration of sodium ions supplied from sodium hydroxide for pH adjustment. From these results, it was concluded that ammonia removal through air stripping at the alkaline pH could be a viable option for preventing the failure of anaerobic digestion of the raw piggery wastewater. Additionally, it was also found that a high concentration of sodium ion originated from sodium hydroxide for pH adjustment inhibited methane production.

1. Introduction

Anaerobic digestion has been recommended as a primary process for treating piggery wastewater, because through which waste reduction, energy production (biogas) and mitigation of pollutant emissions (odor, greenhouse gases and animal pathogens) can be accomplished [1,2]. For example, many farm digesters running in European countries (most of them with animal manure as the main substrate) indicate that anaerobic digestion is applicable in the field. However, the economic feasibility of anaerobic digester treating animal manure was often reported low because biogas production was not satisfactory. One reason might be due to the characteristics of feeding substrates. In many cases, the organic matter is diluted with cleaning water and the fraction of inert materials in the animal manure is high. The high ammonia concentration (3.0–6.0 g NH_4^+–N/L) has often been identified as another important technical reason for the low level of biogas production and unstable system operation [3]. Furthermore, the high ammonia concentration in the effluent of anaerobic digestion also hinders the performance of subsequent biological processes, such as the conventional activated sludge system and the biological A/O (anoxic/oxic) process [4].

In order to mitigate the ammonia inhibition without changing the ammonia level, addition of mineral materials and lowering the temperature from thermophilic to mesophilic conditions were attempted [5]. Decreasing the ammonia concentration was another way to avoid ammonia inhibition. In order to lower the concentration of ammonia, many methods have been practiced. For example, the dilution of the wastewater with fresh water was found to be effective [5,6]. However, this dilution method worsens the economic feasibility of the anaerobic digestion of piggery wastewater due to reduced mass retention time and gas production efficiency as well as the increased dewatering cost. Several different physical, chemical and biological methods, including zeolite adsorption [7], ammonia stripping [8–10], chemical precipitation [11] and a biological A/O process [12] have been investigated for ammonia removal or recovery.

Among these processes, the ammonia stripping method is thought to be the most applicable, especially for wastewaters containing high concentrations of ammonia, such as SSFW (source sorted food waste) digestate [10], chicken manure [13] and poultry litter leachate [14], because this method generates no extra sludge and is associated with modest reagent costs and an easy operation. In this process, the free ammonia is stripped out of the wastewater and enters the gas phase. The efficiency of ammonia stripping is

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strongly dependent on two thermodynamic equilibria, the Henry's law equilibrium (Eq. (1)) and the ammonia dissociation equilibrium (Eqs. (2) and (3)) [8].

$$p = K_c c \quad (1)$$

$$NH_4^+ \leftrightarrows NH_3 + H^+ \quad (2)$$

$$\frac{[NH_3]}{[TNH_3]} = \left(1 + \frac{10^{-pH}}{10-(0.09018+2729.92/T(K))}\right) \quad (3)$$

Here, p is the partial pressure of the ammonia gas, c is its molar concentration in the liquid phase, and K_c is the Henry's law constant. $[NH_3]$ and $[TNH_3]$ represent the concentrations of free ammonia and the sum of free ammonia and ammonium ion, respectively. T (K) is the Kelvin temperature. As shown in Eq. (3), the free ammonia concentration in the aqueous phase depends on the pH and temperature. Higher pH and temperature lead to a higher free ammonia fraction. Liao et al. [9] and Bonmatí and Flotats [8] found that alkaline pH (10.5–11.5) and high temperature (80 °C) were required to achieve high ammonia removal efficiency from piggery slurry. Mass transfer rate of ammonia was also controlled by air flow rate. In biogas stripping of SSFW (source-sorted food waste) digestate, 4.5-fold increase in the ammonia removal rate was observed when the flow rate increased from 0.125 to 0.375 $L_{biogas}\,L_{digestate}^{-1}\,min^{-1}$ [10].

Yang et al. [15] reported that the swine wastewater pretreated in an ammonia stripping process resulted in enhanced acidogenesis. In comparison to the control (4.0 g NH_4^+–N/L), a maximum of 4.7 folds higher acidification was achieved for the ammonia-stripped piggery wastewater (0.8 g NH_4^+–N/L). However, Bonmatí and Flotats [8] concluded that ammonia stripping, as a pretreatment method, was not feasible. They ascribed the infeasibility to the high concentration of remaining free ammonia, the extra cost to neutralize the high pH (8.5–9.9) and the presence of heavy metals, which would be concentrated by air stripping. Considering the conflicting results of ammonia removal on anaerobic process, therefore, it is necessary to evaluate the effect of the ammonia stripping of piggery wastewater on its anaerobic digestion.

