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Recovery of ammonia from digestate as fertilizer

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Abstract

Ammonia inhibition can be a major problem during anaerobic digestion of manure and municipal and industrial sludges. Anaerobic digestion is sensitive to higher NH3-N concentrations, which are inhibiting and at certain levels even toxic for methanogen bacteria. During anaerobic digestion, COD and BOD are converted for 60–80% into biogas. Nitrogen will only slightly be removed due to cell synthesis and due to hydrolysis most of the Kjehldahl nitrogen is converted to ammonium. Because of the reduction of COD in anaerobic digestion the effluent of the anaerobic treatment often results in a COD/N ratio which is too low for further aerobic nitrogen removal. The Nijhuis Ammonium Recovery system (NAR) can solve this problem and removes ammonium from digestate or other substrate for digestion. The NAR is a chemical process based on stripping of ammonia. The ammonium is recovered as ammonium sulphate, which can be used as a fertilizer for agricultural purposes. The NAR was proven to be a robust technology with a stable ammonium removal efficiency of 85–90% for anaerobic digested manure, municipal and other organic waste waters.

The cost effectiveness mainly depends on the concentration of NH3-N in the influent, scale of the installation, the availability of residual heat and the local value and market for ammonium sulphate. Above 2 g/l NH3-N the NAR system is competitive and at higher NH3-N concentrations more cost efficient compared to other state of the art nitrogen removal technologies and ranges between 1–3 €/kg N.

Key words: ammonia stripping, ammonium sulphate, digestate treatment, nitrogen removal

INTRODUCTION

Many anaerobic digesters treating manure, slaughterhouse or municipal waste perform unsatisfactory due to ammonia inhibition. This inhibition is dependent on the concentration of NH_4-N in the substrate and the pH of the substrate due to the equilibrium between NH_4 and NH_3. The equilibrium reaction is shown below.

$$NH_4^+ + H_2O \Leftrightarrow NH_3 + H_3O^+$$

Generally, N-Kjehldahl is toxic for mesophilic bacteria at a concentration of 7 g/l at pH 7.2 and for thermophilic bacteria at 4.5 g/l at pH 7.2 (Borja *et al.* 1996). Inhibition of ammonia reduces biogas production of the digester due to the toxification of the methanogen bacteria.

An ammonium removal and recovery system would not only prevent this inhibition and increase biogas production but also recover the valuable nutrient nitrogen. The objective of this study was to develop a novel ammonium recovery system.

Laboratory experiments were executed in a continuous flow setup using influent and effluent waste streams of digesters at different process settings such as temperatures, pH values and airflows and with different packing materials for the stripping column. Based on the laboratory results a full-scale demonstration plant has been built. The optimal process conditions were determined to

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obtain the highest ammonia removal in a stable and cost efficient system. This paper focusses on the results obtained from the full-scale demonstration plant.

MATERIALS AND METHODS

Laboratory research has been conducted to determine the effect of the of fresh air dosage in relation to the pH, chemical consumption, process stability and to establish the sizing and type of the packed bed and stripping columns.

Based on the results of the laboratory tests a full scale demonstration has been designed. In Figure 1 a schematic overview of the demonstration plant for ammonia recovery is shown.

