New Concepts of Ammonia Removal from Digested Swine Effluents Using Anammox Based Deammonification Process

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Abstract

Production of biogas from swine manure using anaerobic digesters (AD) is projected to be important in the future. However, surplus nitrogen (N) in AD effluents is difficult to remove using current technology (nitrification/denitrification) because low carbon availability after biogas production. We investigated a deammonification process for the removal of ammonia from AD effluents. This process is autotrophic and removes N without carbon. Instant deammonification reaction was obtained by mixing a high performance nitrifying sludge HPNS (NRRL B-50298) with anammox sludge Brocadia caroliniensis (NRRL B-50286), in single, aerated reactors containing fluidized plastic carriers. The process was tested at ambient temperature (23±2°C) using AD swine effluents. Ammonia was removed at rates of 0.7-1.0 kg N/ cubic meter reactor/day and efficiencies obtained were 88-100%. The chemical reaction was consistent with the theory of deammonification. Compared with traditional N removal, the deammonification process reduced 56-57% of the aeration needs. Microbial reverse transcription analyses indicated that bacteria in the influent had little effect on the bacterial community that was active in the single-tank. Results showed physiologically high activity of ammonia oxidizing bacteria (AOB) and anammox bacteria in the reactor.

Introduction

Farmers that would like to implement biological nitrogen (N) removal from the effluent of anaerobic digesters (AD) – for example to comply with regional surplus nitrogen regulations or to take advantage of environmental nutrient crediting programs – are often limited by the lack of carbon available for traditional denitrification, since the carbon is used for the production of biogas. About 30% of the carbon in the manure would be required for successful N removal in AD effluents via nitrification/denitrification treatment, with less biogas production. A better approach would be to use biological deammonification. The deammonification process is a completely autotrophic nitrogen removal approach that combines partial nitritation and anammox and eliminates the carbon needs for denitrification. It also reduces the aeration needs of ammonia removal by about 60%. Thus, it could be a key approach for development of effective biological removal of ammonia (NH_4^+) from AD effluents that are low in carbon and high in ammonia concentration. In this work we describe new findings that allowed rapid implementation of deammonification reaction in AD effluents using mixtures of bacterial cultures and a one-stage process (partial nitritation and anammox in a single tank.)

Material and Methods

We obtained rapid deammonification reaction by mixing two bacterial cultures inside single, aerated reactors: a high performance nitrifying sludge, HPNS, accession number NRRL B-50298 [1], with anammox bacterial sludge, Brocadia caroliniensis, accession number NRRL B-50286 [2]. The reactors contained biofilm plastic carriers (30-40% v/v) that were fluidized by the aeration [3]. The 5-L reactor used 800 mL of anammox sludge and 400 mL of HPNS. Corresponding sludge volumes used to start the 1-L reactor were 230 mL anammox and 80 mL HPNS. The process water temperature was ambient (23±2°C). The single-tank reactors were tested with digested swine wastewater containing 367-586 mg total N/L, 341-568 mg ammonia-N/L, 513-1372 mg COD/L, and

1820-2900 mg alkalinity/L. Aeration rates in the 5-L reactor were 300 to 850 ml/min (N loading rates 0.8-1.4 kg N/m^3-reactor/d). Aeration rate in the 1-L reactor was optimized at 60 mL/min (N loading 650-900 kg N/m^3-reactor/d). The effluent sludge was returned to the reactor at a rate of 1-2Q.

