Nitrous Oxide Process Emissions – From Research to Application

Evaluation and minimization of N_2O formation and emission in deammonification biofilm systems

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Research focus „N_2O“ at the ISAH

1993 – 2000 – 2005 – 2014 – 2022

- N_2O formation
  N_2O measurement
- Nitritation
  Deammonfication
- N_2O mitigation
  Plant optimization
- **Research Project MiNzE**
  FKZ 02WQ1482B
  N_2O mitigation in biofilm systems

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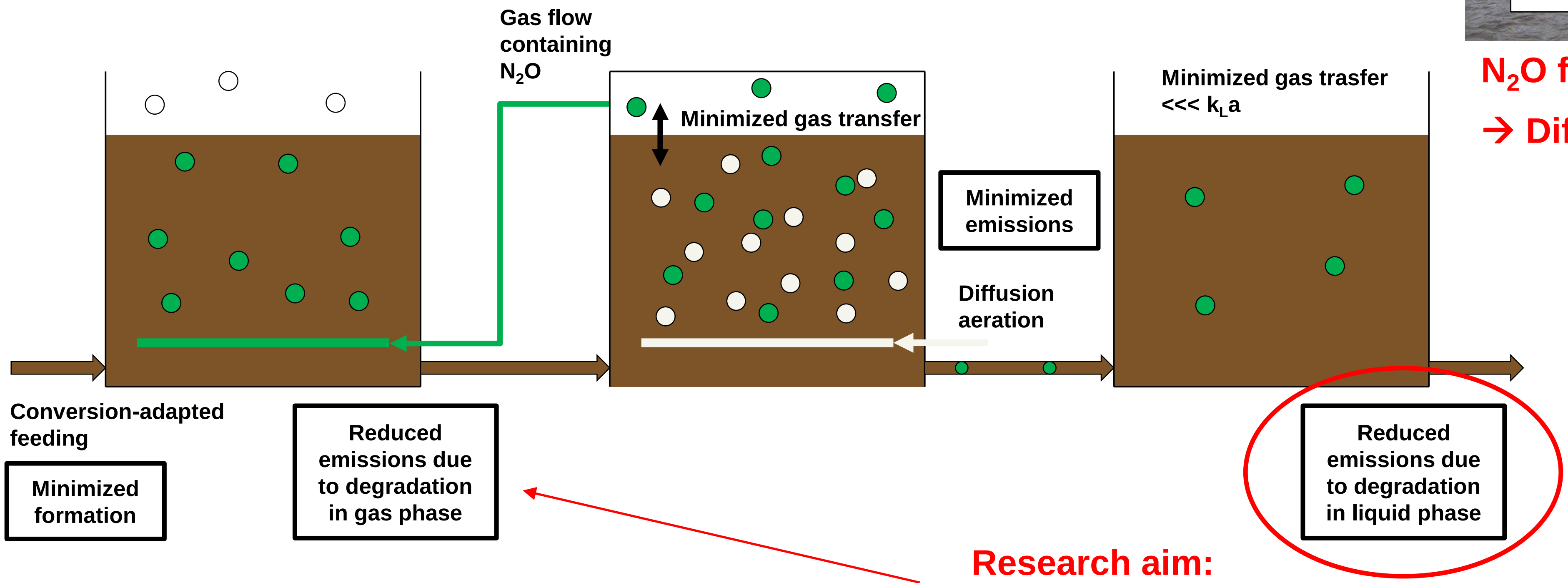
Research Projects (Selection)

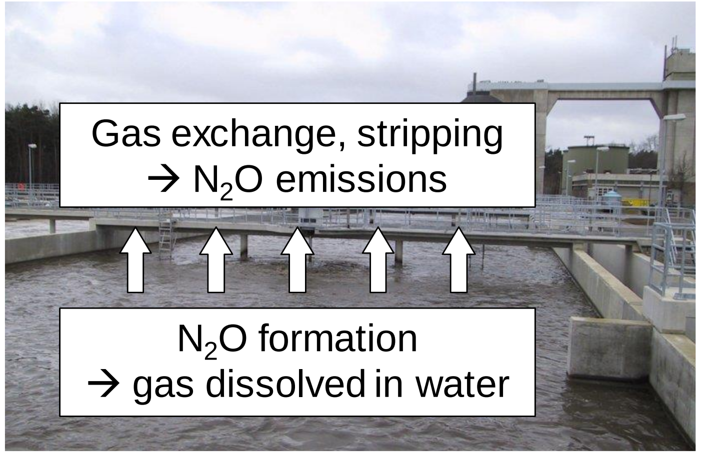
- DFGLach 1+2 (Grundlagenermittlung zur Lachgas-Emission als Neben-produkt der Deammonifikation)
- ReNeMO (Reduzierung der N_2O-Emissionen bei der Stickstoffelimination aus hoch- und schwachbelasteten Abwässern)

State of Science

Minimized Nitrous Oxide Zero-Emission Concept (MiNzE)



Source: ISAH



N_2O formation ≠ N_2O emission!

