Preparing for Nutrient Removal at Your Treatment Plant

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Presentation Outline

• Nutrient Regulations in Texas
  – When will I get nutrient limits in my permit?
  – What will it be?
• Quick Overview of Nutrient Removal
• Existing Treatment Plant Capacity Evaluation
  – TCEQ Design Criteria
• Wastewater Characterization
• Chemical or Biological Nutrient Removal (BNR)?
  – Process Configurations
• Nutrient Recovery
### Current Permits with Nutrient Limits in Texas

<table>
<thead>
<tr>
<th>Total Phosphorus (TP) Limit, mg/L</th>
<th>Number of Permits</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1.0</td>
<td>10</td>
</tr>
<tr>
<td>0.5 to 1.0</td>
<td>43</td>
</tr>
<tr>
<td>≤0.5</td>
<td>10</td>
</tr>
<tr>
<td>0.15</td>
<td>1</td>
</tr>
</tbody>
</table>

* There are two facilities with 6 mg/L and two with 8 mg/L Total Nitrogen limits.
75 Reservoirs for which TCEQ Adopted Chlorophyll $a$ Criteria in June 2010

Courtesy of TCEQ
Proposed Total Phosphorus (TP) Limits in Texas

<table>
<thead>
<tr>
<th>Permitted Flow, MGD</th>
<th>Typical TP Limit, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>0.5 – 3.0</td>
<td>0.5 to 1.0</td>
</tr>
<tr>
<td>&gt;3.0</td>
<td>0.5</td>
</tr>
</tbody>
</table>

• More stringent limits may be recommended to protect unusually sensitive aquatic environments.

• Less stringent limits may be recommended when there are unusual mitigating factors.
Status of Nutrient Criteria

• July 2, 2013: EPA approved TCEQ’s chlorophyll $a$ criteria for 39 reservoirs and disapproved for 36
• July 12, 2013: EPA approved TCEQ’s 2010 Implementation Procedures
• New and amended permits that authorize discharges to the 39 reservoirs will now start receiving TP limits
• TCEQ adoption of estuaries, rivers and streams nutrient criteria in 2017 onward
Aerobic, Anoxic or Anaerobic?

- Aerobic – dissolved oxygen (D.O.) present
- Anoxic – No D.O., but nitrate is present
- Anaerobic – No D.O. and no nitrate
- Relative terms, not to be taken absolutely, especially in biological reactors

![Diagram showing aerobic, anoxic, and aerobic conditions with F/M ratios and dissolved oxygen levels](image-url)
P Removal by Chemical Addition

Phosphate is removed by precipitation

$$\text{PO}_4^{3-} + \text{FeCl}_3 \rightarrow \text{Fe PO}_4\downarrow + 3 \text{ Cl}^-$$

More chemical needed than predicted by equation due to other competing reactions

Alkalinity is consumed by metal salts and vice versa

$$3 \text{ OH}^- + \text{FeCl}_3 \rightarrow \text{Fe(OH)}_3\downarrow + 3 \text{ Cl}^-$$

$$3 \text{ HCO}_3^- + \text{FeCl}_3 \rightarrow \text{Fe(OH)}_3\downarrow + 3 \text{ CO}_2 + 3 \text{ Cl}^-$$
Biological Phosphorus Removal

Requires Volatile Fatty Acids (VFAs) and alternating anaerobic/aerobic conditions

**Anaerobic Conditions:**

- VFA (Microorganism)

**Aerobic Conditions:**

- P
- CO₂
- H₂O
- PPP

Biological Nitrogen (N) Removal

**Nitrification**: Ammonium ion (NH$_4^+$) oxidized in two steps – first to Nitrite (NO$_2^-$), then to Nitrate (NO$_3^-$)

\[
\text{NH}_4^+ + 1.5 \text{ O}_2 + 2 \text{ HCO}_3^- \rightarrow \text{NO}_2^- + 3 \text{ H}_2\text{O} + 2 \text{ CO}_2 \uparrow
\]

\[
\text{NO}_2^- + 0.5 \text{ O}_2 \rightarrow \text{NO}_3^-
\]

\[
\text{NH}_4^+ + 2 \text{ O}_2 + 2 \text{ HCO}_3^- \rightarrow \text{NO}_3^- + 3 \text{ H}_2\text{O} + 2 \text{ CO}_2 \uparrow
\]

7.14 parts of *alkalinity* and 4.57 parts of *oxygen* consumed for every part of NH$_4^+$ oxidized to NO$_3^-$
Biological Nitrogen (N) Removal (continued...)

**Denitrification:** Nitrate (NO$_3^-$) reduced to nitrogen gas in the absence of oxygen (anoxic condition)

$$6 \text{NO}_3^- + 5 \text{CH}_3\text{OH} \rightarrow 3 \text{N}_2 \uparrow + 6 \text{OH}^- + 7 \text{H}_2\text{O}$$

3.57 parts of **alkalinity** formed and 2.86 parts of oxygen “recovered” (or BOD consumed) for every part of NO$_3^-$ denitrified
Existing

Treatment Plant Capacity Evaluation

- Check design and peak flows and load capacities for each treatment unit
- TCEQ “Design Criteria”
- Historical data analysis and actual treatment capability to meet permit limits
- Excess aeration basins capacity available?
- Can your basins sustain more SRT?
- Room for expansion?
- Hydraulic Head?
- Room for Filters? (for stringent limits)
Wastewater Characterization

• Effluent data (for regulatory reporting)
  – $\text{BOD}_5$
  – TSS
  – $\text{NH}_3$-N
  – pH
  – TP

• Measurement Frequency
  – Large Plants: More frequent
  – Small Plants: Less frequent
  – May want targeted and intensive sampling
Wastewater Characterization (continued...)

