Recovery of Ammonia and Production of High-Grade Phosphates from Side-Stream Digester Effluents Using Gas-Permeable Membranes

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Abstract. Phosphorus recovery was combined with ammonia recovery using gas-permeable membranes. In a first step, the ammonia and alkalinity were removed from municipal side-stream wastewater using low-rate aeration and a gas-permeable membrane manifold. In a second step, the phosphorus was removed using magnesium chloride (MgCl2) and reduced amounts of alkali. The side-stream wastewater contained 730 mg N/L, 140 mg P/L and 2900 mg/L alkalinity. The process recovered approximately 79–93% of the ammonia and 80–100% of the phosphorus. Surprisingly, the phosphates produced were very-high grade (42–44% P_2O_5) with a composition similar to the bio-mineral newberyite. However, lower grade phosphate products (27–29% P_2O_5) were produced whenever the N recovery step was bypassed or carbonate alkalinity was added. Therefore, removal of ammonia and alkalinity are important considerations for production of very-high grade phosphate product.

Keywords: Ammonia recovery · Phosphorus recovery · Newberyite

1 Introduction

Conservation and recovery of nitrogen (N) and phosphorus (P) from municipal, industrial and agricultural effluents using anaerobic digesters (AD) is important because of economic and environmental reasons.

A promising new method to recover ammonia (NH_3) from wastewater is the use of gas-permeable membranes (Vanotti and Szogi 2015). The gas-permeable membrane manifolds are submerged in the liquid manure, and the gaseous NH_3 is removed from the liquid matrix before it escapes into the atmosphere. The N removal is done with low-rate aeration in the reactors that naturally increases the pH of the liquid and accelerates the rate of passage of NH_3 (>96%) through the submerged gas-permeable membrane manifold and further concentration in an acid stripping solution reservoir (Garcia-Gonzalez et al. 2015; Dube et al. 2016). The effluent after ammonia treatment is low in ammonia and carbonates. In turn, these conditions improve precipitation of phosphate minerals of high-grade.

G. Mannina (ed.), *Frontiers in Wastewater Treatment and Modelling*,
Lecture Notes in Civil Engineering 4, DOI 10.1007/978-3-319-58421-8_2

The objective of this work was to develop new technology for simultaneous N and P recovery suitable for municipal digester effluents (Vanotti et al. 2016). It combines a gas-permeable membrane technology (N recovery) with P recovery of solid products by precipitation of phosphates. Phosphorus precipitating compounds such as for example, magnesium chloride ($MgCl_2$), are added to the system after the N removal. The new system was first tested using livestock wastewater (Vanotti et al. 2017). In this work, municipal side-stream wastewater was used. Results of this study and others were used to file a US Patent on the new process.

2 Materials and Methods

In this case study, the wastewater was side stream collected from James River municipal plant, Hampton Roads Sanitation District, Virginia. The side stream wastewater was a centrate effluent from waste sludge that was subjected to anaerobic digestion and solids separation and contained about 140 mg/L P and 730 mg N/L. Ammonia was substantially removed in a first treatment step (Fig. 1). In a second step, $MgCl_2$ was added to the N treated effluent in the phosphorus recovery tank. The gas permeable membrane module was connected with a stripping solution reservoir containing diluted acid as described in Dube et al. (2016) and Garcia-Gonzalez et al. (2015). Low rate aeration was delivered to the bottom of tank. Gas-permeable membrane was tubular and made of e-PTFE material. Nitrification inhibitor (22 ppm) was

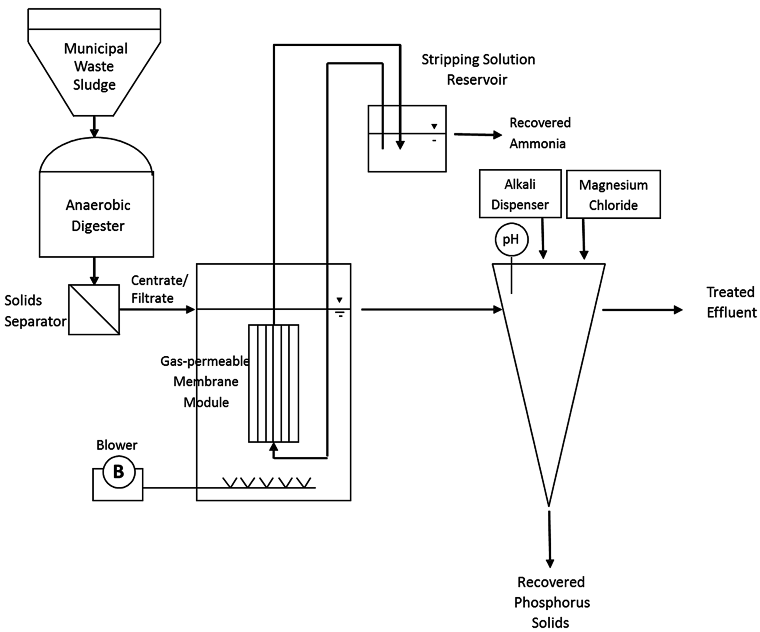

Fig. 1. Schematic diagram of nitrogen (N) and phosphorus (P) recovery system using ammonia separation tank and P recovery tank

