Application of Mainstream Deammonification

Love-Hate Relationship of C & N
Coupling and decoupling of C & N

N-inertisation
wastewater treatment

N-cycle

N-fixation
Haber-Posch
90 gigatons/a

adropogenic cycles
Coupling and decoupling of C & N

**N-cycle**
- N-inertisation wastewater treatment
- N-fixation Haber-Posch 90 gigatons/a

**C-cycle**
- C-inertisation incineration ww treatment
- C-fixation autotrophic growth

adropogenic cycles
Coupling and decoupling of C & N

N-inertisation - wastewater treatment

N-fixation - Haber-Posch
90 gigatons/a

C-inertisation - incineration
ww treatment

C-fixation - autotrophic growth

100 years acceleration
Resource savings in nitrogen removal?

Carbon redirection towards digestion
- Enhanced upstream C removal
- Methanisation instead of oxidation or denitrification
Carbon redirection towards digesters

- **High Rate, CEPT or A-Stage:** 50-80 % COD removal
- **Typical C:N Ratios:** CEPT – 3:1 to 6:1 (add Fe)
  A-Stage – 3:1 to 10:1 (SRT of 0.25d to 0.5 d)
Resource savings in nitrogen removal?

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Metabolic short-cuts for N-removal
• Nitrite shunt
• Deammonification
Metabolic short-cuts for N-removal

nitrite-shunt
deammonification
Net energy consumption for 3 WWTP variants

- **Case A**: Conventional treatment
- **Case B**: Conventional treatment with anammox in the side-stream
- **Case C**: Optimized treatment with anammox in the main-stream

<table>
<thead>
<tr>
<th>Oxygen and Energy need</th>
<th>Mass Flux (g p(^{-1}) d(^{-1}))</th>
<th>Energy (Wh p(^{-1}) d(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Case A</td>
<td>Case B</td>
</tr>
<tr>
<td>Aeration for COD removal</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Aeration for Nitrogen removal(^b)</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Pumping/Mixing energy</td>
<td>-20</td>
<td>-20</td>
</tr>
<tr>
<td>Methane-COD and electrical energy production from biogas</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td><strong>Net Energy</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) Lower because of absence of recirculation flows
\(^b\) Nitrate effluent for cases A and B: 2.5 g p\(^{-1}\) d\(^{-1}\); for case C: 1.1 g p\(^{-1}\) d\(^{-1}\)

**Reference**
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Shifting energy flux from transport to conversion
• usually ca. 30% of energy demand in biological treatment is transport (mixing, recycling, pumping)
• make use of air-flow for transport
Side-stream applications: DEMON

DEMON-features –
• pH-based process control
• cyclone for anammox enrichment
DEMEN hydro-cyclones
Purpose – to separate flocs (mainly AOB) and granules (mainly AMX) in order to select for different SRTs
Set-up of a triple DEMON® cyclone configuration (left) selecting for a high anammox retention time based on density difference between the flocculant- and the granular sludge fraction
DEMON-plant Trento for leachate treatment successful operation down to 15°C
Start-up DEMON Pustertal dilute liquors (HRT=0.75 d)

Full-scale installations in Strass: Cyclons to select granules out of the wastelines of side-stream and main-stream
Required retrofit-effort:
Installation of seeding pipe from sidestream to the mainstream
Set-up of cyclons in the waste line

WWTP Strass, Austria
Required retrofit-effort:
Installation of seeding pipe from sidestream to the mainstream
Set-up of cyclons in the waste line

WWTP Glarnerland, Switzerland
Light microscopy (upper left, lower right) and binocular loupe image (upper right, lower left) of granules from the WWTP Strass
FISH image of Demon biomass sample from Strass WWT plant. No evidence of a comprehensive AOB layer around the granule.
Fluorescence in situ hybridization with the 16S rRNA gene targeting probe AMX820; Granules slice thickness 20 µM
Scanning electron microscope image of an anammox granule of the WWTP Strass. Magnification 200x.
WERF-Mainstream Deammonification
3 different sites and scales

Objective of bench-scale pilot
at DC Water

- Investigate fundamental process kinetics and control mechanisms identified for NOB out-selection, AOB and anammox enrichment, development and calibration of process model.
Blue Plains AWTP

- 370 mgd (AA) to 518 mgd (Max Day)
- TN < 7.5 mg/l & TP < 0.18 mg/l
- Future TN ~ 3 mg/l peak annual flows
- 12°C winter monthly average
Objective of pilot-scale tests at HRSD, Virginia

• Focus on NOB out-selection and control optimization to support design work at considered plant.
• Biofilm Post-Anoxic Anammox

WERF-Mainstream Deammonification
3 different sites and scales
Ammonia vs NOx (AVN) Controller

**Time**

- **NH\textsubscript{4}-N - NO\textsubscript{x}-N = 0**
- **Min AerDur = 4 mins**
- **Max AnDur = 8 mins**
- **Max AerDur = 8 mins**
- **Min AnDur = 4 mins**

