An Overview of Sidestream Treatment Alternatives Used to Increase Nutrient Removal

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Overview

- Regulatory / Global Drivers
- Definition / Characteristics of Sidestreams
- Nitrogen Removal Technologies
- Phosphorus Removal Technologies
- Summary
Regulatory / Global Drivers

- TN and TP effluent limits
  - Some Ohio plants already have TN and/or TP effluent limits - statewide limits possible in near term
  - Other areas in U.S. already have lower limits

- TN and TP limits for land application of biosolids

- Limited global supply of P (phosphate rock)
Definition / Characteristics of Sidestreams

- Flow resulting from treatment of biosolids that is returned to liquid treatment train
  - BFP filtrate
  - Centrate
  - Thickener filtrate
  - Digester supernatant
  - Filter backwash

- Small, typically intermittent flow

- Can contribute significant nutrient (N/P) loading to liquid treatment train
Why Sidestream Treatment?

- Recovers nutrients for beneficial reuse (mining)
- Reduced N/P loading to liquid treatment train
  - Less power / smaller carbon footprint
  - More stable operation
  - Higher safety factor for treatment - can help to meet lower effluent nutrient limits
- Reduced volume / nutrient content of biosolids
Why Sidestream Treatment?

- Reduced struvite formation
- Can often use existing infrastructure
- Can be economical when sidestream constitutes:
  - At least 15% of influent TN loading
  - At least 20% of influent TP loading
  - Typically the case where have significant biological treatment of solids (e.g., anaerobic digestion)
Common Sidestream Treatment Alternatives for N & P Removal

**Sludge Liquor Treatment**

**Biological Treatment**
- 1. Bio-augmentation of nitrification/denitrification
  - In-Nitri
  - BABE process
  - New York AT3
  - MAUREEN process
- 2. Nitrogen removal by nitration and denitration
  - SHARON process
- 3. Nitrogen removal by de-ammonification
  - ANAMMOX process
  - DEMON process
  - CANON process

**Physio-Chemical Treatment**
- 4. Ammonia Stripping
  - Hot air
  - Steam
- 5. Ion exchange in selective resins
  - ARP process
- 6. Struvite (MAP) precipitation
  - OSTARA process
  - PhosPaq process
  - Multiform Harvest
- 7. Breakpoint Chlorination
Nitrogen Removal Technologies

- **Bioaugmentation**
  - In-Nitri®
  - BABE®
  - New York AT-3
  - MAUREEN

- **Nitritation / Denitritation**
  - SHARON®
  - STRASS

- **Nitritation / Deammonification**
  - ANAMMOX®
  - DEMON®
  - Cleargreen™
  - ANITA™-Mox
Conventional Nitrogen Removal Pathway

- Traditional Bioaugmentation
Bioaugmentation Plants

- In-Nitri® - Richmond, VA
- BABE® - Netherlands
- NYC AT-3 - NYC Hunts Point and Bowery Bay
- MAUREEN - Washington, D.C. (Blue Plains)
Nitritation / Denitritation

- Shortcuts traditional nitrification / denitrification
- Uses 25% less oxygen (theoretical)
- Uses 40% less carbon (theoretical)
Nitritation / Denitritation Shortcut

- AOB growth rate > NOB growth rate
- Control SRT and DO to remove NOBs (temp dependent)
### Summary of Performance of Plants Using Nitritation / Denitritation

<table>
<thead>
<tr>
<th>Location</th>
<th>Implementation</th>
<th>Load (lbs N/day)</th>
<th>Inlet Conc. (mg NH4-N/L)</th>
<th>NH4-N Removal Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utrecht</td>
<td>1997</td>
<td>1980</td>
<td>600-900</td>
<td>90-95%</td>
</tr>
<tr>
<td>Rotterdam-Dokhaven</td>
<td>1999</td>
<td>1870</td>
<td>1,000-1,500</td>
<td>85-98%</td>
</tr>
<tr>
<td>Zwolle</td>
<td>2003</td>
<td>900</td>
<td>400-600</td>
<td>85-95%</td>
</tr>
<tr>
<td>Beverwijk</td>
<td>2003</td>
<td>2,640</td>
<td>700-900</td>
<td>85-95%</td>
</tr>
<tr>
<td>The Hague-Houtrust</td>
<td>2005</td>
<td>2,860</td>
<td>900-1,200</td>
<td>85-98%</td>
</tr>
<tr>
<td>Groningen-Garmerwolde</td>
<td>2005</td>
<td>5,280</td>
<td>700-800</td>
<td>≥95%</td>
</tr>
<tr>
<td>Wards Island NYC</td>
<td>2007</td>
<td>11,000</td>
<td>900-1,200</td>
<td>≥95%</td>
</tr>
</tbody>
</table>
Nitritation / Deammonification

