Miljøstyrelsen

Real-time management of nitrous oxide emissions from waste water treatment plants

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Editorial:
Claus Kobberø, Envidan,
Lars Lading, Envidan,
Mikkel Holmsen Andersen, Unisense Environment,
Carina Cupit Bayley, Skanderborg Utility,
Jens Munk-Poulsen, Skanderborg Utility

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Content

Introduction

Skanderborg Utility has a target to be carbon neutral by 2030. In the carbon 2footprint inventory for 2018 and 2019, it is estimated that the carbon footprint from nitrous oxide emissions represents 34% of the total carbon footprint of the wastewater utility. This calculation is based on the use of generally applied emission factors; however, Skanderborg Utility has implemented online nitrous oxide sensors to investigate the actual nitrous oxide emission. It turned out that nitrous oxide emissions are very dynamic in relation to process conditions and the load of the treatment plant and large variations in nitrous oxide emissions were documented cf. MUDP report "Measurement of nitrous oxide emissions from Skanderborg Central Sewage Treatment Plant, MST-117- July00446, 2020".

As nitrous oxide emissions are dependent on various operating conditions, but generally few process parameters, this opens up opportunities to control purification processes to reduce emissions.

The aim of the project is to develop, implement and test a real-time control system at the Skanderborg wastewater treatment plant in order to reduce nitrous oxide emissions while complying with all applicable emission requirements.

The present project has been implemented as part of the MUDP programme "Grants for Measurement and Research with Reduction of Nitrous Oxide MUDP 2019". Through this, support has been obtained to:

- develop a real-time nitrous oxide control in EnviStyr 2.0, which is Skanderborg Central Sewage Plant's current platform for advanced online control (real-time)
- test the implemented nitrous oxide control
- document a baseline of nitrous oxide emissions without nitrous oxide control via the use of 0-point reference throughout the test period (classical NH4-based set-point control in PCT1)
- document the effect on nitrous oxide emissions as well as the other treatment efficiencies of the treatment plant
- evaluate experiments, quantify reductions in nitrous oxide emissions and report results

Skanderborg Utility with project manager Jens Munk Poulsen is the main applicant for the project and has carried out the project with EnviDan A/S and Unisense Environment A/S as sub-consultants. The project has been approved as of 20 December 2019. The project is originally scheduled for completion by 30.06.2020. The project period has run from January 2020 and extended to June 2021 due to construction challenges. Completion and reporting has been postponed to 30.06.2020.

1. Description of the Skanderborg Central Sewage Treatment Plant

Skanderborg Central Sewage Treatment Plant has a designed capacity of 47,000 PE and a known capacity of 40,218 PE. It is a recirculation plant with two parallel lines, each built in a process tank. The process tanks consist of an outer tank and an inner tank. The inner tank is a DN tank and the outer tank is an N/DN tank (with recirculation between the N and DN tanks), with bottom aeration installed in about half of the tank. The degree of denitrification in the outer tank varies according to load and aeration level. The inlet flow is equally distributed between the two process lines. An aerial view of the plant showing the main parts of the plant is shown in Figure 1.

FIGURE Skanderborg**1.** Central Sewage Treatment Plant. Green cross marks location of nitrous oxide sensor.

Control of aeration in PCT1 and PCT2 is generally done in EnviStyr based on online measurement of primary NH-N_4 and NO-N_3 measured with ion-selective electrodes from WTW and measurement of dissolved oxygen (WTW). In the context of this project, a control system is implemented in PCT2 which, in addition to other sensors (ion-selective electrodes), includes online measurement of nitrous oxide ($_2$NO-N) (Unisense En- vironment).

PCT1 is operated during the project period via the utility's SCADA system with classical NH-based$_4$ setpoint control. As a reference to the real-time control in PCT2, nitrous oxide values in PCT1 are also logged via online $_2$NO-N measurement.

2. Lauter gas sensors, location, data collection and processing

2.1 Placement of sensors

Prior to the present project, sensors for measuring the nitrous oxide concentration from the process tanks have been installed in a previous MUDP project. These sensors are still in use, with 1 $_2$NO Wastewater Sensor from Unisense Environment placed in both process lines in the N/DN tanks above the aerated zone, as shown in Figure 1. The actual nitrous oxide emission calculations have been performed in real time in the EnviStyr platform2.0. This allows a calculation of the total nitrous oxide emissions from both process tanks.

2.2 Commissioning of online measurement, measurement period and data flow

In May 2020, the nitrous oxide calculations were taken over by EnviStyr 2.0, which communicates the emissions via the dashboard in EnviPortal. EnviStyr 2.0 obtains the SCADA logged signals via OPC and calculates the nitrous oxide emissions from the aerated/non-aerated zone in PCT1 and PCT2 and the derived total nitrous oxide emission.

In May 2021, a switch to MODBUS will be made, allowing the SRO system to read directly into the laughing gas sensors' signal box.

In the period 01.05.2020 until 01.11.2020, which is considered as a test period, the measurement has been continued, where different real-time control principles have been tested in order to find the most suitable real-time control for minimising nitrous oxide emissions, which will be implemented in the following measurement period from to 01.11.202011.06.2021.

