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Direct Effect of Activated Sludge Concentration on N_2O Emission and CO_2-equivalents at Full-scale.

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Abstract: This work presents results from a 3½-year data-driven nitrous oxide (N_2O) measurement and emission accounting for a 345.000 PE wastewater treatment plant carrying out the activated sludge process in alternating aerobic/anoxic mode. Full-scale data was systematically collected and analysed to infer the underlying mechanisms responsible for N_2O production and the variability of the N_2O emission rate. The N_2O emission and inferred CO_2 footprint were highly variable and yet seasonally dependent, emphasizing the need for long-term continuous monitoring. Based on the online data, potential control strategies were proposed and tested over 2 years in 25% of the full-scale volume to explore their feasibility of mitigating N_2O emissions. In one year, a reduction of 74% in N_2O emission was realized compared to the reference lanes.

Keywords: Nitrous oxide (N_2O) emission; GHG mitigation; control strategies

Introduction

Water Resource Recovery Facilities (WRRFs) contribute significantly to the global greenhouse gas stock through the production and emissions of nitrous oxide (N_2O), and the increase of the wastewater N_2O emission factor (EF_{N2O}) by $IPCC_{2019}$ underlines this. In Denmark, based on a 2-year monitoring campaign on 10 different WRRFs in 2021, a new national EF_{N2O} of 0.84% N_2O-N/TN has been adopted by the Danish EPA. Learnings from the monitoring campaign confirm that N_2O emissions vary significantly with the type of nitrogen removal process and emphasize the need for conducting exhaustive on-site monitoring of the N_2O emissions. To mitigate the inherent emission without compromising effluent quality, it becomes highly relevant to develop reliable and simple online monitoring and control strategies targeted at understanding and reducing N_2O emissions from WRRFs. The present work presents 3½ years of continuous N_2O measurements from a large high-load WRRFs and demonstrates the full-scale feasibility of a simple N_2O control strategy based on analysis of relevant data to significantly reduce emissions.

Methods

BIOFOS's Avedøre WRRF in Copenhagen (Denmark) is a 345,000 PE treatment plant employing the activated sludge process in four parallel tanks (LT1-LT4), each consisting of two alternatingly fed and intermittently aerated compartments regulated by STAR Control®. In the present study, four online dissolved N_2O sensors (Unisense Environment) were installed and maintained in each compartment of two of the four parallel tanks (LT11, LT12, LT31, LT32) for more than 3½ years thus monitoring 50% of the bioprocess. N_2O emissions for aerated and non-aerated zones were calculated online according to ***Baresel et al. 2016***. Following a 1.5-year monitoring period from 2018, compiled data was analyzed to understand the relationship between N_2O emissions and operating conditions, (dissolved N_2O, NO_3^-, NH_4^+, dissolved oxygen (DO), temperature, influent, etc.). During the spring of 2020 and 2021 an adjusted MLSS and DO controller was tested in the controlled tanks LT31 and LT32 while keeping LT11 and LT12 as reference tanks. Equal loading and process balances for all tanks were observed while comparing individual Q_{in} flow meters and cumulative Q_{air}, NH_4^+, and NO_x^- usage and levels.

Results and Discussion

Following well over 3½ years of online monitoring of N_2O in 4 of the 8 process compartments at Avedøre WRRF **Figure 1** shows the latest 3½ years of N_2O monitoring data collected in the SCADA system. The N_2O emission data is shown as daily averages of KgN N_2O/day and highlights the very dynamic seasonal and yearly pattern. The yearly pattern is repeating but the emission magnitude is very different between years.

