Recovery of Wastewater Nitrogen at Local-Scale: a Feasible Option?

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Acknowledgements

- US Environmental Protection Agency
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- Washington Suburban Sanitary Commission (WSSC)
Major Nitrogen Pathways

The Evolution and Future of Earth’s Nitrogen Cycle, Canfield et al., Science, 2010
Distributed Systems in U.S.

- > 25 million U.S. systems (EPA/625/R-00/008)
- Suffolk Co, Long Island 300,000 units
- Cape Cod 123,000 units
- 125 -500 gpd, 40-80 mg/L TN

Eutrophication
Anaerobic/Ion Exchange (AN-IX)

Anaerobic Solids Blanket

*ammonification to NH$_4^+$*

Ion Exchange Chambers

*granular ion exchange media*

Sanitation Water → CH$_4$, H$_2$ → Ion Exchange Chambers → Low Nitrogen Effluent
Anaerobic Treatment (AN)

core resource recovery biotechnology

**Hydrolysis • fermentation • ammonification**

\[ C_{10}H_{19}O_3N \rightarrow CH_3CH_2COO^- + NH_4^+ \]

**Obligate proton reduction • hydrogenesis**

\[ CH_3CH_2COO^- + 2 H_2O \rightarrow CH_3COO^- + 3 H_2 + CO_2 \]

**Acetate cleavage • methanogenesis**

\[ CH_3COO^- + H^+ \rightarrow CH_4 + CO_2 \]

**Hydrogenotrophic methanogenesis**

\[ 4 H_2 + CO_2 \rightarrow CH_4 + 2 H_2O \]
Clinoptilolite ZS403H (IX)

- Natural zeolite
- Crystalline, tetrahedral aluminosilicate
- 40 m$^2$/gram specific surface area
- 1.85 meq./gram CEC
- Effective under anaerobic conditions*

*Water Environment Research
AN-IX Retrofit

AN-IX Reactor

Household Sanitation Water

Primary Treatment

Conventional Onsite System

Soil Dispersal

Ground Surface
AN-IX Nitrogen Recovery

- High total nitrogen recovery $>95\%$
- Simple and reliable
- Local-scale appropriate
- Discontinuous loading
- Seasonal operation
- Suitable for local scale (house, village)
2 Test Sites

Maryland
Mayo Plant

• primary effluent
• 2,800 connections
• ~0.5 mgd

Florida
County Park

• Day use
• 2 bathrooms and ranger residence
4 Chamber AN-IX Prototype
57.6 liter: liquid empty bed

Anaerobic
15.9 Liter
EBCT = 37 hr.

Ion Exchange
41.7 Liter
EBCT = 97 hr.

4 x 8
7.83 kg

8 x 16
8.32 kg

8 x 16
7.13 kg
Mayo pilot
Mean Nitrogen Profiles
Florida AN-IX  Day 1-160

- **Total**
- **Organic**
- **Ammonia**

Chart showing nitrogen profiles in mg/L for Influent, Chamber 1, Chamber 2, Chamber 3, and Chamber 4.
Mayo Recovery through Day 214

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent, mg/L</th>
<th>Effluent, mg/L</th>
<th>% Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen as N</td>
<td>mg/L</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>54.0</td>
<td>1.3</td>
<td>97.7</td>
</tr>
<tr>
<td>Organic</td>
<td>14.3</td>
<td>1.3</td>
<td>91.4</td>
</tr>
<tr>
<td>Ammonia</td>
<td>42.7</td>
<td>0.0</td>
<td>99.4</td>
</tr>
<tr>
<td>Nitrate+nitrite</td>
<td>0.0</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>COD</td>
<td>227</td>
<td>93.8</td>
<td>65.5</td>
</tr>
</tbody>
</table>
Mayo NH$_4^+$ Breakthrough

![Graph showing NH$_4^+$-N concentration over operation time for different columns and influent.](image-url)
1-D Advection Dispersion Adsorption

\[ \frac{dC}{dt} = \frac{1}{R} \left( D \frac{d^2C}{dz^2} - v_0 \frac{dC}{dz} \right) \]
Extended Operation: FL System

[Graph showing NH₄⁺-N concentration over time for different treatment processes]

- Influent
- C1 Anaerobic Upflow
- C2 Ion Exchange
- C3 Ion Exchange
- C4 Ion Exchange
- External Column

