UNISENSE ENVIRONMENT

Direct Real-time N_2O monitoring

Empowering Deammonification Process Controls with Direct N_2O Monitoring

The new possibility of measuring nitrous oxide (N_2O) in the deammonification process yields important insights about the anammox bacteria substrate availability. N_2O is tightly linked to the nitrite (NO_2^-) concentration, the key substrate besides ammonium (NH_4^+). To address the challenging control of the deammonification process, wastewater companies have invested in measurement technology from Unisense Environment. This enables them to measure N_2O levels directly in the process tanks, balance anammox bacteria substrates, and additionally document and minimize the climate impact of the deammonification process.

Background

In modern wastewater treatment plants approximately 20% of the incoming nitrogen is bound in organic form and is diverted to anaerobic digesters for biogas and energy production. Subsequently, the digester sludge is dewatered and the sludge reject water contains the diverted nitrogen in form of concentrated ammonium, typically around 1 g/L. Conventionally, the reject water has been added back to the mainstream processes. However, due to the very low COD/N ratio in the reject water this imposes a strain on the mainstream processes costing more aeration energy and in some cases carbon dosing to fulfill stringent nitrogen removal requirements in the effluent. Henceforth, separate side stream treatment processes have gained much attention and in particular the deammonification process has proven effective for side stream removal of nitrogen leading to reduction of energy for aeration and carbon needed for denitrification. The deammonification process is therefore often coupled with a reduced CO_2 footprint.

Nitrous oxide (N_2O), which is produced from an incomplete nitrogen conversion during wastewater treatment, is one of the wastewater industry's biggest environmental offenders with a carbon footprint 300 times higher than that of CO_2. Often the climate impact from N_2O surpasses the impact from the entire WWTP energy consumption. Conventionally, a key number of 0.5% of the influent nitrogen has been used to calculate the CO_2 footprint from N_2O. However, recent publications have demonstrated that the N_2O emission from side stream processes is much higher, typically in the range of 1% to +6% of the influent nitrogen. This increased N_2O production can easily deteriorate the positive effect from energy savings in the side stream processes. Furthermore, the control strategies for deammonification processes often rely on advanced analytical sensors that have short calibration intervals and high maintenance costs associated with them.

Optimization of the process

Measuring the N_2O parameter in the deammonification process yields important insights about the anammox bacteria substrate availability. **Firstly**, N_2O is tightly linked to the nitrite (NO_2^-) concentration, the key substrate besides NH_4^+, for the anammox bacteria. **Secondly**, the amount of oxygen available for NH_4^+ conversion to NO_2^- is important for balancing the deammonification process. **Thirdly**, measuring the nitrite level is difficult with present sensors and will be indirect as nitrite is formed and consumed inside the biofilm or granolas. Unlike nitrite, N_2O is not consumed by the anammox bacteria and therefore online N_2O monitoring will be a more precise measure of the substrate balance. In the event that too high ammonium oxidation rates lead to nitrite accumulation, N_2O will build up in the liquid as a warning. **Finally**, N_2O is clearly linked to the ammonium loading of the process and no straight correlation between N_2O and pH is obvious. Therefore, the N_2O Wastewater Sensor has proven to be much more reliable than nitrates and pH sensor data for optimizing the deammonification process controls and for N_2O emission reduction.

Deammonification process data example

A number of researchers have shown that there is a correlation between the ammonium conversion rate and the N_2O production rate. In these studies they showed that an increase in the ammonium oxidation rate led to an increased N_2O formation and derived emission due to aeration stripping. Furthermore, transient aeration sequences between low or anoxic oxygen levels to a higher aeration level seemed to be enhancing the N_2O emission rate and pointed to a more continuous aeration strategy.

In the one week dataset below (10 second data interval) the sequence of aeration was gradually changed towards a lower but steady aeration. Monitoring N_2O (***Figure 1***, *red curve*) noticeably demonstrates that the concentration and emission gradually diminishes to less than 10% of the initial N_2O level. Also, the nitrite level was below 5 mg-N/mL throughout the entire period, and was not the primary cause of the large N_2O concentration and emission.