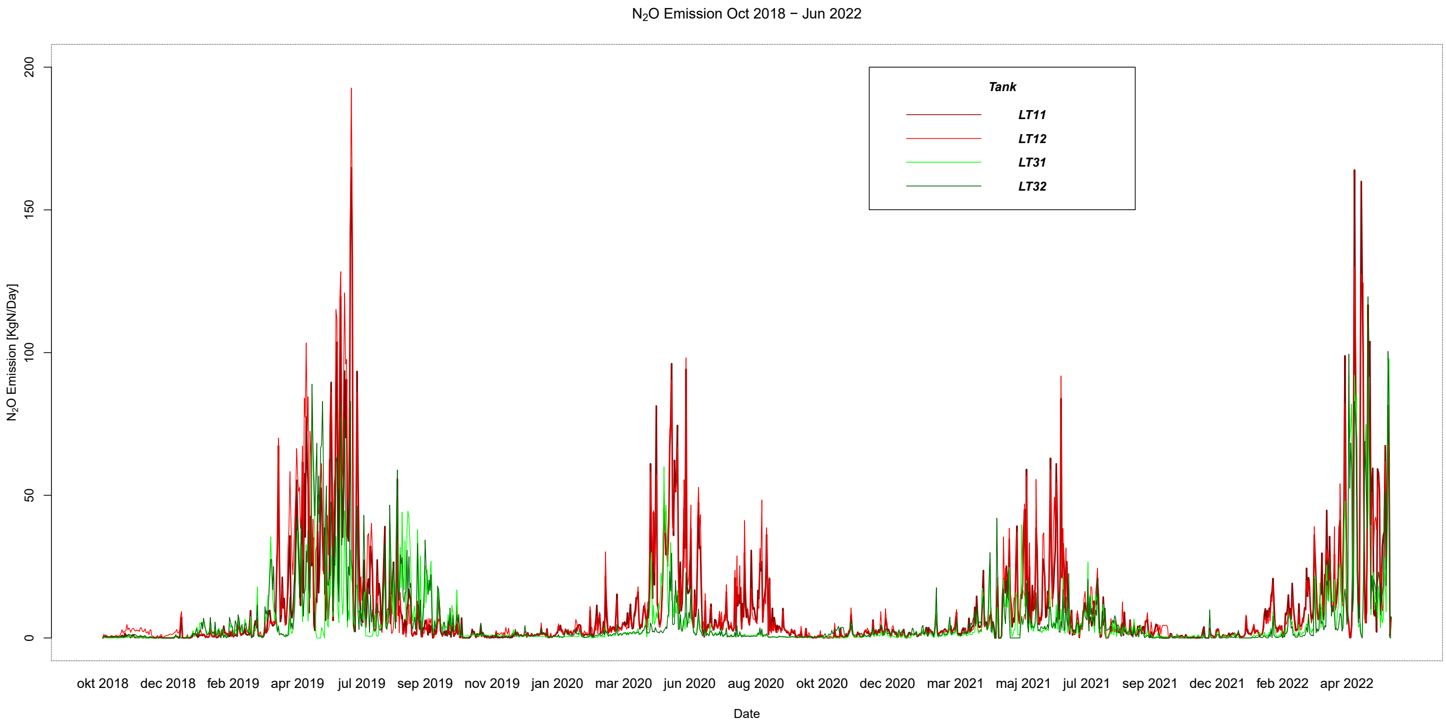

Figure 1: *Data from 3 years N_2O monitoring with four N_2O sensors (1344 days) shown as daily mean N_2O emissions KgN/day. The yearly and especially seasonal variation between winter (Oct-Mar) and summer (Apr-Sep) is observed.*

The cumulative N_2O emissions over 1344 days are shown in **Figure 2** for all 4 tanks. Interestingly, most of the emission is accumulated from March to August with variation between the compartments every year, but an overall similar trend.

