Thermal Process Systems

Targeted Phosphorus Recovery

Patent-Pending Technology

NEWEA
2019 Spring Meeting
June 3rd, 2019

Wentworth by the Sea, New Castle, NH

THERMAL PROCESS SYSTEMS

Phosphorus in Wastewater

AnAer Pilot

Targeted Phosphorus Recovery

Questions

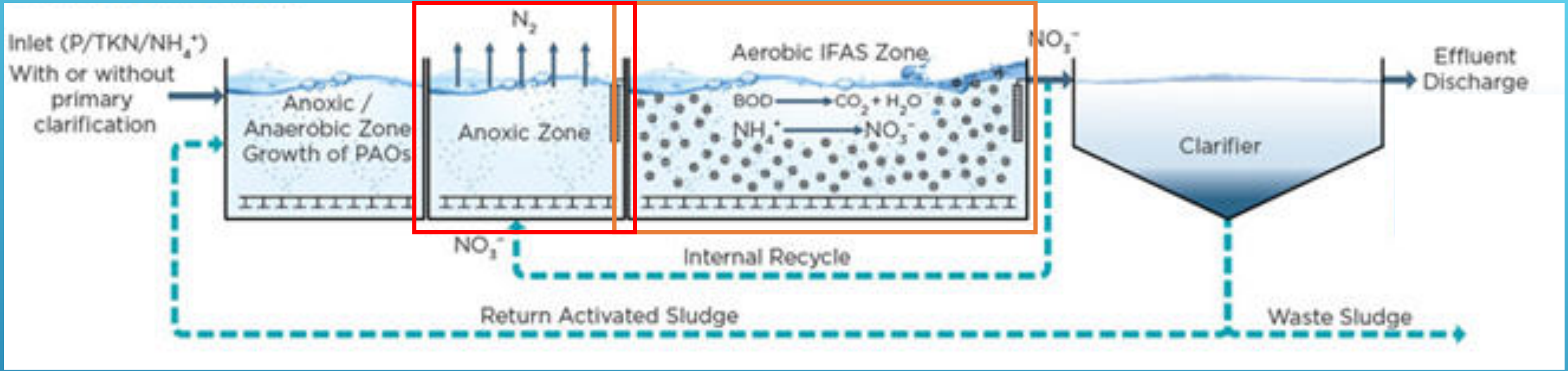
An exceptionally dense bloom in lower Chesapeake Bay on 8/17/2015.
Source: W. Vogelbein/VIMS.

BACKGROUND

Phosphorus in Wastewater Treatment

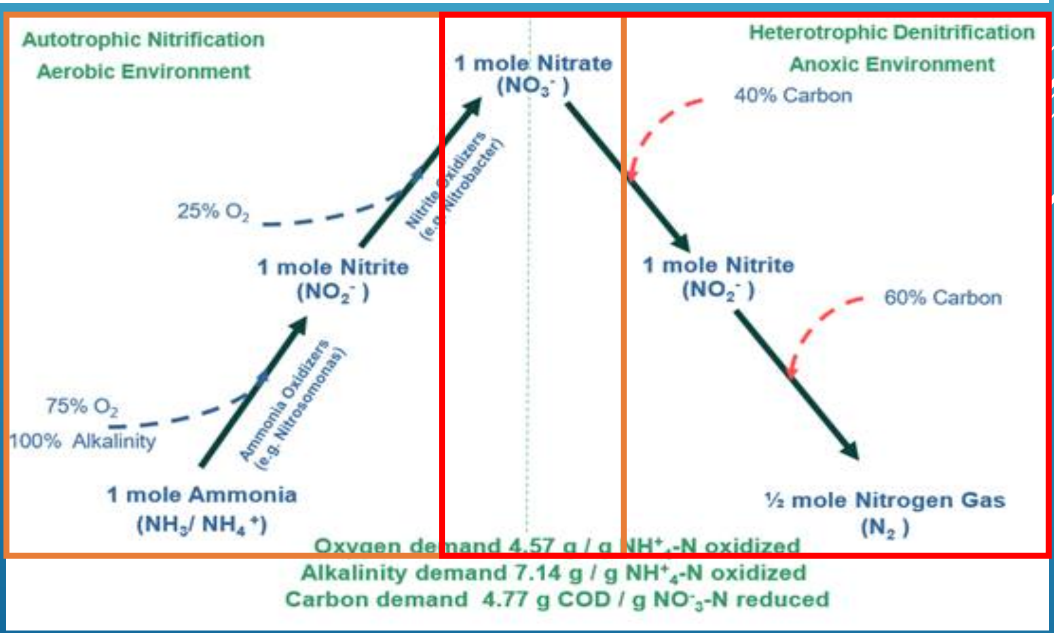
- Nutrient imbalances in soil a result of land applied biosolids
- Leaching to waterways has resulted in harmful effects
- Current regulations limit the amount of phosphorus in effluent streams
- Common practice is shifting phosphorus from liquid waste to solid waste e.g. ferric or alum precipitation
- Does not remove the potential of phosphorus to contaminate waterways later in its lifecycle