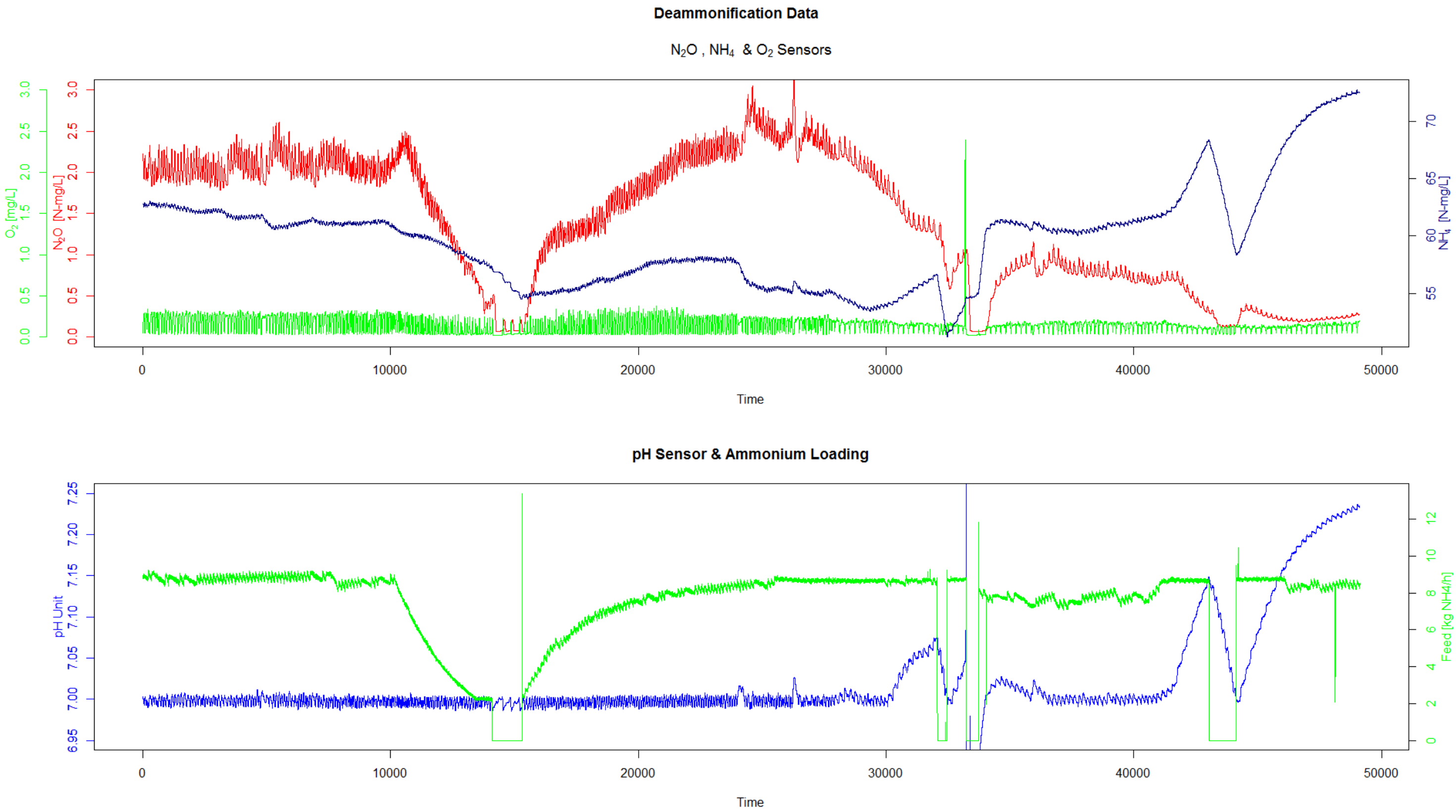

Figure 1: *Example of deammonification monitoring for one week with the N_2O Wastewater Sensor (red), O_2 (green) and relation to other parameters such as NH_4^+ (dark blue), pH (light blue). Monitoring was done through a trail run where different aeration and feed rates, and pH values were tested. N_2O in the process tank closely followed the loading of ammonium (panel B; feed rate in green) and was not clearly correlated to pH.*

When pH is allowed to migrate upwards it is generally a benefit for the bacteria as the maximum substrate conversion activity increases for both the ammonium oxidizing bacteria and the anammox bacteria. In ***figure 1***, the pH was allowed to increase at the end of the 1 week period and although the ammonium concentration increased due to the lower aeration discussed above, it levels out. The ammonium loading of the system was the same as in the beginning of the week. Therefore, the same substrate oxidation rate is observed. But as the ammonium oxidizing bacteria are not at their maximum oxidation rate at the new pH, much less production of N_2O is observed. Finally, a lower ammonium concentration in the process was tested through a lower continuous federate that kept the process substrate limited resulting in lower N_2O, seen 1/3rd into the week.

