HELPING PHOSPHORUS RECOVERY BECOME MORE PROSPEROUS

JIM FITZPATRICK  SENIOR PROCESS ENGINEER
OVERVIEW

• Drivers and WWTP Sources
• EBPR and Struvite Recovery
• Recovery with Lower Effluent Limits
P-RECOVERY DRIVERS AND WWTP SOURCES
MORE MOUTHS TO FEED INCREASES THE NEED FOR PHOSPHORUS

“The phosphorus content of our land, following generations of cultivation, has greatly diminished. It needs replenishing. I cannot over-emphasize the importance of phosphorus not only to agriculture and soil conservation, but also the physical health and economic security of the people of the nation. Many of our soil deposits are deficient in phosphorus, thus causing low yield and poor quality of crops and pastures...."

-President Franklin D. Roosevelt, 1938

About Phosphorus

“We may be able to substitute nuclear power for coal power, and plastics for wood, and yeast for meat, and friendliness for isolation, but for phosphorus there is neither substitute nor replacement.”

Isaac Asimov
PHOSPHORUS LINK TO HARMFUL ALGAL BLOOMS

...but much more complicated than just POTW effluent
P-RECOVERY IMPACTED BY P-REMOVAL AND BIOSOLIDS PROCESSING

P-Removal Processes
- Chemical precipitation and hydroxide floc adsorption
- Enhanced biological phosphorus removal (EBPR)
- Media adsorption/ion exchange

P-Recovery Alternatives
- Calcium phosphate precipitation
  - Hydroxyapatite \([\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2]\) and others
- Struvite precipitation
  - \(\text{MgNH}_4\text{PO}_4\cdot6\text{H}_2\text{O}\)
- Extraction from incinerator ash
PHOSPHORUS WITH EBPR AND ANAEROBIC DIGESTION

Primary Clarifiers

Anaerobic Oxic Basins

Secondary Clarifiers

Particulate P
Chemical Precipitation

Release from PAO

Luxury uptake by PAO

Effluent P (0.5 – 1 mg/L)

PAO in WAS

(PO$_4^{3-}$, Mg$^{2+}$, K$^+$, NH$_4^+$)

Thickening

Soluble P

Dewatering

Biosolids

Particulate P

One Water
EBPR AND STRUVITE RECOVERY
EBPR AND ANAEROBIC DIGESTION

CAUSES

• (PO₄)³⁻, Mg²⁺ and K⁺ quickly released by PAOs in WAS. NH₄⁺ released later during digestion.

CONSEQUENCES

• Struvite formation
• Decreased biosolids dewaterability

Alternatives to overcome unintended consequences

STRUVITE PRECIPITATION

- $\text{Mg}^{2+} + \text{NH}_4^+ + (\text{PO}_4)^{3-} + 6 \text{H}_2\text{O} \rightarrow \text{MgNH}_4\text{PO}_4 \cdot 6 \text{H}_2\text{O} \downarrow$
- Mg usually limiting. MgCl$_2$ commonly added.
- High pH is favorable. NaOH commonly added.
DURHAM AWWTF – ORIGINAL STRUVITE RECOVERY CONFIGURATION

Primary Clarifiers

Activated Sludge EBPR Process

Gravity Thickener

Thickening Centrifuge

Tertiary Chemical Sludge

Fermenter

Pearl® Struvite Reactor

Anaerobic Digestion

Dewatering Centrifuge

Biosolids to Land Application

Crystal Green®
Slow Release Struvite Fertilizer Pellets
5-28-0 10%Mg

90% Phosphate Removed
20% Ammonia Removed

90% Phosphate Removed
20% Ammonia Removed
DURHAM AWWTF STRUVITE RECOVERY FACILITIES

Bottom of Reactors

Top of Reactors

Harvested Pellets

Screen

Output

Drier

Sizing Screen
Waste Activated Sludge Stripping to Remove Internal Phosphorus (WASSTRIp®)

