WELCOME TO THE MAY EDITION OF THE 2018 M&R SEMINAR SERIES
BEFORE WE BEGIN

• SAFETY PRECAUTIONS
  – PLEASE FOLLOW EXIT SIGNS IN CASE OF EMERGENCY
  – AUTOMATED EXTERNAL DEFIBRILLATOR (AED) LOCATED OUTSIDE

• PLEASE SILENCE CELL PHONES OR SMART PHONES

• A QUESTION AND ANSWER SESSION WILL FOLLOW PRESENTATION

• PLEASE FILL OUT THE EVALUATION FORM

• SEMINAR SLIDES WILL BE POSTED ON THE MWRD WEBSITE

• VIDEO STREAM OF THE PRESENTATION WILL BE AVAILABLE ON MWRD WEBSITE (www.MWRD.org: Home Page ⇒ MWRDGC RSS Feeds)
MATTHEW J. HIGGINS, Ph.D.

• Matt Higgins is a currently Professor and Claire W. Carlson Chair in Environmental Engineering at Bucknell University. For the last 20 years, Matt has focused much of his research on biosolids issues including digestion, co-digestion, advanced digestion, conditioning and dewatering, mechanisms for production and control of odors in biosolids, and the reactivation and regrowth of indicators and pathogens in biosolids. He has collaborated significantly with both industry and municipalities, and his work focuses on understanding fundamental issues to solve real-world problems and support the industry’s move toward more sustainable practices and a circular economy. His collaborative work with DC Water, AECOM, Brown and Caldwell and ARA Consult was recently awarded the Environmental Engineering Excellence Award from the American Academy of Environmental Engineers and the Excellence in Innovation Award from the Water Environment Research Foundation.

• Ph.D., Civil and Environmental Engineering, Virginia Tech
  M.S. and B.S., Civil and Environmental Engineering, University of Maine
Understanding the Mechanisms of Dewatering to Explain the Negative Impacts of Biological Phosphorus Removal on Dewatering after Anaerobic Digestion

Matthew Higgins, Ph.D.
Claire W. Carlson Chair in Environmental Engineering
Bucknell University
Lewisburg, PA 17837
A number of plants with anaerobic digestion have observed a decrease in cake solids after biological phosphorus removal or anaerobic selectors were implemented.
Full-Scale Plants – Effect on Dewatering

Reductions in Cake Solids Accompanied by Substantial Increase in Polymer Demand
WRF, HRSD, CWS, Denver Metro Project Goals

Develop a fundamental, mechanistic understanding of bioflocs and their transformations in anaerobic digestion and how bioflocs interact with conditioning chemicals to affect the critical outcomes of:

1. polymer demand;
2. cake solids;
3. capture efficiency.
Project Goals

Apply this knowledge to:

1. improve dewatering at plants, and address issues such as the impacts of BioP and co-digestion;
2. to be able to include prediction of dewatering in appropriate models such as BioWin and SUMO
Project Technical Advisory Committee
Charles Bott, Sudhir Murthy, John Novak

**PI**
Dr. Matthew Higgins
Bucknell University

**Outreach and Communications**
Stacy Passaro
Passaro Engineering, LLC

**Utility Partners**
1. Dr. Chris Wilson, HRSD
2. J. McQuarrie/L. Cavanagh, Denver
3. Dr. George Sprouse, MCES
4. Peter Schauer, CWS
5. Christine DeBarbadillo, DC Water
6. Kamlesh Patel, Chicago
7. Patrick Wescott, Green Bay MSD
8. Ester Rus Perez, Thames Water
9. Heri Bustamante, Sydney Water

**Consultant Partners**
1. Dr. Wendell Kunjar, Hazen & Sawyer
2. Dr. JB Neethling, HDR
3. Dr. Sam Jeyanayagam, CH2M
4. Dr. Chris Muller, Brown & Caldwell
5. Dr. G. Rajagopalan, Kennedy/Jenks
6. Dr. Mo Abu-Orf, Hazen & Sawyer

WRF PSC and Program Manager, Christine Radke
Solution Components

Components in Approximate Order by Mass

1. Water

2. Organics
   A. Exocellular Polymeric Substances (EPS)
   B. Cell Debris
   C. Microbes
   D. Miscellaneous other organics

3. Inorganics
   A. Grit/Sand
   B. Precipitates
   C. Salts

~100x

~1500x
Water: 95-99% of Solution Mass

Types of Water
1. “Free” Water – water in bulk solution
2. “Interstitial” Water – water trapped in between flocs, and in pockets of water
3. “Floc” Water - water that is trapped with the floc

