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Data-driven development and full-scale testing of N_2O control strategies

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Abstract: This work aims to develop and test data-driven nitrous oxide (N_2O) control strategies for a full-scale wastewater treatment plant carrying out the activated sludge process in alternating aerobic/anoxic mode. To this end, full-scale real-time data were systematically collected and analysed to infer the underlying mechanisms responsible for N_2O emissions during both aerobic and anoxic phases. Based on these findings, potential control strategies were proposed and then tested at full scale to explore their feasibility of mitigating N_2O emissions.

Keywords: Nitrous oxide (N_2O) emission; control strategies; aerobic/anoxic phase

Introduction

Wastewater treatment plants (WWTPs) contribute significantly to global greenhouse gas stock through the production/emissions of nitrous oxide (N_2O). The reduction potential for N_2O emissions in WWTPs has been estimated to be around 50% by international case studies (Unisense Environment). Therefore, it becomes highly relevant to develop reliable control strategies targeted at reducing N_2O emissions in WWTPs. However, limited control strategies to reduce N_2O emitted from WWTPs have been developed/tested only through simulations (e.g., Boiocchi et al. (2017)); their realistic efficacy remains to be tested. To this end, this work aims to propose potential N_2O control strategies based on analyses of full-scale relevant data and test their capability of mitigating full-scale N_2O emissions.

Material and Methods

This work looks into Avedøre WWTP in Copenhagenn (Denmark) which applies activated sludge process in four parallel reactors, each consisting of two alternatingly fed and intermittently aerated compartments regulated by STAR Control®. Due to the foremost difficulty in implementing the fuzzy logic controller by Boiocchi et al. (2017) in the current control system (unless it gets decommissioned), we decided to infer potential control strategies by data-driven analyses. To this end, on-line data (N_2O, NO_3^-, NH_4^+, dissolved oxygen (DO), temperature, influent, etc.) were processed to calculate N_2O emissions for aerated and non-aerated zones according to Foley et al. (2010) as well as to deduce the relationships between N_2O emissions and operating conditions.

Results, Discussion and Conclusions

Figure 1 demonstrates the two most commonly repeated types of cyclic patterns. In the first type of cyclic patterns (i.e., cycles 1 to 3), nitrification and denitrification in the aerated (aerobic) phase contribute simultaneously to nitrogen turnover. With the decreasing NH_4^+ due to nitrification, NO_3^- firstly increases while N_2O follows. When entering the non-aerated (anoxic) phase, NO_3^- decreases immediately and continuously, while N_2O firstly increases due to heterotrophic production and then decreases because of heterotrophic consumption which starts when NO_3^- is depleted or reaches a low level. By contrast, in the second type of cyclic patterns (i.e., cycles 4 to 6), when N_2O is not completely removed at the end of anoxic phase (see cycle 4), it will carry over to the subsequent aerobic phase, where significant N_2O emission rates therefore take place. This situation might persist for several cycles until a high N_2O consuming capacity is achieved at certain anoxic phase when sufficient phase length/carbon source or low initial NO_3^- level is present (see cycle 6). The results in **Figure 1** not only confirm the contributions of both aerobic and anoxic phases to N_2O production/emissions but also highlight the necessity of maximizing the consuming capacity of anoxic phase for N_2O reduction.

