Full-scale comparison of N_2O emissions with SBR N/DN operation versus one-stage deammonification MBBR treating reject water

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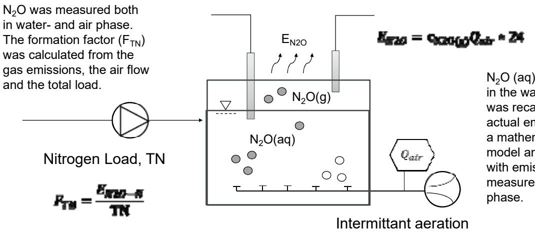
INTRODUCTION

Biological nitrogen removal in wastewater treatment (WWT) is an energy-demanding process. One way to minimize the energy demand is to use deammonification, which includes the nitritation and anammox processes. Using the anammox process means that only half of the ammonium needs to be oxidized to nitrite, thereby saving 60% of the energy demand for aeration. This may also lower the emissions of nitrous oxide (N_2O) since the ammonium oxidizing process accounts for the majority of the nitrogen oxide emissions in such a process [1]. However, the potential N_2O emissions from these types of high-rate processes may increase the total carbon footprint of a WWTP and must be monitored [2]. A reject water treatment tank (1000 m^3) in Norrköping (Sweden) was recently converted from nitrification/denitrification (N/DN) in a sequencing batch reactor (SBR) to a one-stage deammonification with moving bed biological reactor (DeAmmon® technique). The main objective for changing the process was not only to save energy, but also to minimize the total carbon footprint, since previously, measurements of N_2O in N/DN mode resulted in relatively high nitrous oxide emissions, resulting in a high carbon footprint [3].

METHODS

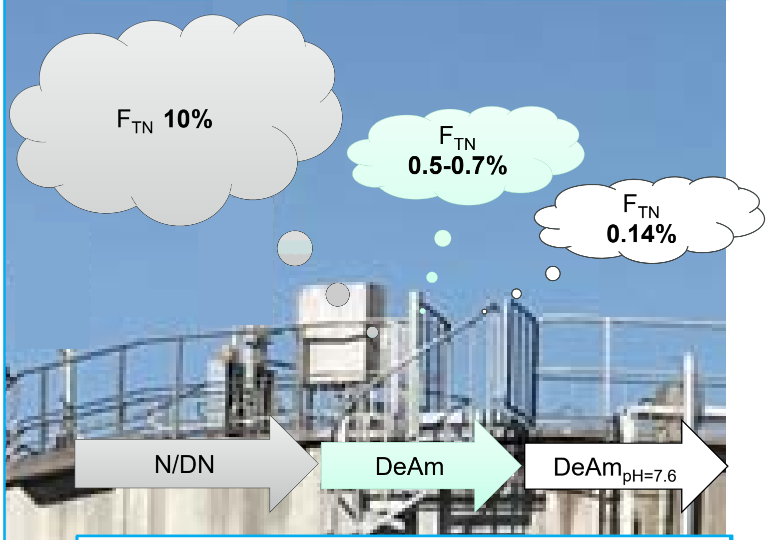
N_2O was measured both in water- and air phase. The formation factor (F_{TN}) was calculated from the gas emissions, the air flow and the total load.



$$E_{N2O} = c_{N2O(g)} Q_{air} * 24$$

$$F_{TN} = \frac{E_{N2O-N}}{TN}$$

N_2O (aq) measured in the water phase was recalculated to actual emissions via a mathematical model and compared with emissions measured in the gas phase.



RESULTS

Measured data is provided in Table 1. Similar loads and influent ammonia concentrations between the different operation modes provide a stable base for comparison. pH was not regulated during the N/DN operation mode while the process in deammonification mode had different pH-setpoints. The change of pH set-point was linked to aeration strategies to avoid adding any chemicals in the process that could cause additional stress to the microbiological fauna. The N/DN operation mode had significantly higher N_2O concentrations in the water phase as well as in the gas phase resulting in higher total emissions of nitrous oxide.

