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 (www. MWRD.org: Home Page ⇒ Reports ⇒ M&R Data and Reports ⇒ M&R Seminar Series ⇒ 2018 Seminar Series)**
- **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
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Understanding the Mechanisms of Dewatering to Explain the Negative Impacts of Biological Phosphorus Removal on Dewatering after Anaerobic Digestion

Matthew Higgins, Ph.D.
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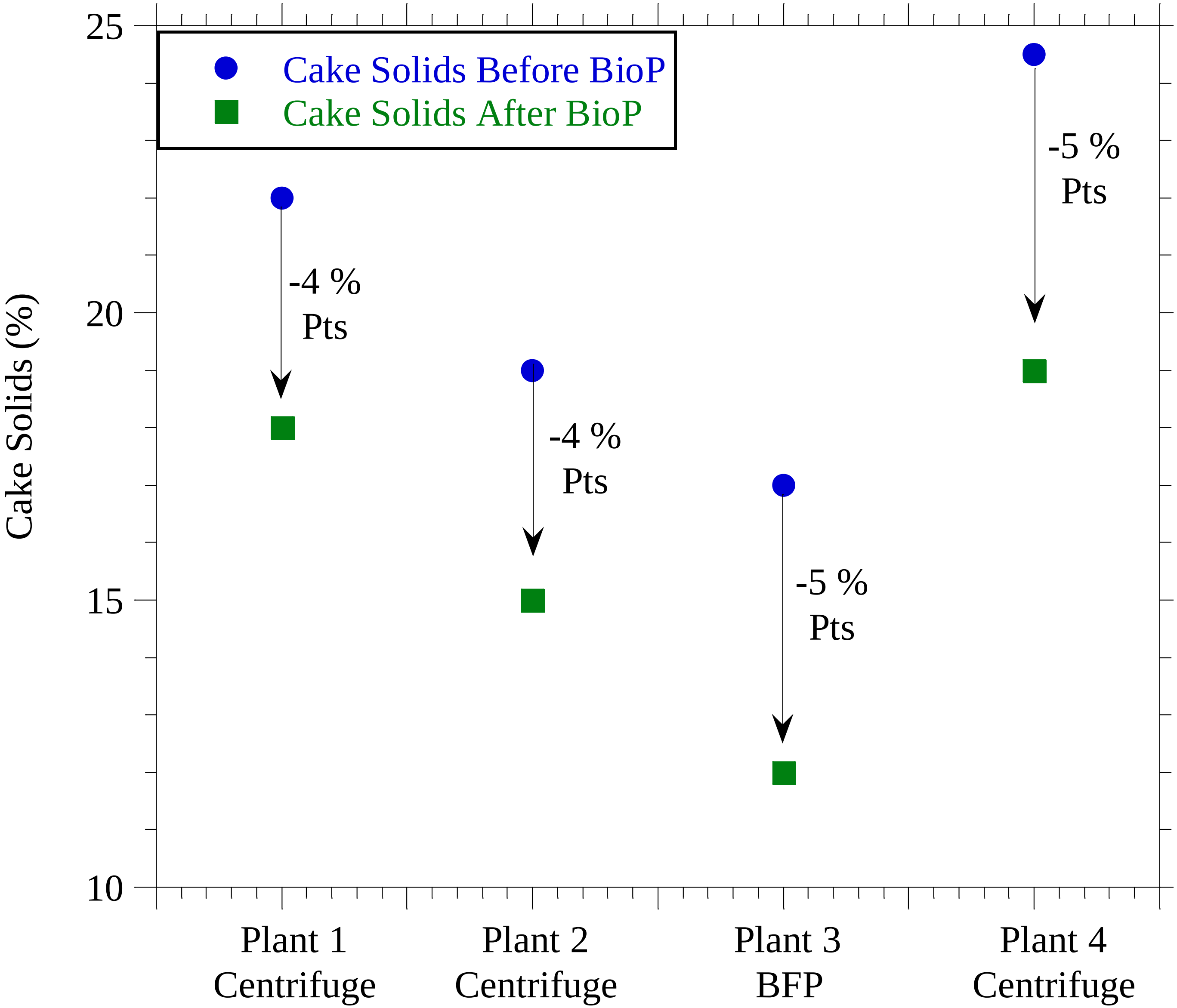
Key Observation of Full-Scale BioP Plants

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

WRF PSC and Program Manager, Christine Radke

Project Technical Advisory Committee

Charles Bott, Sudhir Murthy, John Novak

PI

Dr. Matthew Higgins
Bucknell University

Outreach and Communications

Stacy Passaro
Passaro Engineering, LLC

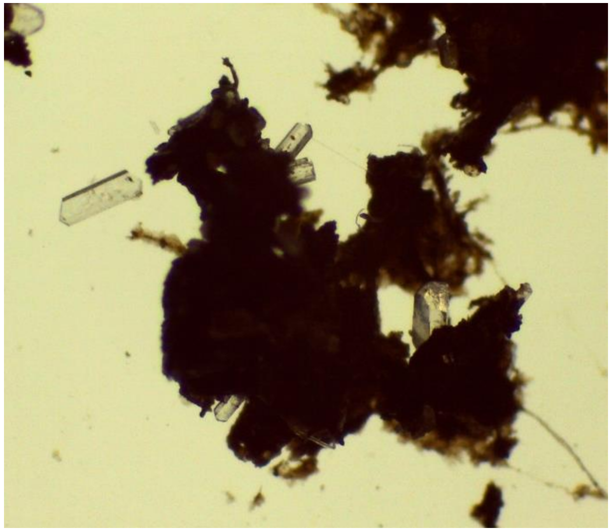
Utility Partners

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

Solution Components



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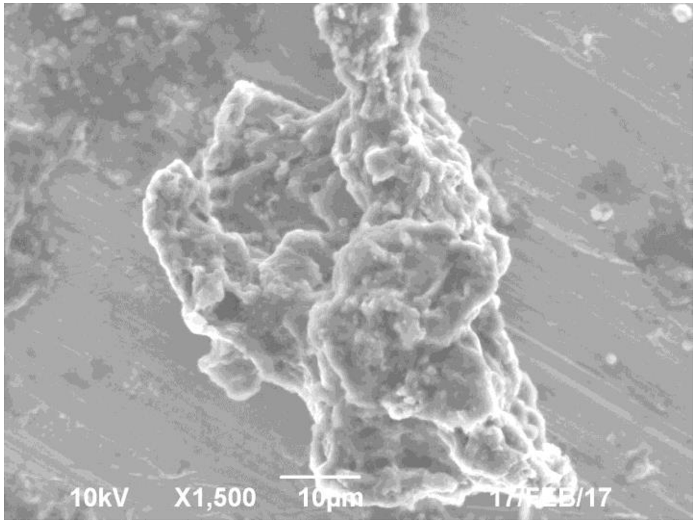
<u>Components in Approximate Order by Mass</u>

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



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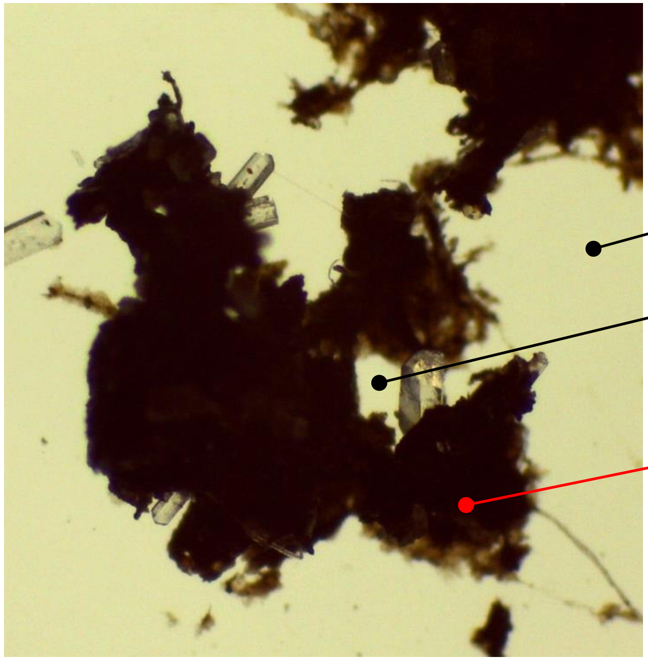
Water: 95-99% of Solution Mass