- More protection from nuisance struvite deposits
- $K^+$ released with $(PO_4)_3^-$ and $Mg^{2+}$ shunted around digester
- $NH_4^+$ released during digestion
- $MgNH_4PO_4\cdot 6H_2O$ precipitated
- Studies ongoing to quantify dewatering improvement from $K^+$ shunting
5 YEARS OF STRUVITE RECOVERY BY CLEAN WATER SERVICES

• Durham AWWTF – 25-mgd ADF, <0.1 mg TP/L May - Oct
  • $2.5 million investment
  • May 2009 - Startup of 3 Pearl 500 struvite recovery units
  • 2011 – WASSTRIP increased P loading to units by ~80%
  • May 2012 - Upsized one Pearl 500 to Pearl 2000

• Rock Creek AWWTF – 35-mgd ADF, <0.1 mg TP/L May - Oct
  • $4.5 million investment
  • Fall 2011 - Installed two Pearl 2000 units
  • Future WASSTRIP planned after fermenters

• 5 to 7 year payback
  • 40% less alum usage
  • 20% less hauled biosolids
  • 20% less NH$_3$-N recycled
  • 90% less P recycled
  • Fertilizer revenue

New generation of phosphorus recovery
GROWTH IN STRUVITE RECOVERY

- Minimize nuisance deposits
- Reduce P & N recycle loads
- Reduce P content of biosolids
- Improved biosolids dewaterability
- Beneficial recovery of nutrients
STRUVITE PRECIPITATION ALTERNATIVES

• Ostara Pearl®
• MHI Multiform™
• Kansas Environmental Management Associates (KEMA) Phred™
• Aquatec Crystalactor®
• CNP AirPrex®
ALTERNATIVES FOR DIGESTER SLUDGE VS. CENTRATE/FILTRATE

Economics – ROI Distribution

- Savings in polymer use and sludge disposal costs: 75%
- MAP Sales: 10%
- Savings in O&M costs: 15%

Biosolids dewatering costs drive recovery decision in many applications
PRE-DIGESTION PHOSPHORUS RELEASE ALTERNATIVES

• WASSTRIP®

• P-stripping with acid/gas phased digestion

• MultiWAS™

P-RECOVERY WITH LOWER PHOSPHORUS LIMITS
## HOW LOW SHOULD WE GO?


### Table 4. Guidelines for assigning initial phosphorus NPDES limits for POTWs discharging 1 MGD or more.

<table>
<thead>
<tr>
<th>Condition of Water</th>
<th>Guidelines for Initial NPDES Permit Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Erie Basin</td>
<td></td>
</tr>
<tr>
<td>Not impaired for nutrients</td>
<td>Set initial permit limit at 1.0 mg/ with long-standing Lake Erie policy.</td>
</tr>
<tr>
<td>Impaired for nutrients</td>
<td>Set initial permit limit at the lower of 1.0 mg/ with design flow or existing permitted load (with trading option, habitat fixed). Include permit language requiring POTW to minimize discharge of phosphorus by optimizing existing treatment facility.</td>
</tr>
<tr>
<td>Ohio River Basin</td>
<td></td>
</tr>
<tr>
<td>Not impaired for nutrients</td>
<td>Include existing effluent load in WLA in TMDL. No phosphorus permit limit; monitoring per guidance.</td>
</tr>
<tr>
<td>Impaired for nutrients</td>
<td>Set initial permit limit at the lower of 1.0 mg/ with design flow or existing permitted load (with trading option, habitat fixed). Include permit language requiring POTW to minimize discharge of phosphorus by optimizing existing treatment facility.</td>
</tr>
</tbody>
</table>


### Table 5. Guidelines for assigning initial phosphorus NPDES limits for POTWs discharging less than 1 MGD.

Actions are the same in the Lake Erie and Ohio River basins. If no effluent data available to estimate load, use a concentration of 3 mg/l.