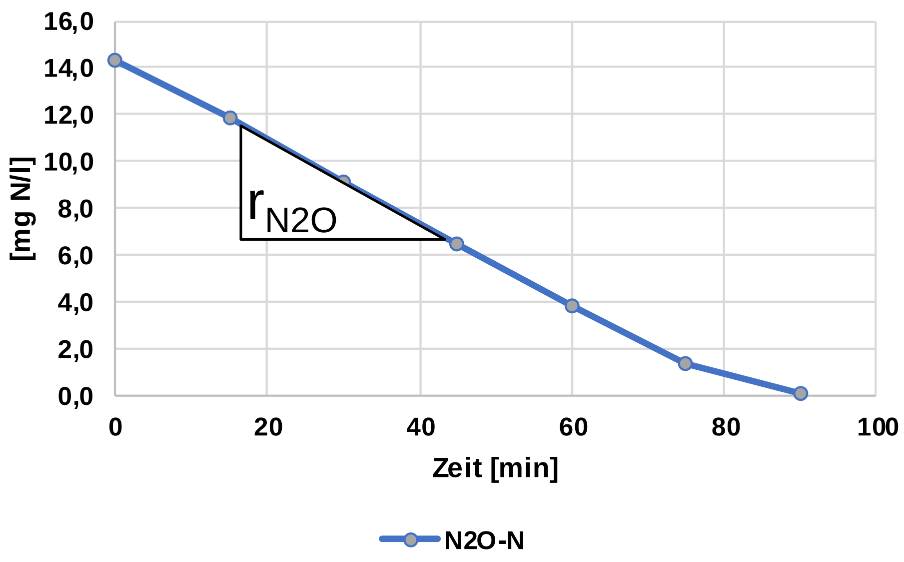
→ Different mitigation strategies

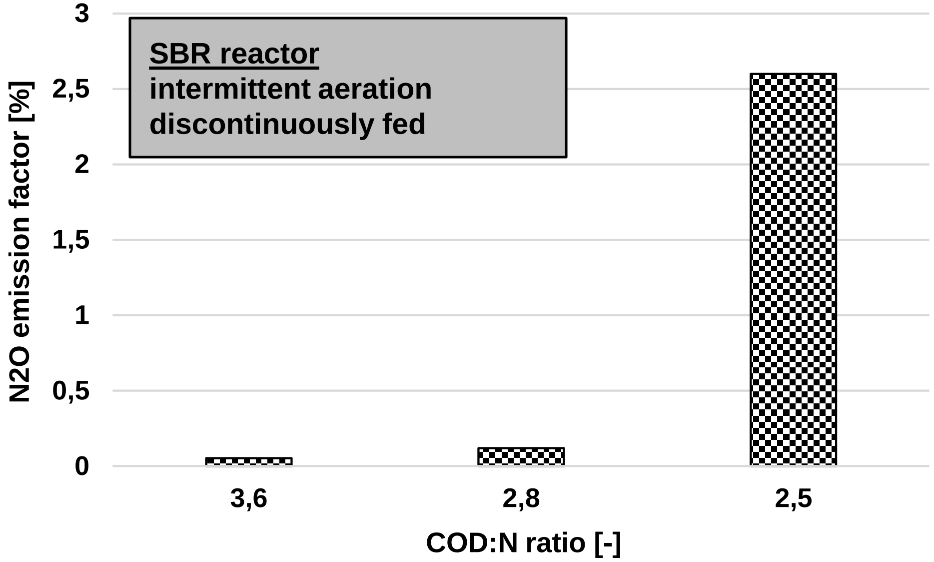
Research aim:
Improved denitrification

- **Anoxic environment**
- **Low HNO_2 concentrations**

Denitrification as N_2O sink and source

- N_2O is an intermediate of the heterotrophic denitrification
- Under optimized process concitions, N2O reduction is the fastest sub process
  → No N_2O accumulation!