- Most energy efficient way to remove N
  - Uses 62% less oxygen
- Does not require supplemental carbon
- Utilizes anammox bacteria (Planctomycetes)
Deammonification Reaction

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

- Ammonium ion is electron donor
- Nitrite is electron acceptor
- Theoretical N removal is 90%
  - Produces 10% nitrate per lb TN fed into process
Use of Anammox Bacteria

- Slow growing organisms
  - About 8 times slower than nitrifying bacteria
  - Tank sizes using traditional activated sludge are very large

- Recent developments
  - Online instruments for easier process control
  - Advancements in understanding of population dynamics
  - R&D has led to wider product diversity
  - Increased emphasis on energy reduction / neutrality

Courtesy of Paques
Higher Growth Rate Possible in Sidestream Reactor

![Graph showing the relationship between temperature and minimum SRT to grow AOB, NOB, and Anammox.](image-url)

- **Min. SRT to Grow AOB, NOB, and Anammox (days)**
- **Temperature (°C)**

Legend:
- **Green Line**: Washout SRT - AOBs
- **Purple Line**: Washout SRT - NOBs
- **Blue Line**: Washout SRT - Anammox
Nitritation / Deammonification Plants
## Summary of Performance of Plants Using Nitritation / Deammonification

<table>
<thead>
<tr>
<th>Location</th>
<th>Type of Process</th>
<th>Commissioned</th>
<th>Influent Load (lbs N/day)</th>
<th>Inlet Conc. (mg NH4-N/L)</th>
<th>NH4-N Removal Efficiency %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hattingen, Germany</td>
<td>Fixed-Film</td>
<td>2003</td>
<td>260</td>
<td>530</td>
<td>80%</td>
</tr>
<tr>
<td>Himmerfjarden, Sweden</td>
<td>Fixed-Film</td>
<td>2007</td>
<td>1,060</td>
<td>780 - 1,000</td>
<td>80%</td>
</tr>
<tr>
<td>Sjolunda, Sweden</td>
<td>Fixed-Film</td>
<td>2010</td>
<td>~1,220</td>
<td>855</td>
<td>90%</td>
</tr>
<tr>
<td>Strass, Austria</td>
<td>SBR</td>
<td>2004</td>
<td>660</td>
<td>1,884</td>
<td>90.3%</td>
</tr>
<tr>
<td>Glarnerland, Switzerland</td>
<td>SBR</td>
<td>2006</td>
<td>440</td>
<td>~1,000</td>
<td>90 - 95%</td>
</tr>
<tr>
<td>Heidelberg, Germany</td>
<td>SBR</td>
<td>2008</td>
<td>660</td>
<td>800 - 1000</td>
<td>90 - 95%</td>
</tr>
<tr>
<td>Paris, France (Pilot)</td>
<td>SBR</td>
<td>2007</td>
<td>---</td>
<td>506</td>
<td>90 - 95%</td>
</tr>
<tr>
<td>Rotterdam, Netherlands</td>
<td>Upflow Granulation</td>
<td>2002</td>
<td>1,100</td>
<td>400 - 650</td>
<td>90 - 95%</td>
</tr>
</tbody>
</table>
Deammonification Processes

- **Sequencing Batch Reactor (SBR)**
  - DEMON®
  - Cleargreen™
  - Retains solids, requires wasting

- **Granular Sludge**
  - ANAMMOX®
  - Retains solids, requires wasting

- **Flow-Through**
  - ANITA™-Mox
  - MBBR process (attached growth only - no suspended solids)
SBR - DEMON® - Strass WWTP, Austria

- First full scale DEMON® system
  - Commissioned in 2004
- Design nitrogen load 661 lb/day
- Sidestream flow rate = 31,000 gal/day
- Avg 86% nitrogen removal (90% NH3 removal)
SBR - Cleargreen™

- Three 8-hour cycles per day
- Pilot completed in Paris, France
- Currently being piloted at Henrico Co., VA