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<u>Types of Water</u>

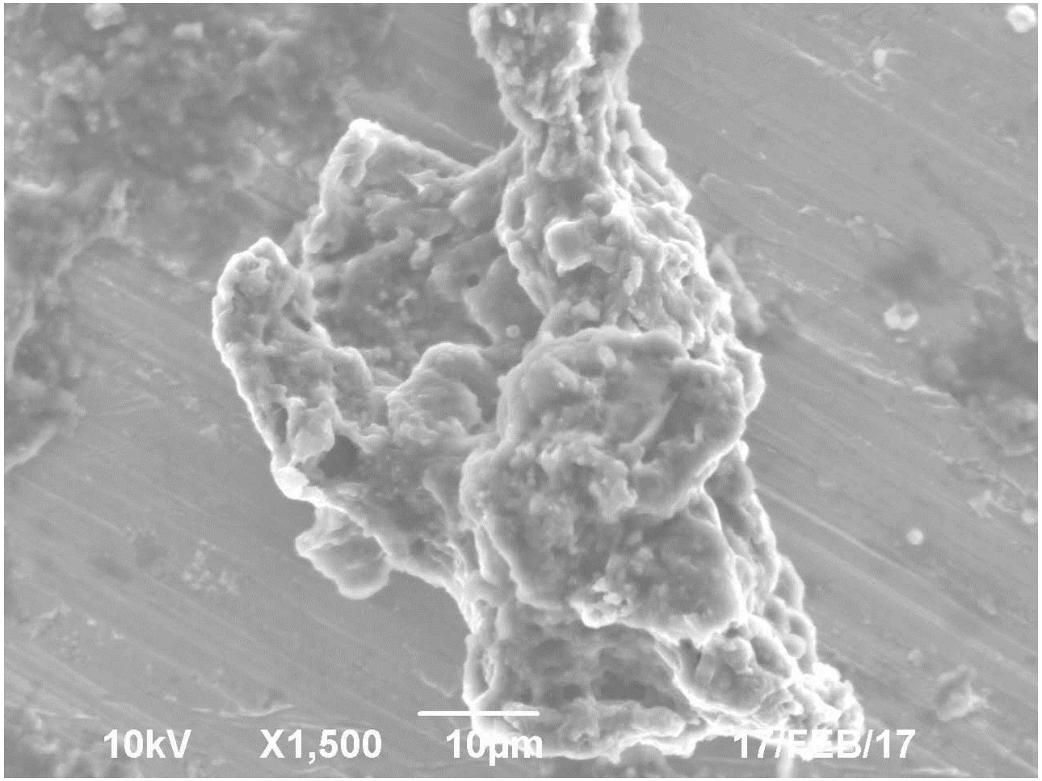
1. "Free" Water – water in bulk solution
2. "Interstitial" Water – water trapped in between flocs, and in pockets of water
3. "Floc" Water - water that is trapped with the floc

"Only free water can be separated during mechanical dewatering."
Dichtl and Kopp, 2000

Biofloc Composition

Bioflocs

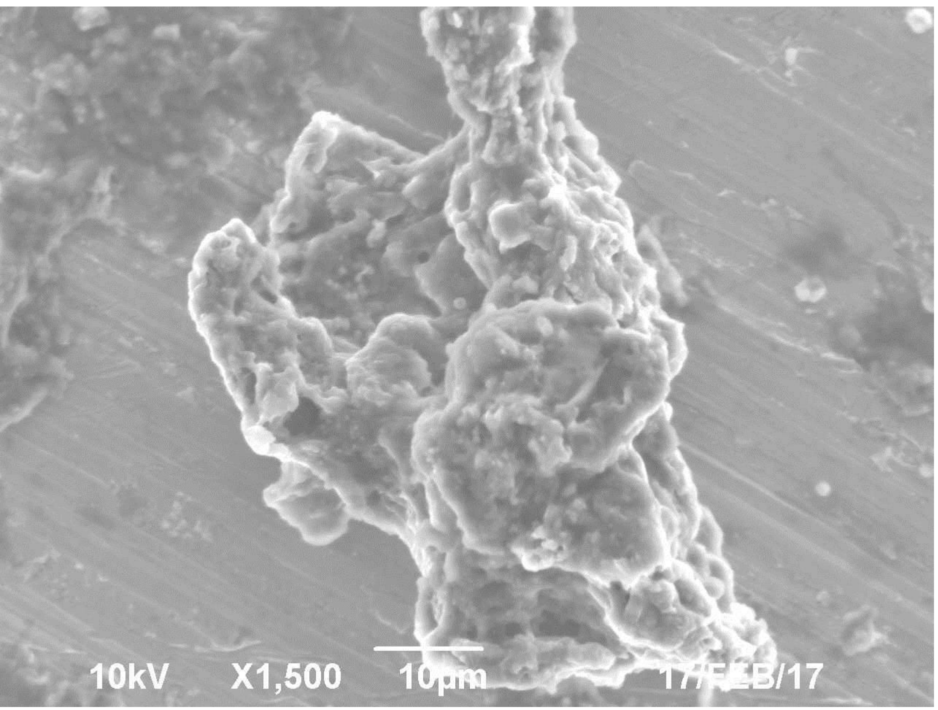
1. EPS – exocellular polymeric substances
2. Microbes
3. Grit, precipitates, misc. inorganics

