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Simple control strategy for mitigating N_2O emissions in phase isolated full-scale WWTPs

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Abstract

Nitrous oxide (N_2O) is a strong greenhouse gas (GHG) and ozone depleter, with a warming potential 300 times higher than carbon dioxide (CO_2). 1.2% of the total antrophopogenic N_2O emissions are believed to originate from the wastewater treatment (WWT) sector. Conventional biological nutrient removal processes relying on nitrification and denitrification are known to produce N_2O. A one year long-term study of N_2O production and emissions was performed at Lynetten, Denmark's largest WWTP. Nitrification and denitrification takes place by alternating process conditions as well as influent and effluent flows in 20 pairs of interconnected and surface aerated reactors. The long-term data revealed that the N_2O emissions contribute to as much as 30% of the total CO_2 footprint from the WWTP. High ammonium concentrations and long aeration phases lead to high N_2O production and emissions rates. Nitrification phases were identified to produce and emit most of the N_2O. High production and emissions were also associated with the afternoon loading peaks at the WWTP. During denitrification phases N_2O was produced initially but consumed consequently. An effective control strategy was implemented, whereby N_2O emissions were reduced from 0.8% to 0.3% of the nitrogen load during the mitigation period.

Keywords: nitrous oxide emissions, mitigation strategies, biological nitrogen removal

INTRODUCTION

Nitrous oxide (N_2O) is a strong greenhouse gas with a warming potential 298 times higher than that of carbon dioxide (IPCC, 2013). Additionally N_2O is a potent ozone depleter and the major current anthropogenic threat to the stratospheric ozone layer (Kanter et al., 2013). Globally, anthropogenic N_2O emissions account for 6% of the total greenhouse gas emissions and 1.2% of the total N_2O emissions are assumed to originate from the wastewater treatment (WWT) sector (U.S. EPA, 2016). The Intergovernmental Panel on Climate Change (IPCC) recommends to use a N_2O emission factor of 0.0032 kg N_2O-N person^{-1} year^{-1} equivalent to 0.035% of the nitrogen load to estimate N_2O emissions from domestic wastewater treatment plants (WWTP) (IPCC, 2006). However full-scale N_2O measurement campaigns have revealed that emissions can range from 0 -14.6% of the influent nitrogen load (Kampschreur et al., 2009). These findings suggests that IPCC emission factor may underestimate true emissions and there is a need to control and reduce N_2O emissions originating from WWT operations. Process models are established tools for process optimisation, evaluation and prediction of operational strategies – even thought there is so far no consesus on how to model N_2O dynamics. The objectives of this study is therefore to i) quantify the N_2O emissions over long-term at a full-scale phase isolated WWTP (Lynetten WWTP); ii) develop a simulation model for the WWTP and calibrate it to predict N_2O emissions; and iii) develop, implement and evaluate potential mitigation strategies based on model-based assesment and emperical knowledge gained from analysis of the long-term data set.

MATERIALS AND METHODS

A one year long N_2O quantification campaign was performed at Lynetten WWTP, Denmark's largest WWTP, with a design load corresponding to 1,000,000 population equivalents. The WWTP is configured as a phase isolated activated sludge system for biological removal of COD, phosphorous and nitrogen. Nitrification and denitrification takes place by alternating process conditions as well as influent and effluent flows in 20 pairwise interconnected and surface aerated reactors (total volume:147.000 m^3; Figure 1). Quantification of N_2O emission rates were performed through N_2O measurements in one of the phase isolated reactors. Electrode and flux-chamber techniques in combination with an infrared off-gas analyser were used to determine both liquid and gaseous phase N_2O concentrations, respectively. Off-gas measurements were performed during campaigns lasting for up to a month whilst liquid phase measurements were continuously taken during a whole year from May 2015 until May 2016. Nitrogen mass balances were based on results from the regular monitoring program at the WWTP and used to calculate N_2O emission factors. A wastewater fractionation campaign was performed and used as input for model calibration of the ASM2d model extended with the ASM-N (Hiat and Graddy, 2008) and the NDHA models (Domingo-Felez and Smets, 2016) to describe N conversions and N_2O dynamics in detail. After experimental data assessment and model-based analysis, two different control strategies were applied and compared to normal operation contiditions.