The test and measurement period has not been a stable period of operation, as there have been a number of technical challenges and changes which have made it difficult to achieve stable conditions for extended periods. During the period the following have been implemented:

- Replacement of fans - smaller fans installed (made before the measurement period started, summer 2020)
- Replacement of recirculation pumps (carried out in the middle of the measurement period, start 2021)
- Additional recirculation (only carried out for the double load tests on each tank)
- Change of recirculation control (made mid-period, start 2021)
- Too much sludge in the plant (was the case in the first half of the measurement period, November to2020 March 2021)

2.3 Maintenance, calibration and data validation

The sensors are calibrated via 2-point calibration every week,6 with 0-point calibration as needed. Sensor heads are cleaned 2-4 times per month with complete replacement every 3-4 months.

For most of the measurement period (01.11.2020 to 11.05.2021), the nitrous oxide sensor values were entered into the SRO system via converter, resulting in a 0-point offset for nitrous oxide sensor and 1nitrous oxide sensor 2 of 0.01 mg/l and 0.02 mg/l $_2$NO-N, respectively. The offset is due to an implementation error of the converter in the SRO system. The scale given by Unisense Environment is between 4-20 mA for a 0-2,0 mg N/l$_2$ NO-N. However, the SRO implemented a scale that was between 3.8-20 mA for a 0-2.0 mg N/l$_2$ NO-N, which resulted in an offset error of - 0.025mg N/l$_2$ NO-N at 4 mA. This 0-point offset was corrected for in subsequent data processing.

From 11.05.2021 onwards, the nitrous oxide sensor values are loaded into the SRO system via MODBUS, after which the nitrous oxide sensor signals are loaded directly from$_2$ the NO controller.

2.4 Calculation of nitrous oxide emissions

The nitrous oxide emission is calculated from the collected SRO data from nitrous oxide concentration, air flow and effluent temperature.

The calculation principle is described in Annex 1 of the MUDP report "Measurement of nitrous oxide emissions from Skanderborg Central Wastewater Treatment Plant, MST-117-00446, July 2020".

3. Impact of operating conditions on nitrous oxide emissions

A number of projects have been carried out in recent years to map nitrous oxide emissions from wastewater treatment and to acquire new knowledge that can be used to optimise the operation of treatment processes in wastewater treatment plants in order to reduce the actual nitrous oxide emissions from biological processes (nitrogen removal - denitrification/nitrification).

Some of the main parameters that increase nitrous oxide emissions are mostly related to specific operating situations, caused for example by an increase in the load of the cleaner plant (high load plants), as shown in Figure or 2,by a change in aeration control.

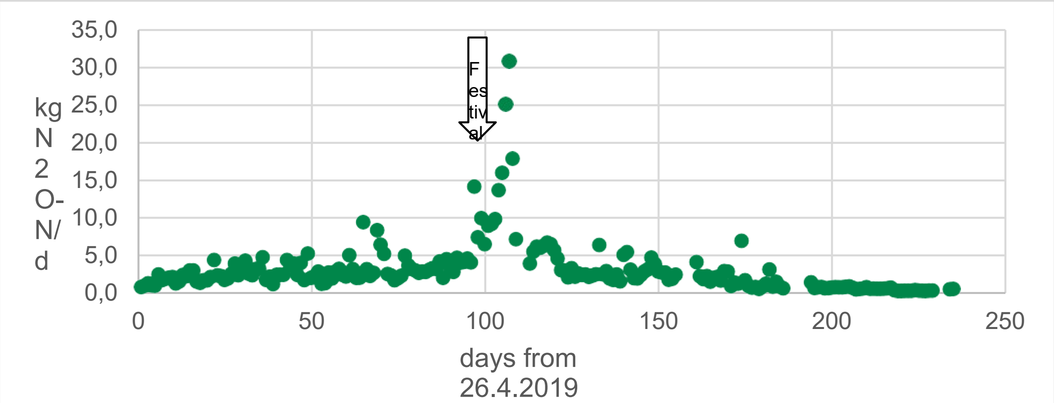


FIGURE Noise**2.** emission due to increased load during Skanderborg Festival These 2019.are

the main2 parameters that are focused on in the present project.

Other factors/conditions that may lead to increased nitrous oxide emissions from the biological processes are given by the following (non-exhaustive list):

- The concentration of NH_4
  - High load of NH_4 (shock load or just an increased concentration)
- Turnover rate of NH_4
- Concentration of O $_2$in process tanks
  - Nitrification: low oxygen saturation point (including actual low oxygen concentrations in process tanks) - typically less than 0.5 mg/l
  - Denitrification: oxygen present - typically above mg/l0,05
- Concentration of NO_2 (due to incomplete nitrification)
- COD/N ratio - typically less than 3.5-4
  - Including also if there is some persistent COD
- Too short sludge age
- Low wastewater temperatures

4. Real-time management

During the test period until 01.11.2020 different control principles have been tested with the aim to implement a control where it is possible to reduce nitrous oxide emissions as much as possible within the framework of the plant's existing wastewater charges, discharge permit and control.

This real-time control via EnviStyr 2.0 is implemented in PCT2, where a classical NH-based4 setpoint control via the Utility's SCADA system is retained in PCT1. PCT1 is therefore used as the reference tank for PCT2. From this, the effect of the new control to reduce nitrous oxide emissions can be assessed for different operating situations.

The control for PCT2 is schematically illustrated in Figure 3.