Bioresource Technology, 2015
COD Profiles  Florida AN-IX

COD Fractionation Day 124

Day 124 COD, mg/L

Mean COD, mg/L

Bioresource Technology, 2015
Typical AN-IX Effluent

- C-BOD$_5$ < 5
- TSS < 5
- pH $7.1 - 7.4$
- ORP < 50
- DON < 2
- Ammonia, nitrate, nitrate ND
NH$_4^+$-N Adsorption Capacity

<table>
<thead>
<tr>
<th></th>
<th>Maryland</th>
<th>Florida</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days Operated</td>
<td>355</td>
<td>662</td>
</tr>
<tr>
<td>Flow Rate, L/day</td>
<td>10.2</td>
<td>10.2</td>
</tr>
<tr>
<td>NH$_4^+$ Capacity, mg N/g dw</td>
<td>11.3</td>
<td>13.5</td>
</tr>
</tbody>
</table>
AN-IX Technology Paradigm

- Prefab module
- SF home: 4 cap., 95% TN removal, 2.5 yr. media replace, 1,400 gal., 44 ft²
- Operation: Monitor NH₄⁺ breakthrough
- Harvest N
Onsite Anammoxozome

*Nitritation + anammox*

\[ \text{NH}_4^+ + 0.75 \text{O}_2 \rightarrow 0.5 \text{N}_2 + 1.5 \text{H}_2\text{O} + \text{H}^+ \]

- Oxygen permeable membrane array
- Lumen air circulation
- Diffusive flux of O\(_2\)

\[ \Delta \text{NH}_4^+-\text{N} \]

\[ \text{mg/L} \]

Day

\[ \text{NO}_2^-\text{N} \]

\[ \text{NO}_3^-\text{N} \]

\[ \text{DO} \]
Value Proposition: Local Nitrogen Cycling

Anaerobic / Ion Exchange Process

Hydrolysis & ammonification
Ion exchange capture of NH₄⁺

NH₄⁺-N Charged Clinoptilolite

Low Nitrogen Effluent Cycle

Sanitation Water

Anaerobic Solids Blanket
Ion Exchange Chambers

Nitrogen Assimilation in Plant Biomass

Biomass Nitrogen
Nitrogen & Media Cycling

- Bioextraction: microbial and plants
- Media regeneration and reuse
Microbial Extraction / Plant Uptake

Fill and Drain Culture

Solanum lycopersicum

Nitrogen Assimilation in Plant Biomass

Spent Clinoptilolite Medium

Nitrogen Uptake

Desorption & Oxidation of NH$_4^+$

Clinoptilolite Grain

Ammonium Oxidizing Biofilm

Nutrient Reservoir

Pump

Plant Root
Clinoponics
Solanum lycopersicum (cherry tomato)

- Plant growth in granular clinoptilolite
- Fill and drain, 3 cycle/day
- Microbially assisted nitrogen extraction

250 mmol/m²·sec Photosynthetic Photon Flux @ 12 hour on/off cycle
Canopy Volume

Spent clinoptilolite provides all nitrogen for growth

![Graph showing Canopy Volume vs. Day of Cultivation]
Flower and Fruit

*Solanum lycopersicum* Day 93

![Bar chart showing the number of flowers and fruits per treatment.](chart.png)

- **T1**: Synthetic nitrogen
- **T2**: Synthetic nitrogen
- **T3**: Synthetic nitrogen
- **T4**: Synthetic nitrogen
- **T5**: Wastewater nitrogen

The chart displays the number of flowers and fruits produced by different treatments. T5 showed the highest number of fruits and flowers compared to the other treatments.
Bioextraction of $\text{NO}_3^-$

![Graph showing bioextraction of $\text{NO}_3^-$ over time. The graph plots $\text{NO}_3^-$ concentration in mg/L against time in days. The concentration is measured for different samples labeled T1 to T5. The graph shows variations in concentration across different time points, indicating the effectiveness of bioextraction over time.](image-url)
## Urban Eco-Structure

<table>
<thead>
<tr>
<th>Scale</th>
<th>Nitrogen Load, lb/year</th>
<th>Clino Replace, years</th>
<th>AN-IX Plan Area, ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Sub-Urban Residence</td>
<td>36</td>
<td>2.5</td>
<td>35</td>
</tr>
<tr>
<td>16-Unit Complex</td>
<td>461</td>
<td>0.30</td>
<td>158</td>
</tr>
</tbody>
</table>
Prognosis

• Local recovery of > 95% Nitrogen
• Appropriate technology
• Local scale recycling
• Urban applications
Thank you

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