Comparing the performance of common ammonia stripping configurations for enhancing the biogas potential of poultry manure

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Introduction

Anaerobic digestion (AD) is a powerful technology for generating clean and sustainable energy from organic waste (Baldi et al., 2018). The process is driven by the activity of certain bacteria and archaea, which can be susceptible to certain toxins such as ammonia (Rajagopal et al., 2013). Poultry manure (PM) is often avoided in biogas plants due to its high nitrogen content, which leads to instability, and possibly complete failure of the process.

One of the most economical and feasible ways to allow AD of PM is ammonia stripping, which relies intensely on the volatility of ammonia by increasing the pH and/or temperature of the solution (Fuchs et al., 2018). Moreover, there are a few configurations to implement ammonia stripping in biogas plants (Figure 1), including Side-stream and post-hydrolysis ammonia stripping. The Post-hydrolysis ammonia stripping configuration has been getting a lot of attention lately due to its immense advantages and the rising number of two-stage AD plants (Huang et al., 2019).

Despite side-stream ammonia stripping being established and already having practical applications, no studies have been conducted to compare its performance with post-hydrolysis ammonia stripping, which is a relatively newer approach than side-stream ammonia stripping. Therefore, this project aims to compare the performance of post-hydrolysis and side-stream ammonia stripping to ultimately improve PM's methane production. Furthermore, it is imperative to discuss the optimal configuration for ammonia stripping by controlling the operating conditions of the stripping tower since these operating conditions are translated into cost and energy.

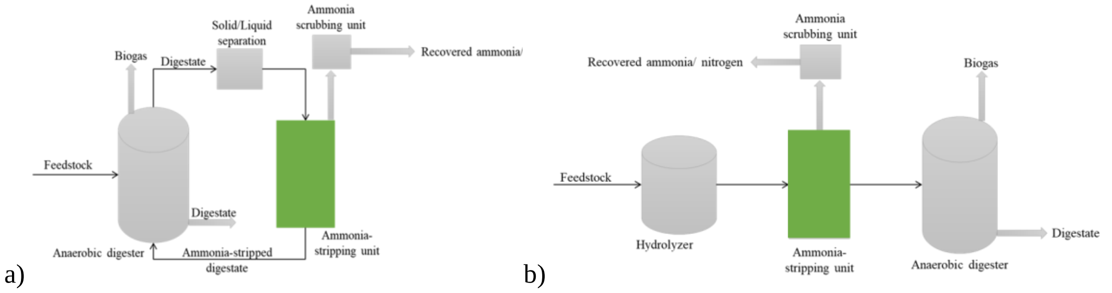

Figure 1: Ammonia stripping configurations tested in this study

Methodology

Four phases were tested in two 10-L continuously stirred tank reactors (CSTRs), including post-hydrolysis ammonia stripping using air (Phase I) and side-stream ammonia stripping using methane at 20% recycling per day (Phase II) and 10% per day (Phase III) and side-stream ammonia stripping with air at a 10% per day (Phase IV). The ammonia stripping was conducted in a long vessel to maximize gas-liquid interaction. The stripping unit's pH, temperature, and gas flowrate were set to 9.5, 55 ºC, and 100 L gas/L/ hour for 3 hours. The reactors were fed with hydrolyzed PM (control, no treatment) at the end of the experiment.

To monitor the performance of the reactors, biogas was collected in gas-impermeable bags and measured using 500 ml syringes daily. In addition, methane content was measured weekly using gas chromatography. Biogas production was correct to standard temperature and pressure. Other performance indicators included ammonia, volatile fatty acids, alkalinity, and chemical oxygen demand monitoring.

Results and discussion

The experiment started with step-feeding the reactors with diluted PM at a low organic loading rate (0.6 g VS/L.day) and increased until the target OLR was reached (2.6 g VS/L.day). Afterwards, the feeding switched to post-hydrolysis ammonia stripping unit effluent. For this, it was found that the hydrolysis converted about 88% of organic nitrogen into ammonia, indicating that biological hydrolysis alone is sufficient for ammonia fermentation without adding any alkaline or acid.

Post-hydrolysis ammonia stripping with air for 3 hours achieved around 70% removal of ammonia and dropped PM ammonia levels from around 6000 to 1800 mg NH_3-N/L. This has led to stable biogas production at about 836 L biogas/kg VS.day. The feeding continued for approximately 60 days, equivalent to three hydraulic retention times (HRTs), to ensure steady-state conditions were attained. Figure 2 shows the biogas production throughout the study period.

