Nutrient Management in Energy Neutral WWTPs
Lessons Learned and the Path Ahead

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Perceptions….  

- Monopoly on a Resource?

Energy Neutrality  

Nutrient Management  

Resource Recovery  

Public Health and Welfare Management
More About Perceptions…


Figure 8. Quality versus energy
(NREL/TP-7A30-53341, January 2012)

Figure 3-4
Variations in Unit Electricity Consumption with Size for Representative Wastewater Treatment Processes
Reality.....BOD Removal

JWWTP, Carson, CA

MWHrs/Month

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec
Reality.....BNR...

- Strass WWTP operated by Abwasserverband Achental-Inntal-Zillertal, Strass, Austria.
- 10 mgd in the Winter
  - 250K p.e.
- 5-6 mgd in the Summer
Strass Data and Results

(Dr. Bernhard Wett, Personal Communication, 2011)
Agenda

- Fundamentals
  - Nutrient Management & Energy

- Baseline
  - Assessing Energy Conservation Measures

- Integrating Innovation
  - Assessing Novel Flowsheets

- Enabling Disruptive Technologies
  - Compatibility With The Technology Trajectory
Fundamentals

Where is Energy Expended in Nutrient Removal

- Nitrogen Management
  - Ammonia and Nitrite Oxidation
  - Nitrate and Nitrite Reduction

- Biological Phosphorus Control
Nitrogen Removal: From Conventional Pathways To Nitritation/Denitritation

- 1 mol Nitrate ($NO_3^-$)
  - Nitrification-Aerobic: 25% $O_2$
  - Autotrophs

- 1 mol Nitrite ($NO_2^-$)
  - Denitrification-Anoxic: 60% Carbon
  - Heterotrophs

- 1 mol Ammonia (NH3/ NH4+)
  - Nitrification-Aerobic: 75% $O_2$

- ½ mol Nitrogen Gas ($N_2$)
  - Denitrification-Anoxic: 50% of Alkalinity

- 100% of Alkalinity
Deammonification: Combining Nitritation & ANAMMOX

In a Simplified Representation

Nitritation-Aerobic

1 mol Nitrite ($\text{NO}_2^-$)

37% $\text{O}_2$

$\text{NH}_3/ \text{NH}_4^+$ 2 mol Ammonia

Results:
1. Less Oxygen
2. No Carbon

ANAMMOX-Anoxic

1 mol Nitrite ($\text{NO}_2^-$)

No Carbon

$\frac{1}{2} \text{ mol Nitrogen Gas (N}_2\text{)}$
Enhanced Biological Phosphorus Removal

Energy Optimization Opportunities???
Applying Process Simulators

Operating With EBPR: 100 MGD WWTP

- Degritted Raw
- Primaries
- Anaerobic_1
- Anaerobic_2
- Aerobic_1
- Aerobic_2
- Aerobic_3
- Aerobic_4
- Sec.Clarifiers
- To Disinfect
- PrimarySludge
- WAS

Air Flow per Zone (scfm)

- Total Avg: 36,800 scfm

(GREELEY AND HANSEN)
Applying Process Simulators

**Operating With EBPR: 100 MGD WWTP**

- Degritted Raw
- Primaries
- Anaerobic_1
- Anaerobic_2
- Aerobic_1
- Aerobic_2
- Aerobic_3
- Aerobic_4
- Sec. Clarifiers
- To Disinfect

**Total Avg Air Flow**

- Bio-P: 36,800 scfm
- BOD: 43,400 scfm
- BODc: 57,300 scfm
Applying Process Simulators

- Process Simulators Can Be Powerful Allies if...

- Net Benefit: 20,000 scfm ~ 1200 HP ~ $800K/yr...
Where Are We?

[Diagram showing three stages: Conservation, Innovation, and Disruption, with a vertical axis labeled Treatment Cost and a horizontal axis labeled Know-How, and a section for BOD Removal]
Diurnal Management

- Diurnal Impacts More Readily Identifiable in Urban Systems

<table>
<thead>
<tr>
<th>CODtotal</th>
<th>NH3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Load Factor

0:00 2:00 4:00 6:00 8:00 10:00 12:00 14:00 16:00 18:00 20:00 22:00 0:00
Dynamic DO Control

![Graph showing Dynamic DO Control with load factor and DO concentration over time]

- **CODtotal**
- **NH3**
Dynamic DO Control

Why is DO Concentration Important?

\[ r_g = \mu_{\text{max}} \left( \frac{[\text{DO}]}{[\text{DO}] + K_{\text{DO}}} \right) \]
Dynamic DO Control

DO Concentration

CODtotal
NH3
Dynamic DO Control

Total Avg Air Flow
Bio-P Base: 36,800 scfm
Bio-P at 1 mg/L: 35,100 scfm
Bio-P at 0.5 mg/L: 25,000 scfm

~120 kW Averaged Savings
$100K /yr

Air Flow per Zone (scfm)

Greeley and Hansen
How About Nitrogen Removal

Total Avg Air Flow
Bio-P Base: 36,800 scfm
Nitrification: 123,000 scfm
Nitrification w/Bio-P: 75,700 scfm
Where Are We?