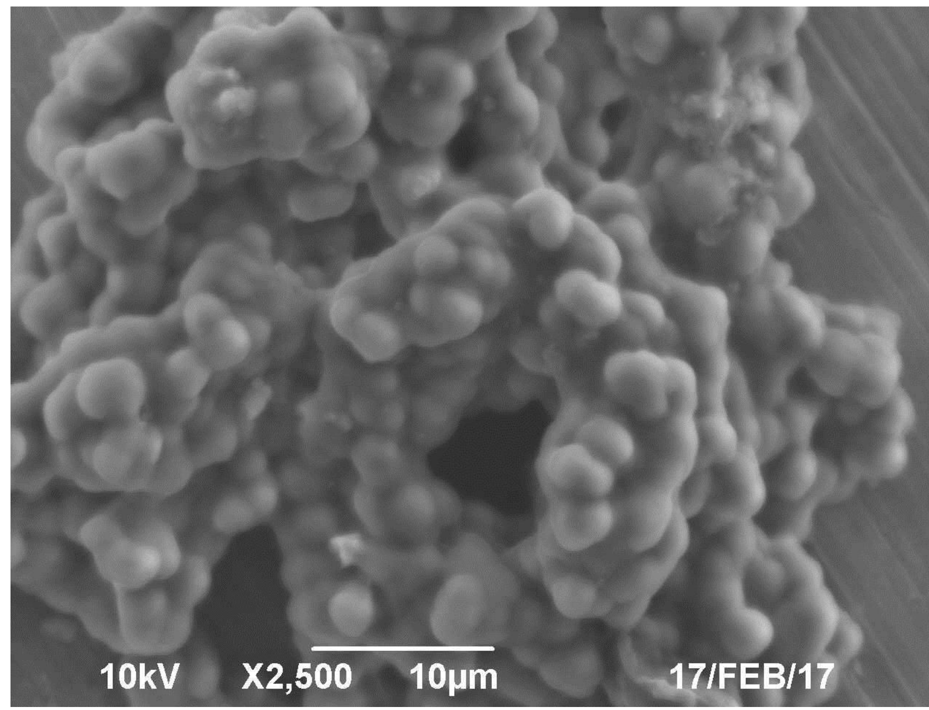


EPS = Exocellular Polymeric Substances

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

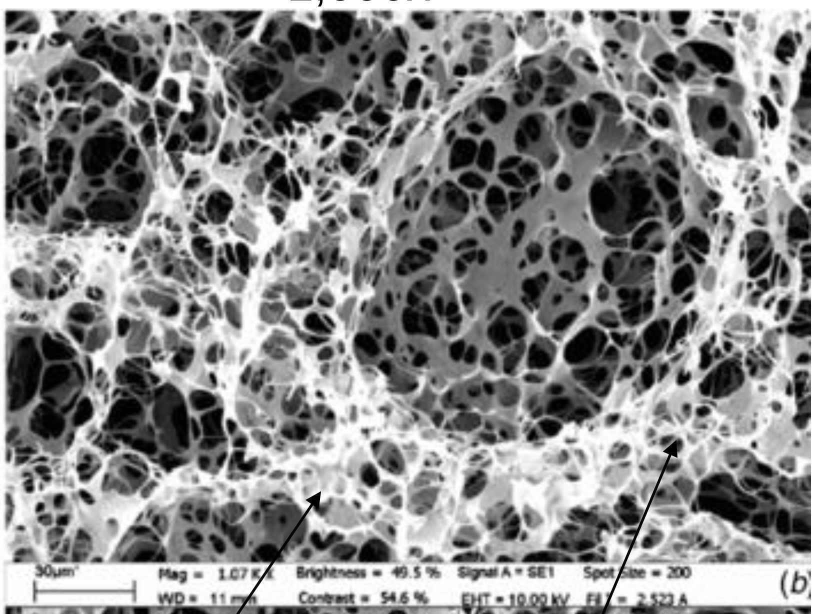




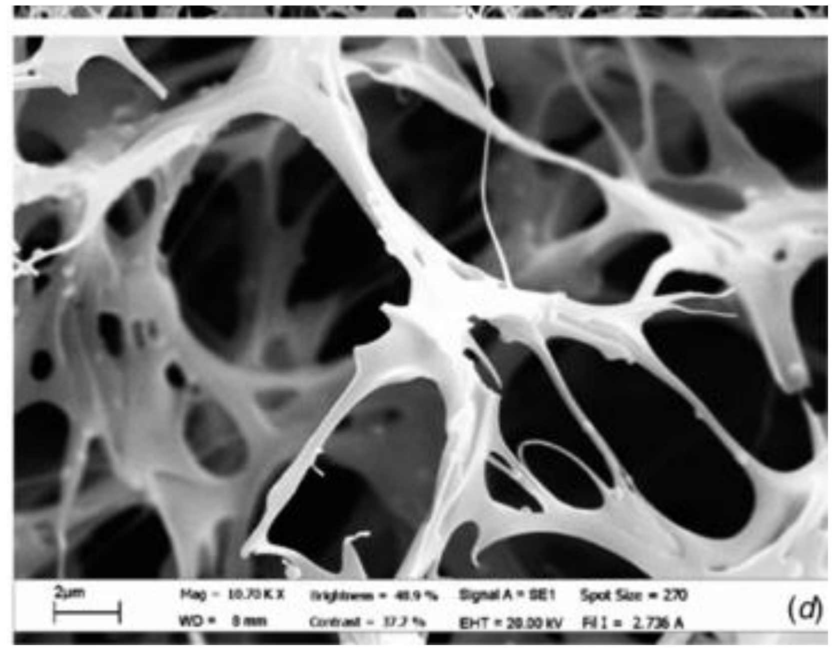
EPS Characteristics – Trapped Water

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

1,000x



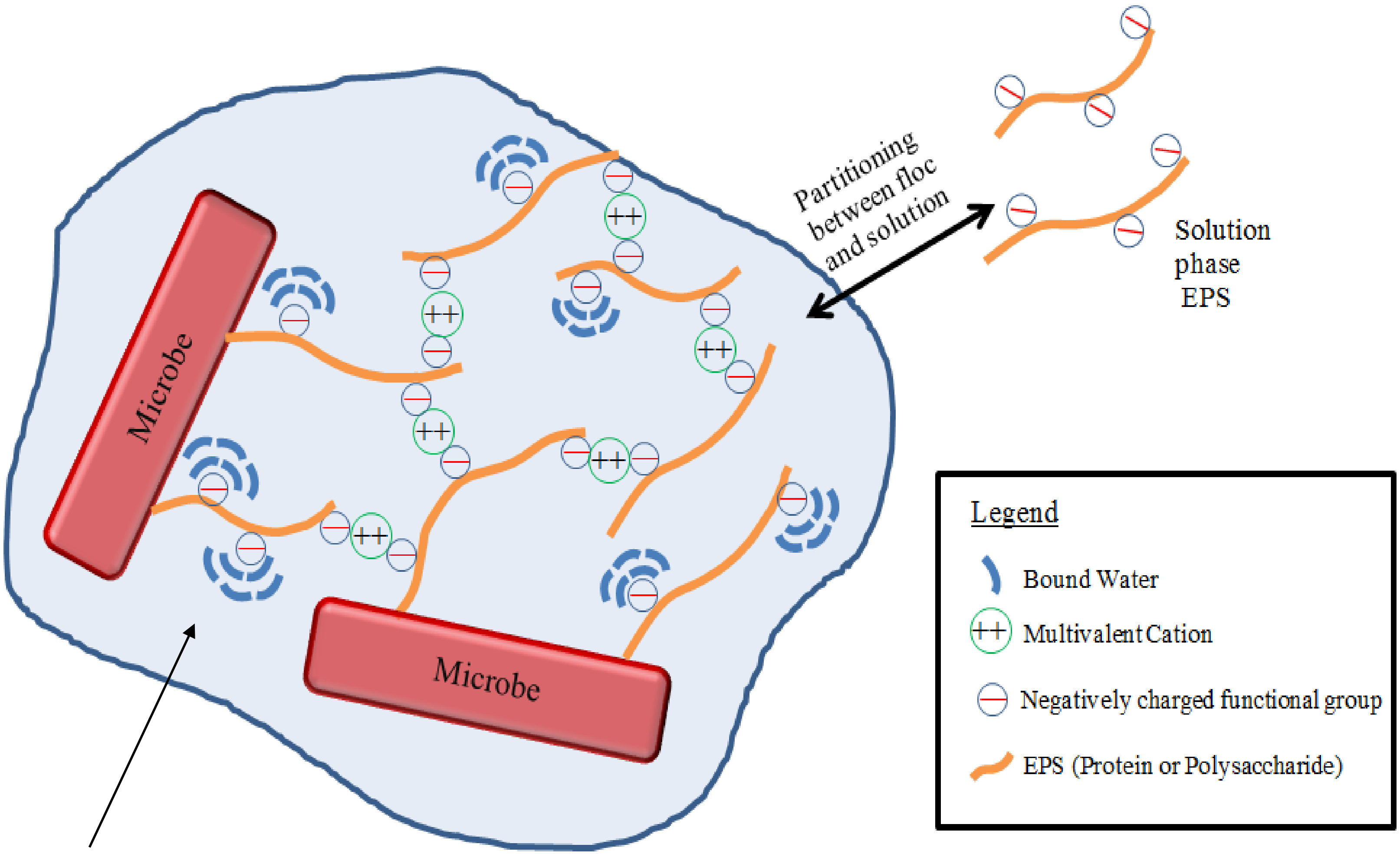
10,000x



Gel “Fibers”
or EPS

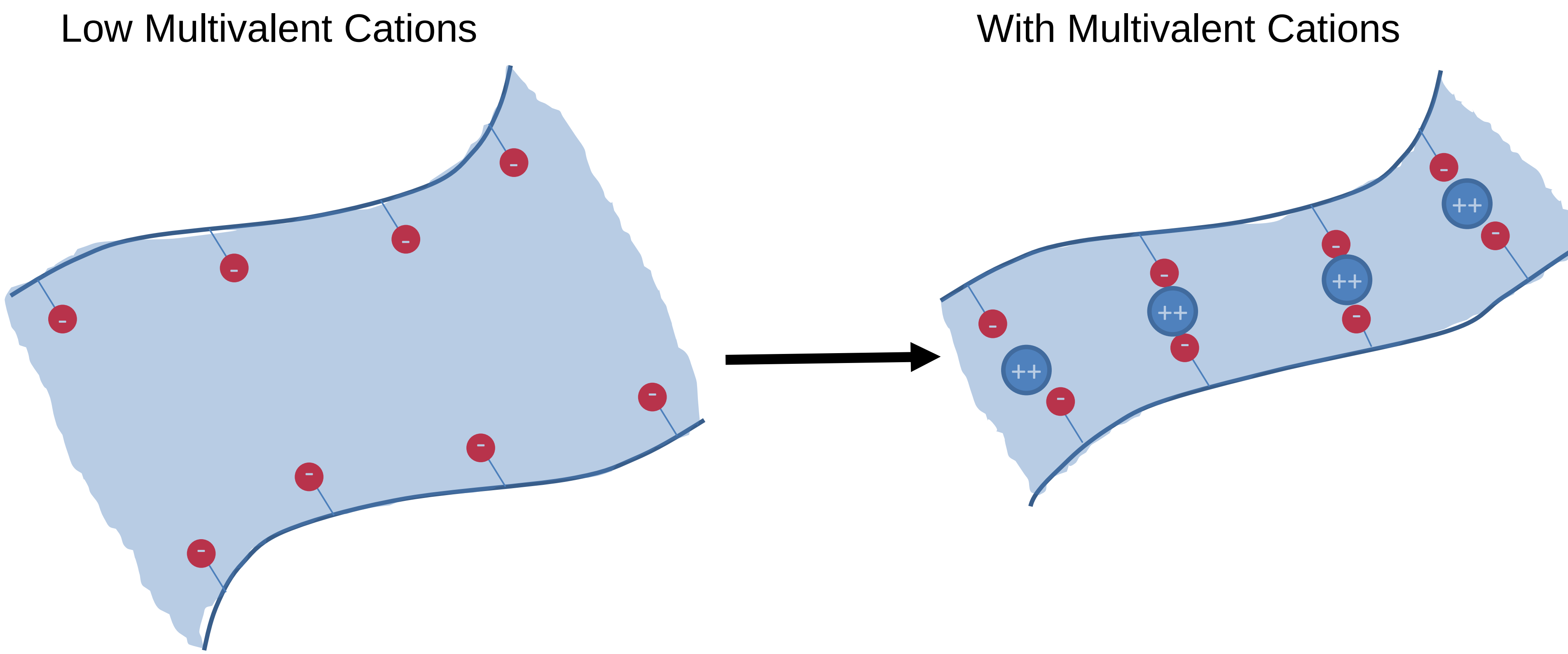
Water in cavities/pores is “trapped” water, has properties of free water, and can move within pores.
This is why Jello wiggles/deforms in response to stress

Working Hypothesis – Biofloc Model



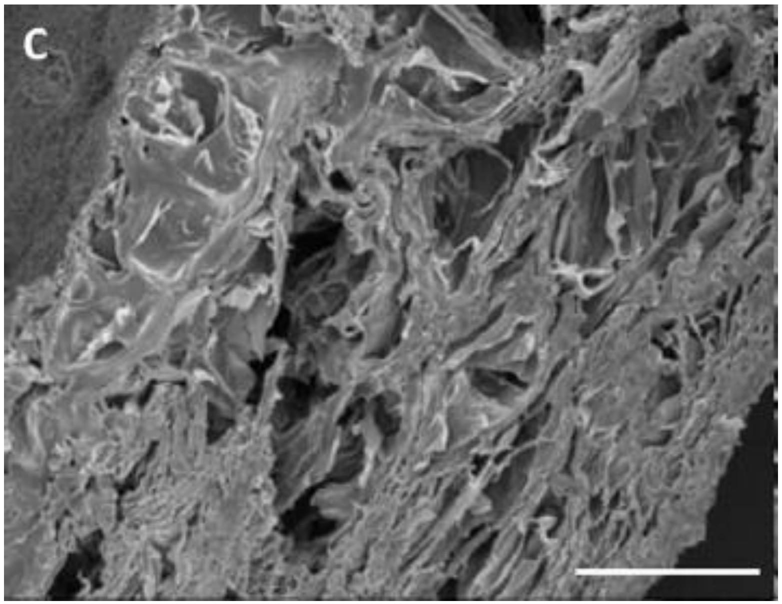
Water held in the floc is the limiting factor for dewaterability

