What Operators Should Know About Phosphorus Removal, Part 2

Webinar for North Carolina Wastewater Operators
March 18, 2021
10:00 - 11:45 AM

Grant Weaver, PE & wastewater operator
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Energy & Nutrient Optimization
of NC Municipal Wastewater Treatment Plants

Biological Nitrogen Removal, Parts 1&2
Activated Sludge, Parts 1&2
Biological Phosphorus Review, Part 1

Today: Biological Phosphorus Removal: Part 2

Mar 25: North Carolina Case Studies, Part 1 (your plants!)
Apr 8: North Carolina Case Studies, Part 2 (your plants!)
Apr 15: Energy Management, Part 1
Apr 22: Energy Management, Part 2
Apr 29: North Carolina Case Studies, Part 3 (your plants!)
THREE steps
Biological Phosphorus Removal

Step 1: prepare “dinner”

VFA (volatile fatty acids) production in anaerobic/fermentive conditions
Step 1: VFA Production
ORP of -200 mV or more negative
25 times as much BOD as orthophosphate
Retention time ... long enough to go septic
Biological Phosphorus Removal

Step 1: prepare “dinner”
VFA (volatile fatty acids) production in anaerobic/fermentive conditions

Step 2: “eat”
Bio-P bugs (PAOs, “phosphate accumulating organisms”) eat VFAs in anaerobic/fermentive conditions ... temporarily releasing more P into the water
Step 2: VFA uptake / P-release
MLSS and VFAs in same tank
ORP of -200 mV or more negative
Nitrate control
Process control tool: 3 times as much ortho-P leaving tank as coming in
Biological Phosphorus Removal

Step 1: prepare “dinner”
VFA (volatile fatty acids) production in anaerobic/fermentive conditions

Step 2: “eat”
Bio-P bugs (PAOs, “phosphate accumulating organisms”) eat VFAs in anaerobic/fermentive conditions ... temporarily releasing more P into the water

Step 3: “breathe” and grow
Bio-P bugs (PAOs) take in almost all of the soluble P in aerobic conditions as they grow and reproduce
Step 3: P-uptake

ORP of +150 mV — no more DO than for ammonia removal

pH of 7.0+

Retention time ... enough to remove ammonia

Enough BOD to support bacteria growth
**Optimizing Bio-P Removal:**
**Mainstream or Sidestream Fermentation**

**Anaerobic Tank**
- 2 hour HRT (hydraulic retention time)*
- ORP of -200 mV*
- 25 times as much BOD as influent ortho-P*
- Ortho-P release (3 times influent ortho-P)*

**Aeration Tank**
- DO of 2.0 mg/L
- ORP of +150 mV
- pH of 7.0+*
- Ortho-P concentration of 0.05 mg/L*

*Approximate: Every Plant is Different
Questions?
Comments?

Grant Weaver
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Technology!
Biological Phosphorus Removal: Mainstream Flow Fermentation Processes
Bio-P Removal: Mainstream Fermentation Process

In Anaerobic Tank...

Bacteria break down complex BOD into VFAs (volatile fatty acids).
**Bio-P Removal: Mainstream Fermentation Process**

### In Anaerobic Tank...

- Bacteria break down complex BOD into VFAs (*volatile fatty acids*).
- PAO bacteria (*phosphate accumulating organisms*) take in VFAs as energy source & temporarily release \( \text{PO}_4 \) (*phosphate*) into solution.

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**Diagram:**
- **Primary Clarifier**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**
- **Gravity Thickener**
- **PO\(_4\)**
- **VFAs**
- **Sludge Storage**
**Bio-P Removal: Mainstream Fermentation Process**

**Primary Clarifier**

**Anaerobic Tank**

**Aeration Tank**

**Secondary Clarifier**

In **Anaerobic Tank** ...

- Bacteria break down complex BOD into VFAs (*volatile fatty acids*).
- PAO bacteria (*phosphate accumulating organisms*) take in VFAs as energy source & temporarily release PO\(_4\) (*phosphate*) into solution.

In **Aeration Tank** ...

- Energized PAO bacteria take PO\(_4\) out of solution.

**Gravity Thickener**

**Sludge Storage**
**Bio-P Removal: Mainstream Fermentation Process**

- **Primary Clarifier**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**

**In Anaerobic Tank ...**

Bacteria break down complex BOD into VFAs (*volatile fatty acids*).