- $\text{BOD}_5$ – Total and Soluble
- COD – Total and Soluble
- $\text{NH}_3$-N
- Total Kjeldahl Nitrogen (TKN)
- Nitrate ($\text{NO}_3^-$) and Nitrite ($\text{NO}_2^-$)
- pH
- Alkalinity
- TP
- Ortho-Phosphorus (OP)
Wastewater Characterization (continued...)

- Influent
- Primary Effluent
- Secondary Effluent
  - Pre- and post-filtration
- Primary Sludge
- Waste Activated Sludge
- Sidestreams: Filter backwash, Thickener return flows, digester supernatant, Dewatering return flows
Wastewater Characterization (continued...)

• Volatile Fatty Acids (VFAs)
  – Critical for BNR, especially for biological P removal
  – Difficult to measure

• Surrogate for VFAs
  – Readily Biodegradable COD (RBCOD)
    • Biological batch feed test method – time consuming
  – Truly Soluble COD (TSCOD) – Faster physical-chemical method* using flocculation

# TP Limits and Reasonably Achievable Technology

<table>
<thead>
<tr>
<th>TP Limit (mg/L)</th>
<th>Biological</th>
<th>Chemical</th>
<th>Biological &amp; Chemical</th>
<th>Filtration</th>
<th>Membranes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;1.0</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td></td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>&lt;0.2</td>
<td></td>
<td></td>
<td></td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>
P Removal by Chemical Addition
Dosing Options

Commonly Used Metal Salts:
Alum – $\text{Al}_2(\text{SO}_4)_3$
Ferric Sulfate – $\text{Fe}_2(\text{SO}_4)_3$
Ferric Chloride – $\text{FeCl}_3$
## Chemical Dose Point Issues

<table>
<thead>
<tr>
<th>Dose Point</th>
<th>Expected Effluent TP</th>
<th>Issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>≥ 1 mg/L</td>
<td>Enhanced BOD and TSS removal; efficient chemical use; reduces P loading on downstream processes; may require polymer for flocculation</td>
</tr>
<tr>
<td>Secondary</td>
<td>≥ 1 mg/L</td>
<td>Less Efficient Chemical use; additional inert solids in MLSS</td>
</tr>
<tr>
<td>Primary and Secondary</td>
<td>0.5 – 1 mg/L</td>
<td>Combines advantages of above; slightly increased cost</td>
</tr>
<tr>
<td>Tertiary</td>
<td>≤ 0.5 mg/L</td>
<td>Required to meet stringent limits; significant increased cost</td>
</tr>
</tbody>
</table>
A2/O Process

- Anaerobic
- Anoxic
- Aerobic (Oxic)
- Nitrified Recycle, 1-3Q (NRCY)
- RAS
- WAS
Five-stage Bardenpho Process

- Anaerobic
- Anoxic
- Aerobic
- Anoxic
- Aerobic

4Q
External Carbon

RAS
WAS
University of Cape Town (UCT) Process

- Anaerobic Recycle, 1-2Q (ARCY)
- Nitrate Recycle, 1-2Q (NRCY)
- Anoxic Recycle, 1-2Q

Diagram:
- Q → Anaerobic → Anoxic → Aerobic → WAS
- RAS

Legend:
- Q: Flow rate
- WAS: Wastewater stabilization system
- RAS: Return activated sludge
Modified UCT Process

Anoxic Recycle, 1-2Q (ARCY)

Nitrate Recycle, 1-2Q (NRCY)

WAS

Q

Anaerobic

Anoxic

Anoxic

Aerobic

RAS

Q

WAS
### Relative Comparison of Biological and Chemical P-removal

<table>
<thead>
<tr>
<th>Parameters of Concern</th>
<th>Chemical</th>
<th>Biological</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital cost</td>
<td>Lower</td>
<td>Higher</td>
</tr>
<tr>
<td>O&amp;M cost</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Ability to meet TP limits</td>
<td>More reliable</td>
<td>Less reliable</td>
</tr>
<tr>
<td>Ease of operation</td>
<td>Simpler</td>
<td>More complex</td>
</tr>
<tr>
<td>Alkalinity and pH issues</td>
<td>Less favorable</td>
<td>More favorable</td>
</tr>
<tr>
<td>Sludge production</td>
<td>More</td>
<td>Less</td>
</tr>
</tbody>
</table>
Process Modeling

• Models help during process selection and design
• Models also help operation and crisis management
• Proper data input and calibration is important

Models are to be used, but not to believed.
-Henri Theil (1924-2000)

All models are wrong, but some are useful.
-George E.P. Box (1919-2013)

A model is a lie that helps you see the truth.
-Howard E. Skipper (1915-2006)
Nutrient Recovery

• Struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$) can form and clog digester pipes

• Better to intentionally form and recover struvite which can be sold commercially

• Several commercial systems: Multiform Harvest, NuReSys, Ostara (Crystal Green), Paques (Phospaq), Procorp (Crystalactor), SH+E Group (Airprex)
Summary

• Nutrient limits coming soon to your TPDES permits
• Capacity evaluation and wastewater characterization helpful for selection of appropriate processes
• Chemical P removal preferred for smaller plants
• BNR economical in the long run, especially for larger plants; requires more skilled operation
• Chemical P removal: higher O&M costs than BNR
• Modeling for process selection, design and operation
• Consider struvite recovery with BNR
Questions, Comments?