Divalent Cation Bridges Reduce “Pocket” sizes

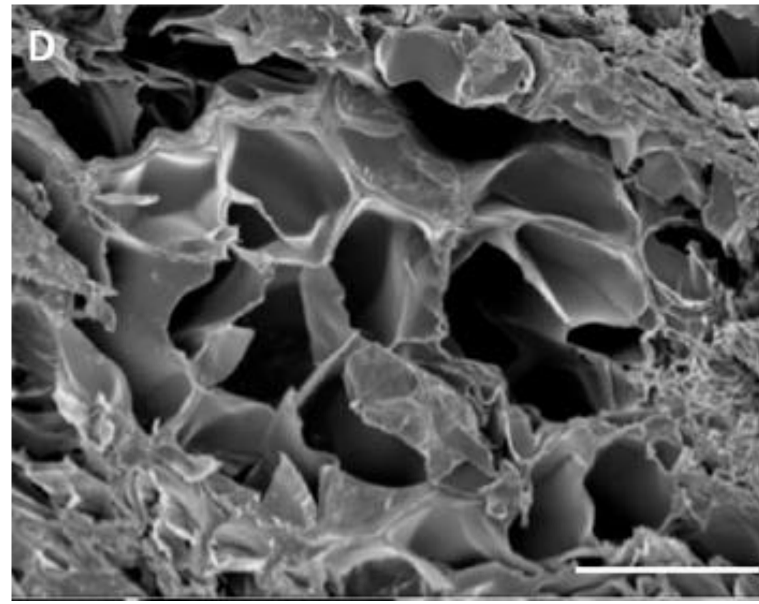


Divalent Cation Bridges Reduce “Pocket” sizes

Gel made with Ca^{2+}



Gel made without Ca^{2+}



OPEN

SUBJECT AREAS:
SOFT MATERIALS
BIOMATERIALS

Received
23 October 2013

Accepted
28 March 2014

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?

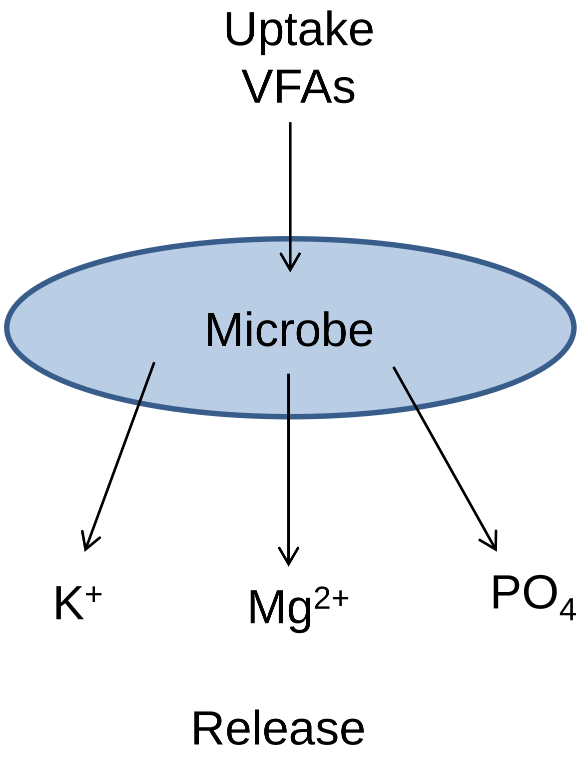
Hypothesis Summary

- 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

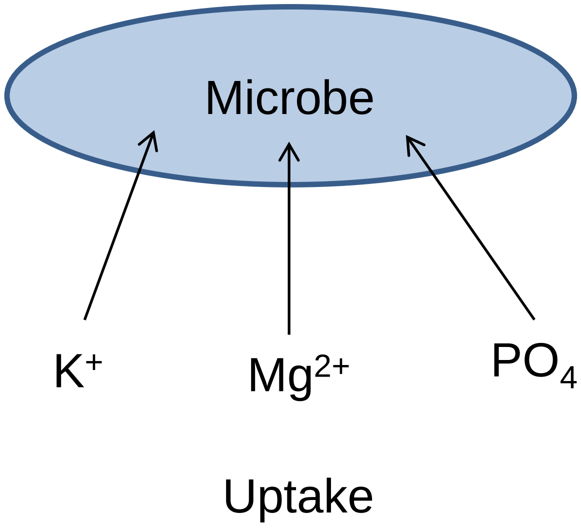
Biological Phosphorus Removal

Cycle Microbes and Feed through Anaerobic and Aerobic Periods

Anaerobic Phase



Aerobic Phase



Hypothesis for BioP Related to Biofloc Model

- Biological phosphorus removal results in a significant increase in digester PO_4^{3-} concentration.

- Divalent cations are sequestered by 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

Complexes	**log (β-values)[1]**
$Ca^{2+} + PO_4^{3-} \leftrightarrow CaPO_4^-$	6.5
$Ca^{2+} + HPO_4^{2-} \leftrightarrow CaHPO_4^o$	15.1
$Ca^{2+} + H_2PO_4^{2-} \leftrightarrow CaH_2PO_4^+$	21.0
$Mg^{2+} + PO_4^{3-} \leftrightarrow MgPO_4^-$	4.8
$Mg^{2+} + HPO_4^{2-} \leftrightarrow MgHPO_4^o$	15.3
$Mg^{2+} + H_2PO_4^{2-} \leftrightarrow MgH_2PO_4^+$	20.0

Precipitates	**K_{sp} values[1]**
$CaHPO_{4(s)} \leftrightarrow Ca^{2+} + HPO_4^{2-}$	10^{-19}
$Ca_3(PO_4)_{2(s)} \leftrightarrow 3Ca^{2+} + 2PO_4^{2-}$	$10^{-28.7}$
$Ca_5(OH)(PO_4)_{3(s)} \leftrightarrow 5Ca^{2+} + OH^- + 3PO_4^{2-}$	$10^{-58.2}$
$MgHPO_{4(s)} \leftrightarrow Mg^{2+} + HPO_4^{2-}$	$10^{-18.2}$
$Mg_3(PO_4)_{2(s)} \leftrightarrow 3Mg^{2+} + 2PO_4^{2-}$	$10^{-25.2}$
$MgNH_4PO_{4(s)} \leftrightarrow Mg^{2+} + NH_4 + PO_4^{2-}$	$10^{-18.2}$

