Introduction to Phosphorus Removal

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Nutrient Removal

• More Complex: Advanced Treatment, Tertiary Treatment
  – Chemical/Physical Treatment
  – Biological Treatment
    • Traditional Treatment-Oxidation Process
    • Nitrogen Removal-Oxidation then Reduction
    • Phosphorus- Reduction then Oxidation

• Conflicting and often a delicate processes
AS Review- Plant Configurations

• Plug Flow-long basin
  – DO may vary
  – DO demand changes
  – Rate of metabolism changes
  – BOD drops
• Multi Ring Ditch
• ~Intermittent fed SBR
AS Review- Plant Configuration

- Complete Mix~ square
  - DO ~ equal
  - DO demand ~equal
  - BOD ~ equal
  - Rate of metabolism ~equal
- Single ring ditch
- ~Continuous fed SBR
Bacterial Habitat

- Different by design
- Different by operations & controls
- Operators must use the tools at their disposal to control the bacteria!

Three Different Habitats
What are Nutrients? Think Fertilizer

• Nutrients
  – Nitrogen and Phosphorus
  – Two main fertilizer elements needed for growing green plants.
  – They contribute to aquatic plant growth,
  – Excess plant growth clogs streams and,
  – When they die add a organic matter/BOD and nutrient load back onto the stream
How do you remove nutrients?

• **Nitrogen**
  – Biologically- nitrification followed by denitrification
  – Chemically- ammonia stripping, breakpoint $\text{Cl}_2$

• **Phosphorus**
  – Biologically-to ~ 0.5-1.0 mg/L
  – Chemically-with or without biological removal
PHOSPHORUS REMOVAL
Phosphorus Importance

• Essential for all life; human deficiency is rare
• Essential for crop production; deficiency in soil is common
• Maury Co, Tenn. was once a world leader in the production of phosphorus fertilizer
Env. Phosphorus Cycle

- Industry
- Influent
- STP
- Effluent
- Waste Solids
- Leachate
- Landfill
- Farmland
- Erosion
- Food Chain
- Industrial Chemicals
- Fertilizer
- P mining
- Lakes and Oceans
Nitrogen/Phosphorus

- Both essential elements for life; human and plant
- Both available from food; human and plant
- Both are part of wastewater influent
- Both can be removed biologically or chemically
- But there is no gaseous form of phosphorus
Fate of Nutrients

• Nitrogen
  – Effluent
  – Sludge/Biosolids
  – Nitrogen Gas

• Phosphorus
  – Effluent
  – Sludge/Biosolids
Phosphorus Removal

• Influent Concentrations:
  – 6-20 mg/L common levels

• Common Effluent Levels
  – Secondary treatment~ 3-4 mg/L
  – With phosphorus removal ~ 1.0- 0.01mg/L

• Common Tennessee Limits ~ 0.5 mg/L

• Limits from other states ~ 0.1 mg/L
Phosphorus Sources

- Sewage, urine
- Soaps & Detergents
- Corrosion control:
  - Water distribution
  - Boiler feed water
- Industrial Sources
  - Food Processing
  - Metal processing
  - Fertilizer mfg.
Phosphorus Forms

• Influent Total Phosphorus 6-20 mg/L

• Organic Phosphorus ~ 2-5 mg/L
  – Acid digestion converts this to Orthophosphorus for testing.

• Inorganic Phosphorus ~ 4-15 mg/L
  – Orthophosphorus, PO$_4^{3-}$ (reactive phosphorus)
Fate of Phosphorus

• **Effluent**
  – Organic P in BOD & TSS
  – Dissolved in the water

• **Sludge or Biosolids**
  – Organic P in the solids
  – Dissolved in the water
Low Effluent Phosphorus

• To achieve **Low Effluent Phosphorus**:

• Phosphorus must be **high in the waste sludge and remain high when sludge or biosolids are removed from the plant**.
Load Must Balance

• Influent: 100 lbs. Phosphorus

• Effluent 90 lbs. Phosphorus

• Waste Sludge 10 lbs. Phosphorus
  – Stored in Digester/Holding Tank or,
  – Removed in Sludge or Biosolids
  – Caution: Decant/Supernatant Phosphorus
Phosphorus does not just disappear.