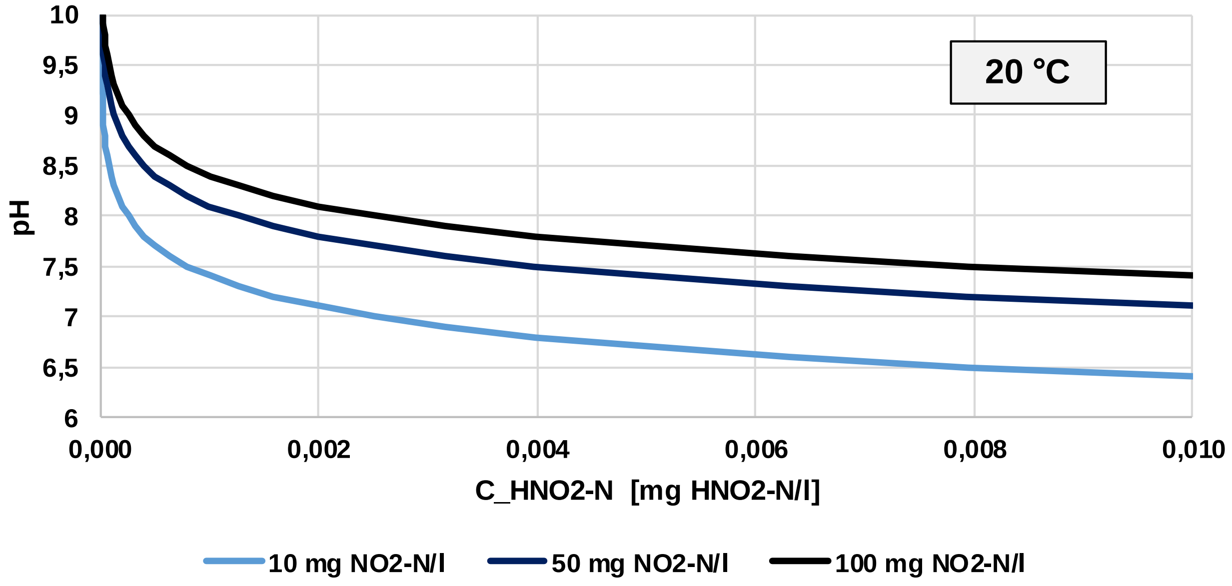


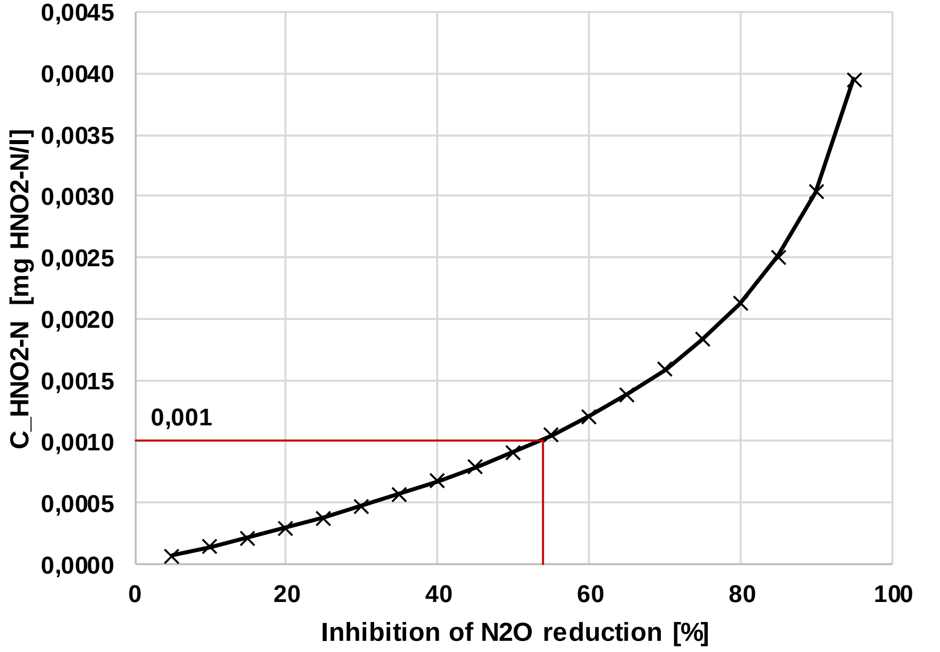
Quelle: Peng et al., 2017

NO_3 → NO_2 → NO → N_2O → N_2

Denitrification as N_2O sink and source

- N_2O accumulates, if velocity of N_2O reduction < velocity of N_2O formation (= NO_2 reduction)
  - optimal conditions: N_2O is converted about twice as fast as NO_2
- HNO_2 inhibits only N_2O reduction → process interruption





Source: Zhou et al. (2008), Vogel (2018)

$$C_{HNO2} = \frac{46}{14} \cdot \frac{C_{N2O-N}}{e^{\left(\frac{-2300}{273+T}\right)} \cdot 10^{pH}}$$

Denitrifikation: NO_3 → NO_2 → N_2O → N_2

inhibition

N_2O formation & emission – biofilm vs. suspended biomass

- Biofilm: **Mass transfer is limited by diffusion**
  → concentration gradients (O_2, NH_4, NO_2, N_2O)
  → Different layers with different boundary conditions
  → Different bacteria groups in different layers

Diffusion rate

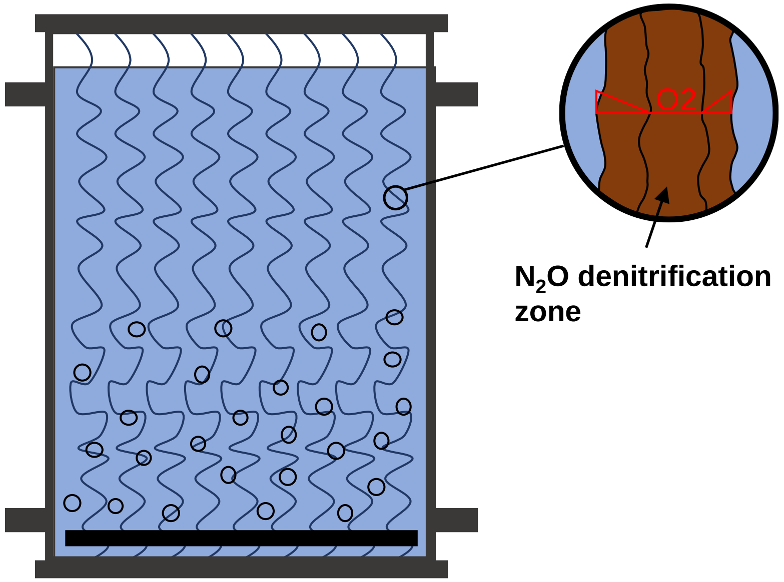
$$r = -D \cdot \frac{dS}{dx}$$

- **N_2O denitrifi**… N_2O formed by AOB can be … usly in the anoxic biofilm layers … place of formation

oxygen concentration, biofilm thickness

- **N_2O emissions:** Only N_2O that is transferred to the bulk … mitted
  … s are limited by the N_2O diffusion rate
  → Diffusion rate depends on N_2O conentration gradient