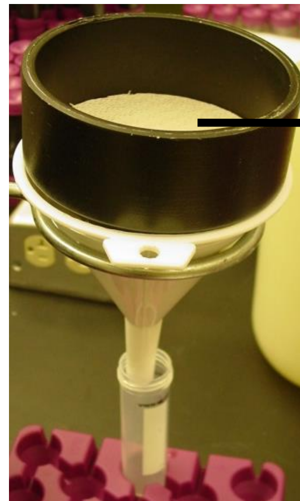
Research Approach – Lab/Fundamentals

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

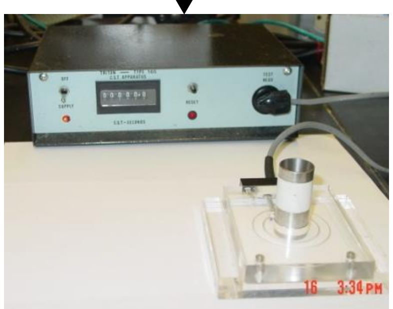
Gravity Drainage



Centrifuge Cup

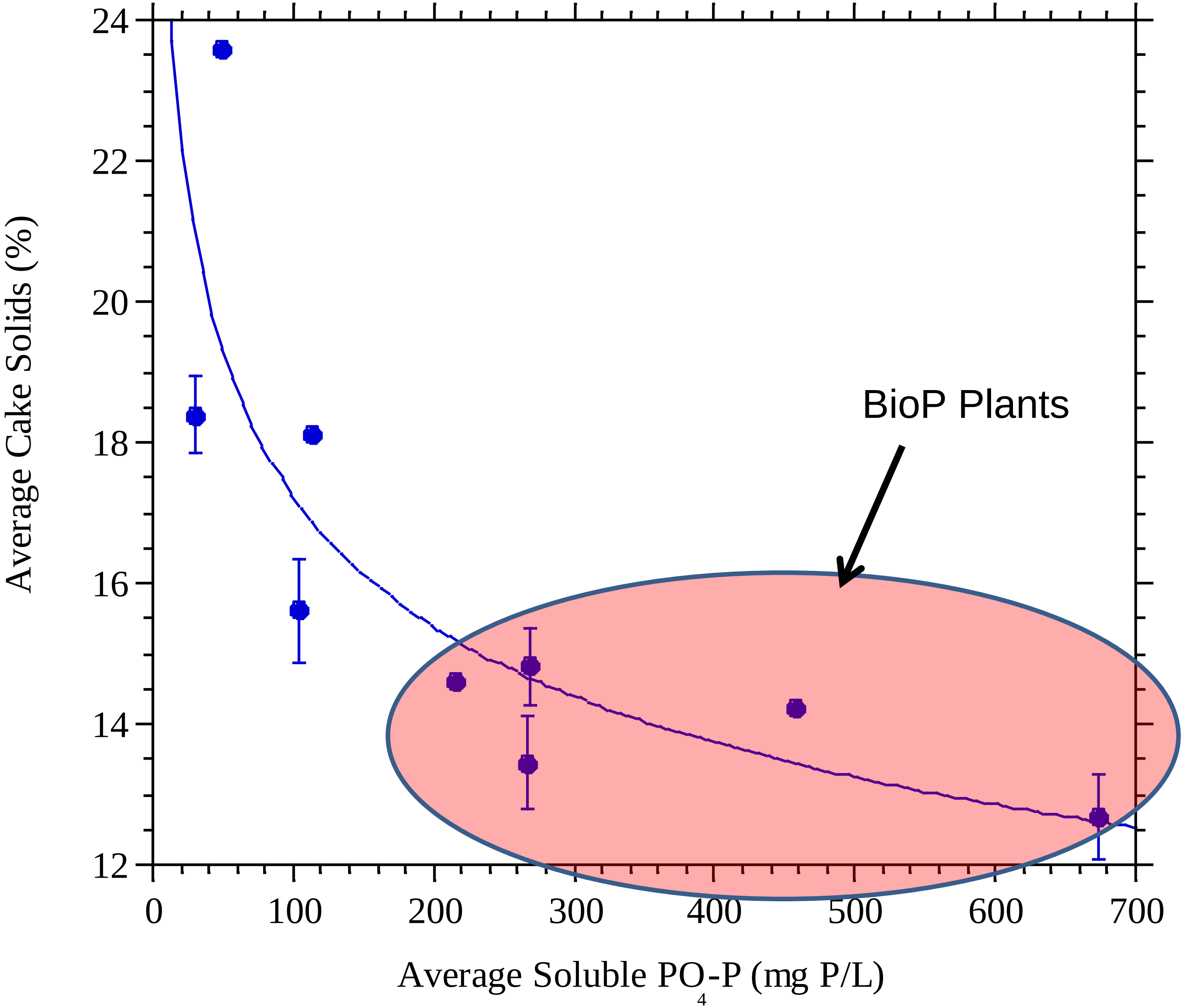
Pressure Applied Using Centrifuge

Filtrate Analyzed for TSS and other parameters

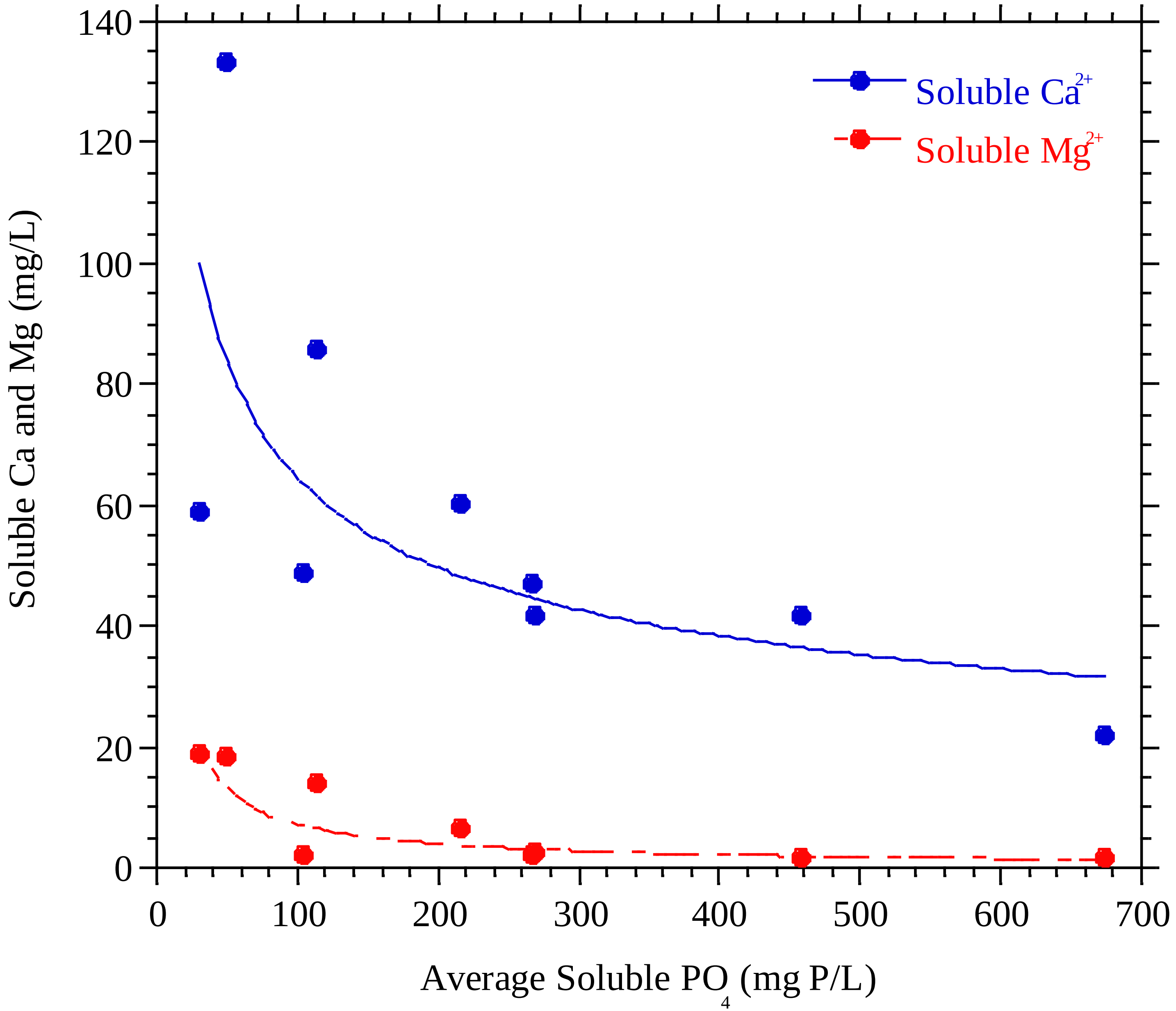


