Excellence in Engineering Since 1946
Phosphorus Removal
Bench Scale and Full Scale Pilots that Result in Improved Phosphorus Removal

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Presented By:
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Strand Associates, Inc.®
Today’s Seminar Outline

- Control Parameters That Impact Performance
- Jar Testing that Simulates Process Needs
- Full Scale Testing
- Automation and In-line Monitoring
Presentation Will **Not** Focus on Emerging Technologies

- Parkson Pilot - Manitowoc
- CoMag Pilot – Fond du Lac
Presentation Will Focus on Optimizing Current Technologies

Necessity... the mother of invention.

Plato
Phosphorus Removal Basics
Chemical P Removal - Principles

Methods of Phosphorus Removal

• Chemical Phosphorus Removal
  - Add lime, iron, or aluminum salt
  - Precipitation/adsorption of soluble phosphorus
  - Relatively simple process
  - Higher sludge production

• Biological Phosphorus Removal
  - Facilitate growth of Phosphorus Accumulating Organisms (PAOs)
  - More complex/higher risk
  - Lower sludge production than with chemical addition
Jar Testing Should Provide Lab Scale Simulations of Full Scale Considerations
Jar Testing in Proper Context Provides Value

- Strengths of jar testing include:
  - Low cost
  - Easy comparison of many conditions
  - Provides proof of concept
  - Allows communication and training

- Limitations of jar testing include:
  - Jar tests do not always scale-up
  - Long term operation not always reflected
  - Full scale conditions can not always be mimicked
Bench Scale Testing for CPR Determines Key Parameters

- Precipitation/Adsorption Reactions
- Dose Rates and Costs
- Side Effects
  - pH Depression
  - Alkalinity Loss
Jar Testing Allows Low Cost Comparisons

Left to Right – Ferric Chloride, Alum, SorbX

Aluminum Byproduct
Jar Testing Provides Visual Comparisons

Impacts on Sludge Production
Jar Testing Provides Visual Comparisons

Impacts on Clarity
Jar Testing Provides Visual Comparisons

Jar 1

Jar 2

Jar 3

Jar 4

Jar 5
Jar Testing Provides Visual Comparisons
Typical Jar Test Result

Ferric Jar Testing Results

<table>
<thead>
<tr>
<th>Phosphorus Concentration (mg/L)</th>
<th>Dose Rate (gallons of ferric chloride per million gallons of wastewater)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphorus</td>
<td>4.35, 1.40, 0.46, 0.18, 0.12</td>
</tr>
<tr>
<td>Target</td>
<td>0.7, 0.7, 0.7, 0.7, 0.7</td>
</tr>
<tr>
<td>Me:P ratio</td>
<td>1.7, 2.7, 3.7, 6.1</td>
</tr>
</tbody>
</table>

Dose Rate (gallons of ferric chloride per million gallons of wastewater)
High pH Results in High Chemical Needs

Figure 2: Alum Jar Testing Results - Influent

Figure 8: Alum Jar Testing pH Results - Influent
Emerging Chemical Performance Suggests Future Consideration Warranted

Results Illustrate pH impacts and phosphorus results for comparing three chemicals at the same volumetric dose rate. SorbX removed the most phosphorus and had the lowest impact on pH.
Jar Stress Tests Can Isolate Performance

- Samples Filtered
- Lowest P level achievable

Total Phosphorus - Bench Scale Stress Test

- Effluent P with BPR and 100 ppmv alum dose typically ~ 0.8 mg/L P
Proper Phosphorus Characterization Provides Targeted Actions

- Particulate P = TSS Removal
- Dissolved Non-reactive P = Source Control
- Ortho P = Create Particulate P (BPR or CPR)

![Graph showing the breakdown of phosphorus types]

- Particulate
- DNP
- Ortho
Evaluation of Industrial Byproduct
Develops a Cost/Benefit Understanding

- Characterizations
  - Metals
  - Organics
  - pH
  - Other

- Negatives
  - Settles
  - Inconsistent

- Positives
  - Provides some P removal
Evaluation of Industrial Byproduct

Primary Influent - Aluminum Byproduct

- TP Concentration (mg/L)
- Molar Ratio

Dose (ppmV)

Total Phosphorus
Future WQBEL (6-month average)
Molar Ratio
CPR Pilot – Multiple Application Points

- Multiple Application Points
  - Reduce loses to competing reactions
  - Potentially develop residual value in multiple systems
  - Inherent redundancy
Each Facility Offers Unique Opportunities

Phosphorus is removed where solids are removed, such as:

1. Primary clarifiers
2. Secondary clarifiers
3. Tertiary clarifiers
4. Filters
Multiple Application Points Result in Multiple P Removal Mechanisms
Understanding Removal Mechanisms Improves Process Understanding

Phosphorus Concentration

<table>
<thead>
<tr>
<th>Concentration (mg/L)</th>
<th>Influent</th>
<th>PRE</th>
<th>Sec. Eff.</th>
<th>Coag Eff.</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014 (thru June)</td>
<td></td>
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</tbody>
</table>