“Only free water can be separated during mechanical dewatering.”
Dichtl and Kopp, 2000
Biofloc Composition

Bioflocs
1. EPS – exocellular polymeric substances
2. Microbes
3. Grit, precipitates, misc. inorganics
EPS = Exocellular Polymeric Substances

EPS
1. Proteins, Polysaccharides, Cell Debris
2. Have lots of negatively charged functional groups
3. Forms a gel within which microbes, water, and inorganics are embedded
EPS Characteristics – Trapped Water

SEM of Gelatin Gel Network, (from De Colli et al., 2012)

1,000x

Gel “Fibers” or EPS

10,000x

Water in cavities/pores is “trapped” water, has properties of free water, and can move within pores. This is why Jello wiggles/deforms in response to stress.
Working Hypothesis – Biofloc Model

Water held in the floc is the limiting factor for dewaterability.
Divalent Cation Bridges Reduce “Pocket” sizes

Low Multivalent Cations

With Multivalent Cations
Divalent Cation Bridges Reduce “Pocket” sizes

Gel made with Ca$^{2+}$

Gel made without Ca$^{2+}$

Increasing Mechanical Strength of Gelatin Hydrogels by Divalent Metal Ion Removal

Qi Xing$^1$, Keegan Yates$^1$, Caleb Vogt$^1$, Zichen Qian$^1$, Megan C. Frost$^2$ & Feng Zhao$^1$

$^1$Stem Cell and Tissue Engineering Lab, Department of Biomedical Engineering, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931; $^2$Polymer and Biomaterial Lab, Department of Biomedical Engineering, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931.
Are you familiar with Divalent Cation Bridging Theory?
Hypothesis Summary

- Extent of dewatering is determined by water trapped in the floc
- EPS has negatively charged functional groups and gel-like properties which bind and trap water in the floc
- Divalent cations bridge negatively charged functional groups, displacing bound water and reducing trapped floc water
Biological Phosphorus Removal

Cycle Microbes and Feed through Anaerobic and Aerobic Periods

### Anaerobic Phase
- **Uptake**
  - VFAs
  - Microbe
- **Release**
  - $K^+$
  - $Mg^{2+}$
  - $PO_4$

### Aerobic Phase
- **Uptake**
  - $K^+$
  - $Mg^{2+}$
  - $PO_4$
  - Microbe
Hypothesis for BioP Related to Biofloc Model

• Biological phosphorus removal results in a significant increase in digester $\text{PO}_4^{3-}$ concentration.

• Divalent cations are sequestered by $\text{PO}_4^{3-}$ species making them unavailable for biofloc formation and divalent cation bridging, resulting in a deterioration in floc properties and subsequent dewaterability.
Why Would BioP Impact Dewatering?

- Microbes release PO\(_4\), K\(^+\), Mg\(^{2+}\) in digester
- PO\(_4\) can complex and precipitate Ca\(^{2+}\) and Mg\(^{2+}\), making it unavailable for floc formation

<table>
<thead>
<tr>
<th>Complexes</th>
<th>log (β-values)(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca(^{2+}) + PO(_4)(^{3-}) ↔ CaPO(_4)(^{-})</td>
<td>6.5</td>
</tr>
<tr>
<td>Ca(^{2+}) + HPO(_4)(^{2-}) ↔ CaHPO(_4)(^{0})</td>
<td>15.1</td>
</tr>
<tr>
<td>Ca(^{2+}) + H(_2)PO(_4)(^{2-}) ↔ CaH(_2)PO(_4)(^{+})</td>
<td>21.0</td>
</tr>
<tr>
<td>Mg(^{2+}) + PO(_4)(^{3-}) ↔ MgPO(_4)(^{-})</td>
<td>4.8</td>
</tr>
<tr>
<td>Mg(^{2+}) + HPO(_4)(^{2-}) ↔ MgHPO(_4)(^{0})</td>
<td>15.3</td>
</tr>
<tr>
<td>Mg(^{2+}) + H(_2)PO(_4)(^{2-}) ↔ MgH(_2)PO(_4)(^{+})</td>
<td>20.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Precipitates</th>
<th>K(_{sp}) values(^1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaHPO(_4)(s) ↔ Ca(^{2+}) + HPO(_4)(^{2-})</td>
<td>10(^{-19})</td>
</tr>
<tr>
<td>Ca(_3)(PO(_4))(_2)(s) ↔ 3Ca(^{2+}) + 2PO(_4)(^{2-})</td>
<td>10(^{-28.7})</td>
</tr>
<tr>
<td>Ca(_5)(OH)(PO(_4))(_3)(s) ↔ 5Ca(^{2+}) + OH(^{-}) + 3PO(_4)(^{2-})</td>
<td>10(^{-58.2})</td>
</tr>
<tr>
<td>MgHPO(_4)(s) ↔ Mg(^{2+}) + HPO(_4)(^{2-})</td>
<td>10(^{-18.2})</td>
</tr>
<tr>
<td>Mg(_3)(PO(_4))(_2)(s) ↔ 3Mg(^{2+}) + 2PO(_4)(^{2-})</td>
<td>10(^{-25.2})</td>
</tr>
<tr>
<td>MgNH(_4)PO(_4)(s) ↔ Mg(^{2+}) + NH(_4) + PO(_4)(^{2-})</td>
<td>10(^{-18.2})</td>
</tr>
</tbody>
</table>
1. Sampling Survey to Evaluate Hypotheses:
   a. Collected digestate from full scale anaerobic digesters with and without bioP
   b. Operated lab digesters
   c. Characterize the solids, solution chemistry and dewaterability with a defined laboratory dewatering protocol
Lab Protocol for Conditioning and Dewatering