- It was discovered by Antoine Laurent Lavoisier about 1785.

- In a chemical reaction, or biochemical reaction, matter is neither created nor destroyed, though its form may change.
Plant Phosphorus Routes

100 lbs Influent P → Activated Sludge

90 lbs Effluent P → WAS Phos, 10 lbs

Land Application P ← Dig. P

Landfill P
Biological Phosphorus Removal

• Three Steps
  – Pass-through Phos
  – Assimilative Removal
  – Enhanced Biological Phosphorus Removal (EBPR)
1. Pass-Through Phosphorus

Low: BOD, TSS = Lower Phosphorus

High: BOD, TSS = Higher Phosphorus

- Keep effluent BOD & TSS low! Filters help.
2. Assimilative Phosphorus

- Keep a lower MLSS, MCRT, & younger sludge, that is waste more!
- 10 day SRT = 22,000 lbs
- 40 day SRT = 13,000 lbs
- 70 day SRT = 10,000 lbs
- More lbs wasted, more Phosphorus removed
Plant Phosphorus Routes

100 lbs Influent P

Activated Sludge

70 lbs Effluent P

WAS Phos, 30 lbs

Land Application P

Dig. P

Landfill P
Nutrient Removal Conflict

- Phosphorus Removal
  - Lower MLSS, MCRT, sludge age
- Ammonia Removal
  - Higher MLSS, MCT, sludge age

Balancing Act: Lowest MLSS/MCRT/sludge age that will fully nitrify. Watch ammonia levels; you may have to accept higher effluent ammonia to get low Phosphorus.
# Bacteriiological Conflict

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nitrifiers</th>
<th>Denitrifiers</th>
<th>PAO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferred SRT</td>
<td>Long</td>
<td>Short</td>
<td>Short</td>
</tr>
<tr>
<td>F/M</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>ORP (DO)</td>
<td>High</td>
<td>Low</td>
<td>Very low $\rightarrow$ High</td>
</tr>
<tr>
<td>rbCOD</td>
<td>No</td>
<td>Yes</td>
<td>Yes: VFA</td>
</tr>
<tr>
<td>NO$_X$-N</td>
<td>Ok</td>
<td>Must</td>
<td>No$^1$</td>
</tr>
<tr>
<td>Temperature sensitivity</td>
<td>Very high</td>
<td>Moderate</td>
<td>Low</td>
</tr>
</tbody>
</table>

1 – When conditions for secondary release are not present.

*Developed after Metcalf and Eddy (2014); EPA (2010); Downing et al. (2009); Kang et al. (2008); Brown et al. (2007); Oleszkiewicz and Barnard (2006).*

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Canadian Water Network, March 2015
3. Enhanced Biological Phosphorus Removal, EBPR

- Phosphorus Accumulating Organisms, PAO’s
- Heterotrophic, Obligate Aerobes
  - Feed on CBOD
  - Must have Oxygen
  - But have a unique metabolic capacity

*Candidatus Accumulibacter phosphatis* (blue cells)
PAO’s Unique Metabolic Capacity

- PAO- phosphorus accumulating organisms
- Also called Luxury Uptake of Phosphorus
- Process includes:
  - Anaerobic zone where phosphorus is released
  - Aerobic zone- Luxury Uptake of Phosphorus
- There are many variations of this basic flow
Biological Phosphorus Removal

- PAO bacteria
- To enhance their proliferation they must be cycled through two habitates
  - Anaerobic (release) stage
  - Aerobic (luxury uptake) stage
PAO Metabolism