EBNR
Nitrogen Removal



Source: www.wateronline.com/doc/biological-nutrient-0001

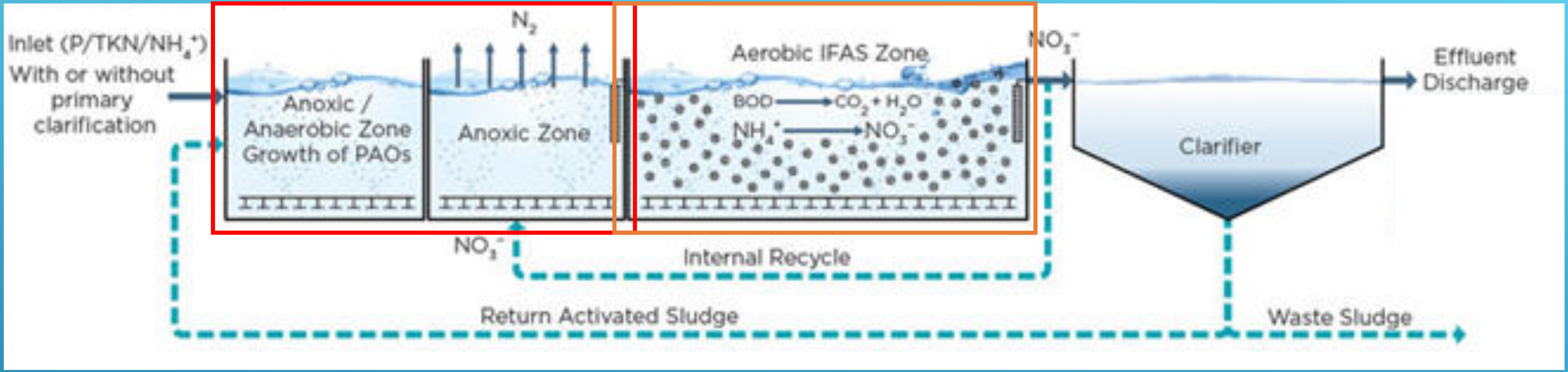
- Aerobic Nitrification
- Anoxic Denitrification
- N is emitted from the system as N_2 gas
- Process recycle streams