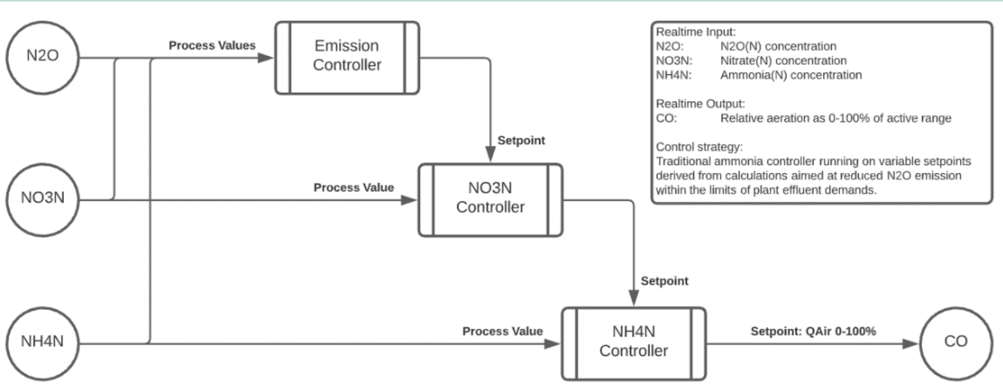


FIGURE Control**3.** principle for reducing nitrous oxide emissions.

The control principle of PCT2 is generally based on simultaneous nitrification/denitrification. The control uses real-time inputs in the form of concentration measurements of ₂NO-N, NO-N₃ and NH-N₄, which are handled in a unified controller where the result is translated into specific controllers for NO-N₃ and NH-N₄. All parameters are included in a dedicated aeration controller.

The primary focus of PCT2 management is to ensure compliance with applicable discharge requirements at all times. Secondarily, the control aims to reduce nitrous oxide emissions from the nitrogen iron as much as possible under the given operating conditions.

5. Test program

5.1 Test programme for the measurement period (01.11.2020 - 11.06.2021)

The following test programme is carried out:

1) *Normal operation (50/50 allocation to PCT1+PCT2):* (tested in the period 01.11.2020 - 11.06.2021)
   - *However, not during the periods 03.05.2021-11.05.2021 and 31.05.2021-03.06.2021, when the other tests are carried out (points 2-4)*
2) *Approximately 75% additional load on PCT2: (tested in the period 03.05.2021 at 7 am -05.05.2021 7 am)*
   - *Familiarisation period during which the control was adapted and active operator monitoring of the outlet quality*
   - *Not used for assessment of results*
3) *100% additional load on PCT2: (tested in the period 05.05.2021 at 8 - 11.05.2021 at 10)*
   - *Tests are carried out to ensure that $_2$NO is produced so that the control can be tested against nitrous oxide emissions*
4) *75/100% additional load on PCT 1 (reference): (tested in the period 31.05.2021 - 02.06.2021only in the time period 7-15 for tests with 100% load)*
   - *It is only the period 7-1502.06.2021 where the %100 load is used*
   - *Tests are carried out to ensure that $_2$NO is produced so that the control can be tested against nitrous oxide emissions*

During the test period, the following operational situations will be tested:

- High/low sludge concentration in PCT1 + PCT2 (varying sludge age)
- Low waste water temperature
- Increased/shock load

5.2 Analysis programme (internal and external)

During the measurement period, inlet, outlet and process analyses are carried out.

Intern analyseprogram (ugentlig analyser): **Indløb:** - COD - Total-N - Total-P **Udløb:** - COD - NH4 - NO3 - Total-N - Total-P - Fe **Proces (ca. hver 2. uge):** - SS - SV	**Udvidet analyseprogram** (under test af dobbeltbelastning) **Proces:** - SS - SV - Slamalder **Indløb:** - COD - Total-N - Evt. NH4	**Online data** - Luftflow (blæser) SRO - Lattergasemission (Envistyr) - SS i PCT (SRO) - Temp. i PCT1+2 (SRO) - Indløbsflow (SRO) - NH4 i PCT1+2 (SRO) - NO3 i PCT1+2 (SRO) - O2 i PCT1+2 (SRO) - N2O i PCT1+2 (SRO) - Effektforbrug

In parallel with the internal analyses (carried out in Skanderborg Utility's own laboratory), the planned external analyses (carried out in DANAK accredited laboratory) for inflow and outflow are also supplemented.

5.3 Control disconnections during the test period

As a starting point, normal operation has been run throughout the measurement period with a classical NH-based$_4$ setpoint control on PCT1 and the new nitrous oxide control on PCT2.

This is only interrupted by control disconnections between the supply SCADA system and EnviStyr 2.0 in the following periods:

-18/11-2020 at to 09.3019/11-2020 at. 7.15
-10/12-2020 at to09.00 11/12-2020 at. 8.25

- 22/1-2021 at 11.4525/1-2021 kl. 07.30
- 02/2-2021 at 07.0003/2-2021 kl. 18.00
- 10/3-2021 at 07.4511/3-2021 kl. 08.30
- 14/3-2021 at 07.3014/3-2021 kl. 22.20
- 07/4-2021 at 10.0008/4-2021 kl. 07.10
- 22/4-2021 at 14.5023/4-2021 kl. 08.20
- 29/4-2021 at 07.0029/4-2021 kl. 14.30
- 05/5-2021 at 01.1505/5-2021 kl. 07.30
- 11/5-2021 at 21.0012/5-2021 kl. 10.30
- 13/5-2021 at 14.4514/5-2021 kl. 08.45
- 10/6-2021 at 14.5011/6-2021 kl. 07.00

During the above periods of control disconnections, PCT2 is operated as PCT1 - classical NH-ba-ered$_4$ setpoint control via the Utility's SCADA system, corresponding to a load sharing of 50/50.

6. Results

6.1 Internal/external analysis data during the measurement period

In Table the internal and external wastewater analyses for inputs are1 shown.