<table>
<thead>
<tr>
<th>Design Flow (MGD)</th>
<th>Condition of Water</th>
<th>WLA and NPDES Permit Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 to 0.15</td>
<td>Not impaired for nutrients</td>
<td>Include existing effluent load in WLA in TMDL. No phosphorus permit limit; monitoring per guidance.</td>
</tr>
<tr>
<td></td>
<td>Impaired for nutrients (phosphorus); this source is predominant contributor to impairment</td>
<td>Set initial permit limit at 1.0 mg/ and design flow.</td>
</tr>
<tr>
<td>0.15 to 0.025</td>
<td>Impaired for nutrients; this source is one of multiple contributors to impairment</td>
<td>Set initial permit limit at 1.0 mg/ and design flow if phosphorus limits will result in a significant improvement in biological assemblages. Monitoring per guidance if no limit.</td>
</tr>
<tr>
<td>Less than 0.025</td>
<td>Any impairment situation</td>
<td>Include existing effluent load in WLA in TMDL. No phosphorus permit limit; monitoring per guidance.</td>
</tr>
</tbody>
</table>
# GENERAL RULES OF THUMB

<table>
<thead>
<tr>
<th>Effluent Concentration (mg-TP/L)</th>
<th>Process Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 to 1.5</td>
<td>A. Chemical precipitation and floc adsorption</td>
</tr>
<tr>
<td></td>
<td>B. EBPR with reliable VFA feed</td>
</tr>
<tr>
<td>0.05 to 0.3</td>
<td>A and/or B with effluent filtration</td>
</tr>
<tr>
<td>&lt;0.05</td>
<td>Tertiary system</td>
</tr>
</tbody>
</table>

Some exceptions to the rules. Case-specific alternative evaluations recommended.

Water Environment & Technology (Oct 2011)

Reaching new lows

Proven and emerging strategies merit consideration as utilities strive to achieve ultralow phosphorus limits

Christine deBarbadillo, James Barnard, Scott Levesque, and Jim Fitzpatrick
MOST ULTRALOW ALTERNATIVES RELY ON ALUM OR FERRIC CHEMISTRY

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Alum or Ferric</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemically enhanced clarification</td>
<td>Yes</td>
<td>Polishing filter generally required. Lamella settler, solids contact, ballasted flocculation options.</td>
</tr>
<tr>
<td>Two-stage granular media filtration</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Low-pressure membrane filtration</td>
<td>Yes</td>
<td>Membrane bioreactor (MBR) or tertiary systems.</td>
</tr>
<tr>
<td>Reverse osmosis</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Media adsorption / ion exchange</td>
<td>No</td>
<td>Filter pretreatment generally required</td>
</tr>
</tbody>
</table>

Alum and ferric chemistry interfere with struvite recovery
NEW PHOSPHORUS ADSORPTION TECHNOLOGY

- Polymeric metal oxide media developed by Asahi Kasei Chemicals

- Long-term pilot studies completed in Japan and U.S.

- 0.13-mgd demonstration at Kasumigaura Lake WWTP (near Tokyo) averaged TP < 0.03 mg/L during first year.

- 10-mgd facility on hold, pending need for ultralow limits
CONCEPT FOR MEDIA ADSORPTION / ION EXCHANGE WITH STRUVITE RECOVERY

Primary Clarifiers ➔ VFA ➔ Fermenter & Thickener ➔ Anaerobic Digestion ➔ (PO$_4^{3-}$, Mg$^{2+}$, K$^+$) ➔ Thickening Centrifuge ➔ Struvite Reactor ➔ MgNH$_4$(PO$_4$)$_6$H$_2$O ➔ Dewatering Centrifuge ➔ Biosolids

Activated Sludge EBPR ➔ Anaerobic Release Tank ➔ Effluent Filter ➔ WASSTRIP® (PO$_4^{3-}$, OH-) ➔ OH- ➔ H+ ➔ ASAHI Phosphorus Adsorption Media

