What Operators Should Know About Phosphorus Removal, Part 1

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

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Energy & Nutrient Optimization of NC Municipal Wastewater Treatment Plants

Biological Nitrogen Removal, Parts 1&2
Activated Sludge, Parts 1&2

Today: Biological Phosphorus Removal: Part 1
Mar 18: Biological Phosphorus Review, 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!)
Why North Carolina operators should care about Phosphorus Removal

From North Carolina’s 2019 *Nutrient Criteria Development Plan*

Development and adoption of nutrient criteria for the following by **2025**:

- High Rock Lake / Yadkin River Basin
- Albemarle Sound / Chowan River Basin
- Central portion of the Cape Fear River

Adoption of nutrient criteria **statewide by 2029**
Introducing a new way of thinking:

**Facility upgrades** aren’t the only way to get phosphorus removal...

**Empowered operators** achieve amazing results!
Change day-to-day operations to create ideal habitats for bacteria to remove phosphorus.
Connecticut
Colchester-East Hampton
East Haddam
Groton
New Canaan
New Hartford
Plainfield North
Plainfield Village
Suffield
Windham

Kansas
Andover
Basehor
Chanute
Chisholm Creek
Derby
Eudora
Garden Plain
Goddard
Great Bend
Halstead
Hiawatha
Holton

Massachusetts
Amherst
Barnstable
Easthampton

Massachusetts, cont’d
Greenfield
Montague
Newburyport
Northfield
Palmer
South Deerfield
South Hadley
Sunderland
Upton
Westfield

Montana, cont’d
Gallatin Gateway
Glendive
Great Falls
Hamilton
Hardin
Havre
Helena
Kalispell
Laurel
Lewistown
Libby
Lolo
Manhattan
Miles City
Missoula
Stevensville
Wolf Creek

New Hampshire
Keene

South Carolina
Greeneville

Tennessee
Athens
Baileyton
Bartlett
Chattanooga
Collierville
Cookeville
Cowan
Crossville
Harriman
Humboldt
LaFayette
LaFollette
Livingston
Millington
Nashville Dry Creek
Norris
Oak Ridge

Texas
Nottingham MUD
(Houston)

Virginia
Strasburg

Wyoming
Laramie
MONTANA
Effluent Phosphorus (mg/L)

Chinook, MT (Oxidation Ditch)
Conrad, MT (Extended Aeration)
Helena, MT (MLE/Conventional Aeration)
Conrad, Montana
Effluent Phosphorus: 2011-2019

- Blue bars: Quarterly Average
- Red line: Average of prior 12 months

Effluent total-Phosphorus (mg/L)

Year:
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
Chinook, Montana  
Population: 1,250  
0.5 MGD design flow
Chinook, Montana
Effluent Phosphorus: 2011-2019

- Monthly Average
- Average of prior 12 months
Helena, Montana  
Population: 30,000  
5.4 MGD design flow
Questions?
Comments?

Grant Weaver
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Wastewater Science
DO (Dissolved Oxygen)
ORP (Oxidation Reduction Potential)
What Does ORP Tell Us About Our Process?

- Anaerobic
- Anoxic
- Oxic
- Nitrification
- BOD removal
- ‘P’ uptake
- Denitrification
- Fermentation
- ‘P’ release

ORP, mV
What Does ORP Tell Us About Our Process?

- Anaerobic
- Anoxic
- Oxic

- Nitrification
- BOD removal
- ‘P’ uptake
- Denitrification
- ‘P’ release

ORP, mV
Questions? Comments?

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Phosphorus Removal: What an Operator needs to know

ONE. Convert soluble phosphorus to TSS (total suspended solids)...
   Biologically
   Chemically

TWO. Remove TSS
**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
Phosphorus Removal: 
What an Operator needs to know

**Orthophosphate** = soluble phosphorus
orthophosphate, reactive phosphorus, phosphate, ortho-P, PO$_4$-P, PO$_4$=, PO$_4$=-P, PO$_4$=-2, PO$_4$=-2-P

**Total-Phosphorus** = soluble + particulate phosphorus (non-reactive)
phosphorus, total-P, TP, t-P, tP, P
Typical plant, an example

Influent phosphorus: 6 mg/L
Effluent phosphorus: 3 mg/L
Effluent TSS: 15 mg/L
Effluent total-P = particulate P + soluble P

How much effluent phosphorus is soluble and how much is in the TSS?