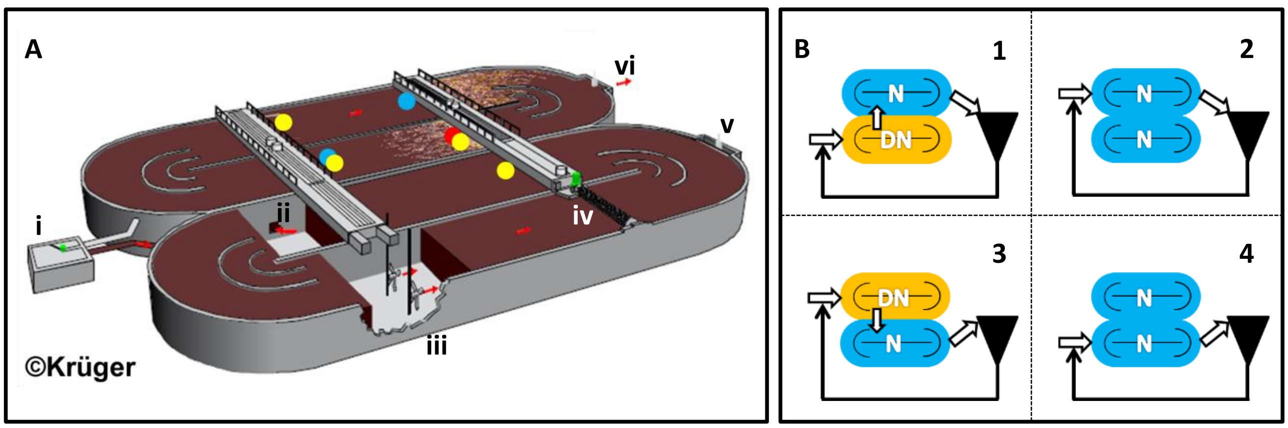

Figure 1A) BioDenipho™ reactor configuration with i) influent distributor, ii) interconnection in reactor wall, iii) submerged mixers, iv) surface aerators, v) effluent weirs vi) discharge, ●) DO sensors, ■) NH_4-N and NO_3-N sensors, ▲) N_2O sensors. **B)** Illustration of alternating influent flows and reactor conditions through a phase cycle.

RESULTS AND DISCUSSION

The long-term data set showed consistent daily dynamics, which strongly related to nitrogen loading rate (NLR), operational phase, and bulk phase NH_4-N concentrations. As illustraded in Figure 2, the dissolved N_2O concentration increased towards the second half of the day. This was also accompanied by increased duration of the operational phase lengths, ie. longer time intervals between the shifts regarding influent flow as well as between anoxic and aerobic conditions in the reactors. Liquid N_2O concentrations were mainly increasing during the nitrification phase, whilst N_2O was consumed after an initial increase during the denitrification phase.

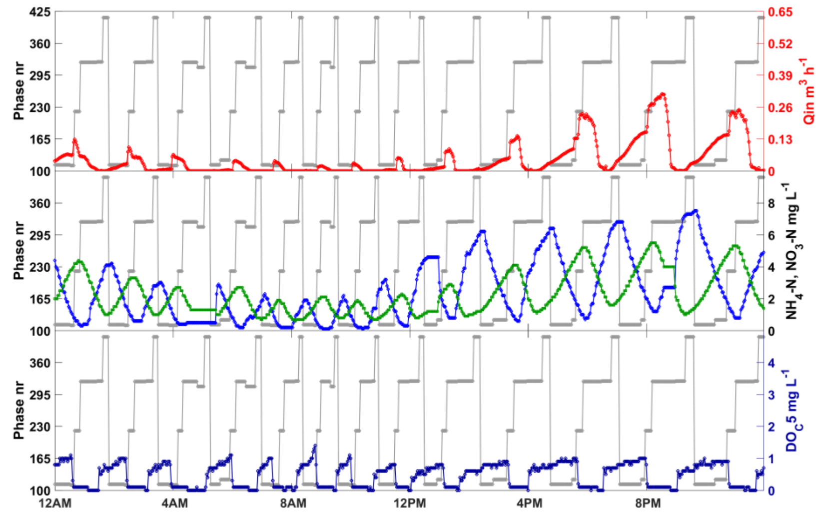

Figure 2. Daily dry weather dynamics during normal operation, **Up:** Liquid phase N_2O (—) concentration (mg L^{-1}); **Middle:** reactor concentrations of NH_4-N (—) and NO_3-N (mg L^{-1}) (—); **Bottom:** bulk DO (—) (mg L^{-1}), the current operation phase (—) is displayed in all graphs.

Based on these results a mitigation strategy was developed. Figure 3 and Figure 4 show a three day period of normal operation and operation with the mitigation strategy, respectively. As can be seen from these graphs the nitrogen loading rates during these days were similar corresponding to $5.1 \cdot 10^{-3}$ and $5.0 \cdot 10^{-3}$ (kgN m^{-3} d^{-1}) respectively. Effluent ammonium concentrations was reduced from an average of 2.3 to 1.8 (mg L^{-1}). N_2O emissions corresponded to 0.3% of the nitrogen load during the mitigation period compared to 0.8% during normal operation conditions.