Calculations show that the aerobic phase accounts for around 90% of the total N_2O emitted in the peak N_2O emission month monitored. As nitrification-associated pathways play the key role in N_2O production in the aerobic phase, nitrification should be properly regulated to control N_2O production in the aerobic phase. In addition, several model-based analyses on the predenitrification-type WWTP configuration indicated the importance of regulating the oxygen in order to reduce the amount of nitrification-associated production of N_2O. This is also the basis and key concept of the fuzzy logic controller (e.g., Boiochhi et al. 2017). Therefore, considering the doable manipulation of DO set-point, which is determined by NH_4^+ level, in STAR Control®, we tested the control over nitrification in the aerobic phase by increasing/decreasing the DO set-point by 0.5 mg/L in one of the two reactors operated in parallel at Avedøre WWTP. As illustrated in **Figure 2**, the increased DO set-point in Reactor 1 didn't cause significant change in the N_2O emission rate. This could be caused by the already high DO set-point in the existing control strategies (i.e., minimum DO of 0.5 even at NH_4^+ level of 0). Compared to the NH_4^+ loading, the oversupply of oxygen wouldn't affect the nitrification much. Another hypothesis is associated with the accompanying contribution of heterotrophic process to N_2O production in the aerobic phase. As shown in **Figure 3**, which compares the N_2O emission rate between reactors with and without decreased DO set-point, a decreased DO set-point in Reactor 3 led to N_2O emission 60% lower than Reactor 1, which might serve as the evidence supporting the dominating role of the hydroxylamine pathway during nitrification in the N_2O production in the aerobic phase. After reverting the DO set-point in Reactor 3 back to the original level, the N_2O emission rate in Reactor 3 was still lower than Reactor 1. However, the discrepancy was closing up, and the N_2O emission rates in Reactor 1 and Reactor 3 might level up in ample time.

The comparison between cycles with and without N_2O carrying over to subsequent cycles in **Figure 4** shows the potential of using the peak NH_4^+ level in the aerobic phase and the NO_3^- at the end of aerobic phase as indicators for initiating N_2O mitigation strategies. When they are significantly higher than regular levels, measures should be taken to ensure sufficient N_2O consumption in the following anoxic phase (e.g., through extending the length of anoxic phase or adding external carbon source). To test the control over the anoxic phase, another experiment could be carried out in the two reactors: Reactor 1 will be operated at the original settings while the criteria for Reactor 3 to exit the anoxic phase will be modified so that more time will be granted to ensure full denitrification, especially N_2O reduction. In order to verify and complement this hypothesis (i.e. the relative importance of aerobic (nitrification-associated) versus anoxic (denitrification-associated)) N_2O production), a longer-term (e.g. one year) assessment of the N_2O emission dynamics is necessary for cyclic as well as other plant configurations.

References

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Figures

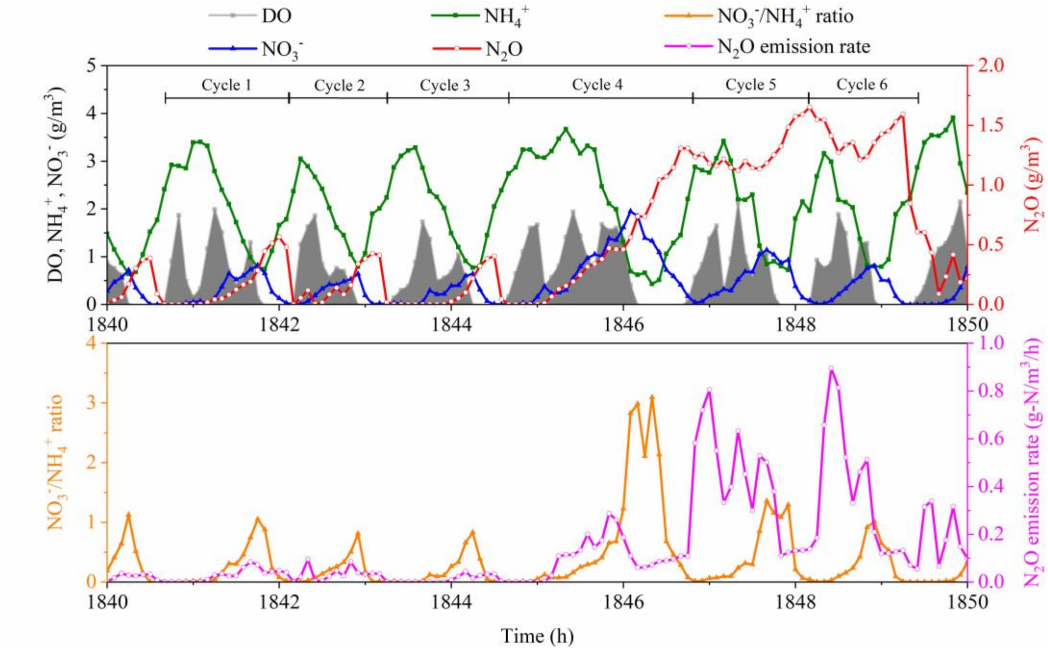

Figure 1 Commonly repeated types of cyclic patterns in Avedøre WWTP.

