# 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 well 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.

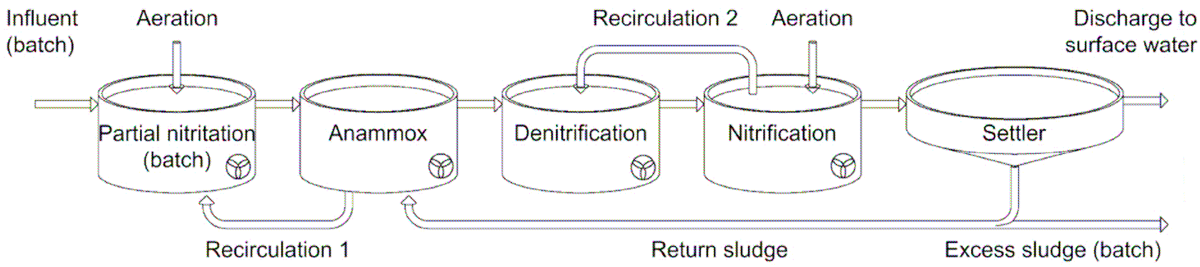


**Figure 1.** Schematic overview of the examined nitrogen removal process.

## 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 open up the possibility of retrofitting existing activated sludge plants to the NAS® process, without adding inoculum enriched in AnAOB. This has demonstrated 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%. This knowledge can therefore be of use for the design of new plants, thus allowing for higher loading rates and consequently more compact reactors.


[SEV1]


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**Reference**


Mulder, A., 2003. The quest for sustainable nitrogen removal technologies. Water Science and Technology 48(1): 67-75.