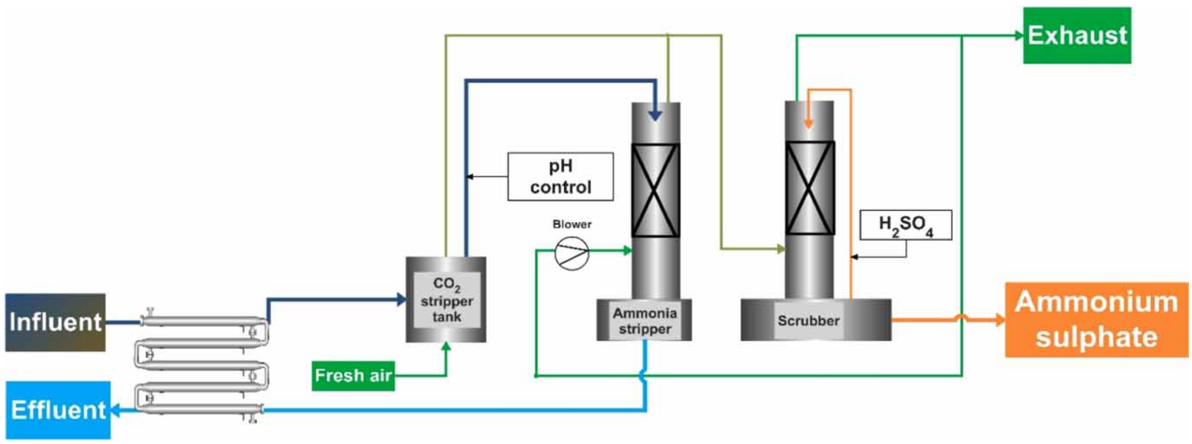

Figure 1 | Schematic overview of the demonstration plant.

The Nijhuis Ammonium Recovery system (NAR) process is designed to treat either raw substrate or digestate and consists of a heat exchanger, a CO_2 stripper tank, an ammonia stripper and a scrubber. In order to prevent clogging of the pall rings in the stripping column, pre-treatment such as a cloth screen, screw press or centrifuge is required. In the CO_2 stripper tank the liquid is heated to 60–70 °C and fresh air is injected to the liquid to strip CO_2. By stripping CO_2 the pH of the treated substance increases which reduces the amount of required dosage sodium hydroxide.

The liquid fraction from the CO_2 stripper tank is treated in the ammonia stripper column where the pH is controlled between 8.5 to 9 and the temperature between 65–75 °C in order to reach a high volatilization of ammonia. The ammonia stripper uses recirculated air from the following scrubber as a carrier gas. To increase the effective contact surface between the liquid and the gas phase a packing material is used. The off-gas from the CO_2 stripping tank and the ammonia stripper is transported to the scrubber column where sulphuric acid is dosed to form ammonium sulphate. A heat exchanger on the effluent flow reduces the heat requirement of the system. Since all residual heat is used for other sources the required heat input is generated by using steam injection.

During the full-scale tests the NAR system has been optimized in order to determine the optimal process settings, the relation between fresh air input and caustic dosage, the process stability and the removal efficiency for NH_3-N.

RESULTS

For this specific plant no more than 75% removal of nitrogen was required for further biological treatment downstream. Therefore the process settings were set to remove ammonium by 75%.

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Figure 2 shows the plant has a stable ammonia removal of an average of 75%. The figure also shows higher removal efficiencies are possible up to 90%.

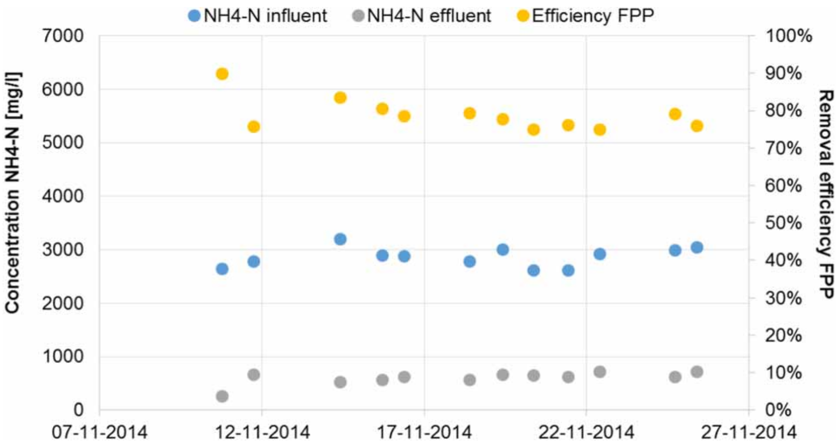

Figure 2 | Influent and effluent concentrations NH_4-N and removal efficiency.

To determine if the NAR system can reach higher removal efficiencies three short term trials have been conducted. During these trials the pH has been increased in order to increase the removal efficiency of the NAR system. The results are shown in Table 1. The removal efficiency for ammonium was on average 90%, the TN removal averages at 85%.