**Anaerobic Zone, two processes**
Substrate = CBOD
Facultative Bacteria, not POA’s
Acetate is a VFA

PHB= Polyhydroxybutyrate, stored energy using VFA’s and O₄ from stored PO₄
P is released

**Aerobic Zone**
Oxygen present PHB is metabolized releasing CO₂ and water, aerobic metabolism like all other heterotrophs for maintenance and growth (new cells)
Phos & O₂ taken in to form new PHB or PO₄ (luxury uptake)
Plant Phosphorus Routes

- Influent P: 100 lbs
- Activated Sludge
- Effluent P: 10 lbs
- WAS Phos, 90 lbs
- Land Application P
- Dig. P
- Landfill P
Three Stage A²/O Process

BIOLOGICAL NUTRIENT REMOVAL (BNR) (1970's)

Recycle flow = 2-5* Q

Anaerobic zone needs VFA’s and **No** oxygen or nitrate, P released here

Nitrate Recycle

Luxury uptake of P as Polyphosphate in aerator

RAS should have little O₂ or NO₃, Nitrate Recycle to remove NO₃

Waste Sludge High in Phosphorus
Enhanced Biological Phosphorus Removal

- EBPR is known for “process instability”

- Requires more:
  - Careful operations
  - Process control testing
  - Communications and teamwork
Other Phos Removal Processes

- Three Stage A²/0
- Five Stage Bardenpho
- University of Cape Town (UCT)
  - Also UCT with Virginia Initiative Process
- Johannesburg and Modified Johannesburg processes
- All have some pattern of Anaerobic/Aerobic
Biological Phosphorus Removal

- Anaerobic zone
- ~ 2 hours HDT
- Fermenter for VFA’s but IBOD is down so adding Alum
- Reducing environment needed, ORP , -150 to -250 mV

Anaerobic Zone
Biological Phosphorus

- Oxidation Ditch
  - Off/On cycles
    - 90 on, DO~2 ORP ~300
    - 60 off, ORP ~ -100mV
  - Subsurface mixing
  - DO controlled and ORP monitored
  - Limits TN=8, TP=2
Other Technology and Methods

• Many proprietary nutrient removal methods
• Side stream treatment processes
  – Treat part of the flow to develop PAO’s then add them to the full flow
  – Treat internal flows such as digester supernatant
Side Stream Anaerobic System

- Influent
- Anaerobic Recycle with PAOs
- Aerobic aerator with luxury uptake
- Waste Activated Sludge
- Anaerobic Fermentation
  - ~ 10% of WAS returned

Low Phosphorus Effluent.
• WAS recycle to old thickener, then to ditch
• 2\textsuperscript{nd} trial, to middle ring
• Success with no Chemicals
• Winter Performance is better
• Ortho P < DL
AUB- North Mouse Creek

- WAS holding tank
  - ORP = -200 mV
  - Side stream fermenter
  - 6000 gpd returned
  - Eff Ortho P < DL
Madisonville

- Aeromod Plant
  - Headworks
  - Anaerobic Zone
  - Selector
  - Aerobic- Off/On Zones
  - Clarifiers
Madisonville

- Anaerobic Zone
  - Sewage only
  - Air Mixed 5 minutes-twice per day
  - ORP -300 to -200 mV

- Selector
  - RAS added
  - Subsurface mixing
  - ORP -200 to -100 mV
Madisonville

- **Effluent**
  - Total Phosphorus 3.0-0.3 mg/L
  - Total Nitrogen ~ 4.0
  - CBOD ~ 5
  - TSS ~ 6
Baileyton

- Low Pressure CS-very septic influent-VFA’s ~ 100 mg/L
- Preaeration Ferm Zone
  - MLSS recycle
  - Did not work??????
- Aeration off/on
  - 10 hr off- 4/2/4
  - TP < 2.0 lbs (< 5 mg/L)
Baileyton Lessons Learned

- Keep Trying
- Onsite Testing Valuable
- Phos Removal may not follow the books
- Digesters: decant & dewatering impact effluent
- TDEC will change limits
Cookeville- Success!