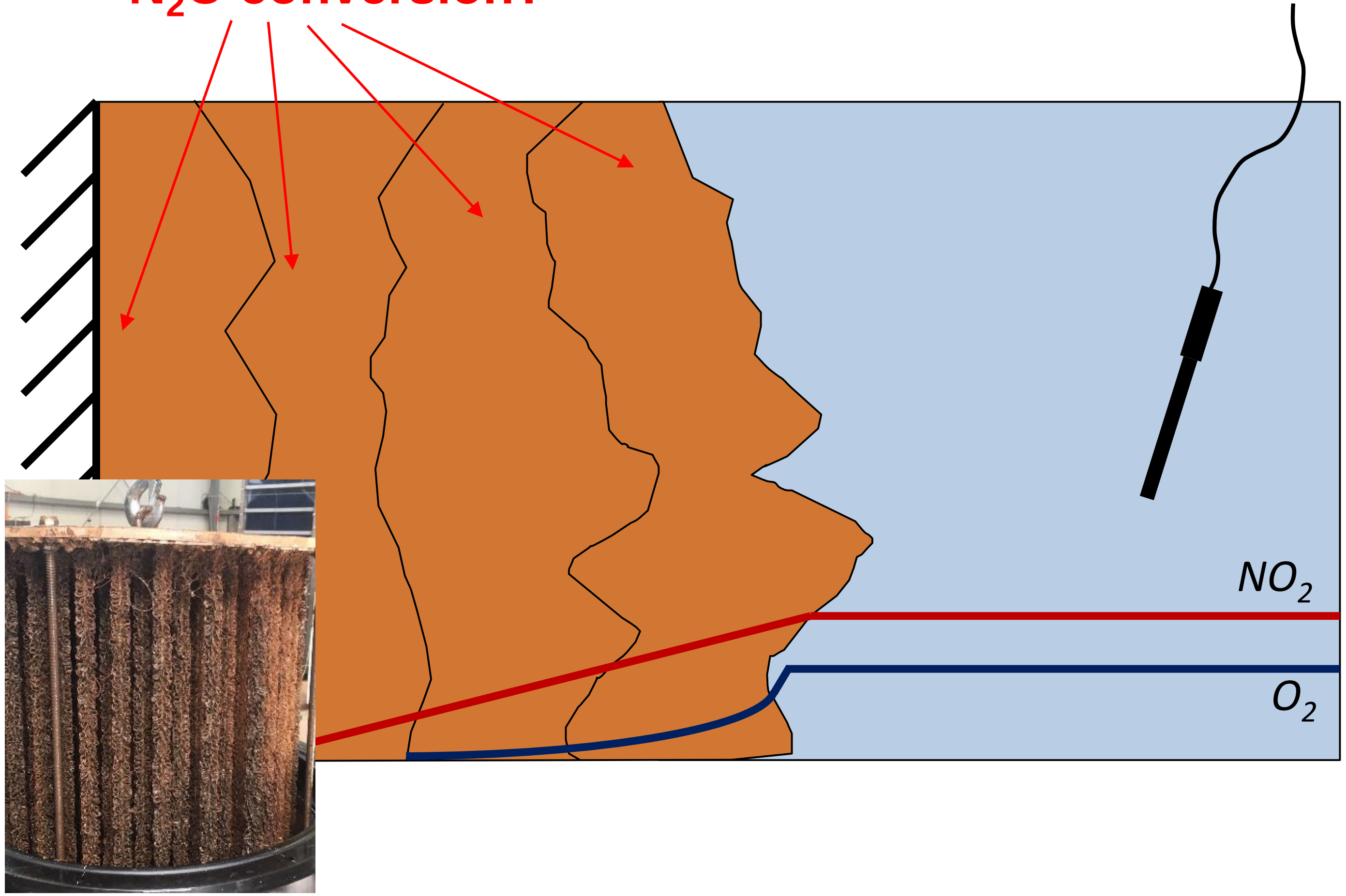
aeration control
aeration system



Challenges of N_2O measurement in biofilm systems

N_2O concentration?
N_2O formation?
N_2O conversion?

N_2O concentration
N_2O accumulation rate (diffusion – emission)



N_2O measurement in the liquid phase, not inside the biofilm

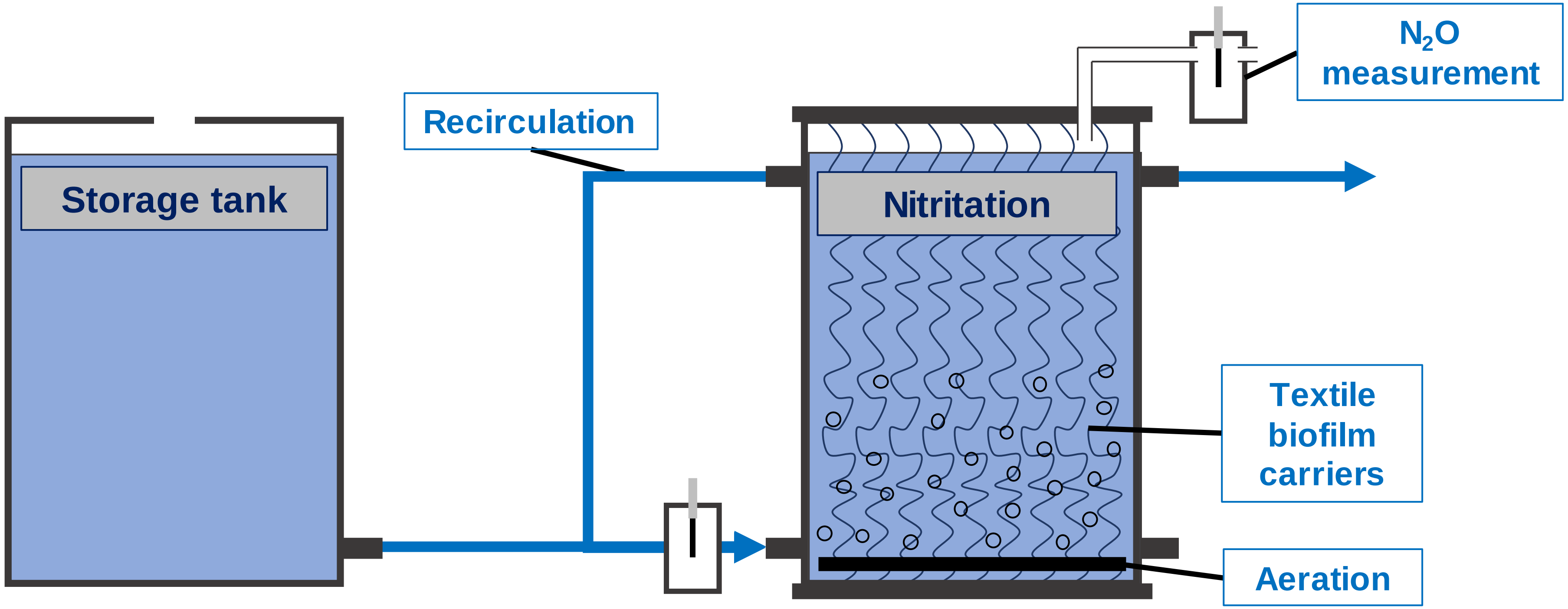
→ No information about formation and degradation processes