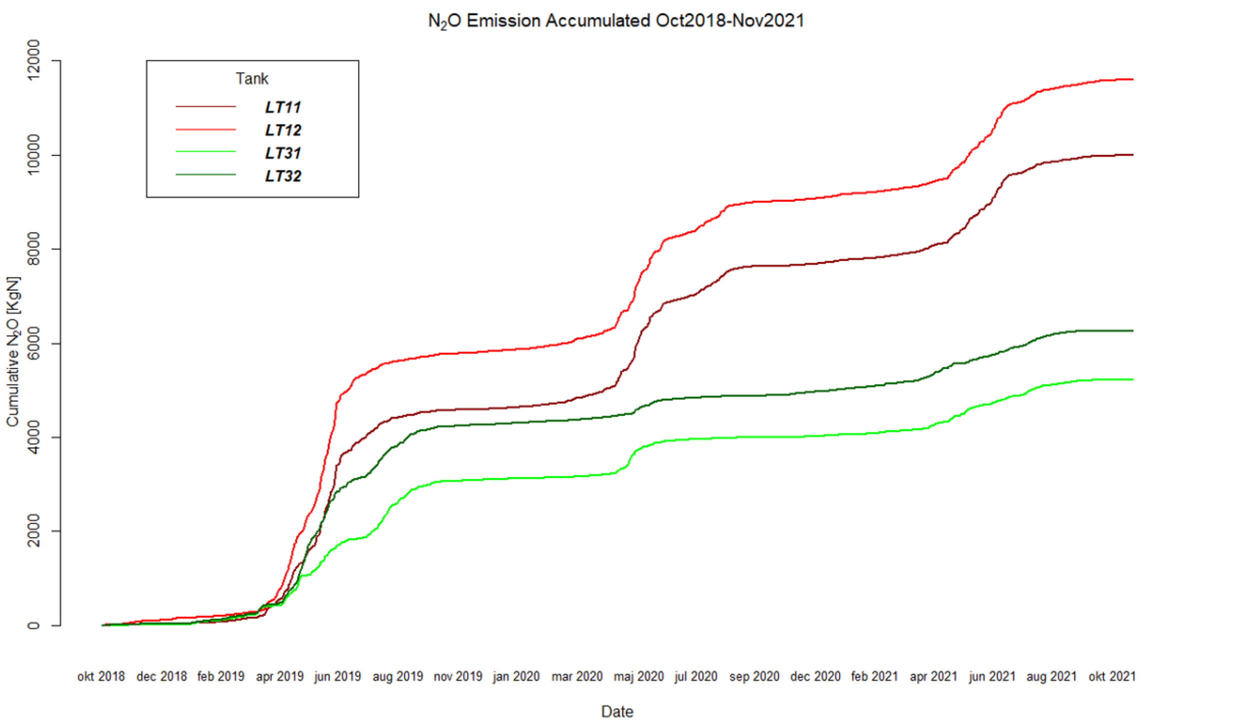

***Figure 2**: Cumulative plot of the N_2O emission from October 2018 to November 2021 from a total of 1344 days. The seasonal mean daily N_2O emission rate between winter (Oct-Mar) and summer (Apr-Sep) amounted on average to 6.22 and 49.79 Ton $CO_{2\text{-}eqv}$/day, respectively.*

Based on the cumulative N_2O emission and the average daily N-loads for the years 2019, 2020, and 2021 of 3,232, 3,138, and 3,592 KgN, the average yearly EF_{N2O} were 3.33%, 2.24%, and 1.61% of daily TN_{Load} (**Table 1**).

Using the IPCC CO_2-equivalent factor ($CO_{2\text{-eqv}}$) of 298 kg CO_2 per kg N_2O, a total CO_2 footprint between 18,396 in 2019 and 9,885 Ton $CO_{2\text{-eqv}}$ in 2021 was demonstrated. Winter and summer emissions amount on average to 6.22 and 49.79 Ton $CO_{2\text{-eqv}}$/day, respectively over the period. The EF_{N2O} of Avedøre WRRF are 2 – 4 fold higher than the average national and $IPCC_{2019}$ factors, indicating the importance of performing on-site monitoring of N_2O rather than relying on average assumption.

As previously published (Andersen et al. 2021), during the period in 2019, where parts of the aeration system were undergoing maintenance, the lower wastewater load resulted in reduced N_2O emissions by 65.5%. Following the results by Law et al. 2012 showing that increased N_2O production can be attributed to increased specific NH_3 oxidation rate by AOBs, we tested ways to decrease the specific AOB NH_3 oxidation rate by simply increasing the MLSS concentration in LT31 and LT32, keeping LT11 and LT12 as reference tanks. As shown in **Figure 3**, over the spring months of 2020 and 2021 a significantly reduced N_2O emission was observed coinciding with the increased MLSS concentration.

Compared with the reference tanks, an overall reduction of 74% in 2020 and 48% in 2021 was achieved with a total $CO_{2\text{-eqv}}$ saving of 13,692 Tons over the 2 years (**Figure 4**).