TABLE Inflow**1.** analyses (internal and external) for the measurement period. Figures in brackets indicate the external analyses.

	Flow	COD	SS	Total-N	Total-P	COD/N
Resource	5.666 (5.663)	1.233 (1.838)	(1.155)	64 (80)	13,3 (12,7)	16,1 (23,4)
Stdafv	2.370 (1.969)	1.515 (1.290)	(1.137)	23,5 (42,1)	9,2 (5,9)	12,7 (11,7)
Maks	18.184 (9.208)	5.576 (4.200)	(3.200)	108 (150)	34,9 (20,0)	51,6 (44,7)
My	2.080 (3.301)	166 (770)	(320)	21,4 (38,0)	3,3 (6,2)	6,6 (11,8)

During the measurement period, there have been problems with sampling in the inlet, but estimated from the sludge production, the load in 2020 and 2021 has been in the same order as in 2018 and 2019. There is therefore no valid data basis for assessing the inflow load during the measurement period, especially for nitrogen. Skanderborg Central Wastewater Treatment Plant is expected to have been loaded with about 32,700 PE (BOD) or 39,800 PE (COD).

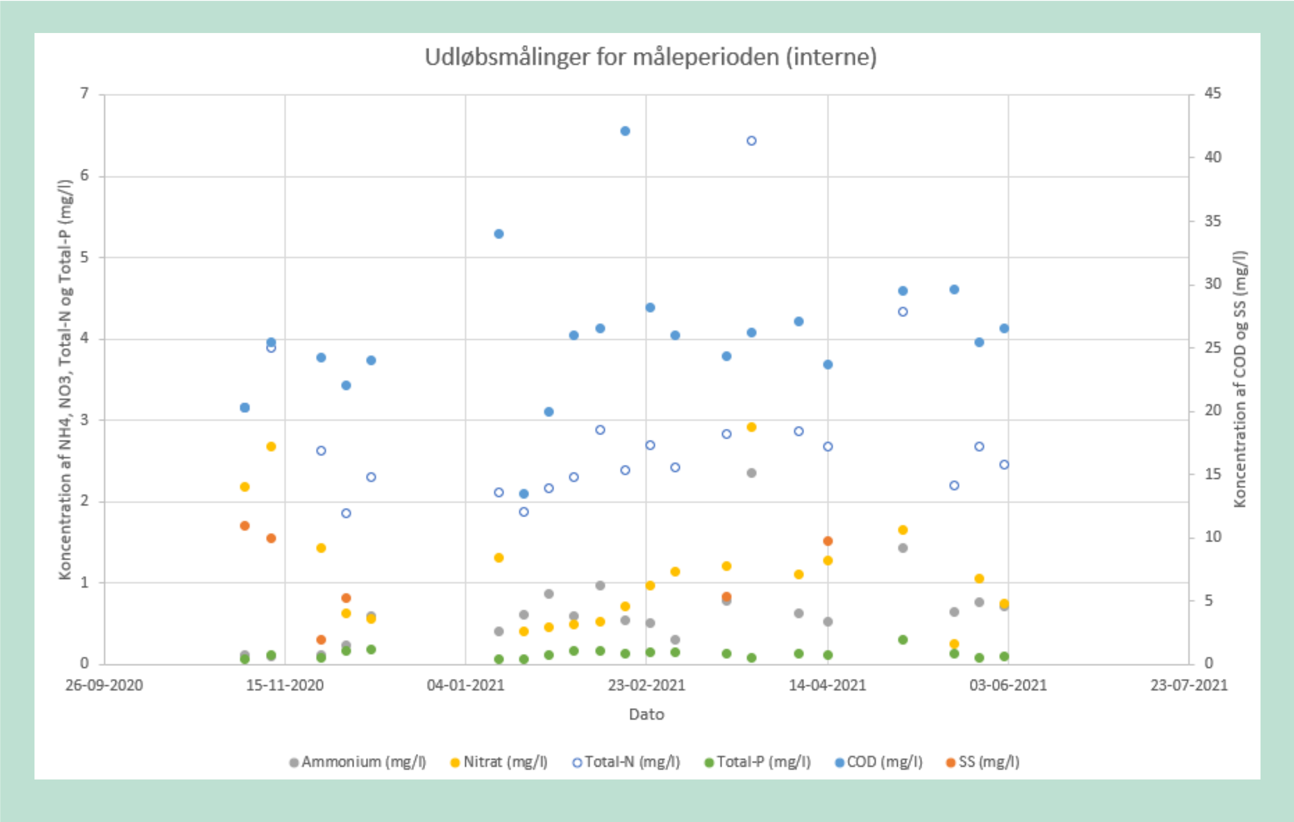
Throughout the measurement period, COD/N ratios are expected to have been high, so that sufficient organic matter has been available throughout the period to ensure full nitrogen removal without increased risk of elevated nitrous oxide emissions.

In Table the internal and external effluent analyses for outfalls are2 shown.

TABLE Outcome**2.** analyses (internal and external) for the measurement period. Figures in brackets indicate the external analyses.