Courtesy of IDI
Pilot Study at Henrico Co. WRF, VA

- Startup of system without anammox seed
- 4 month period to grow anammox bacteria
- 6 month operational period to observe performance
- Pilot started fall 2011
Henrico Co. Pilot Results Show Nitritation
Flow-Through - ANITA™-Mox

- **MBBR process (attached growth)**
  - No clarifier needed
  - DO 1.0 - 2.5 mg/L

- **Single pass reactor**
  - Nitritation and deammonification occur in same reactor

Courtesy of Veolia
NOB/Anammox Biofilms (by Veolia)

“Chip” Prototype
800 m²/m³

BiofilmChip™
1200 m²/m³

K3
500 m²/m³

K1
500 m²/m³

Courtesy of Kruger
## Evaluation of N Removal Costs - Case 1

### Cost to Remove 1 lb N in Mainstream

<table>
<thead>
<tr>
<th>Category/Parameter</th>
<th>5-stage BNR + Tertiary Denitrification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per pound TN removed (capital)</td>
<td>$1.63</td>
</tr>
<tr>
<td>Cost per pound TN removed (O&amp;M)</td>
<td>$1.68</td>
</tr>
<tr>
<td>Total</td>
<td>$3.31</td>
</tr>
</tbody>
</table>

### Cost to Remove 1 lb N in Sidestream

<table>
<thead>
<tr>
<th>Category/Parameter</th>
<th>Nitritation/Deammonification</th>
<th>Nitritation/Denitritation</th>
<th>Bioaugmentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per pound TN removed (capital)</td>
<td>$0.74</td>
<td>$0.60</td>
<td>$0.82</td>
</tr>
<tr>
<td>Cost per pound TN removed (O&amp;M)</td>
<td>$0.39</td>
<td>$1.04</td>
<td>$1.32</td>
</tr>
<tr>
<td>Total</td>
<td>$1.13</td>
<td>$1.65</td>
<td>$2.14</td>
</tr>
</tbody>
</table>
### Evaluation of N Removal Costs - Case 2

#### Cost to Remove 1 lb N in Mainstream

<table>
<thead>
<tr>
<th>Category/Parameter</th>
<th>5-stage BNR + Tertiary Denitrification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per pound TN removed (capital)</td>
<td>$0.90</td>
</tr>
<tr>
<td>Cost per pound TN removed (O&amp;M)</td>
<td>$1.76</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2.66</strong></td>
</tr>
</tbody>
</table>

#### Cost to Remove 1 lb N in Sidestream

<table>
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<tr>
<th>Category/Parameter</th>
<th>Nitritation/Deammonification</th>
<th>Nitritation/Denitrification</th>
<th>Bioaugmentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost per pound TN removed (capital)</td>
<td>$0.54</td>
<td>$0.45</td>
<td>$0.29</td>
</tr>
<tr>
<td>Cost per pound TN removed (O&amp;M)</td>
<td>$0.39</td>
<td>$1.04</td>
<td>$1.32</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$0.93</strong></td>
<td><strong>$1.49</strong></td>
<td><strong>$1.61</strong></td>
</tr>
</tbody>
</table>
Phosphorus Removal Technologies

- Coagulant aided phosphorus precipitation
  - Forms aluminum or iron phosphate and hydroxide
  - Non-proprietary
- Struvite formation
  - Forms struvite
  - Proprietary processes - Ostara and Multiform Harvest
- Of the resulting products from these processes, only struvite is used as a fertilizer additive with market value
Coagulant Aided Phosphorus Precip.

- Low capital cost
- High O&M costs
  - Chemical costs
  - Increased biosolids production
- Widely used
- Does not remove P from watershed
  (precipitate usually combines with biosolids)
Struvite Precipitation

- N:P ratio in struvite = 0.45 lb N required per lb P removed
  - Typically ammonia is in excess

\[ \text{Mg}^{+2} + \text{NH}_4^+ + \text{PO}_4^{-3} + 6\text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O} \text{ (struvite)} \]
Struvite Formation - Ostara

- Struvite crystallization process (multi-pass)
- Ostara markets and sells finished product as Crystal Green™ fertilizer
- Relatively higher capital cost
- All O&M costs are reimbursed to Owner
- Several full scale municipal installations
Ostara Process Schematic

Ostara's Pearl® Process

Upper section of reactor is a clarification section. Flow is recycled to increase removal rates and portion of flow is discharged to head of WWTP.