Source: Pugh, 2015

EBNR

Phosphorus Removal

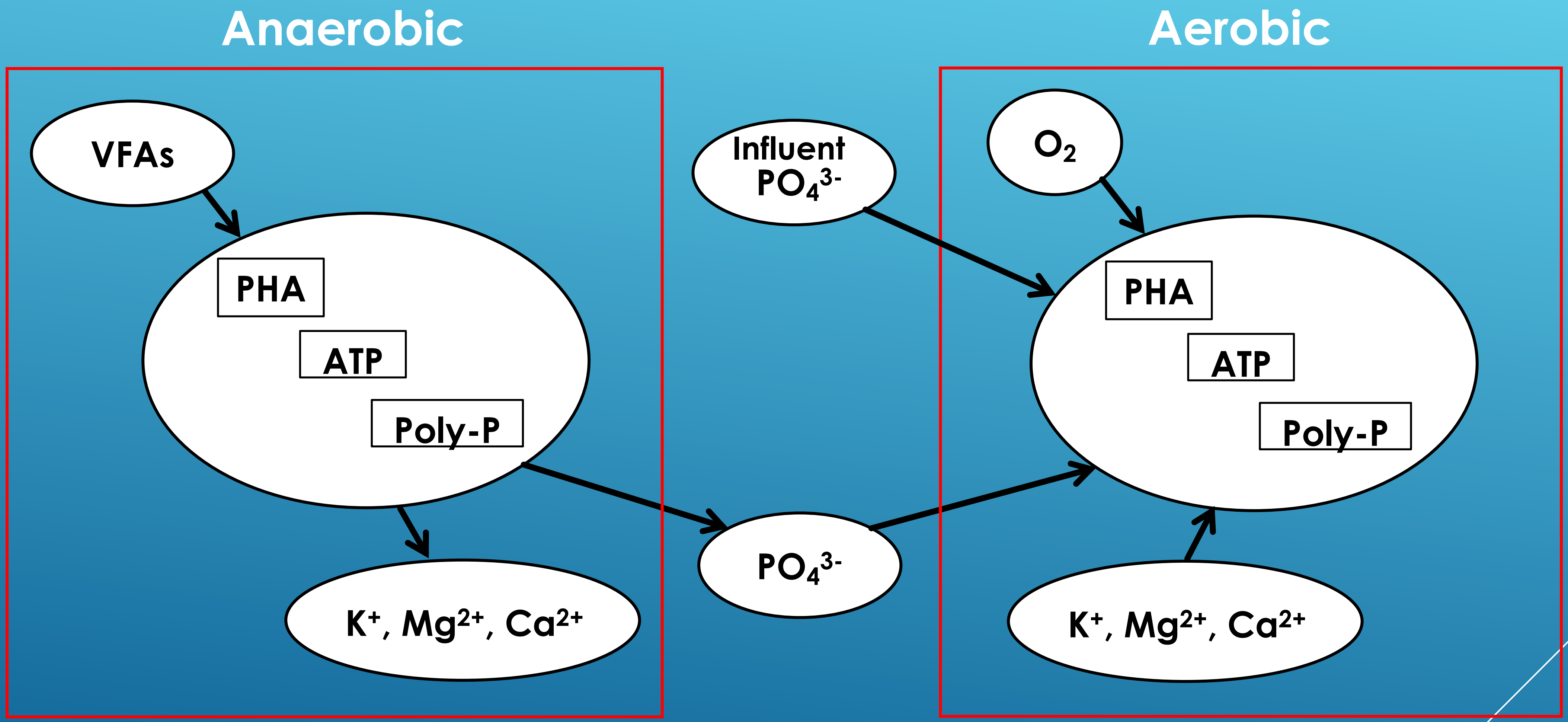


Source: www.wateronline.com/doc/biological-nutrient-0001

- Anaerobic growth of Phosphorus Accumulating Organisms (PAOs)
- Aerobic uptake of phosphate (PO_4^{3-})