- 4 Oxidation Ditches
- 6 Brush Rotors each
- Rotating Brush Rotor operation
- Settled Blanket-Ferm Zone.
Cookeville- Success

- Initial Side Stream
- Layered Ditch
- ORP testing
ORP-Oxidation Reduction Potential

• ORP Measurements
  - pH meter with OPR probe, use mV scale
  - Only “quick” and insightful parameter for unaerated treatment units
ORP: Classic & Practitioners Values

- Ignore Positive Values use DO Meter
- Denit ~ -50 to -150 mV
- Fermentation Zone ~ -200 to -300 mV
## Practitioners ORP Values

### ORP & Metabolic Processes

<table>
<thead>
<tr>
<th>ORP Condition</th>
<th>ORP mV</th>
<th>Process Ranges</th>
<th>Process</th>
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<tbody>
<tr>
<td>Mildly Negative</td>
<td>+50</td>
<td>Classic Anoxic Zone</td>
<td>Anoxic Zone</td>
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<tr>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-50</td>
<td>Extended Anoxic Zone</td>
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<tr>
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<td>-100</td>
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<td></td>
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<tr>
<td>Moderately Negative</td>
<td>-150</td>
<td>Classic Fermentation Zone</td>
<td>Fermentation Zone</td>
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<tr>
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<td>-200</td>
<td>Extended Fermentation Zone</td>
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<tr>
<td></td>
<td>-300</td>
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<td></td>
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<tr>
<td>Strongly Negative</td>
<td>-350</td>
<td>Fully Anaerobic</td>
<td>Anaerobic (Methane) Zone</td>
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<tr>
<td></td>
<td>-400</td>
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<tr>
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<td></td>
</tr>
<tr>
<td></td>
<td>-500</td>
<td></td>
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</tr>
</tbody>
</table>
Influent & Phos. Removal

• $\geq 20 \text{ mg/L } \text{BOD}_5 / 1 \text{ mg/L TP removed}$
  – 30-40: 1 may be better
• $\geq 15 \text{ mg/L } \text{sBOD}_5 / 1 \text{ mg/L TP removed}$
• $7.5 \text{ mg/L VFA} / 1 \text{ mg/L TP removed}$
  – 5-10 mg/L range
  – $> 25 \text{ mg/L VFA needed in Ferm. Zone}$
  – Lack of VFA a common point of failure
Fermentation Zone

- Dissolved Oxygen = 0.0 mg/L
- ORP = -250 mV, perhaps -300 mV
- Mixing: 1-2.5 hp/50,000 gallons
  - Bernard recommends as low as 0.65 hp / 50,000 gallons
- HDT 1-3 hours, with prefermentor ~ 1 hour
- SRT 4-5 days
Fermentation Zone

- Various Shapes & Flow Patterns
- Two Purposes
  - VFA Formation - Slow
  - VFA Uptake - Fast
  - Can be two tanks
- Flexibility - Swing Tanks
Aerobic Zone

• Dissolved Oxygen: 1-6 mg/L
  – 3.0 mg/L being the most frequently recommended
  – Higher values because of nitrification
  – Higher values recommended at head end to satisfy high initial oxygen demand
    • PAO oxygen uptake is rapid
  – Lower residual (0.25-0.5 mg/L) is recommended at Clarifier end to prevent DO transport to Ferm. Zone
Activated Sludge Biomass

- MCRT- 8-15 Days
  - 10 Days ***
- More Assimilative Uptake
- Less opportunity for Secondary Release
- PAO:VFA (VFA’s often low)
Wasting from Aerator