Measure CST

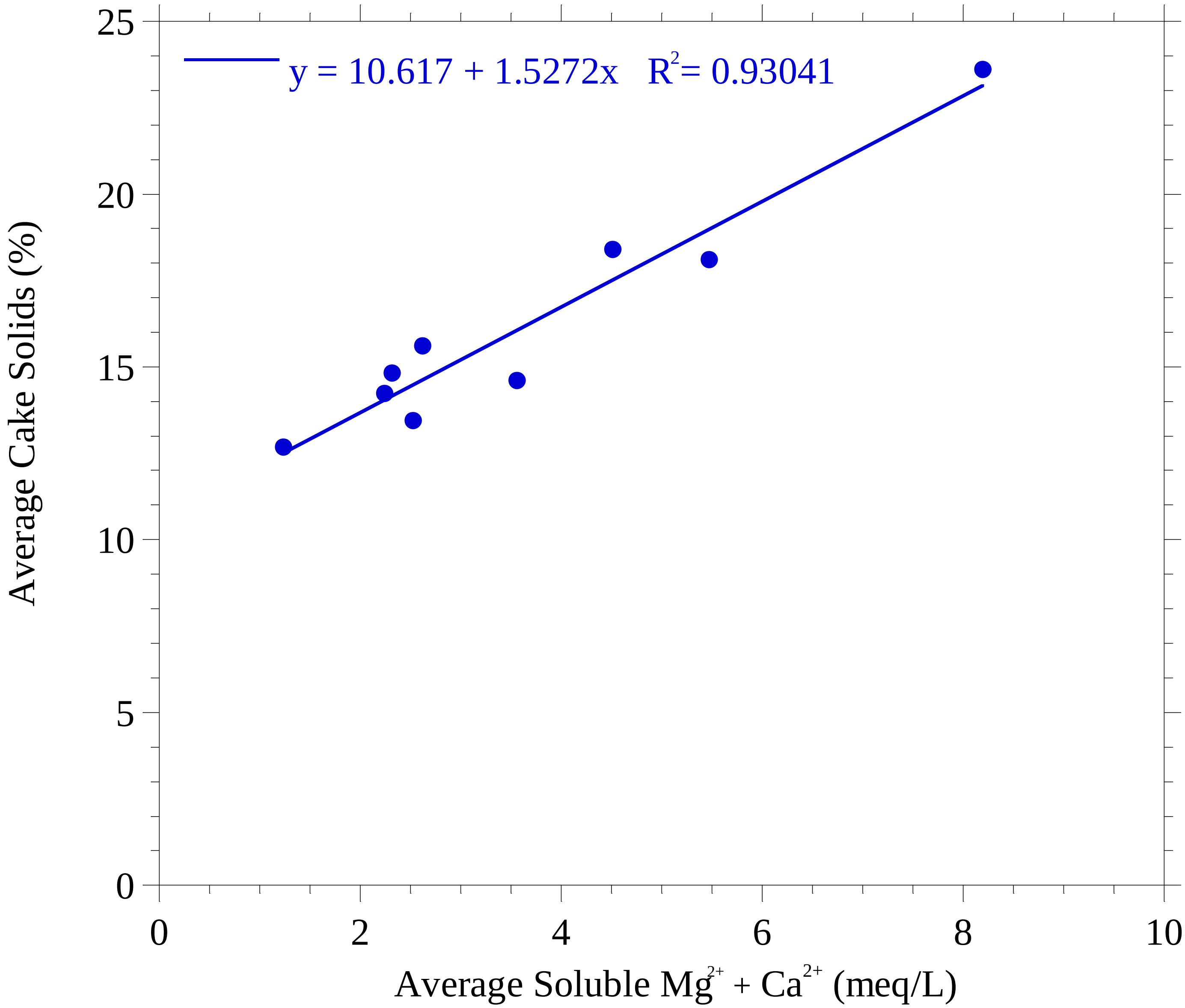
Results – Cake Solids vs PO_4



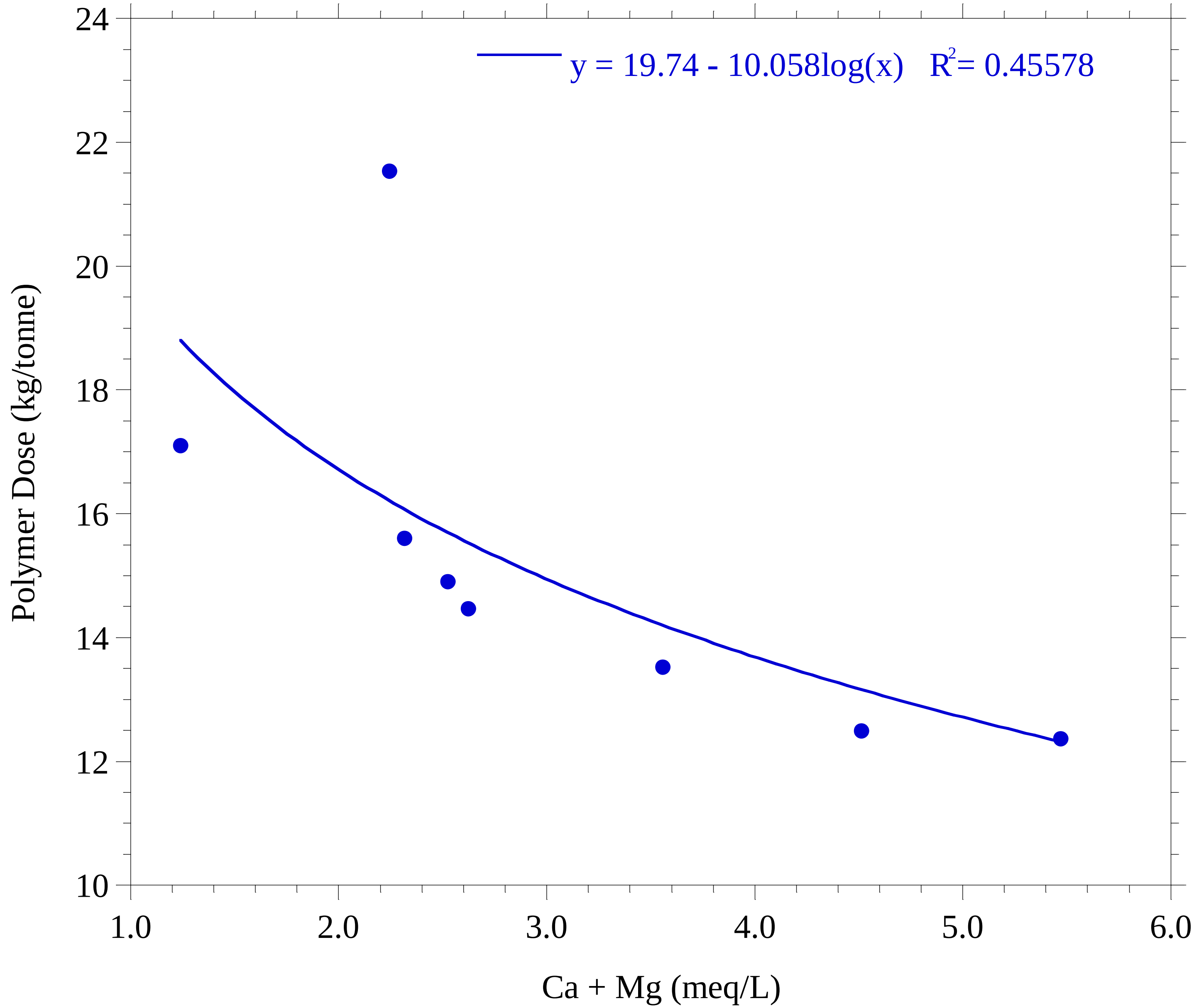
Soluble Ca^{2+} and Mg^{2+} vs PO_4



Results – Cake Solids vs Soluble (Ca^{2+} + Mg^{2+})



Results – Polymer Demand vs Soluble (Ca^{2+} + Mg^{2+})

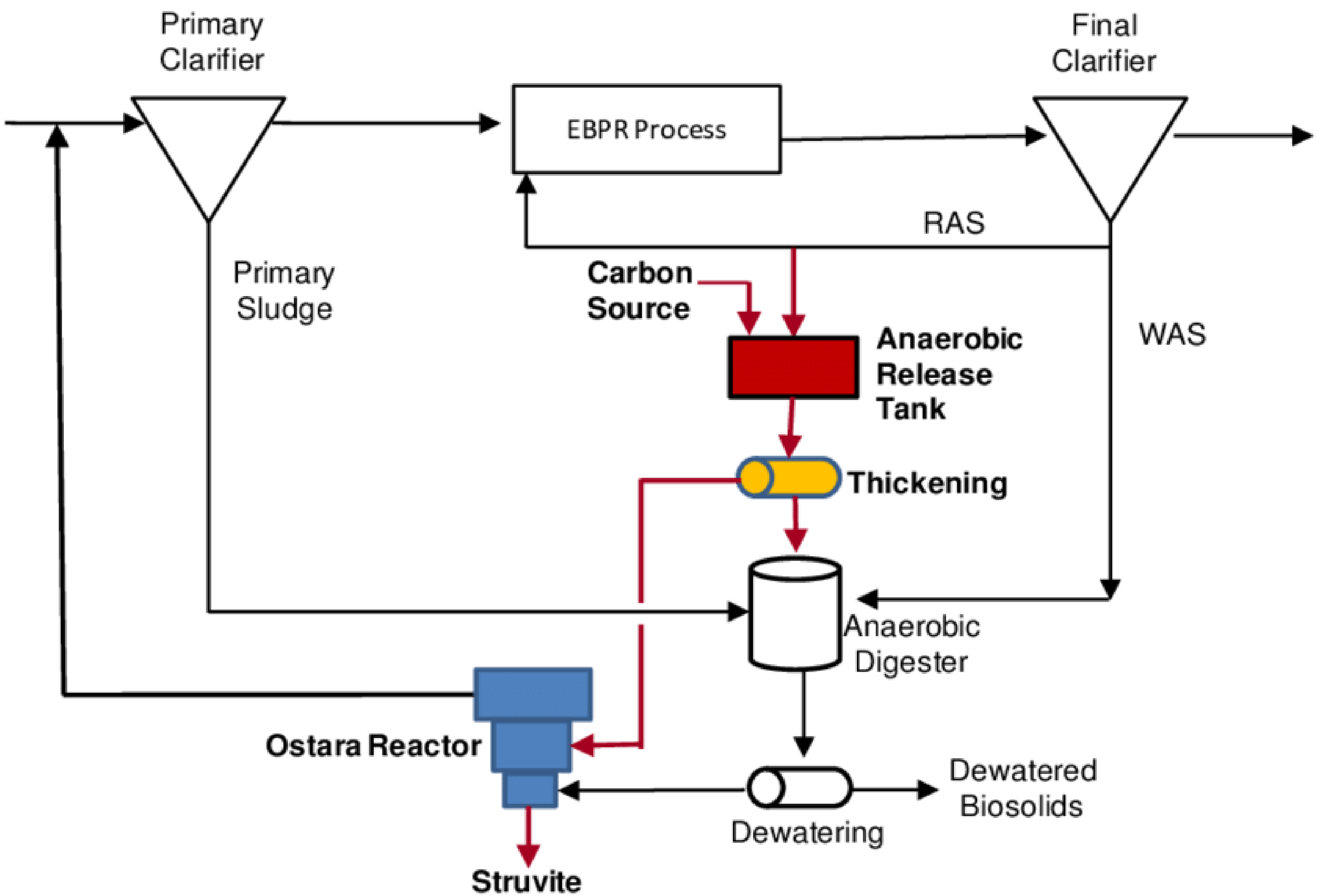


What can we do about the negative impacts?