→ Causes of high N_2O emissions cannot be identified

Obtaining information for the planning of measures:

1. N_2O measurement inside the biofilm
2. **Combination of measurement and modeling**

Pilot plant



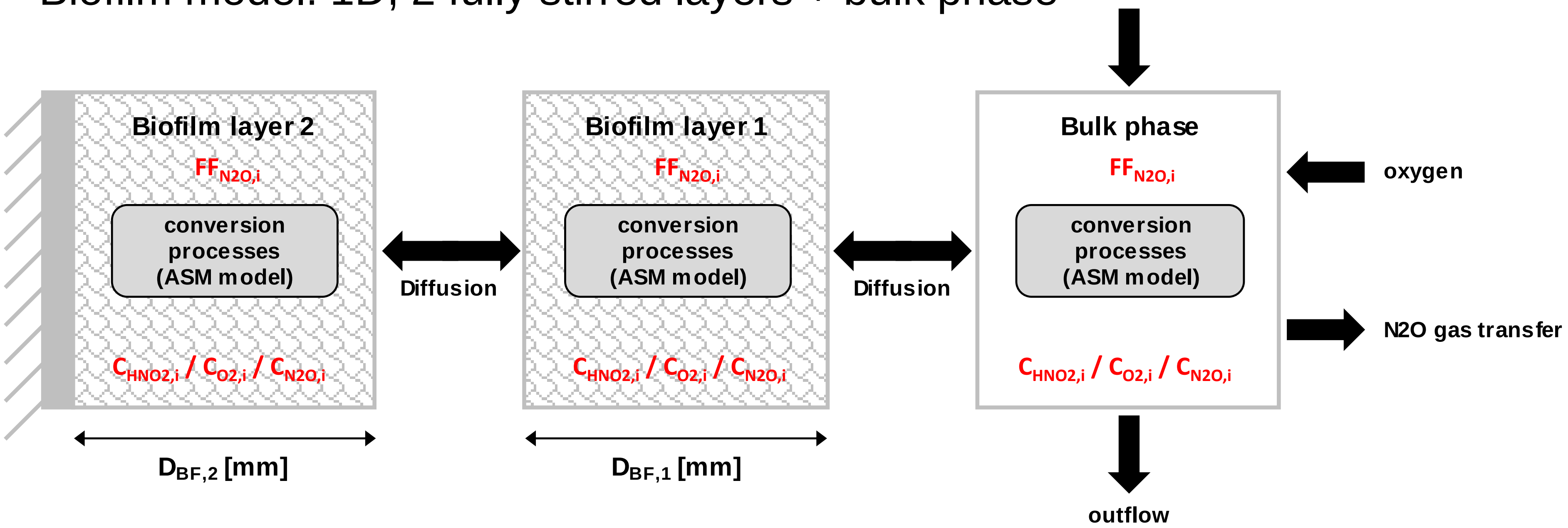
One-step nitritation for sludge water treatment in gas-tight reactors (220 l)

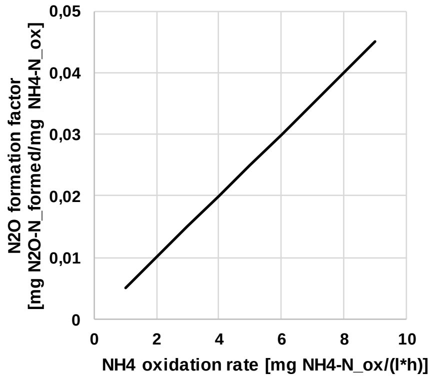
Model of the pilot plant

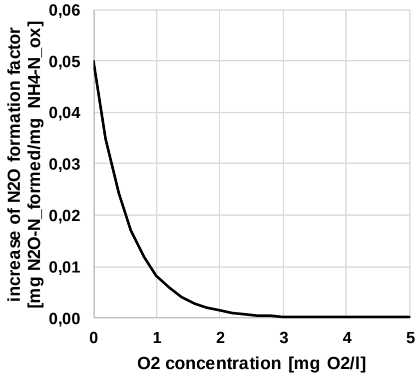
$$FF_{N2O,i} = f(NH_4 - Umsatz, NO_2, O_2)$$

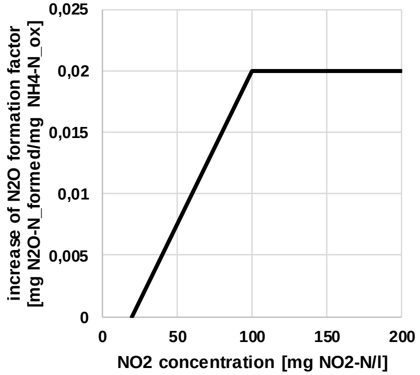
Expanded ASM model (Beier et al., 2021):