Summarized in **Table 1**, 3½ years of online N_2O emission monitoring have demonstrated high and variable EF_{N2O} above the $IPCC_{2019}$ factor based on daily TN_{Load} or daily $TN_{Treated}$. Furthermore, simple process changes have made a significant impact on the cumulative N_2O emission, as shown for the MLSS controlled tanks exhibiting a lower EF_{N2O} of 0.58% and 0.83% of the daily TN_{Load} for the years 2020 and 2021. Clearly, the large seasonal and yearly variations undermine results deducted from typical short-term monitoring campaigns and the present work exemplifies the difficulty in extrapolating even yearly emission results or use of a reference year for a general N_2O emission factor.

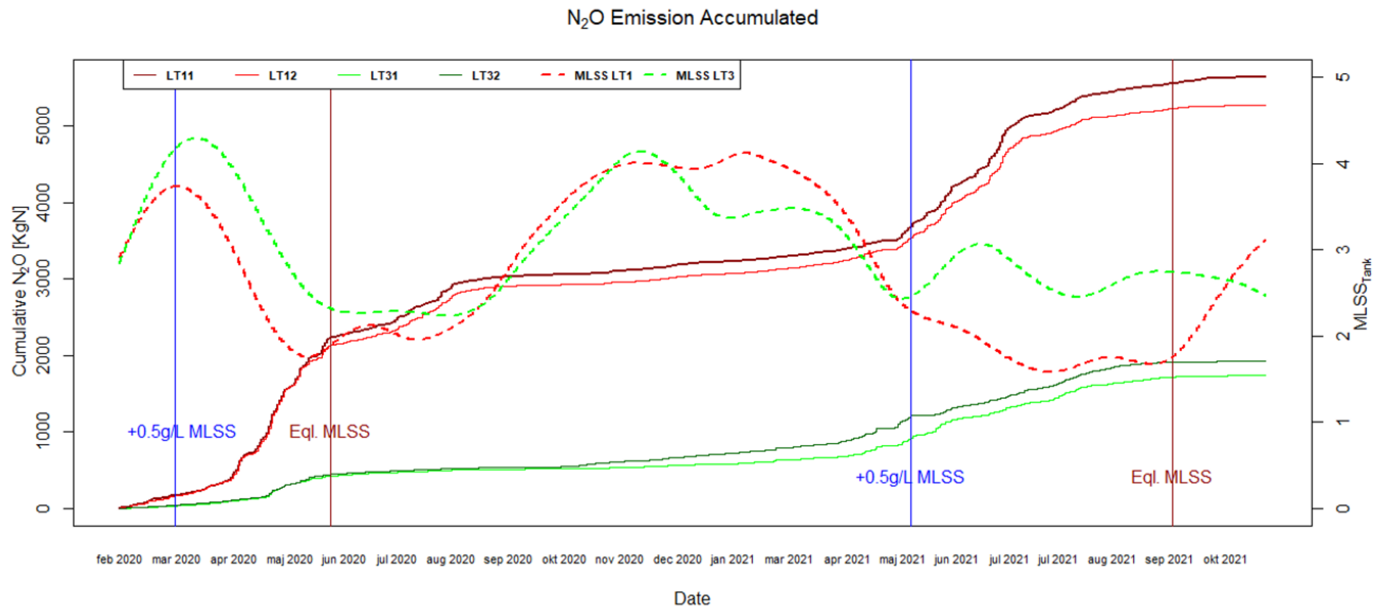

Figure 3: *Cumulative plot of the N_2O emission from February 2020 to November 2021 from a total of 655 days. Comparison of the $CO_{2\text{-eqv}}$ emission per day (Ton $CO_{2\text{-eqv}}$ /Day) between the reference tanks LT11 and LT12 (red) and the higher MLSS tanks LT31 and LT32 (green).*

