A retrofitted activated-sludge plant with sequential nitritation and anammox obtains dischargeable effluent

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Abstract New Activated Sludge (NAS®) represents a hybrid, floc-based nitrogen removal process, based on the control of solids retention times (SRT) and dissolved oxygen (DO) levels. The aim of this study was to examine the performance of a full-scale NAS® plant, which treated anaerobically digested industrial wastewater. The batch-fed partial nitritation step oxidized nitrogen to nitrite (45-47%) and some nitrate (13-15%). Serial anammox, denitrification and nitrification compartments were followed by a final settler. In the anammox step, 77% of the nitrogen was removed, with an estimated contribution of 71% by the genus *Kuenenia,* which constituted 3.1% of the biomass. Overall, a nitrogen removal efficiency of 95% was obtained, yielding a dischargeable effluent. The performance of this novel and cost-effective technology demonstrates the feasibility of retrofitting existing systems based on conventional activated sludge.

INTRODUCTION

For wastewaters with an ammonium level below 5 g N L^{-1} and a relatively low ratio of biochemical oxygen demand to nitrogen (typically ≤ 2.5), nitrogen removal by partial nitritation and anoxic ammonium oxidation (anammox) is economically the preferred treatment (Mulder, 2003). Equilibrating the stoichiometries of aerobic and anoxic ammonium-oxidizing bacteria (AerAOB and AnAOB), yields the overall reaction for this process (eq. 1).

$$NH_4^+ + 0.792\ O_2 + 0.080\ HCO_3^-$$

$$\rightarrow 0.435\ N_2 + 0.111\ NO_3^- + 1.029\ H^+ + 0.052\ CH_{1.4}O_{0.4}N_{0.2} + 0.028\ CH_2O_{0.5}N_{0.15} + 1.460\ H_2O \quad \text{(eq. 1)}$$

The aim of this study was to examine the performance of a novel, floc-based partial nitritation and anammox process. The characterized full-scale nitrogen removal process discharges effluent to surface water and is preceded by anaerobic digestion and struvite precipitation (Anphos®), jointly representing the WWTP of a potato-processing factory. Previously, the nitrogen removal plant was operated as a conventional activated-sludge nitrification/denitrification system. However, by choosing appropriate DO setpoints and SRT, the system was retrofitted to a hybrid nitrogen removal process, consisting of partial nitritation (2370 m^3), anammox (1650 m^3), denitrification (1600 m^3) and nitrification (2300 m^3) (Fig. 1). This novel process was designated New Activated Sludge (NAS®), removing nitrogen without external carbon addition nor pH or temperature control.

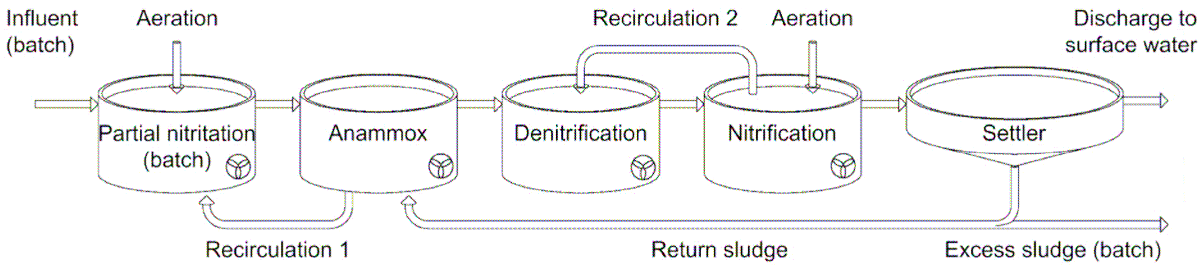

Figure 1. Schematic overview of the examined nitrogen removal process.

RESULTS AND DISCUSSION

The partial nitritation reactor received 1815 ± 300 m^3 d^{-1} with 201 ± 36 mg NH_4^+-N L^{-1}, yielding a hydraulic residence time (HRT) of 32 h and a loading rate of 0.15 kg N m^{-3} d^{-1}, over weeks 10-17 (2010). Over the same period, a SRT of 37 h was applied, and a floccular sludge was obtained (sludge volume index, SVI = 100 ± 23 mL g^{-1} TSS). The partial nitritation reactor was not heated and was at a constant temperature of 36 ± 0°C. The snapshot reactor loading rates were 0.18-0.23 kg N m^{-3} d^{-1}, and the incoming nitrogen was mainly oxidized to nitrite (45-47%) and nitrate (13-15%), also taking into account the organic nitrogen loads of 36, 72 and 25 kg N d^{-1} for the batches 1, 2 and 3, respectively (Table 1). Effluent nitrite to ammonium ratios were 1.37-1.53, which is in the vicinity of the required ratio of 1.32 for the subsequent anammox step.