added to ensure nitrification inhibition. Concentrated acid was added to the stripping solution to an end-point pH of 1 when the pH increased above about 2 as result of active ammonia capture. In a second step, the treated effluent from the N recovery tank was transferred to phosphorus separation tank where it was mixed with $MgCl_2$ and NaOH to obtain a phosphorus precipitate and an effluent without phosphorus or ammonia. $MgCl_2$ was applied to obtain a Mg:P ratio 1.2:1. Alkali NaOH was applied to pH 9.2. The chemicals were mixed for about one minute. After about a 0.5 h gravity sedimentation period, the phosphorus precipitate was dewatered using glass fiber filters, and characterized for total N, P, Mg, Ca, and K and plant available phosphorus.

3 Results and Discussions

Phosphorus recovery of anaerobically digested municipal wastewater via $MgCl_2$ precipitation was enhanced by combining it with the recovery of NH_3 through gas-permeable membranes and low-rate aeration. The low-rate aeration stripped the carbonates in the wastewater and increased pH, which accelerated NH_3 uptake by the gas-permeable membrane system (Fig. 2). The ammonia capture process substantially reduced carbonate alkalinity, from 2990 mg/L to 130 mg/L, and ammonia concentration, from 730 mg N/L to 50 mg/L. These conditions benefited subsequent P recovery. The combined process provided quantitative (ca 100%) P recovery efficiency (Table 1).

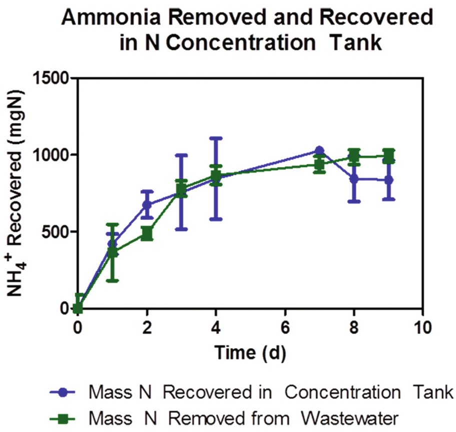

Fig. 2. Mass removal and recovery of nitrogen (N) from municipal wastewater using gas-permeable membranes and aeration

With active NH_3 extraction, the magnesium phosphates that were produced contained high P_2O_5 grade (42%) and high plant availability (Table 2). The phosphorus product was similar to the composition of newberyite ($MgHPO_4$.3H2O), a biomineral found in guano deposits, which has approximately 40.8% P_2O_5 and 13.9% Mg composition and 1:1 P:Mg molar ratio.

Table 1. Changes in concentration and mass balances for nitrogen (N) and phosphorus (P) using side-stream municipal wastewater

	Influent concentration	Effluent concentration	Mass inflow	Mass outflow			Total recovery
			Initial manure	Recovered solid	Recovered by membrane	Effluent	
	mg/L		mg (% of initial)				
N	733	60	1100 (100%)	30 (2.73%)	837 (76.09%)	90 (8.18%)	867 (78.82%)
P	133	20	200 (100%)	212 (106.00%)	0 (0%)	30 (15.00%)	212 (106.00%)

Table 2. Composition of recovered phosphate mineral solid in the system of Fig. 1 using approximately 5.42 mmol/L MgCl2 and approximately 10 mmol/L NaOH

Composition of recovered solid					
N	P (P_2O_5)	Mg	Ca	K	Plant available P (Citrate soluble)
%					
2.56	18.30 (42.0)	14.6	1.4	1.9	98.4

However, in other tests conducted with the same municipal wastewater, whenever the N recovery step was bypassed or carbonate alkalinity was added, the phosphate minerals obtained had lower grade (27–29% P_2O_5) (Vanotti et al. 2016). Therefore, removal of ammonia and carbonates are important considerations for production of very-high grade phosphate products.

4 Conclusions

These results showed that it is possible to produce Mg phosphates with high P_2O_5 content by removing the NH_3 from the liquid with the gas-permeable membrane process. In a first step, the ammonia and alkalinity were removed from municipal side-stream wastewater using low-rate aeration and a gas-permeable membrane manifold. In a second step, the phosphorus was removed using magnesium chloride (MgCl2) and reduced amounts of alkali. The phosphates produced were very-high grade (42–44% P_2O_5) with a composition similar to the bio-mineral newberyite. This is an important finding because recovered phosphates with high P_2O_5 content are more in line with mineral commercial fertilizers and favored by the fertilizer industry.

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http://www.springer.com/978-3-319-58420-1

Frontiers in Wastewater Treatment and Modelling
FICWTM 2017
Mannina, G. (Ed.)
2017, XXIV, 745 p. 355 illus., Hardcover
ISBN: 978-3-319-58420-1