![Graph showing the relationship between treatment cost and know-how, with three phases: Conservation, Innovation, and Disruption, and BOD Removal.](image-url)
Strass Data and Results

- Strass WWTP operated by Abwasserverband Achental-Inntal-Zillertal, Strass, Austria.

- 10 mgd in the Winter
  - 250K p.e.

- 5-6 mgd in the Summer
Strass WWTP Layout
**Strass Data and Results**

- **Plant produces more electricity than it consumes**
  - Continuous energy efficiency improvement
  - Co-generation

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<table>
<thead>
<tr>
<th>Year</th>
<th>Generator</th>
<th>Polynomial (Generator)</th>
<th>Polynomial (Verbrauch)</th>
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</thead>
<tbody>
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<td>1992</td>
<td>2,137,792</td>
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<td>2,109,043</td>
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<td>1993</td>
<td>2,778,122</td>
<td>2,600,365</td>
<td>2,730,700</td>
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<td>1994</td>
<td>1,402,294</td>
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<td>1995</td>
<td>2,694,456</td>
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<tr>
<td>2004</td>
<td>2,894,319</td>
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</tr>
<tr>
<td>2005</td>
<td>2,873,476</td>
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<td></td>
</tr>
</tbody>
</table>

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The chart illustrates the energy consumption and generation over the years from 1992 to 2005, showing a trend of increasing efficiency and output.
Why Strass?

- Reduction of chemical costs for sludge thickening by 50%
- Reduction in sludge dewatering costs by 33%
- Reduction in energy consumption on mass treated basis from approximately 6.5 euro/kg NH4-N removed in 2003 to 2.9 euro/kg NH4-N removed in 2007/2008
  - active management of dissolved oxygen (DO) setpoints
  - conversion to ultra-high efficiency strip aeration
- Sidestream treatment
  - 350 kWh/d to 196 kWh/d by implementing Nitritation/anammox (DEMON®)
- Digester gas utilization
  - cogeneration unit, boosting electrical efficiency from 33% to 39% and overall usage efficiency from 2.05 to 2.30 kW-hr/m³ of digester gas

In a relatively small WWTP; normally considered to be lacking the critical mass necessary to demonstrate innovation.
Strass Data and Results

A-System
- High Rate Activated Sludge

B-System
- Low Rate Biological Nutrient Activated Sludge

Effluent Discharge

Influent Pumps

Cogeneration System

Dewatering Press

Anaerobic Digesters

Thickening

Nitritation/ANAMMOX Reactor

Biosolids to Land Application
Goal: Maximize Organics to Digestion

- The A/B Process for Primary & Secondary Treatment

- The A Process:
  - High Rate Activated Sludge
    - 0.5-0.75 Hr HRT; 8-12 Hr SRT
    - Particulate, Colloidal & SOLUBLE Organics Removal Without Chemical Addition
  - Rapid Transfer from Aerobic Conditions to Anaerobic Conditions for Thickening Preserves Organics (COD & Calorific Energy)
Strass Data and Results

A-System
High Rate Activated Sludge

B-System
Low Rate Biological Nutrient Activated Sludge

Cogeneration System

Thickening

Anaerobic Digesters

Dewatering Press

Biosolids to Land Application

Nitritation/ANAMMOX Reactor

Influent Pumps

Effluent Discharge
So What’s a Sidestream?

- **High Strength Recycle**
  - Typically from Anaerobically Digested Dewatering
  - Thermal Processing Decanting

- **Typical Characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp</td>
<td>25° - 40°C</td>
</tr>
<tr>
<td>Ammonia</td>
<td>600 - 2000 mgN/L</td>
</tr>
<tr>
<td>Ortho-Phosphate</td>
<td>50 – 1000 mgP/L</td>
</tr>
<tr>
<td>Alkalinity as CaCO₃</td>
<td>500 – 4000 mg/L</td>
</tr>
<tr>
<td>TSS</td>
<td>500 – 5000 mg/L</td>
</tr>
</tbody>
</table>
Deammonification: Combining Nitritation & ANAMMOX

In a Simplified Representation

Nitritation-Aerobic

1 mol Nitrite ($\text{NO}_2^-$)