Approximately 1% of effluent TSS (conventional plant) is phosphorus ...

Effluent P = particulate P + soluble P

Particulate (P in the TSS): 15 mg/L TSS x 0.01 = 0.15 mg/L
Soluble = 3 mg/L − 0.15 mg/L with TSS = 2.85 mg/L
Total = 0.15 mg/L (Particulate) + 2.85 mg/L (Soluble) = 3.0 mg/L
Example: effluent phosphorus (mg/L)
Before Phosphorus Removal (Biological or Chemical)
Same example ... after SOLUBLE phosphorus is converted to PARTICULATE phosphorus

Influent phosphorus: 6 mg/L
Effluent TSS: 15 mg/L
Effluent total-P = particulate P + soluble P

Biological Phosphorus removal, when fully optimized, will remove all but 0.05 mg/L of the soluble Phosphorus
Chemical Phosphorus removal, the same, all but 0.05 mg/L

Either way, only 0.05 mg/L of soluble Phosphorus remains

Meanwhile, what used to be soluble Phosphorus is now part of the MLSS (mixed liquor suspended solids) ...

And, as the bio-P bugs take in phosphorus, the percentage of the MLSS and TSS that is Phosphorus increases from 1% to as high as 5%

**Effluent P = soluble P + particulate**

Soluble = 0.05 mg/L

Particulate (P in the TSS): 15 mg/L TSS x 5% = 0.75 mg/L

Total = 0.05 mg/L (Soluble-P) + 0.75 mg/L (Particulate-P) = 0.80 mg/L
Example: effluent phosphorus (mg/L)
After Phosphorus Removal (Biological or Chemical)
**TSS Removal Requirements**

Since all but 0.05 mg/L of the soluble Phosphorus can be converted to TSS Phosphorus (Biologically and/or Chemically)

And, because approximately 5% of Effluent TSS is Phosphorus

... To meet a total-P limit, the effluent TSS needs to be kept to the max TSS number shown in the table.

<table>
<thead>
<tr>
<th>P Limit</th>
<th>max TSS</th>
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<tr>
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</tr>
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<tr>
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</tbody>
</table>
Questions?
Comments?
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 PO$_4$ (**phosphate**) into solution.
**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 PO₄ (*phosphate*) into solution.

In **Aeration Tank**...

Energized PAO bacteria take PO₄ out of solution.
**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 PO$_4$ (*phosphate*) into solution.

**In Aeration Tank ...**

Energized PAO bacteria take PO$_4$ out of solution.
Bio-P Removal: Mainstream Fermentation Process

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

**Gravity Thickener**

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.

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

**Primary Clarifier**

**Aeration Tank**

**Secondary Clarifier**

**Anoxic Tank**

**Anaerobic Tank**

---

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.
**Bio-P Removal: Mainstream Fermentation Process**

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

**Gravity Thickener**
- 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?

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Biological Phosphorus Removal: Combined Sidestream & Mainstream Fermentation
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
- VFAs
- Gravity Thickener
- 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 → PO₄ → Aeration Tank → Secondary Clarifier

Gravity Thickener → Fermentation → Sludge Storage
**Bio-P Removal: Sidestream Fermentation Process**

- **Primary Clarifier**
- **Gravity Thickener**
- **Fermentation**
- **Anaerobic Tank**
- **Aeration Tank**
- **Secondary Clarifier**
- **PO<sub>4</sub>**

**Nitrogen Interference:**
Nitrate (NO<sub>3</sub>) 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
- Gravity Thickener
- Fermentation
- Sludge Storage

No Nitrogen Interference!

PO₄
**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?

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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?

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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
Home Grown Sidestream Fermenter

Primary Clarifier → Aeration Tank → Secondary Clarifier

Gravity Thickener → Aeration Tank

Fermenter
Questions?
Comments?

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**TENNESSEE**
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... and, many more!
Next Week’s Webinar
Phosphorus Removal: part 2

Thursday, March 18
10:00 - 11:45 AM

NC Case Studies (3/25 & 4/8)
Energy Management (4/15 & 4/22)
NC Case Studies (4/29)
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