Table 1. Water and nitrogen streams of three sampled batches for the partial nitritation reactor (averages ± standard deviations). (IN: influent; REC1: recirculation from the anammox reactor; PN: partial nitritation effluent, see also Fig. 1)

	Batch 1			Batch 2			Batch 3		
Stream	IN	+ REC1	→ PN	IN	+ REC1	→ PN	IN	+ REC1	→ PN
Q (m^3 d^{-1})	1740	36	1776	1756	36	1792	2087	36	2123
NH_4^+ (kg N d^{-1})	388	0.3±0.0	133±7	420	0.3±0.0	136±7	507	0.2±0.0	174±13
NO_2^- (kg N d^{-1})	1.5	0.3±0.0	202±7	0.8	0.3±0.0	209±15	0.0	0.4±0.0	238±6
NO_3^- (kg N d^{-1})	1.0	0.1±0.0	65±7	0.1	0.8±0.0	65±2	0.8	0.1±0.0	71±6

In the anammox reactor, a HRT of 6.7 h was applied. Over the combined anammox, denitrification and nitrification stage, a SRT of 46 d was applied and a floccular sludge was obtained with a fair settleability (SVI = 167 mL g^{-1} TSS). During the snapshot sampling, the anammox stage was loaded with 0.33 kg N m^{-3} d^{-1} and removed 77% of the nitrogen load (Table 2). The biomass from the anammox stage consisted for 3.1 ± 2.0% out of the AnAOB genus *Kuenenia*, as determined with fluorescent *in-situ* hybridization (FISH). Using the expected anammox stoichiometry, concurrent denitrification occurred at 0.076 kg (NO_2^-+ NO_3^-)-N m^{-3} d^{-1}, or 29% of the nitrogen removal in the anammox stage.

Table 2. Water and nitrogen streams for the anammox, denitrification and nitrification reactors (averages ± standard deviations). (PN: partial nitritation effluent; RET: return sludge from the settler; REC1: recirculation from anammox to partial nitritation; AN; anammox effluent; REC2: recirculation from nitrification to denitrification; DN: denitrification effluent; OUT: effluent see also Fig. 1)

	Anammox				Denitrification			Nitrification		
Stream	PN	+ RET	→ REC1	+ AN	AN	+ REC2	→ DN	DN	→ REC2	+ OUT
Q (m^3 d^{-1})	2366	4080	36	6410	5601	4800	10401	10997	4800	6197
NH_4^+ (kg N d^{-1})	203±15	0.0±0.0	0.3±0.0	55±1	0.0±0.0	0.0±0.0	0.0±0.0	74±3	0.0±0.0	0.0±0.0
NO_2^- (kg N d^{-1})	266±9	1.0±1.0	0.3±0.0	52±3	89±9	0.0±0.0	27±3	1.0±0.0	0.0±0.0	0.0±0.0
NO_3^- (kg N d^{-1})	79±8	10±3	0.1±0.0	21±4	20±4	24±2	13±3	27±1	45±3	58±4

The denitrification and nitrification reactors provided effluent polishing (Table 2), with long-term HRTs of 3.6 and 5.2 h, respectively. The nitrification effluent contained on average 9.1 ± 3.9 mg NO_3^--N L^{-1}, and no other nitrogen species. Over weeks 10-17 (2010), the four-stage nitrogen removal plant yielded a dischargeable effluent (< 10 mg N L^{-1}), and an overall nitrogen removal efficiency 95 ± 2%.

SUMMARY

To our knowledge, the NAS® process is one of the first nitrogen removal processes to apply anammox in a floccular stage and to obtain dischargeable effluent (<10 mg N L^{-1}) through a hybrid nitrogen treatment train without external carbon addition. The effluent from partial nitritation could be considered as ideally suitable to feed an anammox reactor. The anammox stage removed 77% of its loading rate, with an estimated contribution of 71% by AnAOB. These findings demonstrate the possibility of retrofitting activated sludge plants to the NAS® process, without adding inoculum enriched in AnAOB. When designing new plants, higher loading rates and more compact reactors can be achieved. This has been shown in a 2200 m^3 NAS® plant treating anaerobic digestate containing on average 3350 mg N L^{-1} at an overall nitrogen loading rate of 0.5 kg N m^{-3} d^{-1} and a nitrogen removal efficiency of 99.5%. [SEV1]

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Reference

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