- Nitrification: two-step process
- Denitrification: three-step process
- N_2O formation: dynamic N_2O formation factors [g N_2O_{formed}/g NH_4-N_{ox}]
- Inhibiting effects of HNO_2 and NH_3 are included
- Gas transfer model is included
- Biofilm model: 1D, 2 fully stirred layers + bulk phase



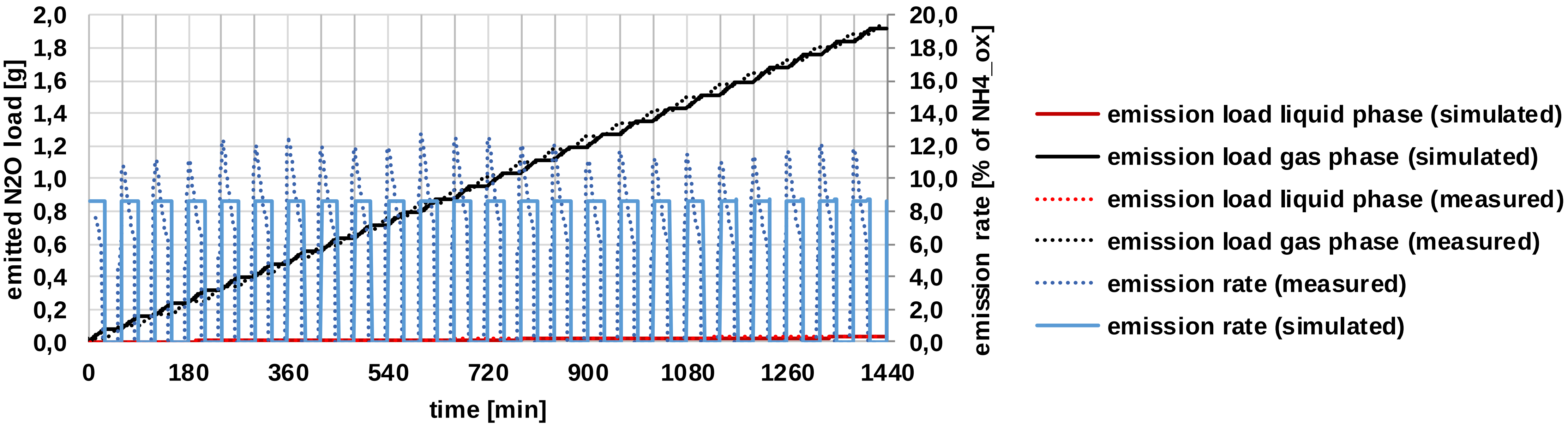






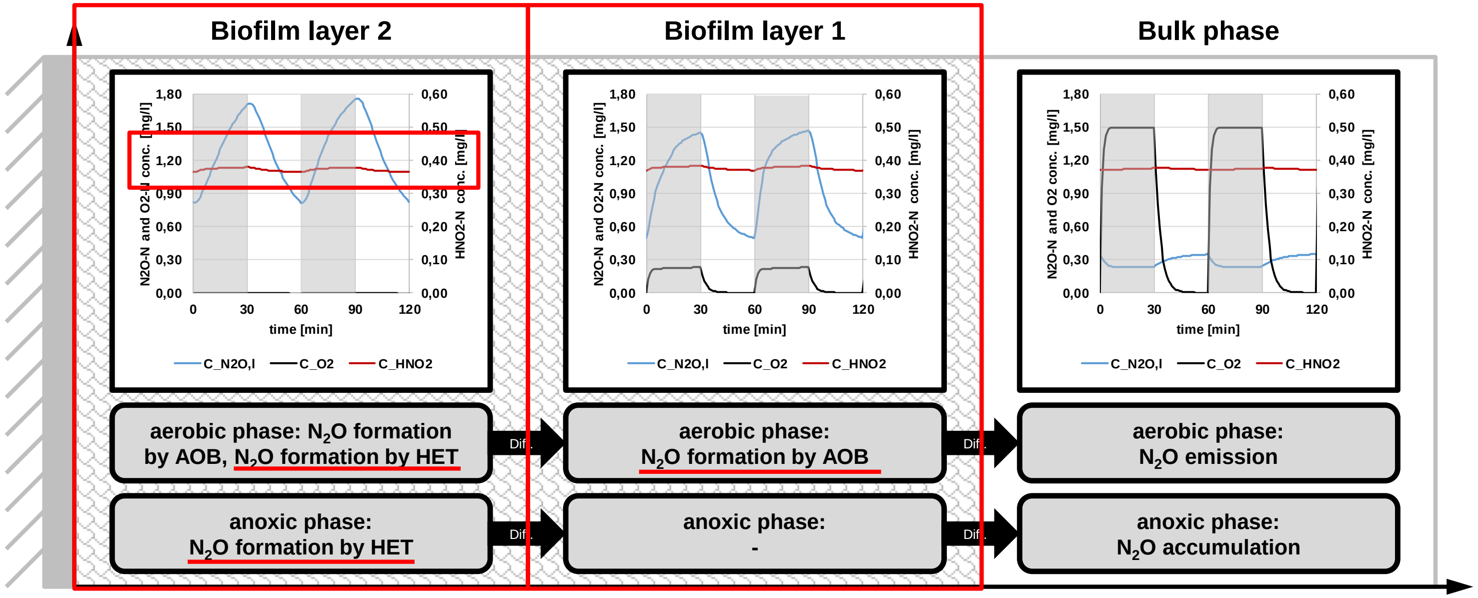
Model calibration (only N_2O)