Second Application Point

Increased Dose and Second Application Point
Waukesha – Monitoring: Upstream of Filter
**Full Scale Test and Stress Test**

- **Concentration (mg/L)**
  - Ferric Pump Fail – Filter serves as Barrier
  - Initiation of Stress Testing
Filter (Backwash)
BPR Pilot Tests Can Focus on Full Scale Trials With Little Capital Expenditure
Phosphorus cycle involves release in anaerobic zone, “luxury” uptake in aerobic zone

**TIME**

<table>
<thead>
<tr>
<th></th>
<th>ANAEROBIC</th>
<th>AEROBIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soluble BOD</td>
<td>0.5 to 2 hrs</td>
<td>2 to 10 hrs</td>
</tr>
<tr>
<td>Soluble Phosphorus (Normal w/BPR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BPR Encourages Luxury P Uptake
Typical BPR Process Schematic

*For Activated Sludge (A/O with RAS Denitrification)*
Pilot Considerations

- Cost Considerations
  - Consumables such as chemical
  - Engineering
  - Lab
  - Manpower
  - Utilities
  - Capitol Improvements

- Repeatability and/or Isolation
- Full Scale or Full Time Implementation
- Effluent Quality
  - Reliability
  - Termination Planning
Full Scale Testing

Full Scale BPR Testing in Conventional AS Plants

- Install cloth, wood, or block baffle walls and submersible mixers for ~2 zones; turn off air to zones
- Install temporary or permanent gates/piping as needed to route PRE/RAS where needed
- Measure SBOD, PO$_4$, nitrate, and DO at various locations
- Monitor changes in sludge production and settleability/dewaterability
Pilots Can Illustrate Ancillary Benefits

![Graph showing Alkalinity vs. Caustic (Gallons)]
Target Key Process Mechanisms by Piloting Operational Adjustments
BPR Requires Proper Substrate to Support a Specific “Habitat”
Because of the preference of the substrate VFA concentrations ultimately determine potential success.

7 to 9 mg of VFA required to remove each mg P.\(^{(1)}\)

VFA losses to competing reactions need to be considered.

\(^{(1)}\) Barnard
Treatment Objectives Define Balance for Each Facility

- BNR Requires BOD Load
- BPR Requires P Removal
- Nitrification Requires Aging
- Denitrification Requires No O₂
- BPR Requires No NO₃ or O₂
- Nitrification Requires Oxygen
- BPR Prefers Low RAS rates
- BNR Prefers High RAS rates

Nitrification Likes it Lighter
In a complete mix tank the SRT and HRT are approximately the same.

Therefore, VFA formation will be limited to HRT.
If cycling the mixer solids will tend to settle and remain in tank making SRT > HRT. Therefore, VFA formation can extended regardless of HRT.
Case Study – Fond du Lac: Ongoing

Goal – Identify if the anoxic zones can be operated differently promoting anaerobic conditions resulting in BPR.

Step 1 Develop Plan

- Identify, isolate, and prioritize test activities
- Determine additional monitoring and indices
- Organize all information
Industrial Loadings Provide Promise of BPR

![Graph showing Biochemical Oxygen Demand with data points for specific dates from April 7, 2014 to October 6, 2014. The graph compares SBOD:SP Pre and BOD:P Pre ratios.](image)
Full Scale Example

AO Process Initiated (BPR)

NRP-40-02 Stopped

AM-40-03

M-40-04

Tank No. 2
Early Efforts Were Impacted By Wet Weather

Influent and RAS Flow

Flow (mgd)

- Inf mgd
- RAS mgd
Currently Nitrate Interference is Being Addressed
ORP Provides a Spectrum of Biological Activity

- ORP Range from Negative to Positive
  - Anaerobic Activity
  - Anoxic Activity
  - Aerobic Activity
    - Aerobic Oxidation
    - Nitrification
    - Denitrification
    - P Release
  - Others:
    - Acid Formation
    - Sulfur Reduction
    - Methanogenesis
Capacity Impacts Environments

Oxidation Reduction Potential

2 Tanks in Service
Average ORP
-113 mV

3 Tanks in Service
Average ORP
-24 mV

3 Tanks in Service
Average ORP
-39 mV

Min  Average  Max
Fond du Lac Interim Understanding

- Industrial loads provide unique dichotomy
  - Heavy BOD could drive process
  - Tendency to slug loads limits aeration tank configurations
    - Other processes can be upset if optimum BPR tankage were implemented
  - Cleaning chemical changes from phosphorus based chemicals to nitric acid based chemicals may have created too much nitrate
- Wet weather impacts add to the difficulty
- Attempts to create an environment to support BPR have not been successful
- Efforts to better understand the system have been successful
Summary

- Piloting operational changes can provide greater understanding of facility and improved performance.
- Jar scale testing can aid in training and proof of concept analysis.
- Impending phosphorus limits has contributed to improvements and increased knowledge base…
- …you won’t know if you don’t try.
Acknowledgements

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