	Flow	COD	SS	NH_4	Total-N	Total-P
Resource	4.686 (4.259)	25,9 (26,0)	7,2 (6,8)	0,66 (0,56)	2,8 (2,4)	0,13 (0,16)
Stdafv	2.125 (1.819)	5,5 (5,7)	3,5 (2,9)	0,50 (0,24)	1,0 (0,4)	0,05 (0,06)
Maks	15.370 (8.117)	42,1 (37)	11,0 (12,0)	2,36 (0,81)	6,4 (2,8)	0,30 (0,26)
My	1.489 (1.300)	13,5 (19)	2,0 (2,5)	0,10 (0,13)	1,9 (1,8)	0,06 (0,09)

Throughout the measurement period, there have been no problems in complying with the applicable emission requirements, as shown in Table 2, Figure 4 and Figure 5.



Internal analysis results for the measurement period.**4**

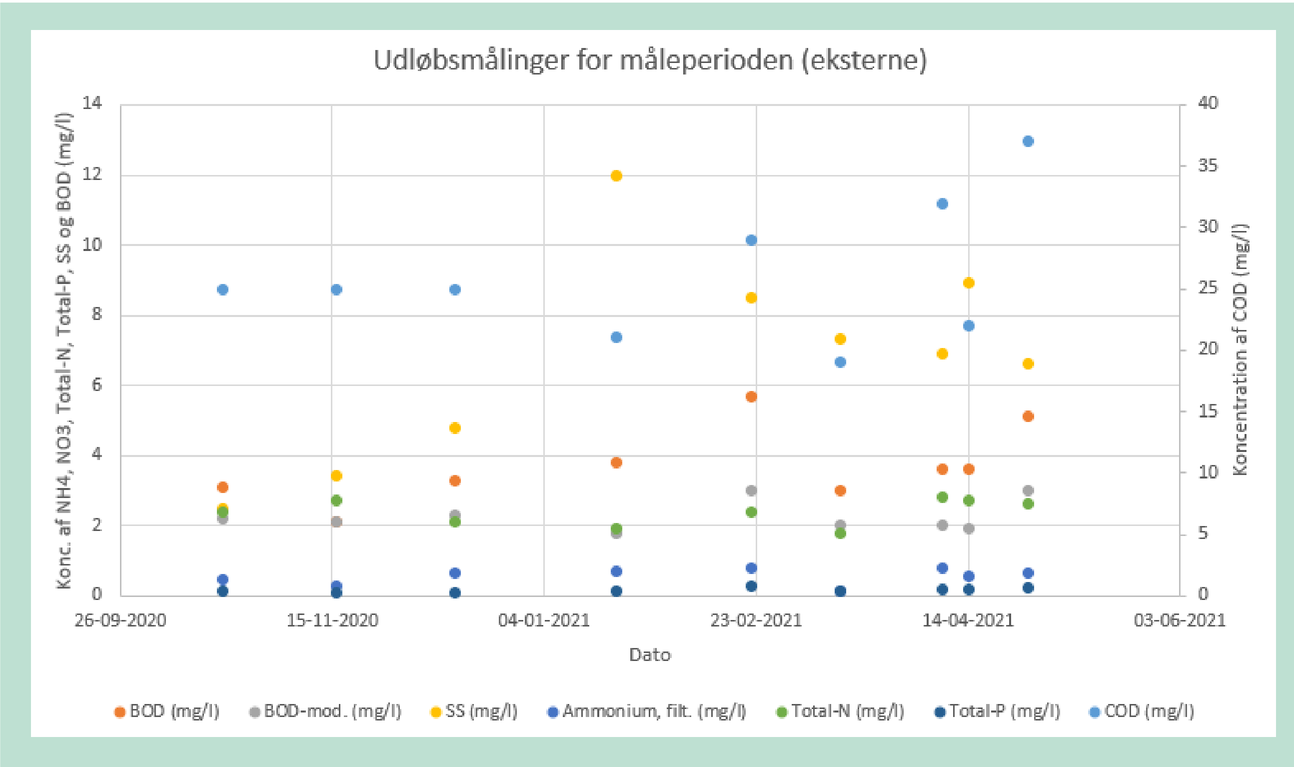


FIGURE External**5.** analysis results for the measurement period.

In addition to the analysis data shown, analysis data (with 5-minute resolution) are also available from the SRO system, where the following parameters (divided into PCT1 and PCT2) were primarily used in the data processing:

- Inlet flow (m³/h)

- Power consumption fans (kW) and air flow (m³/h)
- Measurement of concentrations ($_2$NO-N, NH-N$_4$, NO-N$_3$ and O$_2$)
- Temperature in process

6.2 Normal operation (50/50 distribution to PCT1 and PCT2)

During the longer periods, the treatment plant is operated at normal capacity (equal load sharing to PCT1 and PCT2). Therefore, operational data for this mode are available for the whole measurement period 01.11.2020 - 11.06.2021. However, the following periods are excluded as tests with modified load distribution have been run:

- *03.05.2021 at - 7at 11.05.202110*
- *31.05.2021 - in the 03.06.2021time period 7-15*

At the beginning of the measurement period, the sludge dewatering equipment was replaced, resulting in the treatment plant being operated with a generally sub-optimal sludge content and thus a long sludge age. In the period up to 04.01.2021 the average SS concentration is about 7 kg SS/m³. In the following period this is reduced to about kg 6,3SS/m³. Thereafter, the concentration has been reduced to a normal level around kg 4SS/m³.

The sludge concentration has only been reduced to normal levels around 15 March 2021. As there is no high load, it is expected that no significant laughing gas emission will be observed from either PCT1 or PCT2.
Fumigation emission is shown Figure and Figure6 at 7different 2periods.

