Ion Exchange/Anammox Process for Nitrogen Removal from Wastewater

INTRODUCTION

Nitrogen from onsite wastewater systems adversly affects surface and ground water quality, with particularly acute effects in estuarine waters (US EPA, 2002). This paper presents the Anaerobic/Ion Exchange/Anammox (AN/IX/ANM) process for onsite nitrogen removal. AN/IX/ANM evolves from the Anaerobic/Ion Exchange (AN/IX) process, in which wastewater nitrogen is recovered by anaerobic ion exchange of NH_4^+ on clinoptilolite, a natural zeolite (Smith and Smith, 2015a,b,c). AN/IX/ANM extends AN/IX by adding controlled delivery of oxygen to clinoptilolite media beds in order to foster nitrogen removal through nitritation and anammox. The coupling in single reactors of nitritation (partial nitrification of ammonia to nitrite: $NH_4^+ \rightarrow NO_2^-$) with anammox ($NH_4^+ + NO_2 \rightarrow N_2$) provides a metabolic pathway for complete mineralization of ammonium to nitrogen gas (N_2) (Du et al., 2015; Ma et al., 2015b). AN/IX/ANM can be used for in situ regeneration of exhausted clinoptilolite media, and can also operate in a continuous nitrogen removal mode that couples anaerobic ion exchange with the metabolic platform of nitritation/anammox. The goal of AN/IX/ANM is a passive and low cost process for resilient nitrogen removal in onsite wastewater systems.

MATERIAL AND METHODS

A 57 L AN/IX prototype was operated for over two years on onsite wastewater to remove NH_4^+ by ion exchange on clinoptilolite. The AN/IX reactor contained an initial upflow anaerobic solids blanket chamber followed by three ion exchange chambers packed with granular clinoptilolite. Effluent NH_4^+ remained below detection for over 300 days but the capacity of clinoptilolite to remove NH_4^+ was exhausted after 2 years (Smith and Smith, 2015b). To evaluate AN/IX/ANM, the third ion exchange chamber (AN/IX Chamber 4) was fitted with a permeable tubular membrane array placed laterally across the flow path for controlled oxygenation by diffusive flux through the membrane (Figure 1). The array consisted of nine tubes (peroxide cured silicone; 7.9 mm o.d., 0.79 mm wall thickness; O_2 permeability of 7,961 cm^3-mm /cm^2-sec-cm Hg) x 10^{-10}). Silicone membranes in pressurized hollow fiber configuration were previously used to permeate O_2 and H_2 into biofilm reactors for biological nitrogen removal from combined urine and condensate for spacecraft life support (Smith et al., 2008). Air circulation through membrane lumen was provided by a 15W impeller fan removing air on a 10 minute on/20 minute off cycle. Wastewater flow was continued through the experiment.

RESULTS AND DISCUSSION

Following installation of the membrane array, Chamber 4 NH_4^+-N concentration decreased to less than the influent concentration (Figure 1). The concentration difference across Chamber 4 reached

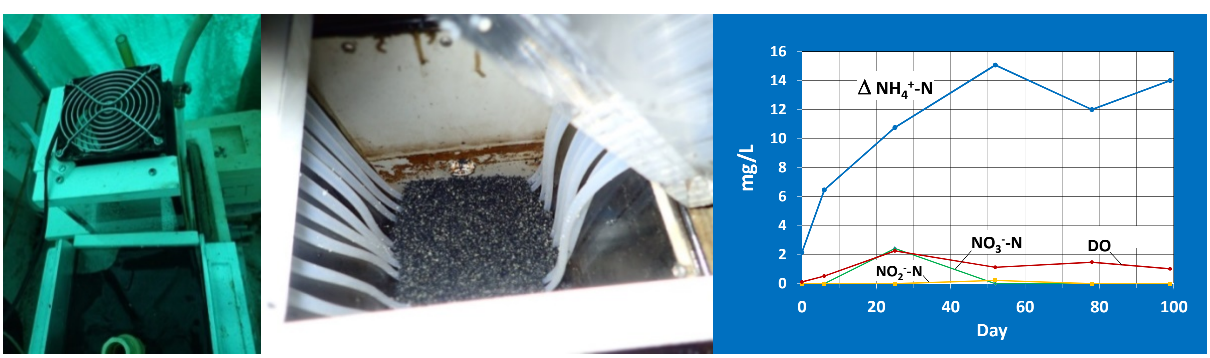

Figure 1. Micro-O_2 Permeation to IX Media in AN/IX Chamber 4.
Left: manifold with air circulator. Center: tubular membrane array. Right: solute time profiles.

ca. 14 mg/L around Day 40 NO_3^- accumulated Day 40 but subsided by Day 40, while little NO_2^- was observed. Chamber 4 DO remained less than 2 mg/L throughout. Nitrogen removal appeared to be enabled by limited O_2 flux to zeolite media by diffusive flux through permeable membranes. Lowering of the NH_4^+-N concentration in Chamber 4 is hypothesized to have resulted in NH_4^+-N release from zeolite due to the reversibility of NH_4^+-N sorption. In this case, the actual mass removal of NH_4^+-N in Chamber 4 would be greater than reflected by the decline in NH_4^+-N concentration alone. In-situ desorption of spent media is one aspect of the AN/IX/ANM process that can be operatively employed in onsite wastewater systems.

These results are preliminary but consistent with nitritation/anammox metabolism in Chamber 4. The main requirements for establishing nitritation/anammox are effective retention of microbial populations, a supply of NO_2^-, and the prevention of nitrite oxidation (Ma et al., 2015b). The granular clinoptilolite media in Chamber 4 provide excellent biomass retention. One of the most effective methods to prevent nitrite oxidation is oxygen limitation (Varas et al., 2015; Ma et al., 2015a; Qiao et al. 2013; Kwak et al. 2012), and diffusional limitation of O_2 has been identified as an operative factor in establishing nitritation with nitrate oxidation (Malvonny et al., 2015). It appears quite possible that
permeable membrane arrays can be configured in AN/IX/ANM to satisfy the controlled O_2 delivery requirement.

CONCLUSIONS

AN/IX/ANM has potential to be a passive and low cost system for nitrogen removal from onsite wastewater. Specifically designed experiments will confirm the initial results, verify nitritation/ anammox metabolism within clinoptilolite media, and develop operating and design experience.

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