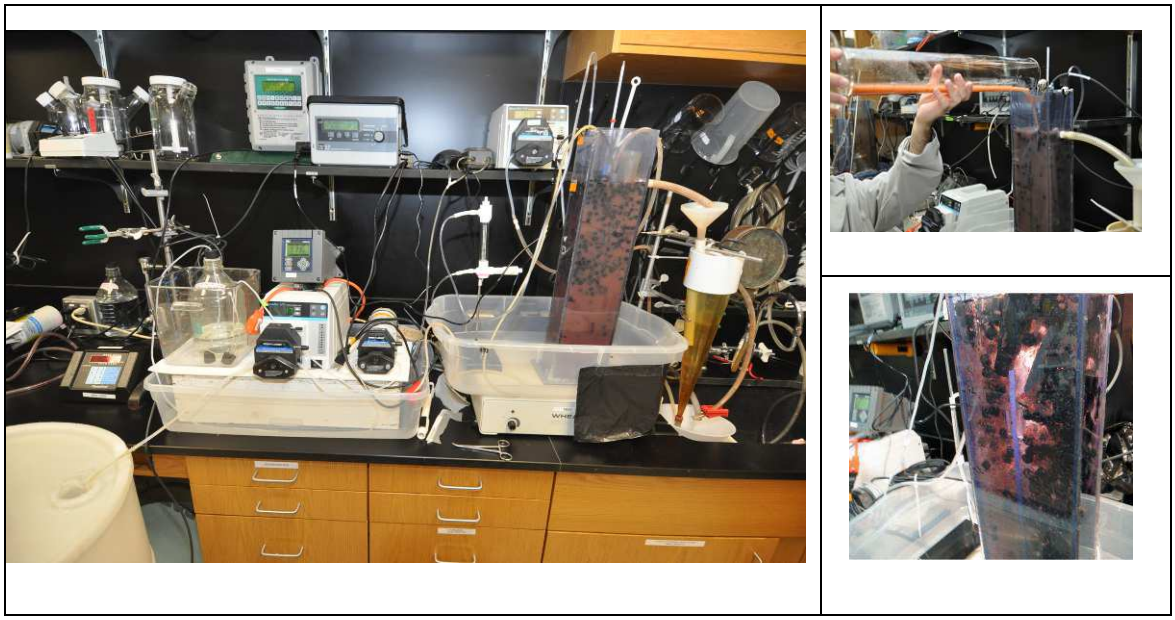

Figure 1. Deammonification treatment using first prototype single-tank reactor. (a) 5-L reactor set-up, (b) mixing of HPNS (cylinder) with anammox cultures, and (c) Reactor detail with fluidized plastic carriers inside.

Figure 2: (a) Deammonification treatment of swine wastewater using another prototype single-tank reactor (1-L), and (b) detail of fluidized reactor.

Results

The deammonification process was optimized with interrupted aeration cycles (23 min ON/7 min OFF). The dissolved oxygen (DO) was generally below 0.5 mg/L during aeration period, and about 0 when the aeration was off. Under these conditions, NH_4^+ removal rates of about 0.7 to 1.2 kg N/m^3-reactor/day were obtained using synthetic inorganic wastewater in the first prototype single-tank reactor (5-L). Figure 3 shows a typical batch test in the same 5-L reactor using AD swine effluent. The test provided both the rate of N removal and the stoichiometry of the single-tank deammonification process. The rate of ammonia removal was 1.03 kg N/m^3-reactor/day with ammonia removal efficiency of 100% and total N removal efficiency of 89% (Fig. 3). The following

stoichiometry (Eq. 1) was derived from the concentration profiles of ammonia, nitrite, nitrate, and carbonate alkalinity:

5-L reactor (Eq. 1): $NH_4^+ + 0.87\ O_2 \rightarrow 0.45\ N_2 + 0.11\ NO_3^- + 1.41\ H_2O + 1.18\ H^+$

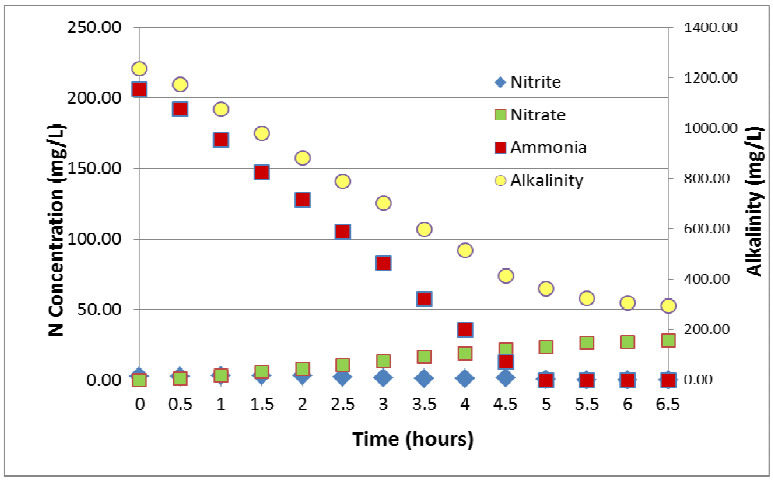

Figure 3: Decrease of ammonia concentration in swine wastewater using single-tank (5-L reactor).