PAO bacteria (*phosphate accumulating organisms*) take in VFAs as energy source & temporarily release PO$_4$ (*phosphate*) into solution.

**In Aeration Tank ...**

Energized PAO bacteria take PO$_4$ out of solution.
Pre-anoxic zone to ...

Strengthen anaerobic conditions in anaerobic tank

Minimize VFA use by denitrifying bacteria – the ones that convert Nitrate ($\text{NO}_3^-$) to Nitrogen Gas ($\text{N}_2$) – by “feeding” influent to the denitrifiers.
**Bio-P Removal: Mainstream Fermentation Process**

- **Primary Clarifier**
- **Anoxic Tank**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**

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**Gravity Thickener**

Pre-anoxic zone to ...

- Strengthen anaerobic conditions in anaerobic tank
- Minimize VFA use by denitrifying bacteria – the ones that convert Nitrate (NO₃⁻) to Nitrogen Gas (N₂) – by “feeding” influent to the denitrifiers.
Bio-P Removal: Mainstream Fermentation Process

Pre-anoxic zone to ...

Strengthen anaerobic conditions in anaerobic tank

Minimize VFA use by denitrifying bacteria – the ones that convert Nitrate (NO₃⁻) to Nitrogen Gas (N₂) – by “feeding” influent to the denitrifiers.
Bio-P Removal: Mainstream Fermentation Process

Pre-anoxic zone to ...
Strengthen anaerobic conditions in anaerobic tank
Minimize VFA use by denitrifying bacteria – the ones that convert Nitrate (NO$_3$) to Nitrogen Gas (N$_2$) – by “feeding” influent to the denitrifiers.
Questions?
Comments?

Grant Weaver
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Biological Phosphorus Removal: Combined Sidestream & Mainstream Fermentation
Bio-P Removal: Sidestream Fermentation Process

1. Primary Clarifier
2. Anaerobic Tank
3. Aeration Tank
4. Secondary Clarifier
5. Gravity Thickener
6. Fermentation
7. VFAs
8. Sludge Storage
**Bio-P Removal: Sidestream Fermentation Process**

- **Primary Clarifier**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**
- **Gravity Thickener**
- **VFAs**
- **Fermentation**
- **Sludge Storage**
Bio-P Removal: Sidestream Fermentation Process

Primary Clarifier → Anaerobic Tank → Aeration Tank → Secondary Clarifier

- Gravity Thickener
- Fermentation
- VFAs

Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

Primary Clarifier → Anaerobic Tank → Aeration Tank → Secondary Clarifier

Gravity Thickener → Fermentation

PO₄

Sludge Storage
**Bio-P Removal: Sidestream Fermentation Process**

- **Primary Clarifier**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**

**Nitrogen Interference:**
Nitrate (NO$_3$) will consume VFAs
Bio-P Removal: Sidestream Fermentation Process

Primary Clarifier ➔ Anoxic Tank ➔ Anaerobic Tank ➔ Aeration Tank ➔ Secondary Clarifier

Gravity Thickener ➔ Fermentation

No Nitrogen Interference!

Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

- Primary Clarifier
- Anoxic Tank
- Anaerobic Tank
- Aeration Tank
- Secondary Clarifier

- Gravity Thickener
- Fermentation
- VFAs
- No Nitrogen Interference!
- Sludge Storage
**Bio-P Removal: Sidestream Fermentation Process**

- **Primary Clarifier**
- **Anoxic Tank**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**

 Processes:

- Gravity Thickener
- Fermentation

Outcome:

- No Nitrogen Interference!
- 

 Storage:

- Sludge Storage
Bio-P Removal: Sidestream Fermentation Process

Primary Clarifier → Anoxic Tank → Anaerobic Tank → Aeration Tank → Secondary Clarifier

Gravity Thickener → Fermentation

PO₄

No Nitrogen Interference!

Sludge Storage
Optimizing Bio-P Removal: Mainstream or Sidestream Fermentation

**Anaerobic Tank**
2 hour HRT (hydraulic retention time)*
ORP of -200 mV*
25 times as much BOD as influent ortho-P*
Ortho-P release (3 times influent ortho-P)*

**Aeration Tank**
DO of 2.0 mg/L
ORP of +150 mV
pH of 7.0+*
Ortho-P concentration of 0.05 mg/L*

*Approximate: Every Plant is Different
Questions?
Comments?
Troubleshooting Biological Phosphorus removal in Plants Designed for EBPR (enhanced biological phosphorus removal)
Less than 3x ortho-P leaving Anaerobic Tank

If Anaerobic Tank isn’t really anaerobic …

... turn off mixer(s)
Questions?
Comments?