- calibration parameter:
  - emitted N_2O load (gas and water phase)
  - temporal profile of the N_2O concentrations in gas and liquid phase
  - converted NH_4 load and consumption of alkalinity (influences N_2O formation)



Baseline scenario

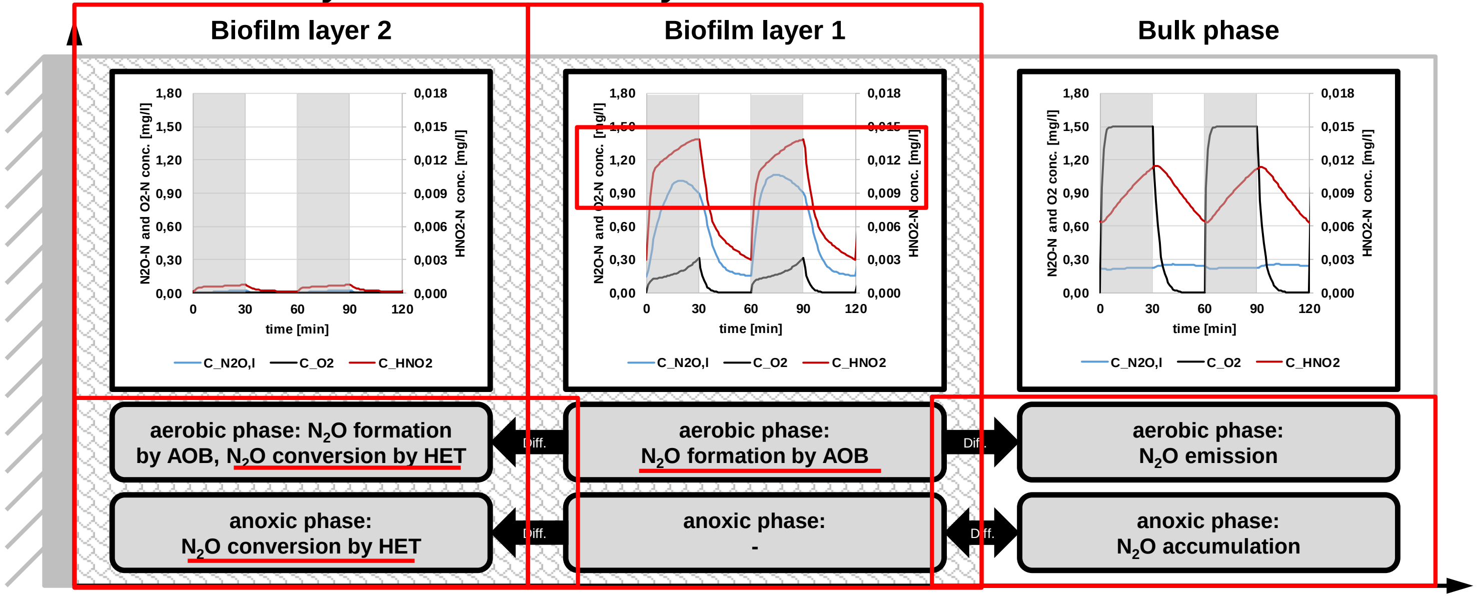
- N_2O formation mainly by AOB in biofilm layer 1 during the aerobic phase (80 %)
  - High NH_4 conversion rate, high nitrite concentration, low oxygen concentration
- Denitrification: Inhibited by HNO_2 (layer 2) → N_2O formation (10 % of total N_2O formed)
  - HNO_2 concentration exceeds threshold for accumulation by far
- Concentration gradient: from layer 2 towards bulkphase



Emission factor: 8.8 %

S1: One-step deammonification

- N_2O formation mainly by AOB in biofilm layer 1 during the aerobic phase
  - High NH_4 conversion rate, **lower** nitrite concentration, low oxygen concentration
    → Lower (- 35 %) formation
- Denitrification of formed N2O **in layer 2** (aerobic and anoxic phase)
  - Layer 2: HNO_2 concentration still exceeds threshold for accumulation for most of the time
- Concentration gradient:
  - From layer 1 towards bulkphase → stripped and emitted (end of the anoxic phase: re-diffusion)
  - From layer 1 towards layer 2 → converted

