Phosphorous Recovery from Wastewater: Current Practices and Future Opportunities

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Why Do We Need Nutrient Recovery Capability in WRRF’s?

- Complements nutrient removal
- Represents resource recovery
- Highly marketable end-product
- Contributes to sustainable nutrient management
- Provides factor of safety for Bio-P
- Minimizes impact of sidestream loads
- Reduces chemical consumption (sidestream treatment)
- Reduction in sludge quantity and hauling costs
- Minimizes nuisance struvite formation
- Reduces P content of biosolids
- Improves biosolids dewaterability
- Higher sludge cake %TS
- Reduces polymer demand
What is Nutrient Recovery?

- Accumulation step to increase N content > 1000 mg N/L and P content > 100 mg P/L
- Release step to generate low flow and high nutrient stream
- Recovery step produces high nutrient content product
Potential Locations for Nutrient Recovery at Water Resource Recovery Facilities (WRRFs)
The WERF Nutrient Recovery Project

Phase 1
State of Science
Review of extractive
nutrient recovery

I. State of Science Report
II. Market Analysis

Phase 2
Provide guidance on the implementation of
recovery technologies at WWTPs

I. Tool for evaluating resource recovery (TERRY)
II. Case Studies

Phase 3
Experimentally evaluate recovery technologies

I. Evaluate high priority embryonic P recovery technologies
WERF Project Team

• Project Team led by:
  – Hazen and Sawyer
  – CH2MILL (now Jacobs)

• Utilities: 20

• National & international experts
  – Universities & research organizations
    • USA
    • Australia
    • Europe
    • Japan

• Technology providers: 6
WERF NTRY3R13: Objectives & Project Team

**Principal Investigators/Project Team**
Wendell O. Khunjar, Thomas Worley-Morse (Hazen and Sawyer)
Sam Jeyanayagam (CH2M HILL)
Kevin Gilmore, Brian Zuidervliet (Bucknell Univ.)

**Technical Advisory Committee**
Paul Pitt (Hazen and Sawyer)
Glenn Daigger (CH2M HILL)
Mark van Loosdrecht (TU Delft)

**Quality Assurance and Control**
Ron Latimer (Hazen and Sawyer)
Julian Sandino (CH2M HILL)
Todd Williams (CH2M HILL)

**Objective 1**
Develop an inventory of technologies capable of recovering carbon-based and other non-nutrient commodity products from wastewater

**Objective 2**
Characterize the market potential and financial climate for selected non-nutrient commodities

**Objective 3**
Prioritize resource recovery needs for future research and development
Phosphorous flows and concentrations in a WRRF

Inlet
100 % ~ 1.80 g P/(E*d)

Primary Sludge
10 % ~ 0.18 g P/(E*d)

Outlet
10 % ~ 0.18 g P/(E*d)

WAS
80 % ~ 1.45 g P/(E*d)

WAS is main carrier for phosphate
Waste activated sludge from a BNR facility contains approximately:

• 12% nitrogen
• 5% phosphorus

Can be recovered as struvite

It has Taken us 6,000 years to realize that our poop is priceless!
Benefits of Nutrient Recovery

- Lowers energy use and greenhouse gas emissions associated with fertilizer production.
- Minimizes struvite scaling.
- Stabilizes Bio-P performance by reducing sidestream loads.
- Lowers biosolids P content – higher land application rates.
- Recovers N & P as struvite, a slow-release fertilizer.
- Enhances biosolids dewaterability.
- Creates a modest revenue stream.
- Aligns with the ‘plant of the future’ vision.
Why is Phosphorous Recovery from WRRF’s so Important?

Phosphate:
- Limited resource (30 - 300 yrs)
- Direct correlation to phosphate production and world population

World Phosphate Rock Reserves

World rock phosphate production vs world population

- Morocco & Western Sahara 85%
- China
- United States
- Jordan
- South Africa
- Brazil
- Russia
- Israel
- Tunisia
- Egypt
- Syria
- Australia
- Senegal
- Togo
- Canada
- Other countries

[Graph showing world phosphate reserves and production vs world population]
Figure 1. Florida’s Agricultural Total Nitrogen and Phosphorus by Source/Use Category

Source: J. Willis, 2019
What is Struvite?

- Struvite is Magnesium Ammonium Phosphate (MgNH₄PO₄)
  - Like kidney stones
- Historical perspective
  - First observed in sewer systems in 1845 in Hamburg, Germany
  - Named after geologist Gottfried von Struve
  - Value as a fertilizer dates back to 1857
- Forms readily when:
  - Molecular ratio of Mg:N:P is 1:1:1
  - pH around 9.0.
- Often an O&M nightmare at plants with anaerobic digesters:
  - Anaerobic digestion releases the necessary ‘raw materials’
  - Turbulence drives out CO₂ resulting in pH rise & struvite scaling
Recovery from Wastewater Requires a Three-Step Framework

- **Accumulation**
  - Bio-P
  - Algae
  - Purple non-sulfur bacteria
  - Adsorption/Ion exchange
  - Chemical precipitation
  - NF/RO

- **Release**
  - Anaerobic digestion
  - Aerobic digestion
  - Thermolysis
  - WAS release
  - Sonication
  - Microwave
  - Chemical extraction