**AnDur Online NH\textsubscript{4}-N - (NO\textsubscript{3}-N + NO\textsubscript{2}-N)**

**AerDur = 0 mins**

**Total cycle duration = 12 mins**

**DO = 0 mg/L**

**DO = 1.6 mg/L**

**Influent (mgN/L)**

<table>
<thead>
<tr>
<th>Effluent (mgN/L)</th>
<th>Eff NO\textsubscript{x} - N</th>
<th>Eff NH\textsubscript{3} - N</th>
<th>A-stage Inf TKN</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.7</td>
<td>20</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>11.17</td>
<td>25</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>11.27</td>
<td>30</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>12.7</td>
<td>25</td>
<td>30</td>
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<tr>
<td>12.17</td>
<td>20</td>
<td>25</td>
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</tr>
<tr>
<td>12.27</td>
<td>15</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

**Nitritation/ Denitrification**
Objective of full-scale pilot at WWTP Strass

- **Demonstration** projects at Strass WWTP and Glarnerland WWTP is to demonstrate the feasibility of the deammonification concept, applicable control strategies.
Frequently used parameter set for maximum AOB- and NOB-growth rates and oxygen affinity ($K_0$)
Oxygen affinity investigated by constant- and declining DO-tests

Monod saturation
Specific nitrogen process rates for AOB and NOB yielded from constant DO-tests.
Comparison of $K_o$-values of total nitrifiers (AOB+NOB) and NOB only in bench-scale batch-reactors at Blue Plains WWTP (left) and in full-scale at Strass WWTP (right)
HIGH DO
Intermittent Air – “N Profiles”

2 mg/L Ammonia Residual

Concentration (mg/L)
NH4-N; NO2-N; NO3-N

SCOD Concentration (mg/L)

Time (hr)

0.0 1.0 2.0 3.0 4.0

NH3 NO2 NO3 SCOD

~ +1 mgN/L

~ -8 mgN/L
Specific nitrogen process rates for AOB and NOB yielded from constant DO-tests

<table>
<thead>
<tr>
<th></th>
<th>AOB-growth</th>
<th>NOB-growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monod</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu_{\text{max}} \cdot \frac{X_a}{Y_a}$</td>
<td>193</td>
<td>137</td>
</tr>
<tr>
<td>$k_0$ [mg DO/L]</td>
<td>0.40</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Our Recipe

• Anammox
  – Anammox Bioaugmentation
  – Anammox Retention

• AOB
  – AOB Bioaugmentation

• NOB Out-Selection
  – Aggressive Aerobic SRT Management
  – Ammonia Residual
  – High DO
  – Intermittent Aeration
  – Rapid Transitions to Anoxia

• Effluent Polishing
Strass Demonstration

- Carousel type aeration tank at Strass WWTP providing a DO-range of 0.00 to 0.55 mg/L along the flow-path at parallel tank operation.

DO=1.4-1.5 mg/L

0.19 mg/L

0.35mg/L

0.01

0.6mg/L

0.09mg/L

1.6-1.7mg/L

Cyclones installed at the B-stage in Strass, Cyclone A (left), Cyclone B since early September 2011 (right).
Full-scale experiments at WWTP Glarnerland plant loading profiles (PE) before and after project start.

Comparison of temperature profiles (°C).

Plant loading profiles (PE) before and after project start.

Comparison of temperature profiles (°C).
Comparison of this year’s and last year’s operational data of the full-scale pilot Strass indicating advanced NOB-repression (typically high nitrate level at Christmas peak-load; similar temperature conditions of ca. 10°C, load conditions and ammonia effluent concentrations of ca. 2-5 mgN/L for both years)
Denaturing gradient gel electrophoresis of amplified Anammox 16S DNA gene fragments of mainstream samples B1-B17
Gene copy number for AOB, Nb, Ns and AMX
Evolution of the anammox biomass of the mainstream cyclone underflow fraction (B-UF) from sampling one to twelve; distribution of granule size fraction (left); abundance of granules mL\(^{-1}\) (middle) and estimated granule volume mL\(^{-1}\) (right)
Abundance of anammox granules of different sample types (PW...process water, B...B-stage, OF...cyclone overflow, UF...cyclone underflow).

Particle size distributions of different sample types (PW...process water, B...B-stage, OF...cyclone overflow, UF...cyclone underflow).
Since operation of the mainstream cyclone no SVI-detoriation occurs (daily SVI-measurements from the last 3 winter seasons)
Nitrite shunt at PUB’s Changi WRP in Singapore

Step-feed BNR operated at 2.5 d aerobic SRT shows higher nitrite vs nitrate effluent values:

\[
\begin{align*}
\text{NH}_4^+ - \text{N} & \quad \text{NO}_2^- - \text{N} & \quad \text{NO}_3^- - \text{N} \\
\text{Avg} & \quad 1.7 & \quad 1.1 & \quad 1.0
\end{align*}
\]

Q=800,000 m³/d

(PUB; Dr. Yeshi Cao)
Another C & N aspect: CO2-stripping depending on transfer efficiency (bench-scale vs full-scale)

The role of inorganic carbon limitation in biological nitrogen removal of extremely ammonia concentrated wastewater

Bernhard Wett*, Wolfgang Rauch

Department of Environmental Engineering, University of Innsbruck, Technikerstr.13, A-6020 Innsbruck, Austria

Received 26 September 2001; received in revised form 10 June 2002; accepted 26 August 2002
60th anniversary 1st ascent of Nanga Parbat 8125 m
Conclusions

- Wastewater treatment and nutrient removal is all about coupling and uncoupling of C & N
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Feasibility/design at 4 utilities

in NL, 3 in G, DC Water and HRSD)
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