Full Plant Deammonification for Energy Neutral Wastewater Treatment

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DC Water

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Manager, Clean Water Quality and Technology
DC Water
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DCWATER.COM
• High Rate, CEPT or A-Stage:
  – 55-75% COD removal
• B-stage: 10 - 15 days SRT
  – Deammonification
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
Fundamentals of Nitrification - Denitrification

Autotrophic Aerobic Environment

Oxygen demand 4.57 g / g NH$_4^+$-N oxidized
Carbon demand 4.77 g COD / g NO$_3^-$-N reduced

1 mol Nitrate (NO$_3^-$)

Nitrite Oxidizers

25% O$_2$

1 mol Nitrite (NO$_2^-$)

Ammonia Oxidizers

75% O$_2$

1 mol Ammonia (NH$_3$/NH$_4^+$)

Heterotrophic Anoxic Environment

1 mol Nitrite (NO$_2^-$)

40% Carbon

½ mol Nitrogen Gas (N$_2$)

60% Carbon

Oxygen demand 4.57 g / g NH$_4^+$-N oxidized
Carbon demand 4.77 g COD / g NO$_3^-$-N reduced

dcwater.com
Fundamentals of Deammonification

Autotrophic Aerobic Environment

ANAAMOX
Anaerobic Ammonium Oxidation
Autotrophic Nitrite Reduction
(New Planctomycete, Strous et. al. 1999)

\[
\begin{align*}
\text{Oxygen demand } & 1.9 \text{ g / g NH}_4^+ \text{-N oxidized} \\
\end{align*}
\]

\[
\begin{align*}
\text{NH}_4^+ + 1.32 \text{ NO}_2^- + 0.066 \text{ HCO}_3^- + 0.13 \text{ H}^+ & \rightarrow \\
0.26 \text{ NO}_3^- + 1.02 \text{N}_2 + 0.066 \text{ CH}_2\text{O}_{0.5}\text{N}_{0.15} + 2.03 \text{ H}_2\text{O} \\
\end{align*}
\]

Partial Nitrification
46% O\(_2\)

1 mol Ammonia
\((\text{NH}_3/\text{NH}_4^+)\)

Oxygen demand 1.9 g / g NH\(_4^+\)-N oxidized
How mature is deammonification technology?

- Main-stream Deammonification
  - Emerging technology
- Side-stream Deammonification
  - State of the Art
- Conventional N-removal technologies
  - Established
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.
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
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.
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
Our Recipe

• Anammox
  – Anammox Bioaugmentation
  – Anammox Retention (long SRT maintained in granules or biofilms)
• AOB
  – AOB Bioaugmentation
Cyclone, Sieve or Biofilm Media?

Three anammox retention procedures
1) Cyclones- Strass
2) Sieves- Blue Plains
3) Biofilm Media- HRSD
Cyclone for selective SRT

cyclone under-flow (recycled) and overflow (wasted)
Our Recipe

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

- Effluent Polishing
Oxygen Affinity

SNPR (mgN/gVSS.d) vs DO (mg/L)

- A - AOB
- A - NOB
- AOB Monod
- NOB Monod
Frequently used parameter set for maximum AOB- and NOB-growth rates and oxygen affinity ($K_O$)

<table>
<thead>
<tr>
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<th>AOB-growth</th>
<th>NOB-growth</th>
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<tbody>
<tr>
<td>$\mu_{max} [1/d]$</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Arrhenius</td>
<td>1.07</td>
<td>1.06</td>
</tr>
<tr>
<td>$k_O [mg DO/L]$</td>
<td>0.25</td>
<td>0.50</td>
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</table>
Oxygen and Nitrogen Affinities

From: Current WERF Study

DC Water Trials

Low/Constant DO

Low/Intermittent aeration

High/Intermittent aeration
Dissolved Oxygen Slope and Profiles

HIGH DO INTERMITTENT AERATION
(05/04/2012)

2.5min/20min

DO, mg/L

Time, hh:mm
HIGH DO
Intermittent Air – “Anammox Activity”

HIGH DO INTERMITTENT AERATION
(1 MONTH)

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

~ - 4.2 mgN/L
~ - 5 mgN/L

Time (hr)

NH₃
NO₂
NO₃
HIGH DO
Intermittent Air – “N Profiles”

2 mg/L Ammonia Residual

-8 mgN/L

+1 mgN/L

Time (hr)

Concentration (mg/L)

NH4-N, NO2-N, NO3-N

SCOD Concentration (mg/L)

NH3
NO2
NO3
SCOD
HIGH DO
Intermittent Air – “N Profiles”

No Ammonia Residual

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

Time (hr)

- ~ +4 mgN/L
- ~ -8 mgN/L

NH₃ NO₂ NO₃ SCOD
HRSD Process Schematic

A-stage HRAS

B-stage NiD eMA/anammox

RWI Influent

Air

WAS

RAS

Air

WAS

RAS
Ammonia vs NOx (AVN) Controller

- **Ammonia (NH₄-N)**
  - **AnDur:** 0 mins
  - **AerDur:** 0 mins
  - **DO:** 0 mg/L
  - **Online NH₄-N - (NO₃-N + NO₂-N):** 0

- **Nitrite (NO₂-N) & Nitrate (NO₃-N)**
  - **Min AerDur:** 4 mins
  - **Max AerDur:** 8 mins
  - **Min AnDur:** 4 mins
  - **Max AnDur:** 8 mins
  - **DO:** 1.6 mg/L
  - **Total cycle duration:** 12 mins

**DO:** 0 mg/L
**DO:** 1.6 mg/L

**NH₄-N - NO₂-N = 0**
AVN control

Aerobic Duration
Anoxic Duration
NH4-N-NOx-N

Minutes
mgN/L

8:09 PM 8:38 PM 9:07 PM 9:36 PM 10:04 PM 10:33 PM 11:02 PM 11:31 PM 12:00 AM
Process Performance

Nitritation/ Denitrification

Post- Anoxic Anammox MBBR

Influent (mgN/L)  Effluent (mgN/L)

11/7  11/17  11/27  12/7  12/17  12/27

Eff NOx-N  Eff NH3-N  A-stage Inf TKN

Inf TIN  Eff TIN

11/7  11/17  11/27  12/7  12/17  12/27

mgN/L
Strass Demonstration

- Carousel type aeration tank at Strass WWTP providing a DO-range of 0 to 1.7 mg/L along the flow-path.

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)
The last samples show ammonia removal during anaerobic activity test (anammox activity).

Only 25% of NOx produced from ammonia oxidation is converted to nitrate during aerobic activity test of the last sample.
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)
MODEL PARAMETER CALIBRATION
Simulation Results

High/Intermittent aeration

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<tr>
<th>DO Profiles</th>
<th>N Profiles</th>
<th>AMX Activity</th>
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<tbody>
<tr>
<td><img src="image" alt="DO Profiles Graph" /></td>
<td><img src="image" alt="N Profiles Graph" /></td>
<td><img src="image" alt="AMX Activity Graph" /></td>
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<td>$\mu_{\text{max}} \times X_a / Y_a$</td>
<td>193</td>
<td>137</td>
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<td>$k_O$ [mg DO/L]</td>
<td>0.40</td>
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Specific nitrogen process rates for AOB and NOB yielded from constant DO-tests
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