Table 1 | Removal efficiencies of the full scale NAR for ammonium and total nitrogen

	NH4-N [mg/l]			TN [mg/l]		
Date	**Influent**	**Effluent**	**NH4-N removal [%]**	**Influent**	**Effluent**	**TN removal [%]**
25-9-2014	2,100	240	89	2,500	420	83
15-10-2014	2,244	204	91	2,376	265	89
10-11-2014	2,650	265	90	2,950	500	83
Average	2,331	236	90	2,608	395	85

In Figure 3 the concentration of the produced ammonium sulphate is shown after optimization of the gas scrubber. The results show that ammonium sulphate concentrations between 25–40% can be reached.

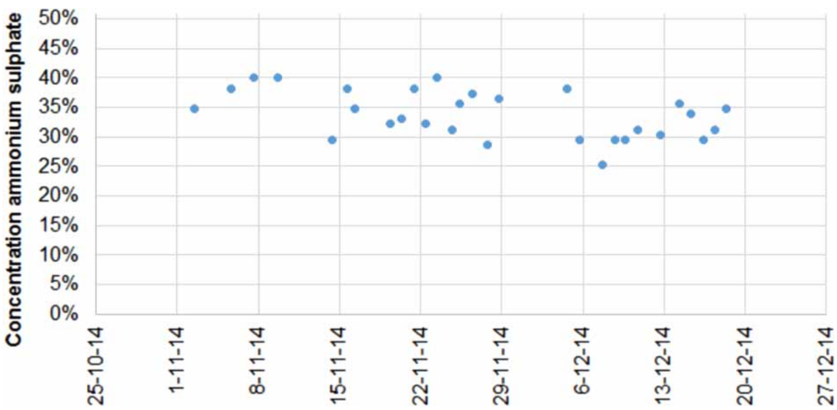

Figure 3 | Concentration of ammonium sulphate.

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ECONOMICAL RESULTS

When calculating the economic feasibility the main cost drivers which affect the costs are:

- Scale of the plant (CAPEX)
- Additional heat input
- Caustic consumption
- Sulphuric acid consumption
- Market value of ammonium sulphate

In order to determine the economics two reference cases are described below. Firstly the case the results of the full-scale demonstration plant for treatment of 75 m^3/d excluding the decanter. Secondly a reference for a larger scale treatment plant of 200 m^3/d. The starting points for each of these cases are shown in Table 2.

Table 2 | Starting points per reference

Parameter	Unit	Full-scale DEMO	Reference 2
Flow	[m^3/d]	75	200
NH3-N influent	[g/l]	2.5	2.5
Efficiency	[%]	80%	80%
NH3-N effluent	[g/l]	0.5	0.5
N removed	[kg/d]	150	400
Process temperature	[°C]	70	70
Process pH		9	9

The total costs per item are shown in Table 3 and are expressed as costs per kg N. The capital costs are estimated based on a NAR system without a front-end dewatering equipment. The total costs are calculated as two different figures, distinguished by the availability of residual heat.

Table 3 | Costs per item per kg nitrogen removed

Costs	Full-scale DEMO [€/kg N]	Reference 2 [€/kg N]
CAPEX	€ 0.75	€ 0.56
Caustic (33%)	€ 0.39	€ 0.39
Sulphuric acid (70%)	€ 0.40	€ 0.40
Heat	€ 0.40	€ 0.40
Installed power	€ 0.36	€ 0.17
CIP/process stability	€ 0.38	€ 0.38
Maintenance	€ 0.18	€ 0.13
Ammonium sulphate[a]	€ −0.39	€ −0.39
Total without heat available	**€ 2.47**	**€ 2.04**
Total with heat available	**€ 2.07**	**€ 1.64**

[a]The market value of ammonium sulphate is highly regional dependent.

The calculations in Table 3 are based on an influent stream containing a NH_3-N concentration of 2.5 g/l. The effect of the influent concentration on the costs per kg N removed is shown in Figure 4. When residual heat is available, this results in the costs per kg N shown in Figure 5.