Mix Polymer and Solids → Gravity Drainage → Filtrate Analyzed for TSS and other parameters → Pressure Applied Using Centrifuge

Measure CST
Results – Cake Solids vs PO$_4$
Soluble Ca$^{2+}$ and Mg$^{2+}$ vs PO$_4$
Results – Cake Solids vs Soluble (Ca^{2+} + Mg^{2+})

\[ y = 10.617 + 1.5272x \quad R^2 = 0.93041 \]

Average Cake Solids (%)

Average Soluble Mg\(^{2+}\) + Ca\(^{2+}\) (meq/L)
Results – Polymer Demand vs Soluble (Ca\textsuperscript{2+} + Mg\textsuperscript{2+})

\[ y = 19.74 - 10.058 \log(x) \quad R^2 = 0.45578 \]
What can we do about the negative impacts?

1. Don’t do BioP, and use Fe or Al for P-removal
2. Phosphorus Stripping Prior to Digestion
3. Metal Addition (Fe, Ca, Mg, Al)
4. AirPrex
P-Stripping (WASSTRIP)

Ferment Biomass to release P, then thicken WAS before digestion

Source: Jeyanayagam et al., 2012, WEFTEC Proceedings
Lab Digester Reactors

- Feed Inlet
- Gas Collection Bag
- Mixer Motor
- Gas Sampling Port with septa for gas analysis
- Gas Collection Port to Respirometer or Bag
- Mixing Paddle
- Outlet Valve

Volume = 10 L
SRT = 20 days
Q = 0.500 L/d
Reactor Feeds

- WAS/Primary Blend
- WAS/Primary Blend with WAS StorageP
- WAS/Primary Blend with WAS Storage + K⁺
Results – Cake Solids for Digesters

<table>
<thead>
<tr>
<th>Cake Solids Range (%)</th>
<th>Control Digester</th>
<th>WAS Storage Digester</th>
<th>WAS Storage with K⁺ Digester</th>
</tr>
</thead>
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The chart shows the distribution of cake solids for different digesters, comparing control digesters with WAS storage digesters and digesters with potassium (K⁺) storage. The box plots indicate the range and distribution of cake solids for each condition.
Investigations into Improving Dewaterability at a Bio-P/Anaerobic Digestion Plant

Rebecca Alm, Adam W. Sealock, Yabing Nollet, George Sprouse

Metal Addition


With P-Stripping

No P-Stripping

Cake Solids (%TS)

Iron Dose (g Fe/kg dry feed solids)

TWAS+FeCl3

STWAS+FeCl3

STWAS+Fe(OH)3
AirPrex

source: www.tpmag.com
AirPrex Pilot – Denver Metro

- 20 data points analyzed
- 8.72% reduction in wet tons hauled
- **17.61% decrease in polymer consumption**

*Source: Wisdom et al., WEF Residuals and Biosolids Conference, 2017*
Summary

- Biological phosphorus removal will increase phosphate in anaerobic digesters
- Phosphate impacts digester chemistry
- Chemistry is complex, phosphate binds multivalent cations (Ca, Mg, Fe, Al?) which increases water content of flocs
- Approaches to solving BioP issue revolve around reducing phosphate in digester, or increasing cation concentrations
Acknowledgements - Funding

Denver Metro
Acknowledgements

Steven Beightol
Research Associate, Bucknell University
- performed the dewatering tests
- performed analytical testing and characterization
- compiled data