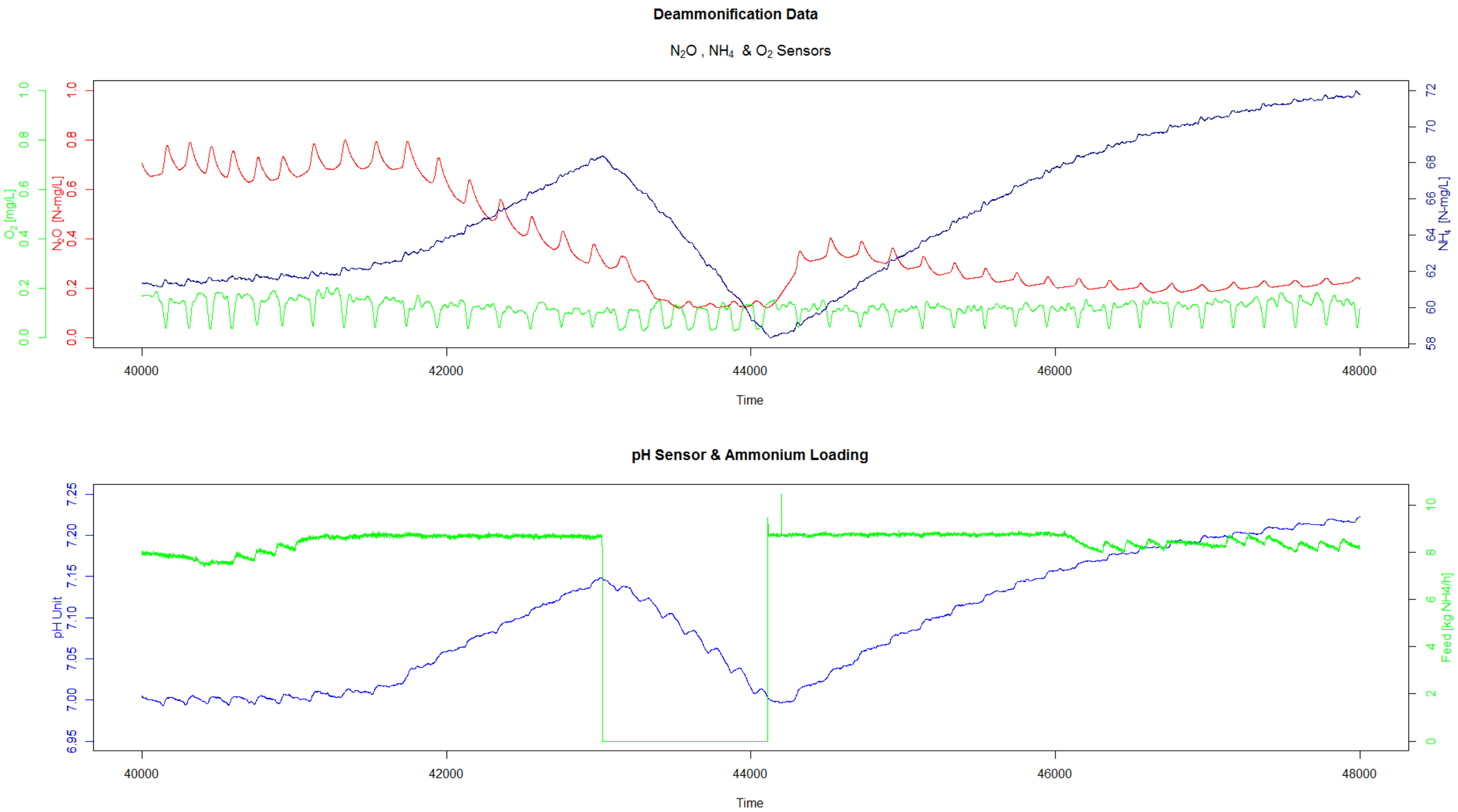

Figure 2: *Example of a loading control based on the N_2O signal (red) with floating pH value (light blue) and disabled pH control schema. NH_4^+ (dark blue), O_2 (green), and feed rate (Panel B, green). The aeration is almost continual in this particular test.*

In ***figure 2***, an enlargement of the last 2 days of the monitoring period is depicted demonstrating the transition from a slightly higher and sequential aeration to a lower and ultimately steady aeration. The oxygen change is small but the effect on the N_2O level is clear. Controlling the deammonification process by balancing the ammonium and nitrite substrates through inclusion of N_2O in the control scheme can therefore decrease the N_2O emission many fold.

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Control strategies possible with online input from direct N_2O monitoring

- **Implement continuous influent and aeration strategies**
  - Steady state inflow and aeration.
  - No perturbation from aeration pauses and no lag phases.
  - Load control based on N_2O sensor and steady-state N_2O sensor signal.
  - Aeration control based on N_2O sensor.

- **Implement multi parameter aeration control**
  - Too high NH_4^+ turnover leads to NH_4^+/NO_2^- imbalance.
  - High NO_2^- leads to high N_2O and N_2O-emission
    - N_2O works as ***proxy sensor for*** NO_2^-

- **Unstable and drifting pH control**
  - pH uncertainties lead to AOB and anammox inhibition.
  - AOB and anammox activity drops dramatically at pH below 7.0.

- **Avoid NO_2^- accumulation and inhibition**
  - > 5 mg-N/L nitrite leads to slow 'irreversible' inhibition of the anammox biomass.
  - ***Can happen unnoticed*** as substrate limited biomass deeper in the granules initially takes over from newly inhibited outer biomass eventually leading to sudden process breakdown, when the whole granule has been inhibited.
  - Keep NO_2^- accumulation in check through reliable N_2O monitoring.
    - Works at any biomass concentration and without any specific calibration.
  - Keep heterotrophs in check.
    - Higher COD/N ratios will lead to heterotrophic growth and incomplete denitrification resulting in high N_2O.

- **Consider recycling the aeration gas**
  - Better mixing, biofilm and granola size control without over-aeration.
  - Lower N_2O and better O_2 control.
  - Control air replenishment based on NH_4, N_2O, and pH rates of change.

Aim *for a low steady state N_2O level and* ***act*** *on high N_2O*

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