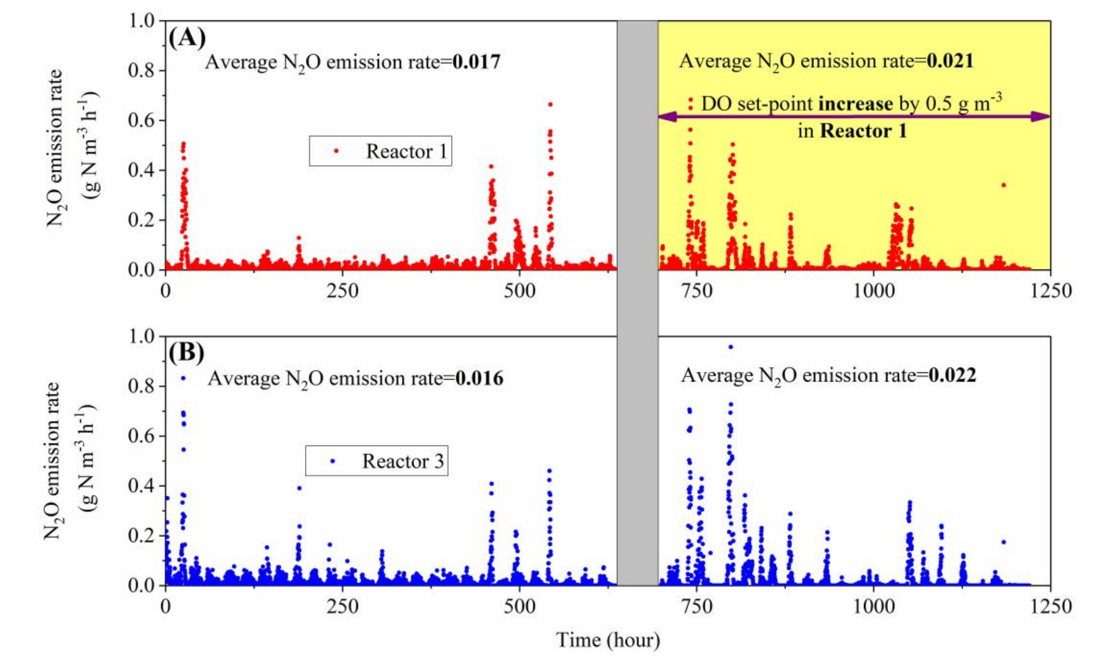

Figure 2 Comparison of N_2O emission rate between reactors with and without increased DO set-point.