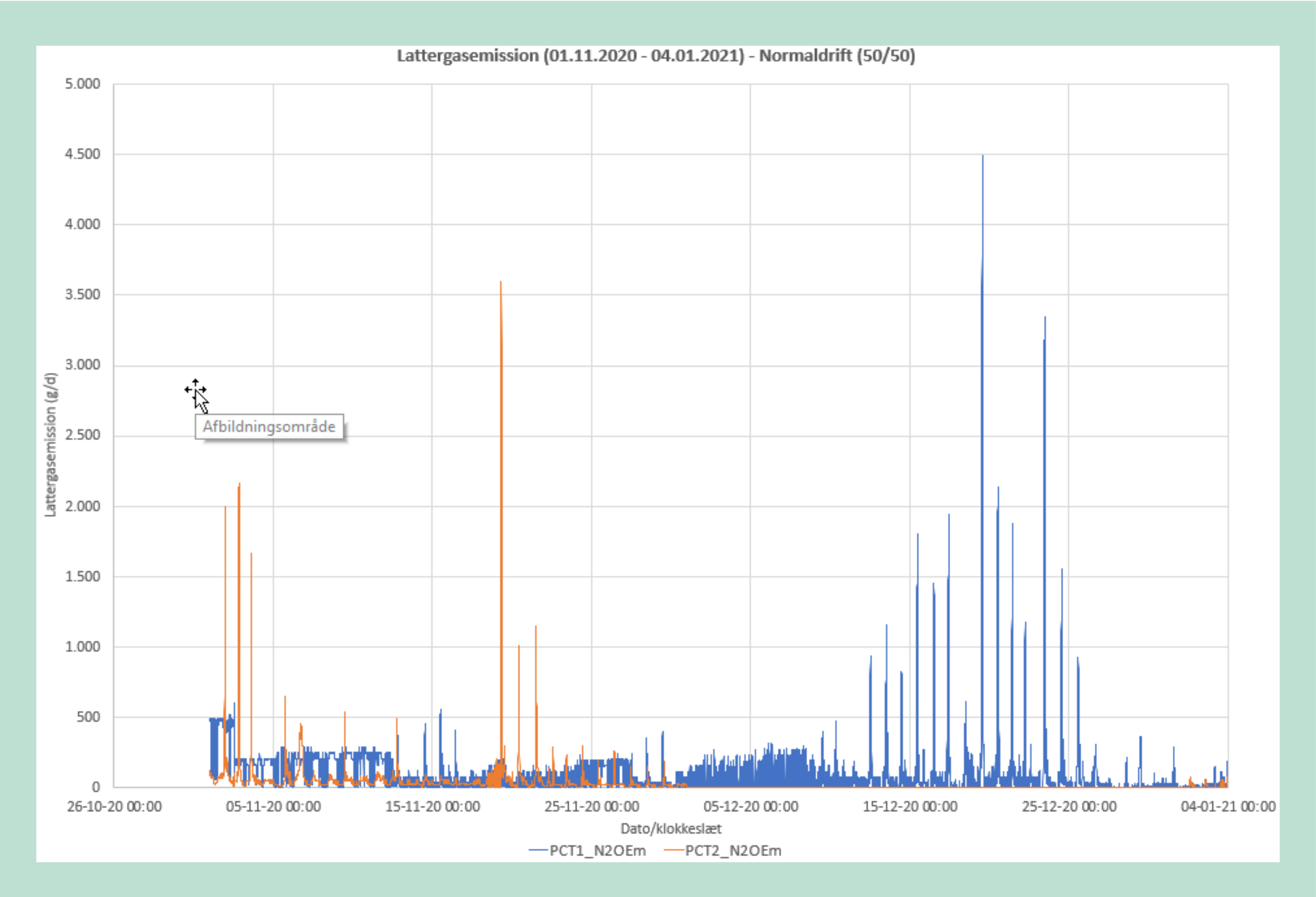


FIGURE Off-gas**6.** emissions at normal operation (50/50) in the period 01.11-2020-04.01.2021.