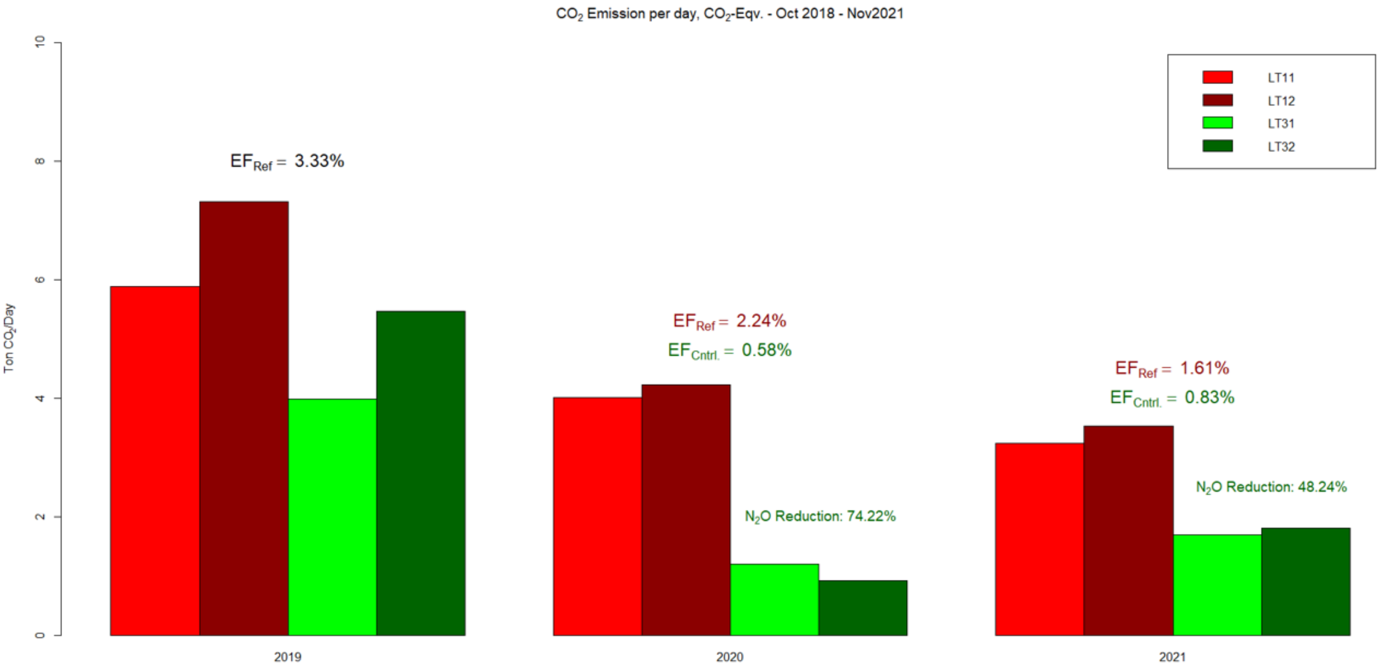

Figure 4: *Comparison of the $CO_{2\text{-}eqv}$ emission per day (Ton $CO_{2\text{-}eqv}$ /Day) between the reference tanks LT11 and LT12 (red) and the higher MLSS tanks LT31 and LT32 (green). In 2019 no MLSS increases were made, but a 25-day repair in LT31 resulted in lower emissions. The N_2O emission factors are shown as EF_{N2O} in % N_2O/TN_{Load}. The emission reduction between the reference and controlled tanks are also shown in %.*

Table 1: *Comparison of N_2O emission factors (% N_2O/TN_{Load} or % $N_2O/TN_{Treated}$) between the reference tanks LT11 and LT12 and the MLSS controlled tanks LT31 and LT32. In 2019 no MLSS increases were made in any tanks and all 4 tanks were used for the average EF_{N2O}. Included is the average daily TN_{Load} for all years.*

	Influent Load	Reference Tanks		Controlled Tanks	
Year	Kg TN_{Load}/Day	EF TN_{Load}	EF $TN_{Treated}$	EF TN_{Load}	EF $TN_{Treated}$
2019#	3232	3.33%	3.79%	-	-
2020	3138	2.24%	2.51%	0.58%	0.65%
2021	3592	1.61%	1.81%	0.83%	0.94%
2022*	3321	4.02%	4.53%	-	-

**In 2019 & 2022 all 4 tanks used for average EF_{N2O}. *For 2022 average 3-year load and treated values used for the period Jan-Jun.*

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