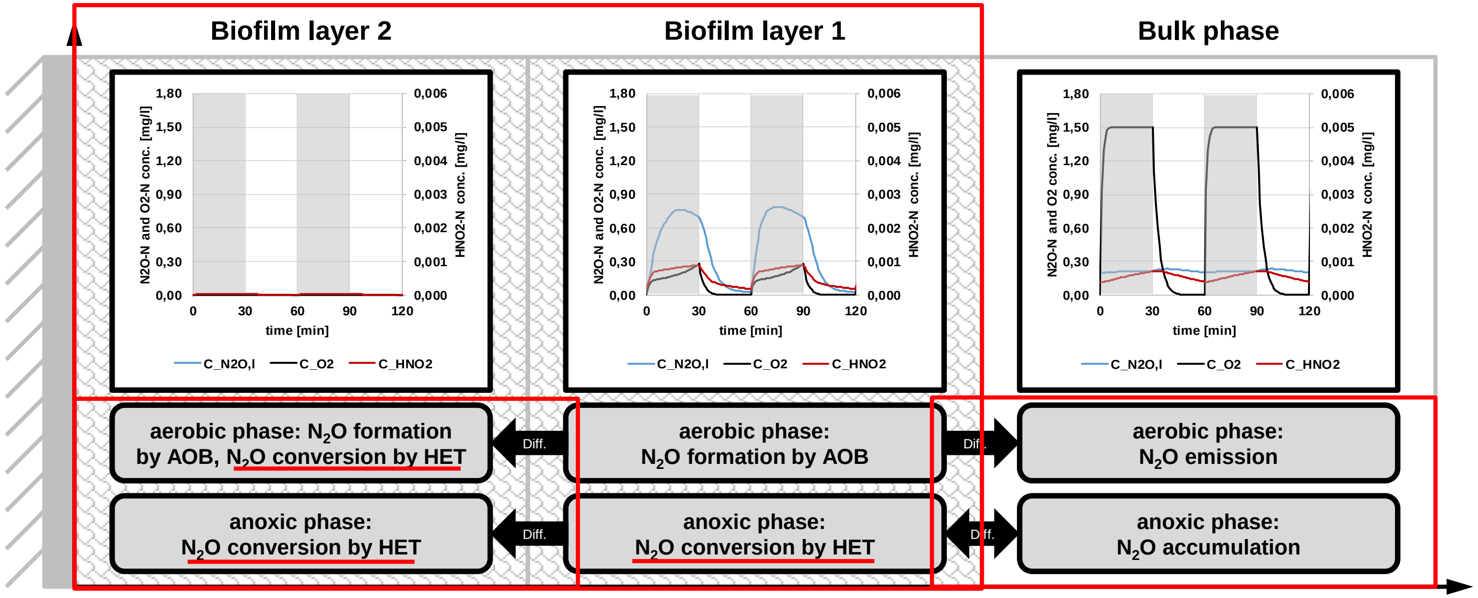


Emission factor: 3.3 %

Reduction of emission: 63 %

S2: One-step deammonification + increased pH (= 7)

- N_2O formation mainly by AOB in biofilm layer 1 during the aerobic phase
  - High NH_4 conversion rate, **lower** nitrite concentration, low oxygen concentration
    → Lower (- 35 %) formation
- Denitrification of formed N_2O **in both layers** (layer 1: only in anoxic phase)
- Concentration gradient:
  - From layer 1 towards bulkphase → stripped and emitted (anoxic phase: re-diffusion)
  - From layer 1 towards layer 2 → converted

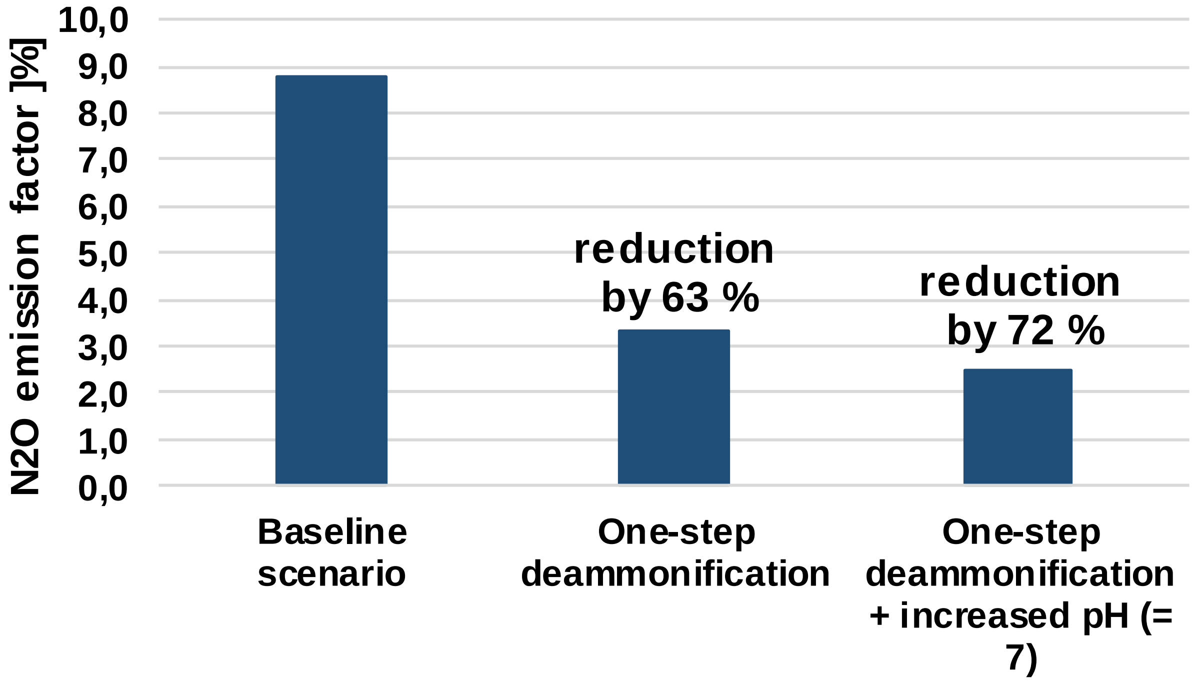


Emission factor: 2.5 %

Reduction of emission: 72 %

Summary

- Combining modeling and simulation, dynamics of N_2O formation, conversion and diffusion inside the biofilm can be separated
- With adapted operation strategies, a significant recution of N_2O emissions can be achieved
- Denitrification is a key process regarding N_2O mitigation
  - Anoxic environment required
  - HNO_2 inhibition has to be considered
- Further measures:
  - Adapted aeration control (reduced formation vs increased conversion)
  - Reduced stripping



Thank you for your Attention!

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