Struvite Fertilizer

MgNH$_4$(PO$_4$)$_6$H$_2$O
SUMMARY

• The need for phosphorus recovery is growing
• Viable recovery processes are commercially available
• 5 years of full-scale struvite recovery in U.S.
• If lower effluent TP required:
  • Various alternatives available
  • New adsorption/ion exchange media doesn’t require metal salts
    • Repeatable in-situ regeneration of media
    • Potential integration with struvite recovery and EBPR
EXTRAS
RETURNING TO AGRICULTURAL ROOTS

STRUVITE PRODUCT ALTERNATIVES

Ostara Crystal Green®

Multiform Harvest Fertilizer

AirPrex® MAP fertilizer

KEMA TerraPhos™
# PEARL® INSTALLATIONS

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>WWTP Capacity</th>
<th>Startup Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold Bar/Clover Bar (demonstration)</td>
<td>Edmonton, AB</td>
<td>80 MGD</td>
<td>May-07</td>
</tr>
<tr>
<td>Durham AWWTP</td>
<td>Tigard, OR</td>
<td>20 MGD</td>
<td>May-09</td>
</tr>
<tr>
<td>Nansemond WWTP</td>
<td>Suffolk, VA</td>
<td>20 MGD</td>
<td>May-10</td>
</tr>
<tr>
<td>York WWTP</td>
<td>York, PA</td>
<td>20 MGD</td>
<td>Jun-10</td>
</tr>
<tr>
<td>Rock Creek AWWTP</td>
<td>Hillsboro, OR</td>
<td>30 MGD</td>
<td>Mar-12</td>
</tr>
<tr>
<td>Slough STW</td>
<td>United Kingdom</td>
<td>15 MGD</td>
<td>Dec-12</td>
</tr>
<tr>
<td>H.M. Weir WWTP</td>
<td>Saskatoon, SK</td>
<td>20 MGD</td>
<td>Jan-13</td>
</tr>
<tr>
<td>Nine Springs WWTP</td>
<td>Madison, WI</td>
<td>40 MGD</td>
<td>Jan-14</td>
</tr>
<tr>
<td>Truckee Meadows WRF</td>
<td>Reno, NV</td>
<td>40 MGD</td>
<td>Dec-14</td>
</tr>
<tr>
<td>F. Wayne Hill WRC</td>
<td>Gwinnett County, GA</td>
<td>50 MGD</td>
<td>Jan-15</td>
</tr>
<tr>
<td>Gold Bar/Clover Bar</td>
<td>Edmonton, AB</td>
<td>80 MGD</td>
<td>Mar-15</td>
</tr>
<tr>
<td>Stickney WRP</td>
<td>Stickney, IL</td>
<td>1,200 MGD</td>
<td>Oct-15</td>
</tr>
<tr>
<td>Bonnybrook WWTP</td>
<td>Calgary, AB</td>
<td>110 MGD</td>
<td>Mar-16</td>
</tr>
<tr>
<td>Amersfoort</td>
<td>Amersfoort, Netherlands</td>
<td>15 MGD</td>
<td>Mar-16</td>
</tr>
</tbody>
</table>
## AIRPREX® INSTALLATIONS

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>WWTP Capacity</th>
<th>Startup Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berlin WWTP</td>
<td>Germany</td>
<td>125 mgd</td>
<td>2003</td>
</tr>
<tr>
<td>Moenchengladbach WWTP</td>
<td>Germany</td>
<td>70 mgd</td>
<td>2007</td>
</tr>
<tr>
<td>Reest &amp; Wieden WWTP</td>
<td>Holland</td>
<td>31 mgd</td>
<td>2012</td>
</tr>
<tr>
<td>Amsterdam WWTP</td>
<td>Holland</td>
<td>120 mgd</td>
<td>2014</td>
</tr>
</tbody>
</table>
ASAHI ADSORPTION TECHNOLOGY

Carrousel Operation
- Two columns in series
- Third column stand-by

Offers *in situ* media regeneration and phosphorus recovery