EBNR

Phosphorus Accumulating Organisms



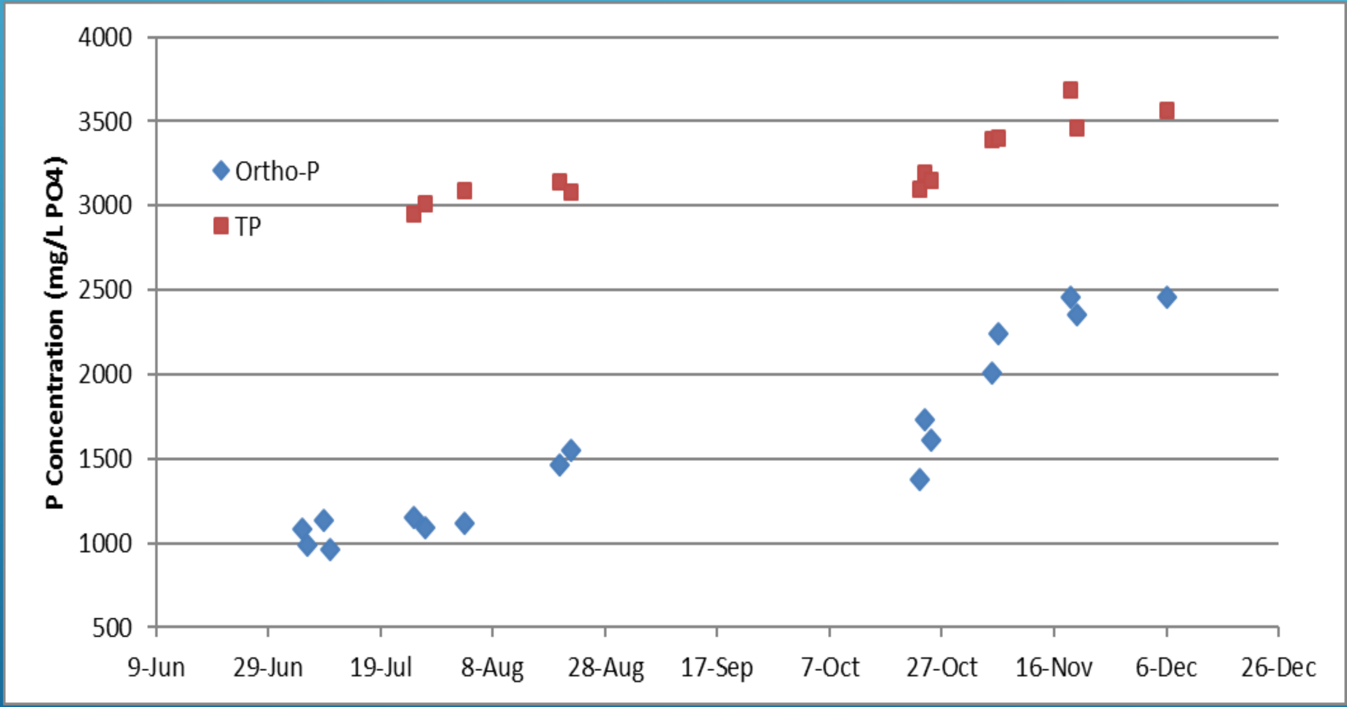
A BIG ISSUE HIDING IN PLAIN SIGHT

EBNR is very effective at removing P from wastewater

BUT…

It concentrates all that P into the solids that enter the digestion process

- Cell lysis and bacterial decay rupture cell membranes and release contents
- Phosphate precipitates have become a big operational concern
- PAOs are rich in all the ingredients
- Easy for plants to recycle large amounts of P causing a "cycle up"
  - Need to maintain removal of influent P, even at lower levels