Grant Weaver
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3x ortho-P leaving Anaerobic Tank but high effluent P

1. Poor removal in Aeration Tank ...
   2.0 mg/L DO / +150 mV ORP
   6.8+ pH
   If seasonal, maybe too little BOD

2. Rerelease ... most likely in clarifier(s)
   Profile ortho-P through the plant
Questions?
Comments?

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Getting creative ...

Biological Phosphorus removal from plants not designed as EBPR (enhanced biological phosphorus removal) facilities
**Home Grown Sidestream Fermenter**

- Primary Clarifier
- Anaerobic Tank
- Aeration Tank
- Secondary Clarifier
- Gravity Thickener
- Fermentation
- Sludge Storage
Home Grown Sidestream Fermenter

Primary Clarifier → Aeration Tank → Secondary Clarifier

Gravity Thickener

Sludge Storage
Home Grown Sidestream Fermenter

Primary Clarifier → Aeration Tank → Secondary Clarifier

Gravity Thickener → Sludge Fermenter Storage
Questions?
Comments?

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What kind of plant is yours?
BREAK TIME
Norris, Tennessee  
Population: 1,450  
0.2 MGD design flow
Norris, Tennessee
Norris, TN:
Nitrogen Removal

Nitrogen Removal
Raise MLSS concentration
Cycle aeration:
ON 2-3 hours
OFF 1½-2 hours
Norris, Tennessee
Effluent Nitrogen: 2011-2020

Effluent total-Nitrogen (mg/L)

- Monthly Average
- Average of prior 12 months
Norris, TN: First try at Phosphorus Removal

Phosphorus Removal
Recycle RAS through fermenters
Norris, TN: Second try at Phosphorus Removal

Phosphorus Removal
Create Fermentation Zone in Aeration Tank
Norris, TN: Third try at Phosphorus Removal

**Phosphorus Removal**
Recycle RAS through fermenters
-and-
Create Fermentation Zone in Aeration Tank
Norris, Tennessee
Effluent Phosphorus: July 2017 - December 2020

- Monthly Average
- Average of prior 12 months
Questions?
Comments?

Grant Weaver
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Harriman, Tennessee  
Population: 6,200  
1.5 MGD design flow
TENNESSEE: QUEST FOR ENERGY EFFICIENCY INSPIRES OPERATORS’ PURSUIT OF NUTRIENT REMOVAL

Energy Efficiency Measures Provide Opportunities for Nutrient Reduction

At many publicly owned treatment works (POTWs), operators experimenting with cost-saving energy efficiency find their plants also benefit from improved nitrogen removal. These successes provide staff with confidence to implement low-cost modifications and operational changes to further reduce effluent nutrient discharges. EPA’s National Study of Nutrient Removal and Secondary Technologies investigates optimization efforts across the country, and this fact sheet highlights achievements at the Harriman POTW in Tennessee.

In 2011, the Tennessee Water and Wastewater Energy Efficiency Partnership (TWEPE) was formed between many associations, including EPA and the Tennessee Department of Environment and Conservation (TDEC). The partnership supplied Tennessee wastewater utilities with energy efficiency tools and expertise to support operators in reducing energy costs and pollution. This included providing in-person technical assistance to staffs across Tennessee, including Harriman POTW in 2014.

Harriman POTW

Harriman POTW has a design capacity flow of 1.5 million gallons per day (MGD) and an average daily flow of 925 MGD. The plant has two equalization basins, two oxidation ditches, two secondary clarifiers, chlorine disinfection, and two aerobic digesters. Each ditch has two fixed-speed rotors, and no chemicals are added for phosphorus removal. Prior to the partnership’s visit, aeration for Harriman POTW’s oxidation ditches and digesters consumed

Harman POTW: Donnie Fitzhugh and Ray Freeman

43% of the plant’s total energy use. The four ditch rotors ran continuously and the digester blowers ran 16 hours each night during the week and continuously on weekends. Harriman POTW’s staff started by following the partnership’s suggestion to cycle the four rotors 1 hour on/1 hour off, which decreased aeration energy use by 50%. They noticed a drop in effluent Total Nitrogen (TN), although concentrations were still high, averaging over 20 mg/L. Inspired to realize greater energy savings, staff continued to refine the plant’s aeration cycling on their own, resulting in a TN concentration consistently under 10 mg/L beginning in 2017.