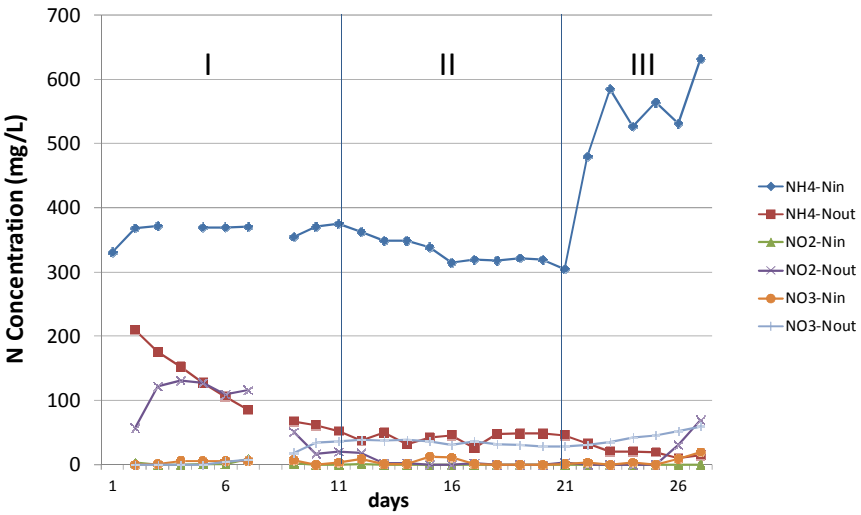

Figure 4: Nitrogen removal in single-tank (1-L). I = synthetic effluent, II & III =swine effluents.

Deammonification reaction was also quickly established in the 1-L reactor. After mixing the bacterial cultures, the reactor was started in continuous flow with synthetic inorganic wastewater (phase I). Then, at 10 days, the reactor was run with AD swine wastewater of varied N concentration (phase II and III) (Fig. 4). The stabilized ammonia removal efficiency during phase I (synthetic wastewater) was 85% with N loading rate of 0.86 kg N/m^3-reactor/day and NH_4-N concentration of 365 mg/L. The performance was not hindered when switched to swine effluent. Ammonia removal efficiency was 88% in phase II and 97% in phase III. Corresponding N loading rates were 0.80 and 0.66 kg N/m^3-reactor/day, and NH_4-N concentrations were 341 and 568 mg/L, respectively. The stoichiometry was derived from the changes of ammonia, nitrite, nitrate, and alkalinity between influent and effluent during phase III (Eq. 2):

1-L reactor (Eq. 2): $NH_4^+ + 0.85\ O_2 \rightarrow 0.44\ N_2 + 0.07\ NO_3^- + 0.04\ NO_2^- + 1.40\ H_2O + 1.19\ H^+$

The reactions obtained in the single-tank process in both reactors (Eq. 1 and 2) were consistent with the theory of the deammonification process combining partial nitritation and anammox with regards to alkalinity and oxygen consumption (Eq. 3).

Single-stage theory (Eq. 3): $NH_4^+ + 0.85\ O_2 \rightarrow 0.44\ N_2 + 0.11\ NO_3^- + 1.43\ H_2O + 1.14\ H^+$

Compared with nitrification/denitrification (that requires about 2 mol of O_2 per mol of NH_4^+ removed), our results obtained with the deammonification process applied to swine effluents required only 0.85 to 0.87 mol of O_2 per mol of NH_4^+ removed (Eq. 1 and 2) and reduced the oxygen requirement to remove the ammonia by 56-57%.

Bacterial communities in single tank

The research used reverse transcription PCR (RT-PCR) method to help detect active bacteria in a single-tank deammonification reactor and differentiate from bacteria in the wastewater AD swine influent [4]. The numbers of clones detected by RNA-RT analyses showed the relative quantities of ribosomes, which correspond to physiological activities in the reactor. Many bacterial groups (23 operational taxonomic units, OTUs) were detected in the single-tank (1-L). Ammonia oxidizing bacteria (AOB) (OTU1-3), had the most abundant ribosomes (51%), indicating flourishing growth and physiologically high activity. Candidatus Brocadia caroliniensis (anammox bacteria) was secondarily abundant (4.4% of ribosomes), being definitely working in the reactor. OTU 17 and 18 (Chlorobi) occupied only 2.2%, showing minor activity. The analyses of the influent (AD swine influent) detected bacteria belonging to phyla Bacteroidetes, Firmicutes, Chloroflexi and Synergistetes, which are strictly or facultative anaerobes. Almost all clones in the anaerobically digested influent were not detected in the single-tank deammonification reactor. This indicated that most of bacteria in the inflow sludge had disappeared in the single-tank reactor and had little effect on the bacterial community in the deammonification single-tank reactor.

Conclusion and perspectives

We evaluated deammonification treatment using single, fluidized, aerobic reactor tank by mixing a high performance nitrifying sludge and anammox bacteria. Surprisingly, the two bacteria groups were able to associate quickly and effectively in the aerated single tank providing a streamlined ammonia removal process. Thus, the single tank configuration offers the potential to further reduce the cost of treatment of ammonia in livestock wastewaters containing high ammonia. Deammonification treatment can be a key technology for development of more economical and energy efficient biological ammonia removal systems in the near future.

References

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