Modelling simultaneous methane and ammonium removal in a one-stage aerobic granular sludge reactor

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Concern

Reject water from anaerobic digestion contains NH_4^+ and CH_4

- Eutrophication
- Toxic for living organisms

- Greenhouse gas (34 CO_2 equivalent)
- High impact on global warming

Removal of CH₄ and NH₄⁺

Nitrite-dependent anaerobic methane oxidation (N-damo)

could be combined with

Anaerobic ammonium oxidation (anammox)

N-damo vs. anammox bacteria

	N-damo	anammox
Slower growth rate of N-damo - $\mu_{\max}$ [d ⁻¹]	0.0495	0.052
≈ biomass yield (autotrophic growth) – Y [gCOD.g ⁻¹ N*]	0.16	0.17
Lower nitrite affinity of N-damo - K_{NO_2} [gN.m ⁻³]	0.6	0.005
More sensitive to nitrite inhibition - $K_{i\text{NO}_2}$ [gN.m ⁻³]	40	400

* N-NH₄⁺ for anammox bacteria and N-NO₂⁻ for N-damo bacteria

Could we combine **N-damo** and **anammox** in
NON-AERATED granular sludge reactors to
simultaneously remove **CH₄** and **NH₄⁺**?

Granular sludge reactors

- Low footprint
- High SRT
- Different microbial communities

Could we combine **N-damo** and **anammox** in NON-AERATED granular sludge reactors to simultaneously remove **CH₄** and **NH₄⁺**?

Yes, we can !

IF

- influent $\text{CH}_4:\text{NH}_4^+:\text{NO}_2^-$ ratio close to stoichiometric
- biomass loading rate sufficiently low
- preferably small granules

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Biosystems Engineering

Modelling simultaneous anaerobic methane and ammonium removal in a granular sludge reactor

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Could we combine **N-damo** and **partial nitrification-anammox** in AEROBIC granular sludge reactors to simultaneously remove **CH₄** and **NH₄⁺** from reject water?

Mathematical model

One dimensional mathematical model – Aquasim

Assessment of bacterial competition in aerobic granules

● Consumed
● Produced

	O_2	NH_4^+	NO_2^-	CH_4	NO_3^-	N_2
Anammox bacteria		●	●		●	●
N-damo bacteria			●	●		●
Anaerobic Heterot.			●		●	●
AOB	●	●	●			
NOB	●		●		●	
MOB	●			●		
Aerobic Heterot.	●

Could we combine **N-damo** and **partial nitrification-anammox** in AEROBIC granular sludge reactors to simultaneously remove **CH₄** and **NH₄⁺** from reject water?

Scenario analysis

- Effect of O₂ concentration in the bulk liquid
- Effect of influent NH₄⁺ concentration
- Biomass distribution in the granules

Most optimistic scenario: CH₄ stripping not considered

Effect of O₂ concentration in the bulk liquid

NH₄⁺ = 300 g N.m⁻³

CH₄ = 100 g COD.m⁻³

Granule size = 0.75 mm

O₂ = 0.1-1.5 gO₂.m⁻³

Optimum at
limited O₂ concentrations:

0.2 – 0.3 gO₂/m³

- If higher, anammox and N-damo bacteria inhibited
- If lower, not enough conversion to NO₂⁻

Effect of O_2 concentration in the bulk liquid

$NH_4^+ = 300 \text{ g N.m}^{-3}$

$CH_4 = 100 \text{ g COD.m}^{-3}$

Granule size = 0.75 mm

$O_2 = 0.1\text{-}1.5 \text{ gO}_2.\text{m}^{-3}$

Optimum at
limited O_2 concentrations:

$0.2 - 0.3 \text{ gO}_2/\text{m}^3$

99% CH_4 removal achieved
95% N removal achieved

Effect of influent NH_4^+ concentration

$\text{NH}_4^+ = 100\text{-}2000 \text{ gN.m}^{-3}$

$\text{CH}_4 = 100 \text{ gCOD.m}^{-3}$

Granule size = 0.75 mm

$\text{O}_2 = 0.2 \text{ gO}_2.\text{m}^{-3}$

Coexistence of **anammox**
and **N-damo**:

Influent NH_4^+
300 – 500 gN/m^3

- If higher, anammox bacteria outcompete N-damo bacteria
- If lower, not enough substrate (NH_4^+ and NO_2^-)

Biomass distribution in the granules

$$\text{NH}_4^+ = 300 \text{ g N/m}^3$$

$$\text{O}_2 = 0.2 \text{ g O}_2/\text{m}^3$$

$$\text{CH}_4 = 100 \text{ g COD/m}^3$$

Granule size = 0.75 mm

- Anammox bacteria located closer to the surface area compared to N-damo bacteria
- AOB dominate the outer oxic part
- no MOB – no aerobic methane oxidation

Conclusions

- Simultaneous NH_4^+ and CH_4 removal feasible in aerated granular sludge reactors, neglecting CH_4 stripping
- Careful control of bulk oxygen concentration required
 - high enough for NH_4^+ conversion to NO_2^-
 - low enough to prevent inhibition of N-damo and anammox
- Influent ammonium concentration
 - high enough for NO_2^- production
 - low enough to prevent outcompetition of N-damo

Thank you for your attention

Questions?

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