When the scenario was switched to side-stream ammonia stripping at 10% of the digester volume recycled daily, the reactors almost crashed. To mitigate that, the recycling ratio was increased to 20% recycling ratio to smoothen the transition between scenarios. As a result, the biogas production stabilized at 462 L biogas/kg VS.day, which is about 45% less than the biogas production achieved using post-hydrolysis ammonia stripping.

Since treating 20% of the reactor's volume daily may be impractical, the recycling ratio was dropped to 10% after steady-state conditions were attained using a 20% recycling ratio. However, an abrupt drop in biogas potential to 317 L biogas/kg VS.day was observed primarily due to the ammonia levels increasing past inhibitory levels (2500-3000 mg NH_3-N/L). The increase in ammonia levels is due to the lower recycling ratio, whereas the ammonia removal efficiency remained the same (50-60%) since the stripping column conditions were not changed.

After the side-stream ammonia stripping treatment at a 10% recycling ratio reached steady-state conditions, the stripping gas was switched to air instead of methane to evaluate the two systems under similar tower conditions. Interestingly, using air in side-stream ammonia stripping did not have a negative impact on the microorganisms and resulted in an increase in biogas production to 453 L biogas/ kg VS.day

Eventually, the reactors were fed without implementing any treatment, and the ammonia levels increased rapidly to 6000 mg NH_3-N/L, and the biogas production dropped to around 185 L biogas/ kg VS.day. This shows that the digestion of PM would not be optimal without implementing an ammonia-targeted treatment.

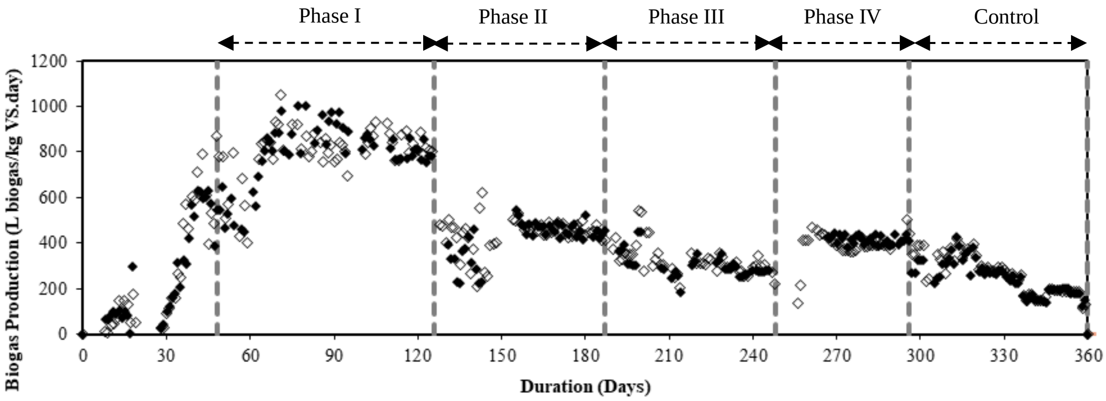

Figure 2: Biogas production of the two CSTRs throughout the study period.

It is important to note that the side-stream ammonia stripping approach discussed in this study differs from the literature. In the literature, side-stream ammonia stripping is often performed using biogas recirculation at significantly harsher conditions. For example, using biogas recirculation, pH must be pushed above ten and temperatures are usually maintained at 65-80 ºC for a prolonged period of 1-3 days per batch. On the other hand, this study proves that substituting biogas recirculation with air or methane can achieve high ammonia removal efficiency at gentler stripping tower conditions, i.e., pH 9.5, 55 ºC, for only 2-3 hours. The only trade-off in these conditions is the gas flowrate required, which must be high to achieve high removal efficiency within a short time.

Conclusion

This study compared the performance of post-hydrolysis and side-stream ammonia stripping configurations to improve poultry manure's methane potential. Post-hydrolysis ammonia stripping showed superior results compared to ammonia stripping, even when treating significantly lesser amounts and at gentler conditions. In other words, implementing post-hydrolysis ammonia stripping can be more economical and lead to higher biogas potential and energy from poultry manure.

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