In July 2018, Ray Freeman took over as Chief Plant Operator, and, assisted by Operator Donnie Fitzhugh, the two began a quest to drive effluent TN as low as possible. They experimented by ratcheting down rotor
run times in small increments and alternating the rotors' operation. The plant now operates 1 rotor per ditch, cycling 1 hour on/2 hours off in the summer and 1 hour on/3 hours off in the winter.

"I started by taking baby steps to reduce power consumption. In that process, I could see the reduction in nitrogen. I just kept altering DO levels and equipment run times until I could no longer reduce TN without negatively affecting other parameters, such as BOD." - Ray Freeman

Dissolved oxygen (DO) readings are obtained with a hand-held probe near the influent inlet on the aft side of the first rotor. The DO upper set point averages 1.5 mg/L on the aft side of the rotor, with the lower set point targeted to 0.38 mg/L or less. The plant does have a limited SCADA system that incorporates some timers for the digesters, but the two operators closely monitor and manage all aeration cycling in the ditches by hand. Beginning in 2020, the average effluent TN concentration was an impressive low of 2 mg/L.

Ray also adjusted the digester vessels so only one blower is needed to aerate both digesters for six hours each night, further reducing plant energy costs. These aeration strategies save the plant $30,000/year in energy costs, achieving a total reduction in aeration energy use nearing 85%.

Ray and Ronnie have now turned their attention to reducing total phosphorus (TP) effluent concentrations and improving the plant's biological phosphorus removal. Over the summer, they began interrupting the 1 hour on/2 hours off schedule twice each day to let the rotors run for 2 hours to drive DO up to 2 mg/L. This was followed by 2 hours off before resuming the 1 hour on/2 hours off schedule. When the plant transitioned to the winter 1 hour on/3 hours off schedule, the 2 hours on/2 hours off cycle was introduced only once per day. Harriman POTW's average effluent TP concentration has already been reduced 25% by these rotor cycling changes over the course of the year.

### Harriman Daily Maximum Monitoring Data

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Effluent TN Concentration (mg/L as N)</th>
<th>Effluent TP Concentration (mg/L as P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 - Q4 2017</td>
<td>9.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Q1 - Q4 2020</td>
<td>2.1</td>
<td>1.4</td>
</tr>
</tbody>
</table>

*Percent Removal 77% 25%*

*Monitoring data from the first phases of optimization (2014-2016) are not available.*

### Optimization Opportunities and Benefits

Optimizing existing treatment systems not only effectively reduces nutrient discharges from POTWs, but it can also result in significant energy and cost savings for utilities. Support from regulatory agencies, onsite consulting, and, most importantly, operator ambition and enthusiasm enabled these Tennessee POTW operators to reach both their nutrient reduction and energy efficiency goals.

### Acknowledgements

Nutrient monitoring data were collected from EPA's Integrated Compliance and Information System-National Pollutant Discharge Elimination System (ICIS-NPDES) and internal plant records. Energy savings are also from internal plant records, TDEC and the TWEPP Partnership Team aided POTWs in Tennessee in improving their energy efficiency and, in some cases, nitrogen discharges. Grant Weaver of CleanWaterGes has supported Harriman staff with improving biological phosphorus removal.
### Harriman, Tennessee

<table>
<thead>
<tr>
<th>Actual Flow</th>
<th>Effluent Nitrogen (mg/L)</th>
<th>Effluent Phosphorus (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(MGD)</td>
<td>Historical Average</td>
<td>After Optimization</td>
</tr>
<tr>
<td>1.2</td>
<td>21.5</td>
<td>2.3</td>
</tr>
</tbody>
</table>
Harriman - As Designed
Harriman - As Operated
Harriman - As Operated
Harriman - As Operated
Questions?
Comments?

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KANSAS
Great Bend, KS
Nitrogen Removal in Ditch
   Rotor equipped with VFD and controlled by in-tank DO probe
   Ammonia → Nitrate
   Nitrate → Nitrogen Gas
Anoxic Zone converted to Fermenter
   Gate CLOSED
   Mixers turned OFF
Phosphorus Uptake in Ditch
Questions? Comments?