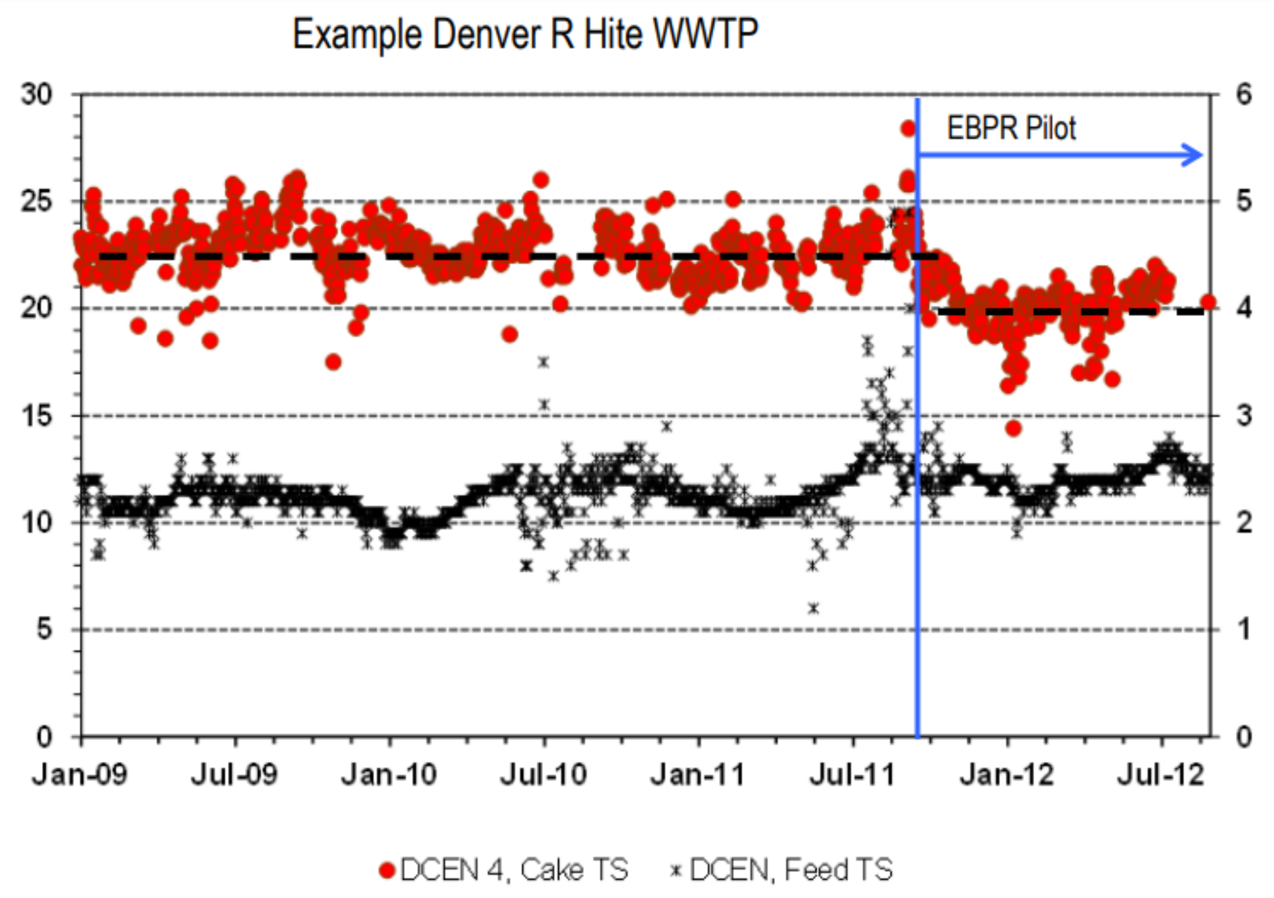


Aerobic Digester P levels at a BNR facility

BIOSOLIDS DEWATERING

The Effects of Phosphorus

- Increase in P corresponds with decline in dewatering performance
  EBNR facilities especially susceptible
- Several compounding factors
  - Availability of ortho-P
  - Mono- to Divalent ratio (M/D)
  - Extracellular Polymeric Substances (EPS)



