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Simple control strategy for mitigating N₂O emissions in phase isolated full-scale WWTPs

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Abstract

Nitrous oxide (N₂O) is a strong greenhouse gas (GHG) and ozone depleter, with a warming potential 300 times higher than carbon dioxide (CO₂). 1.2% of the total anthropogenic N₂O 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 N₂O. A one year long-term study of N₂O 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 N₂O emissions contribute to as much as 30% of the total CO₂ footprint from the WWTP. High ammonium concentrations and long aeration phases lead to high N₂O production and emissions rates. Nitrification phases were identified to produce and emit most of the N₂O. High production and emissions were also associated with the afternoon loading peaks at the WWTP. During denitrification phases N₂O was produced initially but consumed consequently. An effective control strategy was implemented, whereby N₂O 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 (N₂O) is a strong greenhouse gas with a warming potential 298 times higher than that of carbon dioxide (IPCC, 2013). Additionally N₂O is a potent ozone depleter and the major current anthropogenic threat to the stratospheric ozone layer (Kanter et al., 2013). Globally, anthropogenic N₂O emissions account for 6% of the total greenhouse gas emissions and 1.2% of the total N₂O 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 N₂O emission factor of 0.0032 kg N₂O-N person⁻¹ year⁻¹ equivalent to 0.035% of the nitrogen load to estimate N₂O emissions from domestic wastewater treatment plants (WWTP) (IPCC, 2006). However full-scale N₂O measurement campaigns have revealed that emissions can range from 0 -14.6% of the influent nitrogen load (Kampschreur et al., 2009). These findings suggest that IPCC emission factor may underestimate true emissions and there is a need to control and reduce N₂O 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 N₂O dynamics. The objectives of this study is therefore to i) quantify the N₂O 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 N₂O emissions; and iii) develop, implement and evaluate
potential mitigation strategies based on model-based assessment and empirical knowledge gained from analysis of the long-term data set.

MATERIALS AND METHODS
A one year long N₂O 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 m³; Figure 1). Quantification of N₂O emission rates were performed through N₂O 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 N₂O 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 N₂O 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 N₂O dynamics in detail. After experimental data assessment and model-based analysis, two different control strategies were applied and compared to normal operation conditions.

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 NH₄-N concentrations. As illustrated in Figure 2, the dissolved N₂O concentration increased towards the second half of the day. This was also accompanied by increased duration of the operational phase lengths, i.e. longer time intervals between the shifts regarding influent flow as well as between anoxic and aerobic conditions in the reactors. Liquid N₂O concentrations were mainly increasing during the nitrification phase, whilst N₂O was consumed after an initial increase during the denitrification phase.
Figure 2. Daily dry weather dynamics during normal operation, **Up**: Liquid phase N₂O (—) concentration (mg L⁻¹); **Middle**: reactor concentrations of NH₄-N (—) and NO₃-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 5.1·10⁻³ and 5.0·10⁻³ (kgN m⁻³ d⁻¹) respectively. Effluent ammonium concentrations was reduced from an average of 2.3 to 1.8 (mg L⁻¹). N₂O 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$_2$O (---) (mg L$^{-1}$) and emitted N$_2$O (---) (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$_2$O (mg L$^{-1}$) and N$_2$O (kg m$^3$ d$^{-1}$) emission rates during N$_2$O sensor controlled operation.

CONCLUSIONS
In this work we revealed that, during dry weather conditions, mitigation strategies can reduce N$_2$O 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.
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REFERENCES