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Pratt, Kansas  Population: 6,600  1.0 MGD design flow
Effluent total-Phosphorus
Pratt, Kansas

Phosphorus concentration (mg/L)

Jan16  Jul  Jan17  Jul  Jan18  Jul  Jan19  Jul  Jan20  Jul

Rolling 12-mo AVG

total-P
Questions?
Comments?

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Osawatomie, Kansas  Population: 4,300  MGD design flow
Effluent total-Nitrogen
Osawatomie, Kansas

- Monthly average tN
- Rolling AVS tN

Nitrogen concentration (mg/L)

Jan16, Jul, Jan17, Jul, Jan18, Jul, Jan19, Jul
Questions?
Comments?

Grant Weaver
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Wichita, Kansas

Population: 390,000

54.4 MGD design flow
Wichita Pilot Study

Nitrogen Removal
Cycle aeration on/off in Aeration Basin 6

Phosphorus Removal
Side stream fermenter using abandoned centrate tanks

Increase BOD loading
Take Trickling Filters off-line
Questions?
Comments?

Grant Weaver
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Conrad, Montana          Population: 2,500          0.5 MGD design flow
Conrad, Montana

Aeration Basin

Digester
Conrad, Montana
Nitrogen Removal

Nitrogen Removal
Raise MLSS concentration
Cycle aeration:
ON 2-3 hours
OFF 1 1/2-2 hours
Conrad, Montana
Phosphorus Removal

1. Convert Digester to Fermenter and Circulate WAS

Phosphorus Removal
Conrad, Montana
Phosphorus Removal

Phosphorus Removal
1. Convert Digester to Fermenter and Circulate WAS
Conrad, Montana
Phosphorus Removal

1. Convert Digester to Fermenter and Circulate WAS
2. Fermentive zone(s) in Aeration Basin
Conrad, Montana
Effluent Phosphorus: 2011-2020

- Red: Quarterly Average
- Blue: Average of prior 12 months
Questions?
Comments?

Grant Weaver
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Helena, Montana  
Population: 30,000  
5.4 MGD design flow
Helena, Montana
Helena, Montana

Nitrogen Removal

- Raise MLSS concentration
- Add third Aeration Basin
- Monitor ORP, NH$_4$ & NO$_3$
- Adjust Internal Recycle
Helena BioReactor
Helena, Montana
Effluent Nitrogen: 2011-2020

Expected total-Nitrogen (mg/L)

- Monthly Average
- Average of prior 12 months
Helena, Montana
Phosphorus Removal, short term plan

Phosphorus Removal
Generate surplus VFAs in primary clarifier and feed to anoxic zone
Helena BioReactor

Anoxic Tank → Anoxic Tank → NO$_3$ $\rightarrow$ N$_2$ 

Aeration Tank → Aeration Tank → Aeration Tank

VFAs
Helena BioReactor

- Anaerobic Tank
- Aeration Tank
- Anoxic Tank
- Aeration Tank
- Aeration Tank
- NO$_3 \rightarrow$ N$_2$
- VFAs

Diagram shows the flow of processes:
- NO$_3$ is converted to N$_2$.
- VFAs are used in the process.
- The flow is directed through each tank in a sequential manner.
Helena, Montana
Phosphorus Removal, long term plan

Phosphorus Removal
Convert first anoxic zone to fermenter by relocating Internal Recycle to second anoxic zone
Helena BioReactor

Diagram:
- Anoxic Tank
- Aeration Tank
- Anoxic Tank
- Aeration Tank
- Anoxic Tank
- Aeration Tank

Flow:
1. Anoxic Tank to Aeration Tank
2. Aeration Tank to Anoxic Tank
3. Anoxic Tank to Anoxic Tank
4. Anoxic Tank to Aeration Tank

Note: P indicates a process or reaction point.
Helena BioReactor
Helena, Montana
Effluent Phosphorus: 2011-2020

- Monthly Average
- Average of prior 12 months
Questions?
Comments?

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Acknowledgements

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TENNESSEE
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KANSAS
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MONTANA
Paul Lavigne (retired), Pete Boettcher, Josh Vial & Ryan Weiss (MDEQ), Keith Taut (Conrad) & Mark Fitzwater and staff (Helena)

... and, many more!
Next Week’s Webinar
North Carolina Case Studies: part 1

Thursday, March 25
10:00 - 11:45 AM

NC Case Studies (4/8)
Energy Management (4/15 & 4/22)
NC Case Studies (4/29)