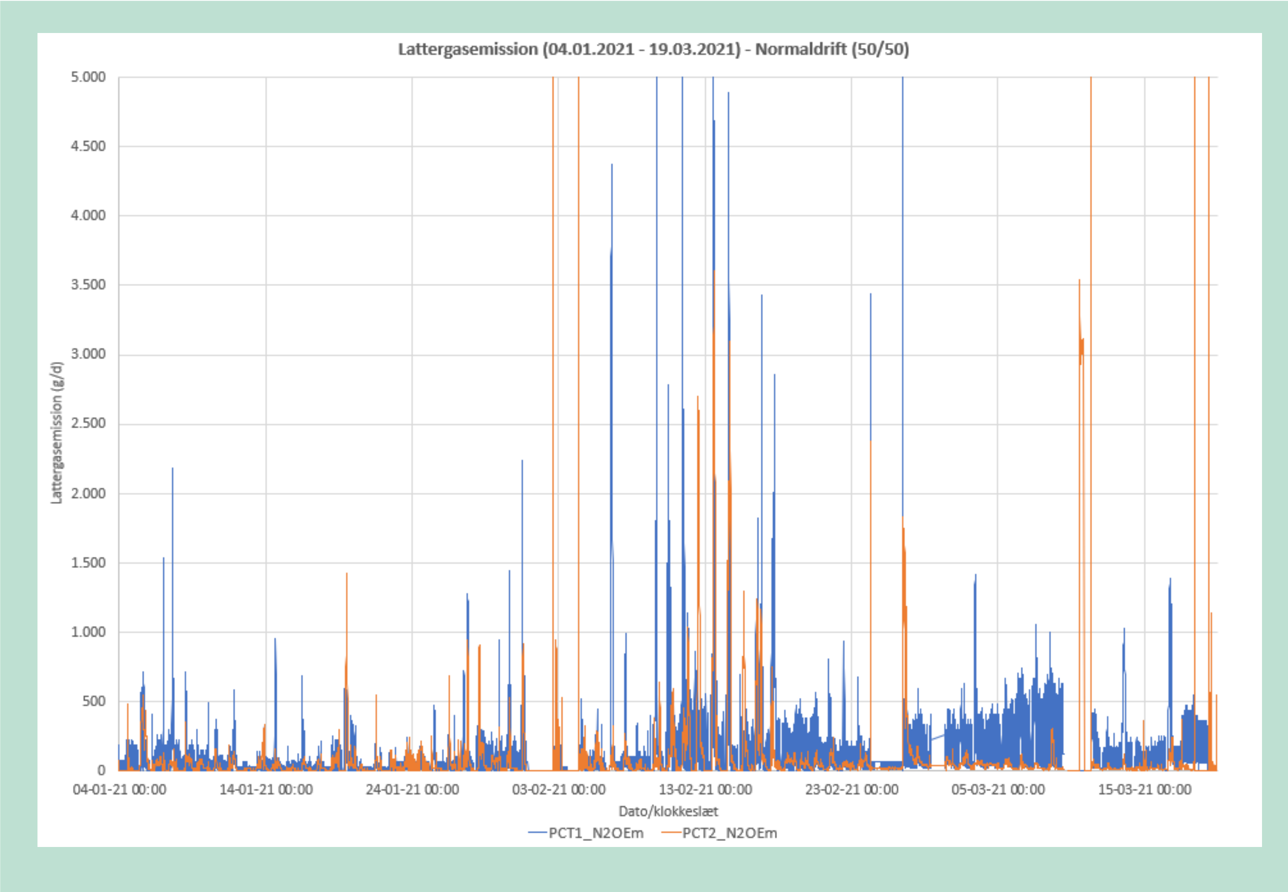


FIGURE Off-gas**7.** emissions at normal operation (50/50) in the period 04.01-2021-19.03.2021.

As shown above, a higher nitrous oxide emission can be observed from PCT1 than PCT2 in the normal load. This is more clearly seen if the accumulated nitrous oxide emission is considered.

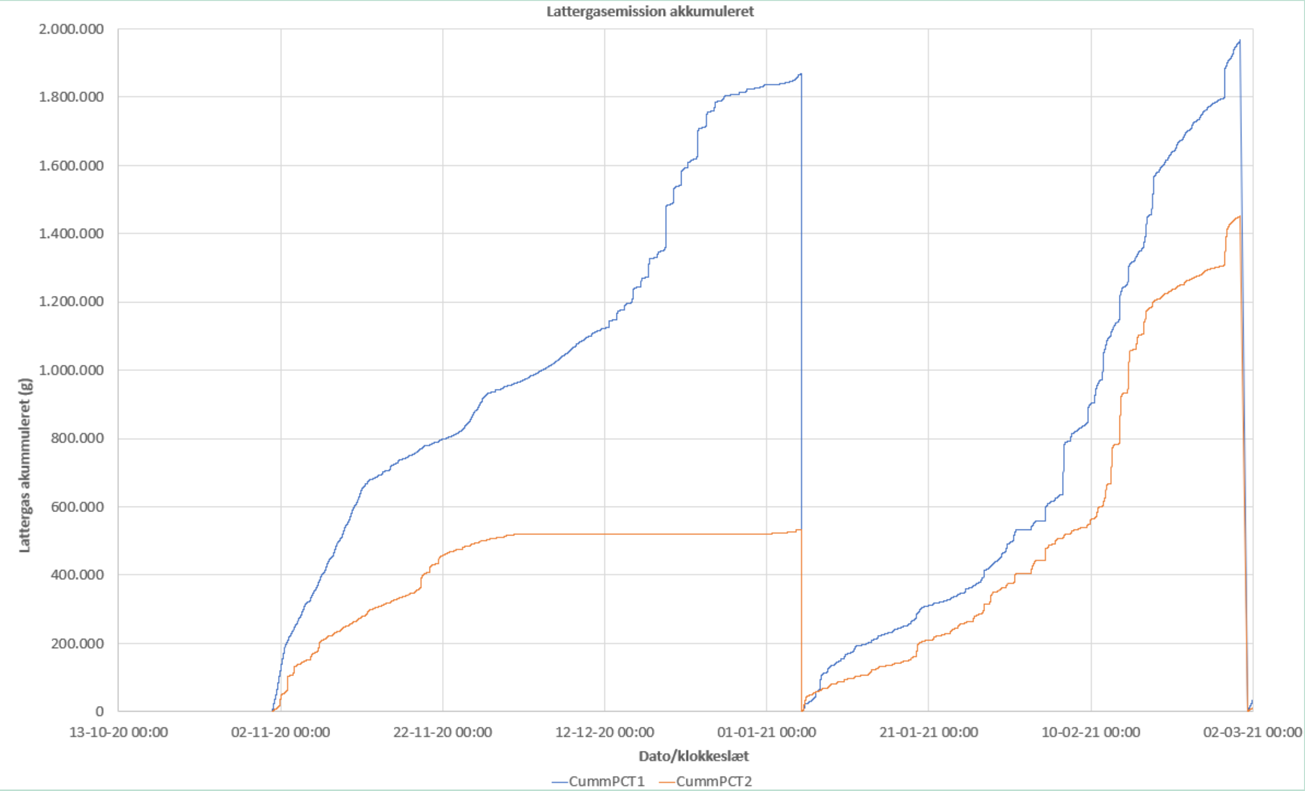


FIGURE Accumulated**8.** nitrous oxide emissions at normal operation (50/50) in the period 01.11-2020-19.03.2021.