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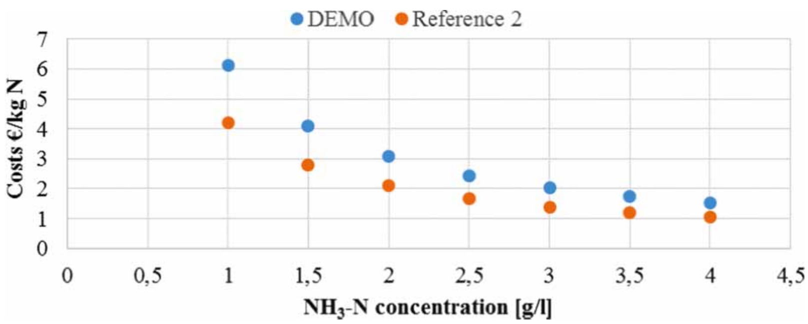

Figure 4 | Effect of NH_3-N concentration of the costs per kg N.

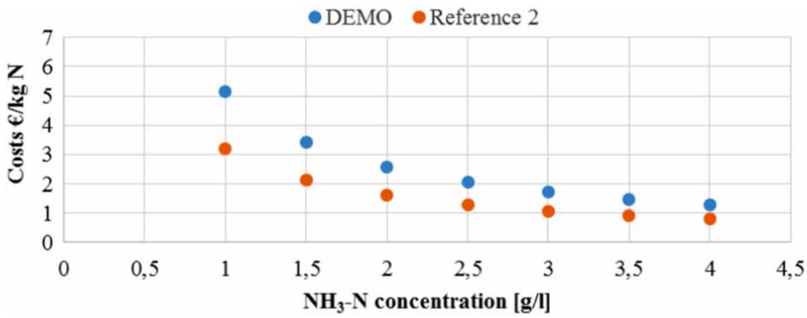

Figure 5 | Effect of NH_3-N concentration of the costs per kg N removed with residual heat available.

Figures 4 and 5 show that the costs per kg N decreases significantly at an increasing influent concentration of NH_3-N. By increasing the concentration of NH_3-N the costs drivers as heating, caustic dosage, process stability and CAPEX remain similar and the costs for an increased sulphuric acid dosage cancels out against the extra cost generation of ammonium sulphate. Since the amount of N removed increases and the costs remain similar, a higher concentration of NH_3-N results in a significantly lower cost per kg N.

Table 4 shows the range of costs per treatment technology (van Velzen & Schoon 2007). The data shows that the NAR system is competitive compared to other new technologies.

Table 4 | Range of costs for various ammonium removal technologies

Technology	Efficiency	Range of costs in €/kg removed
Biological treatment including additional C-source	>95%	2.5–5.5
New technologies (BABE, SHARON, Anammox)	Up to 75%	1.5–3.0
Nijhuis Ammonia Recovery	80–90%	1.0–3.0
Other biological technologies/ MBR	Up to 75%	>5.5

CONCLUSIONS

The results show that stable nitrogen removal rates of more than 80%–90% can be achieved by the NAR system. Ammonium sulphate can be produced at a desirable concentration between 30–40%. The value of ammonium sulphate depends on the produced concentration and local market.

The cost effectiveness of the NAR system mainly depends on the concentration on NH_3-N in the influent. Below 2 g/l NH_3-N the NAR system is less cost effective compared to other nitrogen removal technologies. At concentrations of NH_3-N above 2 g/l the costs per kg N of the NAR system can decrease to 1 €/kg/N at 4 g/l NH_3-N.

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Other significant influences on the cost price per kg N are the scale of the installation, the availability of residual heat and the local value and market for ammonium sulphate.

It can be concluded that the Nijhuis Ammonia Recovery system is an efficient treatment system removing and recovering ammonium from anaerobic digested manure, municipal and other organic waste waters at NH_3-N concentrations above 2 g/l.

The NAR system is competitive compared to other new technologies for nitrogen. At influent NH_3-N concentrations higher of 2.5 g/l and higher ammonium stripping is highly cost efficient compared to other technologies.

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