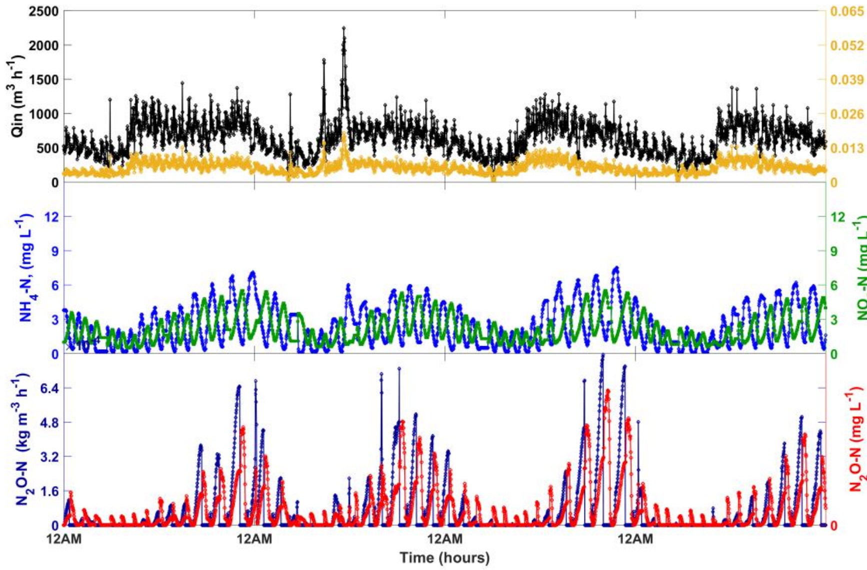

Figure 3 Up: Dry weather influent flow (—) (m^3 h^{-1}) and NLR (—) (kgN m^3 h^{-1}); **Middle:** reactor concentrations of NH_4-N (—) and NO_3-N (—) (mg L^{-1}); **Bottom:** bulk phase concentration of N_2O (—) (mg L^{-1}) and emitted N_2O (—) (kg $m^{-3}d^{-1}$) during normal loading and operation conditions.

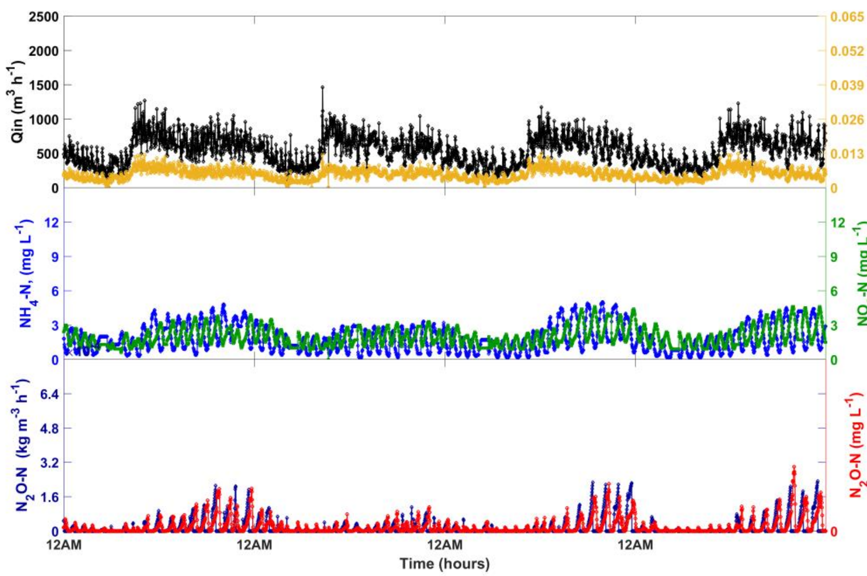

Figure 4 Up: Dry weather influent flow (m^3 h^{-1}) and NLR (—) (kgN m^3 h^{-1}); **Middle:** effluent reactor concentrations of NH_4-N and NO_3-N; **Bottom:** bulk phase concentrations of N_2O (mg L^{-1}) and N_2O (kg $m^{-3}d^{-1}$) emission rates during N_2O sensor controlled operation.

CONCLUSIONS

In this work we revealed that, during dry weather conditions, mitigation strategies can reduce N_2O production and emissions from a phase isolated full-scale WWTP. In addition, the liquied effluent quality from the biological reactor improved while the mitigation strategy was in operation.

Aknowledgement
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