Table 1 – Overview of process data and results for the two different techniques N/DN and deammonification respectively and three different pH-setpoints within deammonification

Nitrogen process	N/DN	Deammonification (nitritation/anammox)			
Technique	SBR	MBBR with continuous inflow and intermittent aeration			
pH-setpoint	Not controlled	6.6	7.1a	7.1b	7.6
Load (kgNH4/d)	210	195	250	210	155
NH4-in (mg/L)	1000	941(±81)	1204(±82)	894(±81)	1022(±128)
pH-measured	6.2-7.5	6.74(±0.18)	7.05(±0.06)	7.05(±0.06)	7.68(±0.16)
NH_4-N-out	30-90	154(±38)	55(±18)	247(±15)	124(±27)
NO_2-N-out	10-25	3.9(±1.0)	4.1(±0.3)	3.8(±1.6)	1.8(±1.0)
NO_3-N-out	90-150	257(±128)	74(±12)	330(±36)	73(±38)
N reduction TN	80%	67%	88%	50%	86%
NH_4-N	95%	88%	95%	79%	91%
Average mg N_2O(aq)/L	13.2	0.41(±0.09)	0.24(±0.14)	0.21(±0.03)	0.10(±0.05)
Average ppm N_2O(g)	973	39(±42)	na(±na)	43(±38)	8.1(±12.5)
N_2O of TN-load	10.4%	0.71%	0.47%	0.71%	0.14%

In Figure 1, a detailed study of nitrous oxide in the water phase during aeration cycles in the different operation modes is shown. During aeration (DO=2 mg L^{-1}) the gas is emitted to the air and the concentration in the bulk phase is decreasing. During mixing (DO=0 mg L^{-1}) the nitrous oxide is formed and partly reduced in the water phase. At pH 6.6 the N_2O-N(aq)-curve show an increasing trend during mixing while at pH 7.6 the concentration is first increasing and later decreasing. The figure also shows lower total emissions (kgN_2O d^{-1}) for pH 7.6.

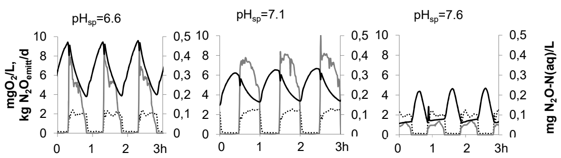


Figure 1. Detailed study of oxygen, nitrous oxide in bulk and emitted nitrous oxide during three aeration cycles (each cycle is 1h). Oxygen concentration in bulk (mgO_2 L^{-1}) is shown with dots (·), emitted nitrous oxide (kgN_2O d^{-1}) is shown with a grey line (-) and nitrous oxide in bulk (mg N_2O_{aq} L^{-1}) is shown with a black line (-). Three representative hours are shown for one representative day from each phase.

DISCUSSION

The results from full-scale operation of one reject water treatment process with two different operation techniques (N/DN and deammonification) shows a lower nitrous oxide emission factor for the deammonification technique. This can be linked to the lower feeding rate [5], lower nitrite concentrations in the bulk phase [6] as well as lower load of ammonia converted by Ammonium oxidizing bacteria (AOB) during deammonification [1].

Further optimization shows that a higher pH-setpoint during deammonification resulted in even lower emissions. A detailed study of the aeration cycles reveal that N_2O(aq) is mainly formed during mixing phases at a lower pH, resulting in higher concentration during aeration, while at higher pH both formation and reduction of the gas takes phase. This results in lower N_2O(aq)-concentration during aeration, lower N_2O(g) concentrations and hence lower total emissions of nitrous oxide emissions from the plant.

CONCLUSIONS

Monitoring nitrous oxide emissions during full-scale operation of a reject-water nitrogen treatment plant have resulted in:

- Significantly lower nitrous oxide emissions were measured with deammonification technique (<1% of TNin) compared to nitrification/denitrification technique (10% of TNin).
- By increasing the process pH-setpoint in deammonification mode, emissions decreased to as low as 0.14% of TNin.

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Acknowledgements: LK is financed by a Piia scholarship from Vinnova (Swedish Governmental Agency for Innovation Systems), with co-funding from Purac AB and ABB AB. This research is also funded by IVL Swedish Environmental Research Institute Foundation (SIVL). The authors would like to thank Nodra AB (former Norrköping Vatten och Avfall) for their cooperation and contribution to the project.