- **Extraction**
  - Chemical crystallization
  - Electrodialysis
  - Gas permeable membrane and absorption
  - Gas stripping
  - Solvent extraction
<table>
<thead>
<tr>
<th>Feature</th>
<th>Ostara Pearl®</th>
<th>Multiform Harvest</th>
<th>NuReSys</th>
<th>Phospaq</th>
<th>Crystalactor</th>
<th>Airprex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of reactor</td>
<td>Fluidized Bed Reactor (FBR)</td>
<td>FBR</td>
<td>Completely Stirred Tank Reactor (CSTR)</td>
<td>CSTR</td>
<td>FBR</td>
<td>CSTR</td>
</tr>
<tr>
<td>Point of Recovery</td>
<td>Centrate/Filtrate</td>
<td>Centrate/Filtrate</td>
<td>Centrate/Filtrate; digested sludge</td>
<td>Centrate/Filtrate</td>
<td>Centrate/Filtrate</td>
<td>Digested sludge</td>
</tr>
<tr>
<td>Recovery efficiency</td>
<td>80-90% P, 10-40% NH3-N</td>
<td>80-90% P, 10-40% NH3-N</td>
<td>&gt;85% P, 5-20% N</td>
<td>80% P, 10-40% NH3-N</td>
<td>85-95% P for struvite, 10-40% NH3-N &gt; 90% P for calcium phosphate</td>
<td>80-90% P, 10-40% NH3-N</td>
</tr>
<tr>
<td>Full-scale installations</td>
<td>10</td>
<td>2</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>
Fluidized Bed Reactor
(Ostara, Multiform Harvest, Crystalactor)

FBR

Effluent
80-90% P removal
15-30% N removal

Dewatering

Dryer
MgNH₄PO₄•6 H₂O

Struvite

Magnesium

Caustic

Sand (Crystalactor)

Centrate/Filtrate
High NH₃-N and PO₄-P
Waste Activated Sludge Stripping to Recover Internal Phosphate (WASSTRIP®)
AirPrex
Struvite Recovery from Digested Biosolids

- Grit chamber
- Primary Clarification
- Aeration
- Secondary Clarification
- Effluent
- Inlet
- Grit
- Returned activated sludge
- Process water
- Digester
- Biogas
- AirPrex
- Dewatering

Pie Chart:
- Struvite Sales: 10%
- Savings in maintenance cost (pipe clogging and abrasion of centrifuges) etc.: 15%
- Savings in sludge dewatering and disposal: 75%
WERF Deliverables

- Final WERF report including TERRY released August 2015
- User manual and tutorial
- Who do we envision using TERRY?
  - Utility managers, research and development personnel
  - Consultants
  - Regulators
Tool for Evaluating Resource Recovery (TERRY)

- User friendly Excel tool
  - High level evaluation of site-specific feasibility of implementing extractive nutrient recovery
  - Used by several major US and Canadian utilities

- Allows
  - Net present worth comparison of struvite recovery & chemical sidestream P treatment
  - Business case evaluation taking into account 13 criteria such as:
    - Cost
    - Technology performance
    - Environmental/social impacts
    - Technology maturity
    - Plant-wide impacts
  - Payback analysis
  - Technology factsheets available within the tool so that technology options can be compared
Beneficial Use of Biosolids

Technologies producing higher quality products and recovering more energy

- Anaerobic Digestion
- Dewatering
- Thickening
- Dewatering
- Incineration with Energy Recovery
- Pyrolysis/Gasification
- Drying
- Soil Amendment
- Fertilizer
- Biosolids
- Compost
- Ash
- Char
More than 100 full-scale plants operational world-wide! > 80 recover Struvite (> 60 are municipal) with limited P recovery potential. Ash based recovery route will rapidly take over in volume, once rolled out in Germany!

Source: Kabbe and Hoener WEFTEC 2019
Beneficial Use of Biogas
Technologies with greater efficiencies and lower emissions
Disruptive Approaches are Needed to go from Treatment to Product Recovery

- Nitrification
- TN & TP
- Environmental Protection
- cBOD, Solids & pathogens

Increasing Level of Disruption

Sustainability & Human Survival

Basic Sanitation

Nutrient, Energy, Water

Chemicals

Biofuels

Metals

Biorefinery

Wastewater Treatment
What does the WRRF of the future look like?

Key attributes of a WRRF of the future:

• Operate as a production center/biorefinery
  ➢ Water factory
  ➢ Energy factory
  ➢ Resource (nutrient and organics) factory
    ➢ Fertilizer manufacturing facility for example
• Carbon neutral; energy self-sufficient
• Centralized and decentralized systems
• Highly automated
• Increasingly resilient
• Doing more with less (intensification)
• In a highly regulated environment
Some summary thoughts…

• Leadership must articulate a vision for the future – be bold!
• Consider non-traditional approaches to bridge gaps – dare to disrupt!
• Utility staff must be involved, empowered, motivated, and accountable – seek buy in!
• Know where are you starting from – develop a baseline!
• Implement changes incrementally, reassess frequently, and have a contingent plan – no regrets!
• Involve the community you serve – communicate!
• Learn from others; share results – collaborate!
“You’ve got to be very careful if you don’t know where you are going, because you might get there.”

Yogi Berra

“In theory there’s no difference between theory and practice. In practice there is.”

Courtesy: Glen Daigger
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QUESTIONS?

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