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

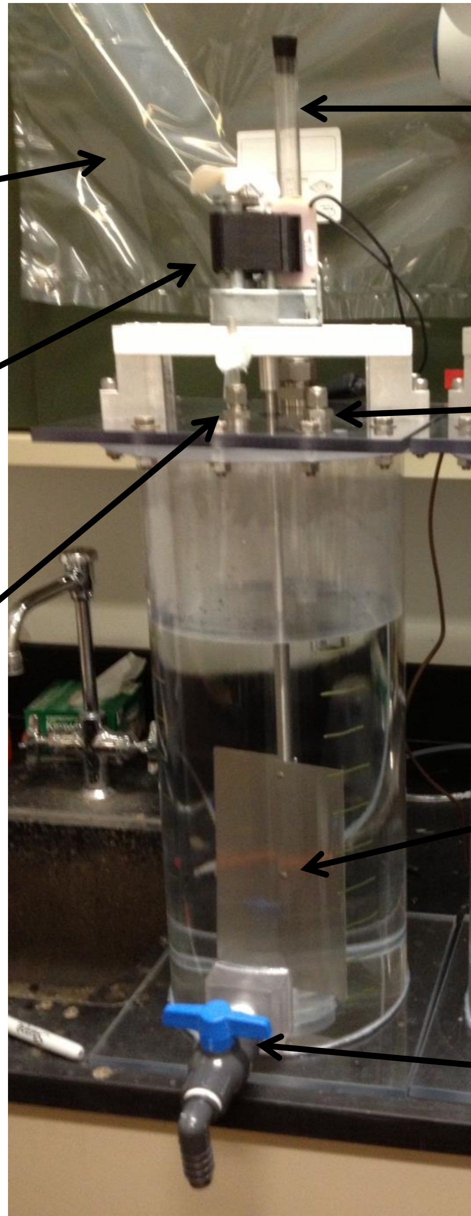
P-Stripping (WASSTRIP)

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 Collection Port to Respirometer or Bag