The following can be deduced from the above figures for normal operations:

- In general, emissions are highest from PCT1, whereby control in PCT2 results in lower emissions.
- In the middle part of the measurement period (January-March 2021), when SS is reduced slightly and operating conditions are stable, emissions from PCT1 and PCT2 follow each other (emissions from PCT2 are lowest).
- The average nitrous oxide emission from PCT1 and PCT2 is 112 g/d and g/d60 respectively, corresponding to about 86% higher emission from PCT1.
- The average kW consumption for PCT1 and PCT2 is 20.2 kW and 20.3 kW respectively - so regardless of the control principle at normal operation/load, the energy consumption is identical.

6.3 Increased load %100 to either PCT1 or PCT2

Experiments are performed where the full load (100%) is applied to either PCT1 or PCT2 to ensure that nitrous oxide emission is produced and can be measured. By testing this for both process tanks, these tests can be combined to assess the effect of the control on nitrous oxide emissions and compliance.

6.3.1 PCT (1distribution 100% to PCT1/0% to PCT2)

(tested in the period 31.05.2021 - 03.06.2021- only in the period 7-15)
From 31.05 at 7 am to 02.06 at 6.59 am I drove the whole period with about 75% load on the PCT1 (also outside working hours), as a period of getting used to it in order to tune/prepare the steering for the full load.

Therefore, only the time period on 02.06 from 7-15 is used in the results below, when there has been 100% load of PCT1.

Result:

1) Average nitrous oxide emission g/d3.114
2) Average power consumption: kW25,5
3) Not possible to meet the emission requirements for nitrogen (NH-N_4 and Total-N) - Total- rose above mg/l10 (therefore test period was reduced)
4) Poor cleaning - The test period was terminated as the cleaning process could not keep up at all. Total-N had increased to about 12 mg/total N/l in the effluent during the test period.

6.3.2 PCT (2distribution 100% to PCT2/0% to PCT1)

(tested in the period 10 am 05.05.20218-11.05.2021 10 pm)

Throughout the period, %100 load was run on PCT2, which is therefore used in the results below.

Result:

1) Average nitrous oxide emission g/d837
2) Average power consumption: kW29,0
3) No problems with compliance with emission requirements for nitrogen (NH_{-4} N and Total-N).

7. Conclusion

The aim of the project was to develop, implement and test a real-time control system at Skander- borg Central Wastewater Treatment Plant to reduce nitrous oxide emissions while complying with all applicable emission requirements.

As the tests carried out show, it can be concluded that

- Successfully developed and tested a real-time latent gas control in EnviStyr 2.0
- The implemented nitrous oxide control resulted in a reduced nitrous oxide emission at full load corresponding to an emission reduction of about 27% compared to the nitrous oxide emission without nitrous oxide control (reference PCT1).
- At full load, the average nitrous oxide emission for PCT1 and PCT2 was calculated to be 3,114 g/d and 837 g/d, respectively
- In normal operation, the average nitrous oxide emission for PCT1 and PCT2 was calculated to be 112 g/d and 60 g/d, respectively
- The nitrous oxide control also resulted in a reduced nitrous oxide emission in normal operation - the emission was reduced by about 46% (the average nitrous oxide emission for PCT1 and PCT2 calculated at 112 g/d and g/d60 respectively)
- The nitrous oxide control also allowed all the emission requirements to be met
- The Lattergas control resulted in a marginally higher power consumption.

Therefore, the overall assessment is that, via a real-time control principle based on simultaneous nitrification/denitrification, it is possible to deliver an energy-efficient and nitrous oxide-reducing process.

As an added benefit, full implementation of this real-time management for lateral gas has been shown to result in a capacity expansion of existing tanks. It is thus possible to handle increased production during the particularly busy period of the Skanderborg Festival without increasing the concentrations of substances in the effluent.

Real-time control of nitrous oxide emissions from waste water treatment plants

Skanderborg Utility has previously conducted a MUDP project with online laughing gas measurement. It turned out that nitrous oxide emissions are very dynamic in relation to process conditions and the load of the treatment plant, and large variations in nitrous oxide emissions were documented cf. the MUDP report "Measurement of nitrous oxide emissions from Skanderborg Central Treatment Plant, MST-117-00446, July 2020".

As nitrous oxide emissions are dependent on various operating conditions, but generally few process parameters, this opens up opportunities to control cleaning processes to reduce emissions.

The objective of this project has been to develop, implement and test a real-time control system at Skanderborg Central Wastewater Treatment Plant to reduce nitrous oxide emissions while complying with all applicable emission requirements.

The overall assessment is that a real-time control principle based on simultaneous nitrification/denitrification is able to deliver an energy efficient and nitrous oxide reducing process.

As an added benefit, full implementation of this real-time nitrous oxide management has been shown to result in a capacity expansion of existing tanks. It is thus possible to handle increased production during the particularly busy period during the Skanderborg Festival without increasing the concentrations of substances in the discharged effluent.

Danish EPA
Tolderlundsvej 5
5000 Odense C

www.mst.dk