Microbiology of Biological Nutrient Removal

Felicia Hix
Fleming Training Center
Outline

- Overview of BNR Systems
- Oxidation of Organic Compounds
- Carbon, Nitrogen & Phosphorus Cycles
- Polyphosphate Production and Breakdown
- Anaerobic, Anoxic & Aerobic Microbiological Processes
- Summary
Biological Nutrient Removal (BNR) Systems

- Remove nitrogen and/or phosphorus
- Reduce oxygen requirements (denitrification)
- Reduce alkalinity requirements (denitrification)
- “Strange” microbiology
  - Obligate aerobes live in anaerobic conditions
- “Usually” controls sludge settleability
  - Floc-formers store food better than filaments
  - Upstream BOD$_5$ uptake “starves” filaments
Typical BNR System

- Anaerobic Fermentation
- Anoxic
- Nitrate Recycle
- Aerobic
- Effluent
- Return Sludge
- Waste Sludge High in Phosphorus
Oxidation of Organic Compounds

- Oxidation is loss of electrons
- Organics are oxidized
- Electron acceptor is reduced
Electron Acceptors

- Aerobic respiration: $O_2$
- Anaerobic respiration: $NO_3^-, SO_4^{2-}, CO_3^{2-}$
- Anoxic: $NO_3^-$
- Anaerobic fermentation: Alcohols and organic acids
Carbon Cycle

- Atmospheric CO₂
- Solar energy
- Atmospheric O₂
- Hydrospheric O₂

Photosynthesis by producers → Organic carbon

Respiration by producers, consumers, and decomposers

Fossil fuels

Sedimentary rock strata
Nitrogen Cycle
Phosphorus Cycle

IP from parent rock

OP in fungi and bacteria

Plant OP

Animal OP

OP in guano

OP in near-shore oceans

OP and IP in deep ocean sediments

OP-organic phosphate

IP-inorganic phosphate

Geological uplift
Polyphosphate

Production

Polyphosphate + Energy $\rightarrow$ Longer polyphosphate chain

$PO_4^{-3}$

Breakdown

$PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-}$ $\rightarrow$ Energy

cleave

$PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-} - PO_4^{-}$ + $PO_4^{-3}$
Anaerobic Section

*(Anaerobic Fermentation)*

Influent Q

with soluble BOD

\[ \text{Q + RSF} \]

To Anoxic Section

\[ \text{RSF} \]

Return sludge with facultative fermentation bacteria and obligate aerobic polyphosphate bacteria or phosphate accumulating organisms (PAOs)
Anaerobic Section Microbiology

- Facultative Fermentation Bacteria
  - Energy
  - Waste Products
  - Acids & Alcohols

- Obligate Aerobic Bacteria (Acinetobacter & Pseudomonas spp.)
  - PO₄³⁻
  - Accumulated Food

BOD
Anoxic Section

NO$_3^-$ from Nitrate Recycle

Nitrogen Gas to Atmosphere

From Anaerobic Section

Q + RSF + Recycle

To Aerated Section
Anoxic Section Microbiology

- BOD
- $\text{NO}_3^-$
- Energy
- $\text{CO}_2$
- $\text{N}_2$
Aerobic Section
*(Aerobic Respiration)*

Nitrate Recycle to Anoxic Section

From Anoxic Section
(Q + RSF + Recycle)

To Clarifier
(Q + RSF)
Aerobic Section Microbiology

Poly-phosphate bacteria

Accumulated Food

Energy for cell maintenance, reproduction and polyphosphate production

O₂

CO₂

NH₄⁺

NO₂⁻

NO₃⁻

Poly-phosphate

Energy for cell maintenance, reproduction and polyphosphate production

Nitrosomonas

Nitrifying Bacteria

Nitrobacter
Genera of Nitrifying Bacteria

- **Ammonia Oxidizers**
  - Nitrosomonas
  - Nitrosococcus
  - Nitrosospira
  - Nitrosorbio

- **Nitrite Oxidizers**
  - Nitrobacter
  - Nitrospira
  - Nitrococcus
  - Nitrospina

C- Ammonia oxidizers appear red and Nitrospira appear green
Microbiological Summary

BNR System

BOD → O₂ → NH₃ → PO₄⁻³ → BNR System → Energy (cells) → CO₂ → N₂ → High P solids
Anoxic Polyphosphate Accumulation

- Not as efficient as anaerobic process

- Can be accomplished using altered operational strategies
  - On/Off aeration
  - Oxidation ditch operated with anoxic sections
Protozoa

- Aerobic organisms
- Do not like anaerobic conditions
- Extended time
- Degree of anaerobic, very low oxidation reduction potential (ORP)
- Fermentation and anoxic sections
- “Off” period of “off/on”
Oxidation Reduction Potential

- Allows evaluation of biological conditions with or without DO available

- Simple and cheap
  - Portable pH meter
  - ORP probe
  - Immerse probe in tank and read

- Responds to chemical ion concentrations
### ORP Control

(Goronzy, 1992)

<table>
<thead>
<tr>
<th>Process</th>
<th>Range, mV</th>
<th>e⁻ Acceptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>cBOD oxidation</td>
<td>+50 to +200</td>
<td>O₂</td>
</tr>
<tr>
<td>Poly-P production</td>
<td>+40 to +250</td>
<td>O₂</td>
</tr>
<tr>
<td>Nitrification</td>
<td>+150 to +350</td>
<td>O₂</td>
</tr>
<tr>
<td>Denitrification</td>
<td>-50 to +50</td>
<td>NO₃⁻</td>
</tr>
<tr>
<td>Poly-P breakdown</td>
<td>-40 to -175</td>
<td>NO₃⁻, SO₄⁻</td>
</tr>
<tr>
<td>Sulfide formation</td>
<td>-50 to -250</td>
<td>SO₄⁻</td>
</tr>
<tr>
<td>Acid formation</td>
<td>-40 to –200</td>
<td>Organics</td>
</tr>
<tr>
<td>Methane formation</td>
<td>-200 to -350</td>
<td>Organics</td>
</tr>
</tbody>
</table>
Summary

- An/Ax/Ar conditions
- High RAS rate
- High recycle rate
- Remove N
- Remove P
- Reduce most filament growth
- Can occur with modified operation
- Monitor with ORP