Gas Sampling Port with septa for gas analysis

Mixing Paddle

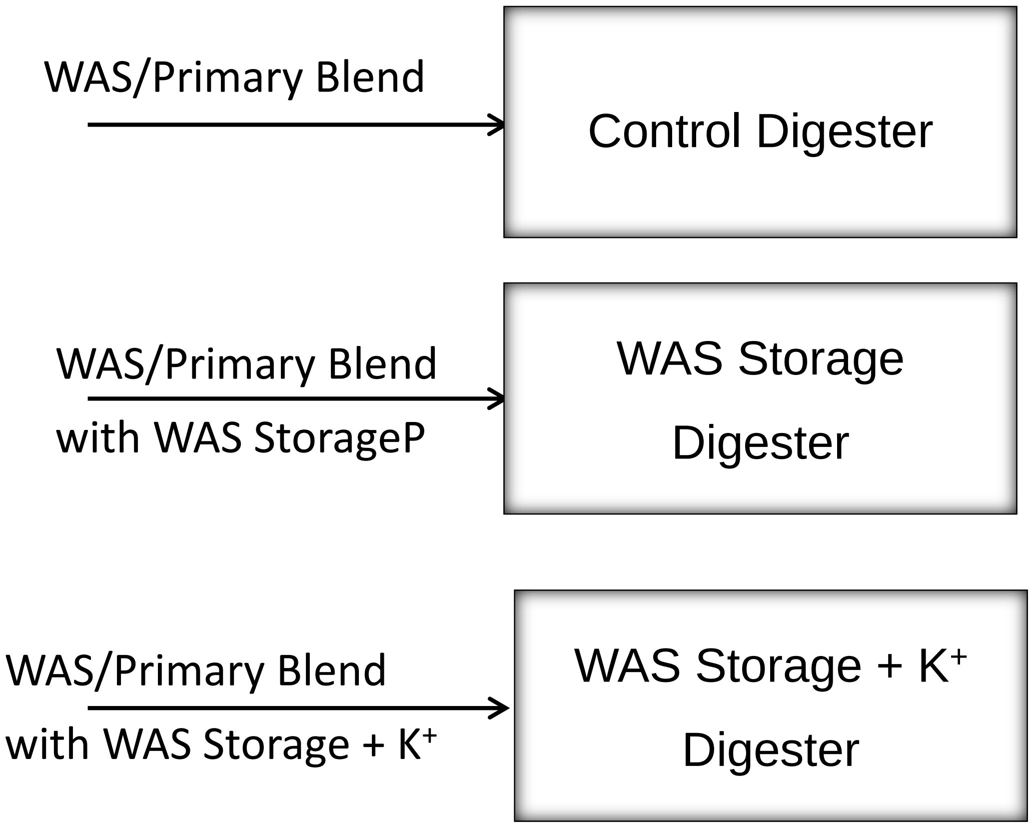
Outlet Valve

Volume = 10 L

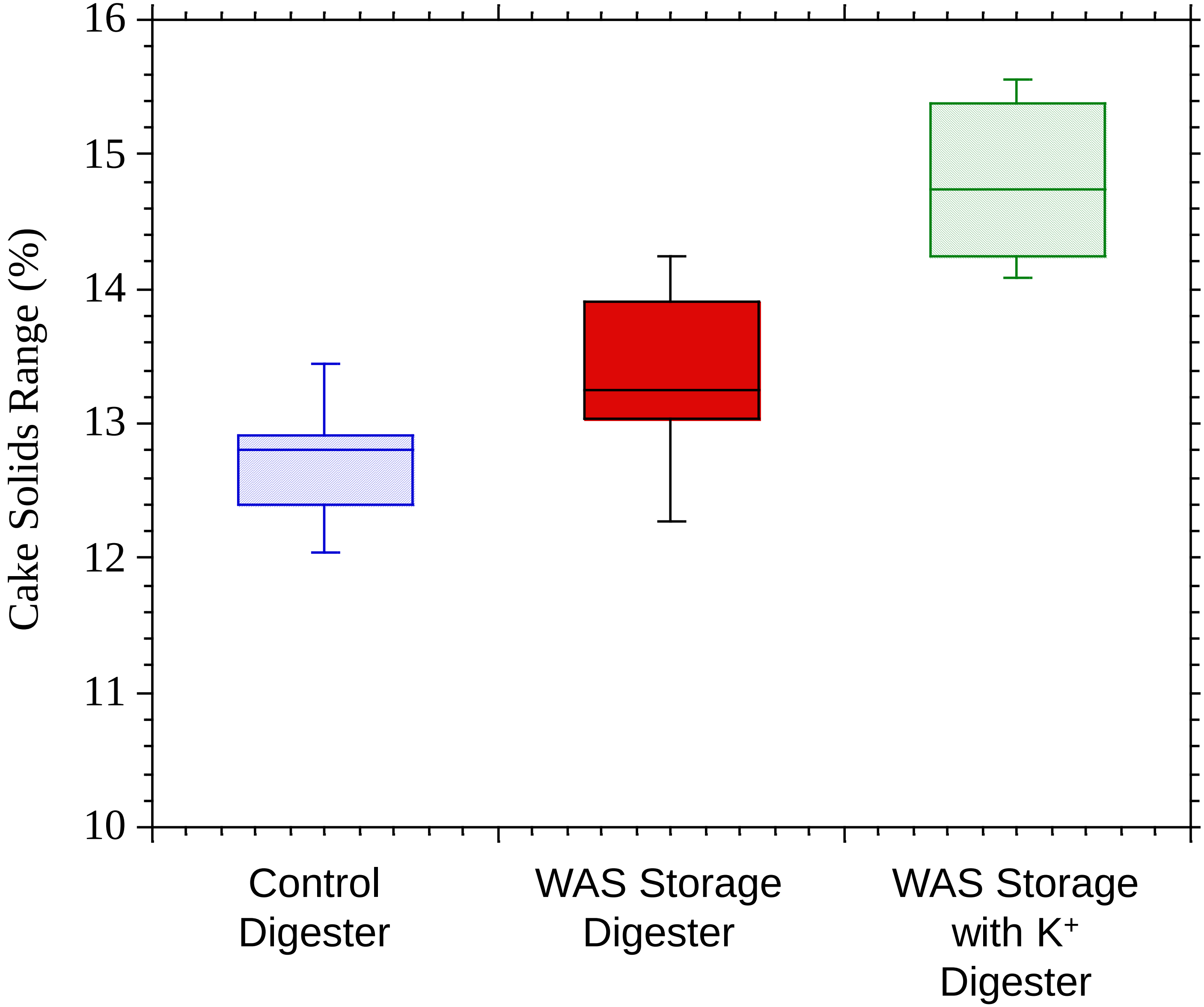
SRT = 20 days

Q = 0.500 L/d

Reactor Feeds



Results – Cake Solids for Digesters

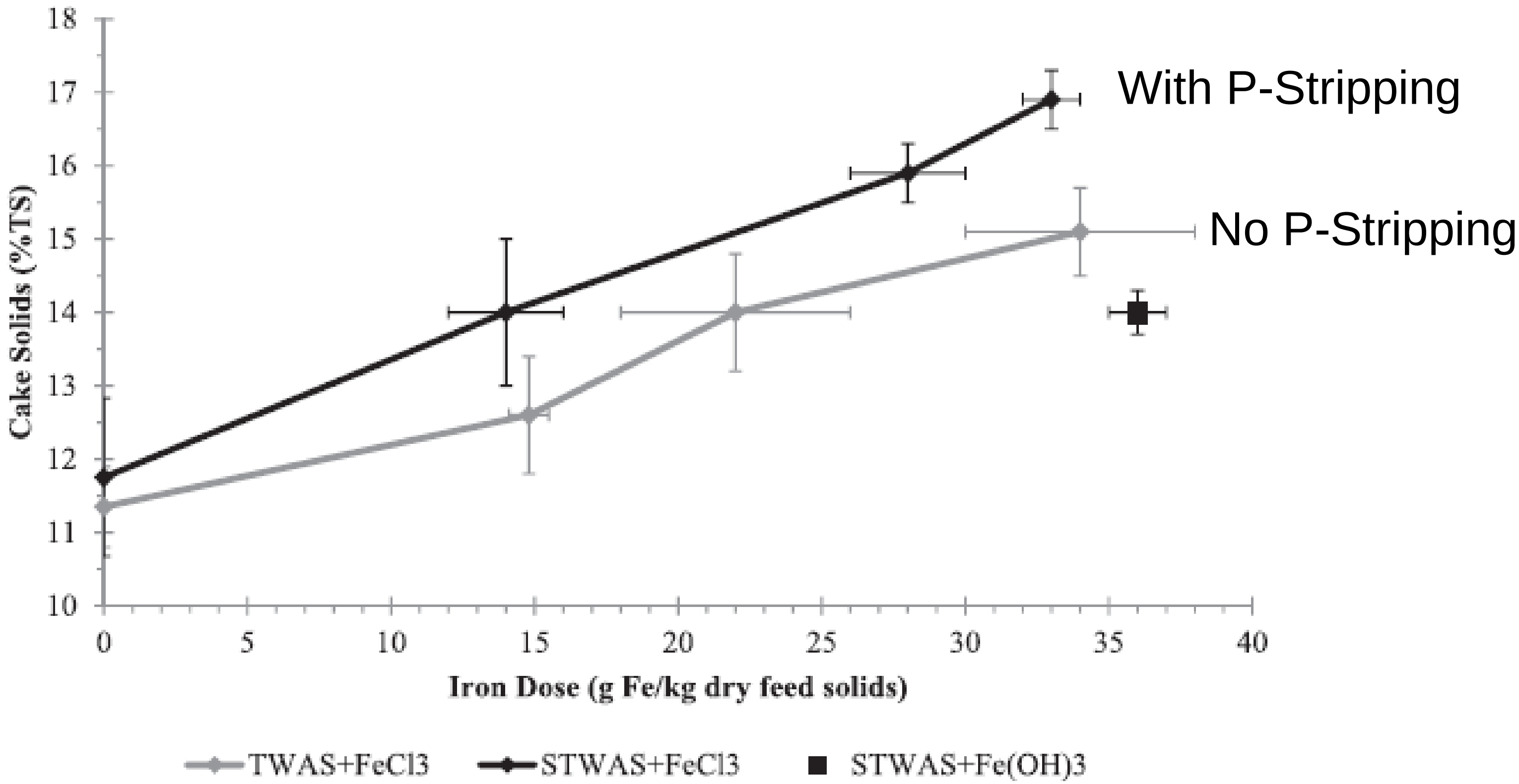


Metal Addition

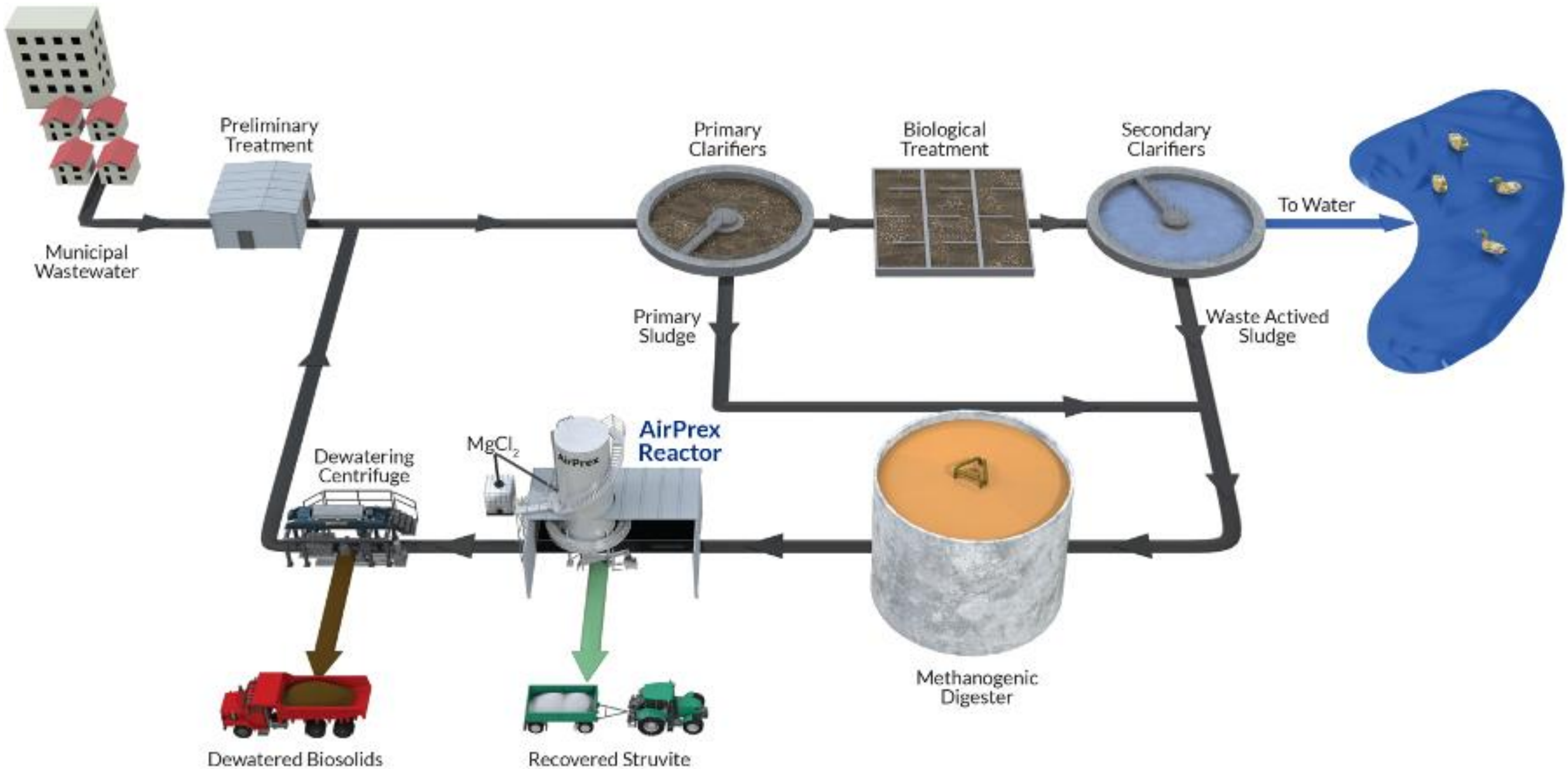
Source: Water Environment Research, 2016

Investigations into Improving Dewaterability at a Bio-P/Anaerobic Digestion Plant

Rebecca Alm[1], Adam W. Sealock[1], Yabing Nollet[1], George Sprouse[1]*

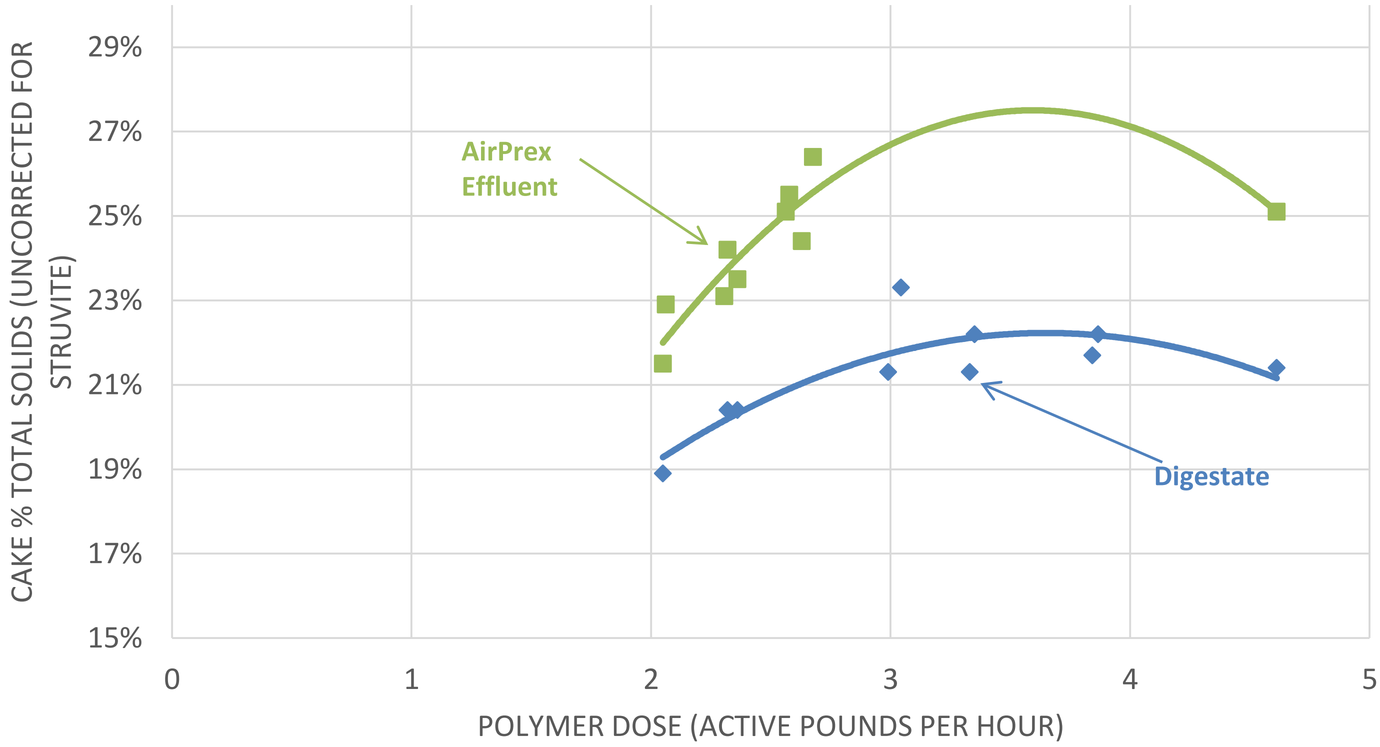


AirPrex



source: www.tpomag.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

THE Water Research FOUNDATION

www.werf.org

HRSD

Cleaning wastewater every day for a better Bay.

Clean Water Services

Denver Metro

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