In this study, the feasibility of ammonia stripping as a pretreatment method for the anaerobic digestion of piggery wastewater was systematically evaluated. First, the buffering capacity of piggery wastewater and the effects of the operational parameters for ammonia stripping (dosage of sodium hydroxide, pH and aeration rate) on ammonia removal were examined. Secondly, the effects of ammonia removal on the anaerobic digestion of piggery wastewater were investigated in batch experiments. Finally, the feasibility of different ammonia stripping conditions on subsequent anaerobic digestion was carefully monitored in semi-continuous experiments.

2. Materials and methods

2.1. Piggery wastewater and seed sludge

The raw piggery wastewater used in this study was obtained from a farm near the Yongin Wastewater Treatment Plant in Yongin, Republic of Korea, and was stored at 4 °C. The unacclimated inoculum (about 25 g/L of VSS) was obtained from a domestic anaerobic sludge digester at the Yongin Wastewater Treatment Plant, and the inoculum (approximately 15 g/L of VSS) acclimated to a high concentration of ammonia was obtained from the 20-L bench scale digester treating 2-fold diluted piggery wastewater containing approximately 4.0 g NH_4^+–N/L for more than a year.

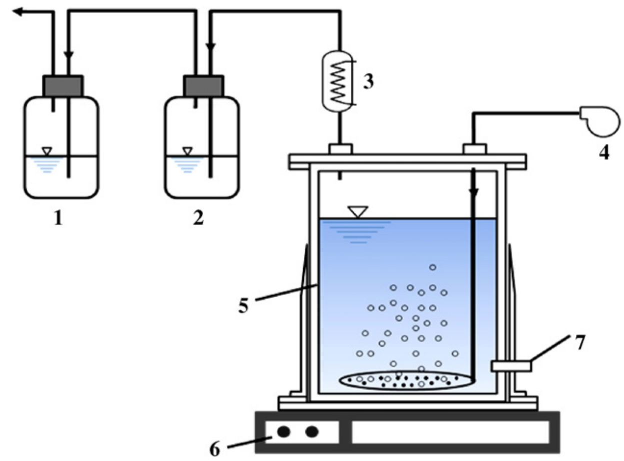

Fig. 1. Schematic diagram of the ammonia stripping reactor of piggery wastewater. (1) 20% NaOH solution, (2) 50% H_2SO_4 solution, (3) condenser, (4) air pump, (5) main reactor vessel, (6) temperature controller, (7) effluent port.

2.2. Measurement of buffering capacity

While being magnetically stirred, a 40% (w/w) sodium hydroxide solution was gradually added through a volumetric burette to 500 mL piggery wastewater or mixed liquor (7000 mg/L of VSS) from an MBR (membrane bioreactor) treating domestic wastewater. When the pH was stabilized, the cumulative volume of added sodium hydroxide solution and the corresponding pH values were recorded. The sodium ion concentration was calculated from the added amount of sodium hydroxide.

2.3. Experimental setup and procedure

2.3.1. Ammonia stripping experiments

Ammonia stripping of the piggery wastewater was conducted in a 1.0 L reactor (ID 80 mm × H 200 mm) with a working volume of 0.5 L as shown in Fig. 1. Air was introduced into the liquid phase via an aquatic air stone. The air flow rate was controlled at 1.0, 2.0, 4.0 or 10.0 $L\,L^{-1}\,min^{-1}$ by a flow meter, and the pH of the wastewater was adjusted to pH 9.0, pH 9.5, pH 10.0 or pH 11.0 using a 40% (w/w) sodium hydroxide solution. Considering volume changes by pH adjustment and water evaporation, the real ammonia concentrations in each set of experiment were experimentally determined. The ammonia stripping reactor was kept at 37 °C. The exhaust gas was passed through solutions of 50% (w/w) H_2SO_4 and 20% (w/w) sodium hydroxide to prevent release of ammonia and other volatile compounds into atmosphere.

2.3.2. Batch biomethanization of ammonia-stripped piggery wastewater

Batch anaerobic digestion was performed in a 160-mL serum bottle with the working volume of 50 mL. The main focus of this section was to show the kinetics of biogas generation during the first day rather than to obtain the ultimate methane yield. The unacclimated sludge was used as an inoculum, and raw piggery wastewater and ammonia-stripped piggery wastewaters were used as substrates. Each bottle contained 0.53 g COD of biomass as an inoculum. The control reactor contained 1.24 g COD per bottle as a substrate (raw piggery wastewater). The bottles receiving pH 7.2, pH 9.0, pH 10.0, and pH 11.0 air-stripped piggery wastewater contained 1.09, 1.15, 1.15, and 1.16 g COD per bottle as substrate, respectively. Likewise, the bottles receiving 0 $L\,L\,min^{-1}$, 1.0 $L\,L\,min^{-1}$, 2.0 $L\,L\,min^{-1}$, 4.0 $L\,L\,min^{-1}$, and 10.0 $L\,L\,min^{-1}$ air-stripped piggery wastewater contained 1.22, 1.07, 1.00, 0.83, and 0.63 g COD per bottle as substrate, respectively. Finally, distilled