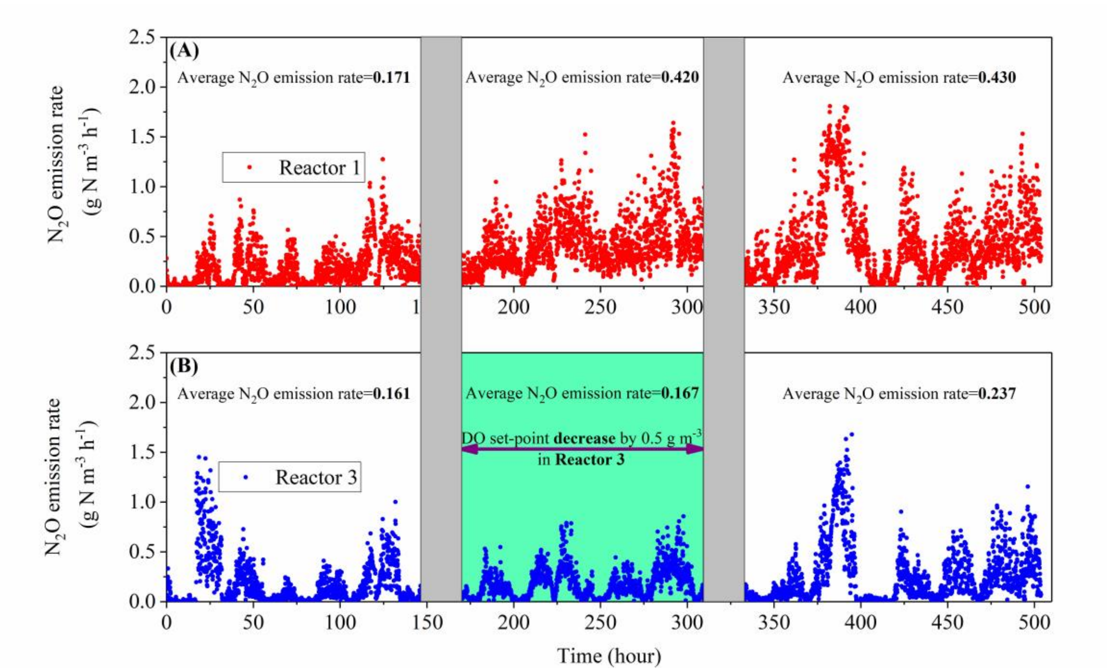

Figure 3 Comparison of N_2O emission rate between reactors with and without decreased DO set-point.

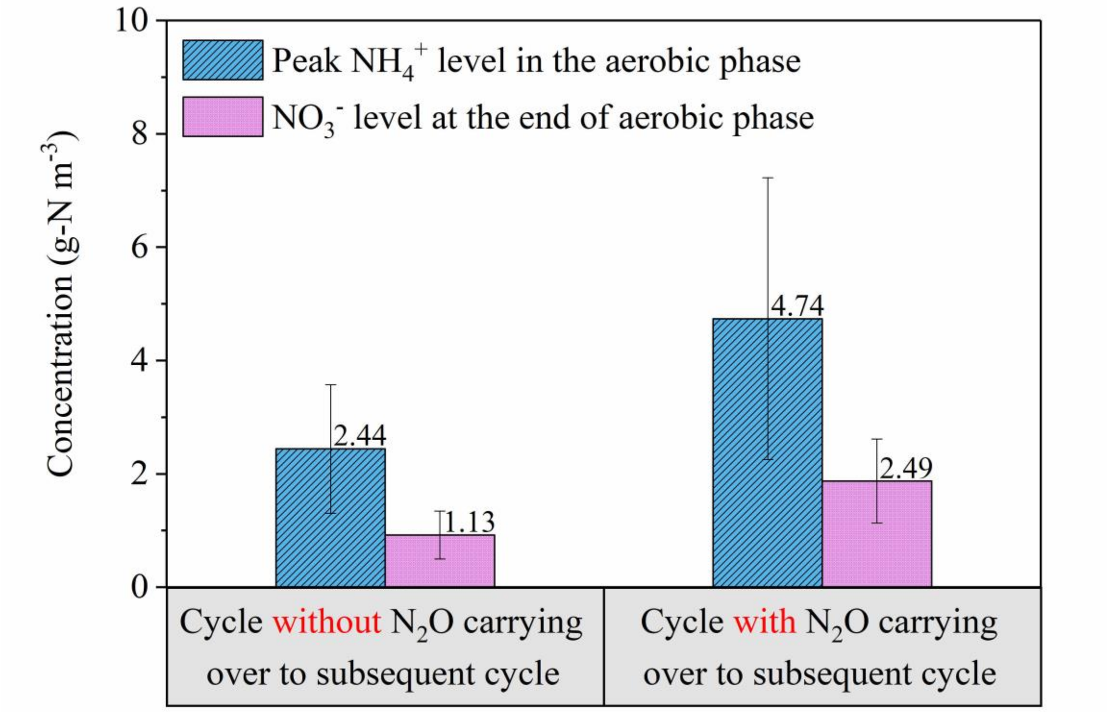

Figure 4 Peak NH_4^+ level in aerobic phase and NO_3^- at the end of aerobic phase for cycles with and without N_2O carrying over to subsequent cycles.