Smaller particles remain in reactor increasing in size until heavy enough to fall towards bottom of reactor.

Larger particles fall to the bottom and are harvested.

Harvested pellets from reactor dried and bagged for shipping off site.

For pH balance.

Centrate Streams (side streams) NH₄⁺ + PO₄⁻³

Equalized Centrate Feed Tank

Struvite Fertilizer Product

Caustic

Magnesium Chloride

Reacted Effluent

Recycle Pump

Returns to head of WWTP

Reacted Feed Pump
Crystal Green™ Fertilizer

- Typically used as fertilizer for parks and golf courses
- Specialized product with green attributes
  - Slow release fertilizer
  - Produced with minimal greenhouse gas emissions
  - Renewable resource
  - Reduces mining of phosphorus for use in commercial fertilizers
Ostara - Two Purchase Options

• Annual Fee
  – Ostara owns the equipment
  – Municipality pays annual fee to treat sidestream (significant)

• Capital Purchase
  – Municipality pays for equipment up front and owns equipment

• All O&M costs are reimbursed to municipality in both cases

• Ostara owns, markets, and sells the struvite pellets in both cases
Struvite Formation - Multiform Harvest

- Struvite crystallization process (single pass)
- Smaller footprint / reactors
- Produces low-quality fertilizer that is blended and refined in secondary markets
- Relatively lower capital cost
- Several industrial installations (no full scale municipal installations)
Multiform Harvest Process Schematic

1. Wastewater filtrate high in P and N
2. Sodium Hydroxide added to increase pH
3. Magnesium Chloride added to form crystals
4. Struvite crystals form
5. Struvite crystals combine to form pellets
6. Wastewater leaves top of cone with over 80% reduction in P and over 20% reduction in N
7. Cone shape keeps growing suspended struvite pellets while holding small crystals.
8. Struvite pellets are harvested from the bottom of cone

Multiform Harvest

- Crystals Combine to Form Pellets
- Struvite Crystals Form
- Treated Effluent Returns to Head of WWTP
- Struvite Pellets Harvested at Bottom of Cone

Equalized Centrate Feed Tank

Caustic

Magnesium Chloride

For pH Balance

Reactor Feed Pump

Struvite Fertilizer Product
Multiform Harvest Purchasing

- All equipment purchased, owned and operated by municipality (typically lower capital cost, no reimbursement for O&M)

- Multiform Harvest provides royalty free license and technical support in exchange for the struvite product

- Multiform Harvest owns, markets, and sells the struvite pellets
Ostara and Multiform Harvest Products

Ostara Pearl

Multiform Harvest
Classification of Struvite Fertilizer Product

- Classification varies from state to state
- Classification will affect available uses
- So far the product has been classified/regulated under U.S. Dept. of Agriculture
- Getting rid of end product still responsibility of struvite formation process supplier
Full Scale Ostara Facility

- Nansemond WWTP, Suffolk, VA (Hampton Roads Sanitation District) - 30 MGD
  - Effluent discharged to James River (which flows to Chesapeake Bay)
  - Upgraded to 5-stage BNR in 2010
  - High influent TP (avg 8.6 mg/L), mainly due to large industrial contribution
    - Periodic upsets to BPR

- Two sidestream treatment processes considered (with centrate EQ)
  - Ostara
  - Precipitation with ferric chloride
Struvite Recovery Facility - Nansemond WWTP
Ortho-P Removal Averaging
About 90%
Ammonia Removal Averaging About 30%
WASSTRI™ Can Further Reduce Upstream Struvite Formation

- Patent held by Clean Water Services (Ostara has rights to the patent)
Combined N / P Removal

- Paques combined anammox/struvite system
  - High ammonia concentration needed in struvite reactor
  - Short SRT - no significant impact on temp
  - N removal decreases pH (lower struvite solubility product)
Combined N / P Removal

- Combined system with WASSTRIPLAN™
  - Keep thickener filtrate separate (low NH3, cold)
  - N removal first to take advantage of high temp
Summary

• Sidestream treatment can significantly reduce N and P loading to mainstream process
  – Helps to meet effluent TN and TP limits
  – Reduces volume / nutrients in biosolids
  – Recovery of renewable P resource
  – More stable mainstream process operation
  – Less power / smaller carbon footprint

• N removal - 3 categories (biological)
  – Nitritation/deammonification has lowest NPC

• P removal - struvite formation vs chem precip
  – Payback highly site specific
Questions?

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