- Operators #1 AS Control Method

- EBPR Wasting
  - Fully Aerobic
  - Uptake is Complete
Digester Phos. Return

100 lbs  
Influent P  

Activated Sludge  

Decant & Dewatering P  
50 lbs  

WAS Phos, 90 lbs  

Land Application P  
40 lbs  

Landfill P  

??10 lbs  
Effluent P
Aerobic Digesters

• Keep the Phos in the Sludge
  – Avoid Secondary Release
    • JJ&G- 6hr anoxic/2hr aerobic, BNW???
  – Low MCRT
    • Move sludge or biosolids out ASAP
    • Volatile Solids Reduction releases P
Secondary Release

• Great effort to “train” PAO’s into a cycle of release and uptake.
• Given the right condition release can occur where we do not want it to happen—secondary release.
  – Digesters, Anoxic Zones, Clarifier Blankets, RAS wells, Oversized Ferm. Zone.
  – Test internal processes and flows!
Glycogen Accumulating Organisms

• GAO’s compete with PAO’s for VFA’s but do not remove phosphorus.

• Competition Factors- GAO’s Prefer:
  – Higher Temperatures
  – Lower pH
  – Longer MCRT
  – Very high organic loading
EBPR- Known for “process instability”

Know the Basics and Theory

Know your Plant

Test, Test, Test

Experiment- Notify TDEC

Ask for Help
Phosphorus Removal

• Permit Limits?
  – Long-term Limits, Pounds
• BOD/TSS Pass Through
• Assimilative Removal
• Enhanced Biological Phosphorus Removal

• Chemical Phosphorus Removal
Chemical Phosphorus Removal

• Common Chemicals
  – Aluminum & Ferric
  – Lime, pH>11
  – Proprietary Products

• Need feed equipment
• Mixing
• Alkalinity
• Effluent filters improve removal

Alum Feed System
Chemical Precipitation of Phos.

- **Coagulation** - chemicals added which change the electromagnetic forces between suspended particles
- **Flocculation** - gentle mixing to build floc which will settle or be more easily filtered
- **Sedimentation/Filtration** - removal of the Phosphorus floc from the water
Chemical Process Equipment

- Chemical Storage - Bulk tanks, day tanks, piping, valves, containment
- Chemical Feeding - Dry, liquid
- Mixing - Flash Mix, Flocculation
- Settling/Filters
- Chemical Sludge - with WAS to solids processing
Process Operations

- Proper equipment operation
- Calibration of feed equipment
- Monitoring- more that ever!
  - pH, Alkalinity, Ortho & Total Phosphorus
  - Influent & Effluent and also through the process
- Process Adjustments- Flow, Loading, Performance
Chemical Phosphorus Removal

- Alum dose ~ 1.75 gallons alum/lbs P
- Ferric Sulfate ~ 1.3 gallons ferric sulfate /lbs P
- Varies with:
  - Alkalinity, pH
  - Limit to meet
Chemical Phosphorus Removal

- Ferric Sulfate, 24 gpd in 0.24 MGD, fed into influent interceptor, meeting a 0.5 mg/L limit
- SBR with BioP removal to ~1.0 mg/L then alum @ 60 gpd into 1.5 MGD to reach 0.5 mg/L limit.
Athens Utility Board, Original

- **Limits**
  - TN=5mg/L, TP=1mg/L

- **Ditch Rings**
  - Outer- anoxic
  - Middle, DO~1.0
  - Inner, DO~2.0

- **Ferric Chloride added to clarifier center well**
  - 60-120 gpd into 2.0 MGD
Phosphorus Removal

• Filters
  – TSS will contain 1-7% Phosphorus
  – Effluent filters improve removal with or without chemical addition
  – Plants constructed to remove P will have filters.

• Flow Equalization

Floc. basin and filters
Phosphorus Removal

- May be a limited parameter in the future.
- Two main removal methods.
- Phosphorus only leaves the plant in effluent or sludge.
- Retrofits may be chemical or biological.

- Operator Knowledge in Key.
Questions, Comments, Discussion