37% $\text{O}_2$

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

Results:
1. Less Oxygen
2. No Carbon

ANAMMOX-Anoxic

1 mol Nitrite ($\text{NO}_2^-$)

No Carbon

$\frac{1}{2}$ mol Nitrogen Gas ($\text{N}_2$)
Use of Advanced Process Analysis Tools

- Conduct COD, Calorific and Electrical Consumption/Generation Balance
- Identify Sinks, Potential Sources of Energy and Opportunities
- Graphical Format for Operations Team to Consult/Interpret
- Trending of Balances Over Time to Assess “Minor” Tweaks
COD Balance
Calorific Energy Balance

Calorific Energy Balance Diagram:

- Influent Pumping (100%)
- Preliminary (100%)
- Primary (1%)
- Secondary (15%)
- Tertiary (2%)
- Effluent Pumping (2%)
- Effluent (100%)
- PS Thickening (45%)
- Thickening (20%)
- Sidestream Treatment (3%)
- Stabilization
- Dewatering
- Disposal
- Biosolids
- Digester Gas
Electrical Energy Balance

Diagram showing the flow of energy through various processes:
- Influent Pumping
- Preliminary
- Primary
- Secondary
- Tertiary
- Effluent Pumping
- External Electrical Energy
- Process Buildings
- Renewable Energy Production
- Stabilization
- WAS Thickening
- PS Thickening
- Sidestream Treatment
- Dewatering
- Disposal
- Biosolids
- Energy Recovery
- Effluent
Achieving Energy Neutrality

![Energy Consumption Chart]

The chart shows the energy consumption and production over the years from 1996 to 2005. The categories include pumping station, mechanical treatment, A-stage, B-stage, sludge treatment, off-gas treatment, and buildings. The total consumption and electricity production are highlighted with different colors and markers. The chart indicates a trend towards energy neutrality, with the total consumption and electricity production gradually aligning.
Achieving Energy Neutrality

(Dr. Bernhard Wett, Personal Communication, 2011)
Achieving Sustainable Nitrogen Removal

- Integrating Innovation

- Electrical Demand
  - High Efficiency Strip Panel Aeration
  - Effective Control of the Mass Loading Diurnal

- Carbon Balance
  - Preserving and Routing Organic Carbon to Digestion for Biogas Production

Net Result: Cost Effective Nitrogen Removal
Where Are We?

Treatment Cost vs. Know-How

Conservation → Innovation → Disruption

BOD Removal
The Future:
Back to Our Side of the Pond
Deammonification: Combining Nitritation & ANAMMOX

In a Simplified Representation

Nitritation-Aerobic

1 mol Nitrite (NO₂⁻)

1 mol Nitrite (NO₂⁻)

ANAMMOX-Anoxic

½ mol Nitrogen Gas (N₂)

2 mol Ammonia (NH₃/ NH₄ +)

37% O₂

No Carbon

Results:
1. Less Oxygen
2. No Carbon
Nitrogen Removal: From Conventional Pathways To Nitritation/Denitritation

1 mol Nitrate ($\text{NO}_3^-$)

- **Nitrification-Aerobic**
  - Autotrophs
  - 25% O$_2$
  - 1 mol Nitrite ($\text{NO}_2^-$)

1 mol Nitrite ($\text{NO}_2^-$)

- **Denitrification-Anoxic**
  - Heterotrophs
  - 75% O$_2$
  - 100% of Alkalinity
  - 50% of Alkalinity
  - ½ mol Nitrogen Gas (N$_2$)

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

- 100% of Alkalinity
- 50% of Alkalinity
- 40% Carbon
- 60% Carbon

- 40% Carbon
- 50% of Alkalinity
Almost Conventional Process Configuration
Combined Sidestream and Mainstream Nitritation/Denitritation

[Graph showing nitrite (NO2-N) and nitrate (NOx-N) concentrations over time from January 2003 to August 2004.]

- NO2-N concentration is plotted on the y-axis in mg/L.
- NOx-N concentration is also plotted on the y-axis in mg/L.
- The x-axis represents the dates from 1/1/03 to 8/29/04.
- The graph highlights periods of nitrite and nitrate concentration peaks and troughs.
- A legend indicates different markers for NO2-N and NOx-N.
Combined Sidestream and Mainstream Nitritation/Denitritation
Eye on the Future

- **Low SRT Mainstream**
  - Nitritation/Denitritation Demonstrated at Full Scale
    - Minimize Carbon Oxidation
    - Maximize Use of Inherent WW Carbon

- **Commercially Viable Main Stream**
  - Deammonification At the Cusp
    - Torrent of Research Activity on Deammonification
Eye on the Future

- Disruptive Technologies
  By Definition Will Be...

  *Disruptive!*

An Amazing Time to Be an Engineer
Discussion