Source: Benisch, 2015

BIOSOLIDS DEWATERING

Phosphorus Availability and M/D

- High concentrations of ortho-P increase the chances of precipitates forming

  Struvite: $K_{sp} = -\log([Mg^{2+}][NH_4^+][PO_4^{3-}])$

  Brushite: $K_{sp} = -\log([Ca^{2+}][HPO_4^{2-}])$

- Increase in M/D results in poorer dewatering

$$\frac{M}{D} = \frac{Na^+ + K^+}{Mg^{2+} + Ca^{2+}}$$

Source: Kara, 2007

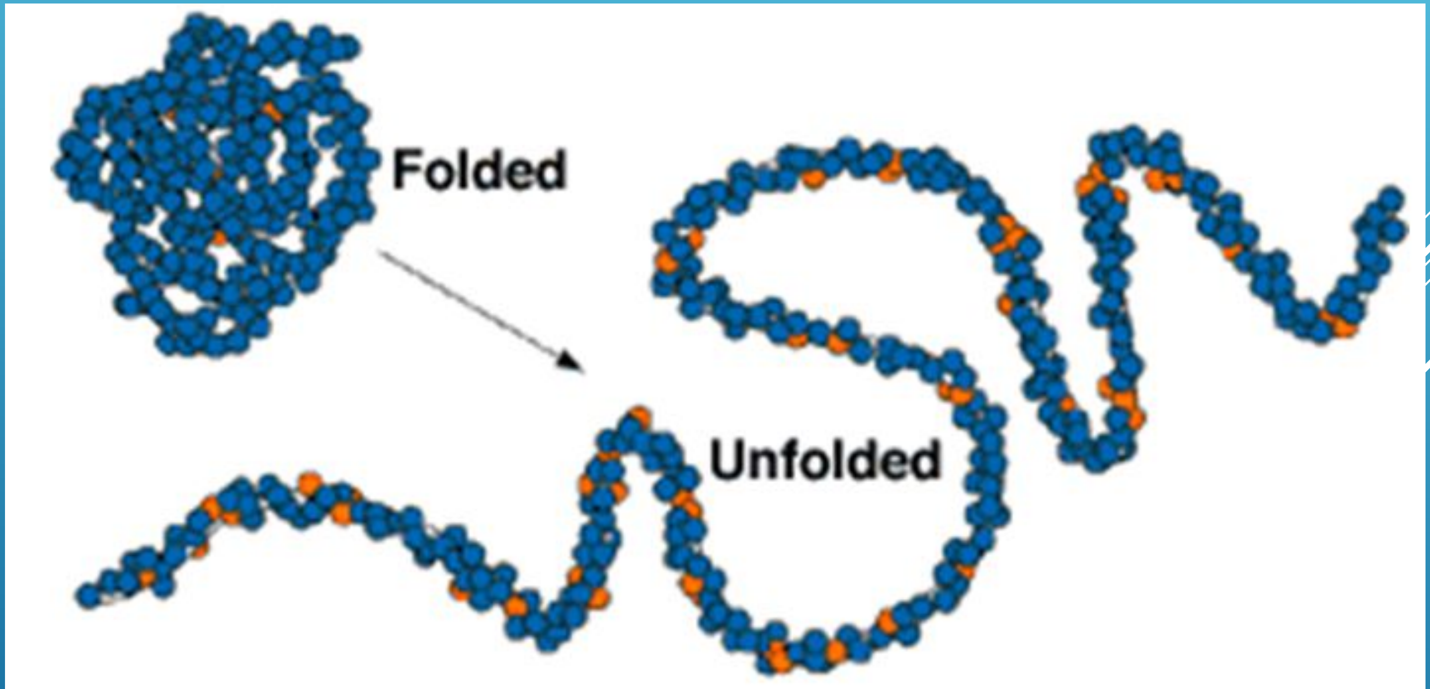
M/D increases when Na^+ or K^+ increase, Mg^{2+} or Ca^{2+} decrease

Divalent P precipitates have negative effects on dewatering

BIOSOLIDS DEWATERING

Extracellular Polymeric Substances

- EPS is a combination of macromolecules excreted by bacteria
  - Negatively affects dewatering because of high stored water content
  - Primary macromolecules are polysaccharides and proteins
- Ortho-P adheres to proteins
  - Unfolds proteins; used in food processing to stabilize emulsions
  - Expands EPS
  - Allow more space for water storage → poor dewatering



Sources: Selling; Rus, 2016

MANAGING P IN DIGESTION

- P recovery technologies target struvite and brushite formation
  - e.g. Ostara®, Struvia™, AirPrex™, NuReSys™, CalPrex™, etc.
  - Often done as an intermediary or pretreatment step
- Many plants remove P during dewatering via metal salt coagulants
  - e.g. $Fe_2(SO_4)_3$ & $Al_2(SO_4)_3$
  - Forms a precipitate ($FePO_4$ & $AlPO_4$) that drops into the cake
  - P not precipitated returns to head of the plant in the filtrate, centrate, etc.

MANAGING P IN DIGESTION

- Continuously recycling P can cause a plant to "cycle up"
- Coagulant dosing optimized for dewatering may not capture all PO_4^{3-}
  - Excess recycled P may be minimal at first, but builds up to critical levels over time
  - PAOs reach a saturation point where effluent P limits cannot be met
- Metal salt addition during dewatering is constrained
  - Amount of metal salt required to precipitate all incoming P becomes very large
  - Lowers pH that brings corrosion concerns to dewatering equipment
  - Chemicals are expensive

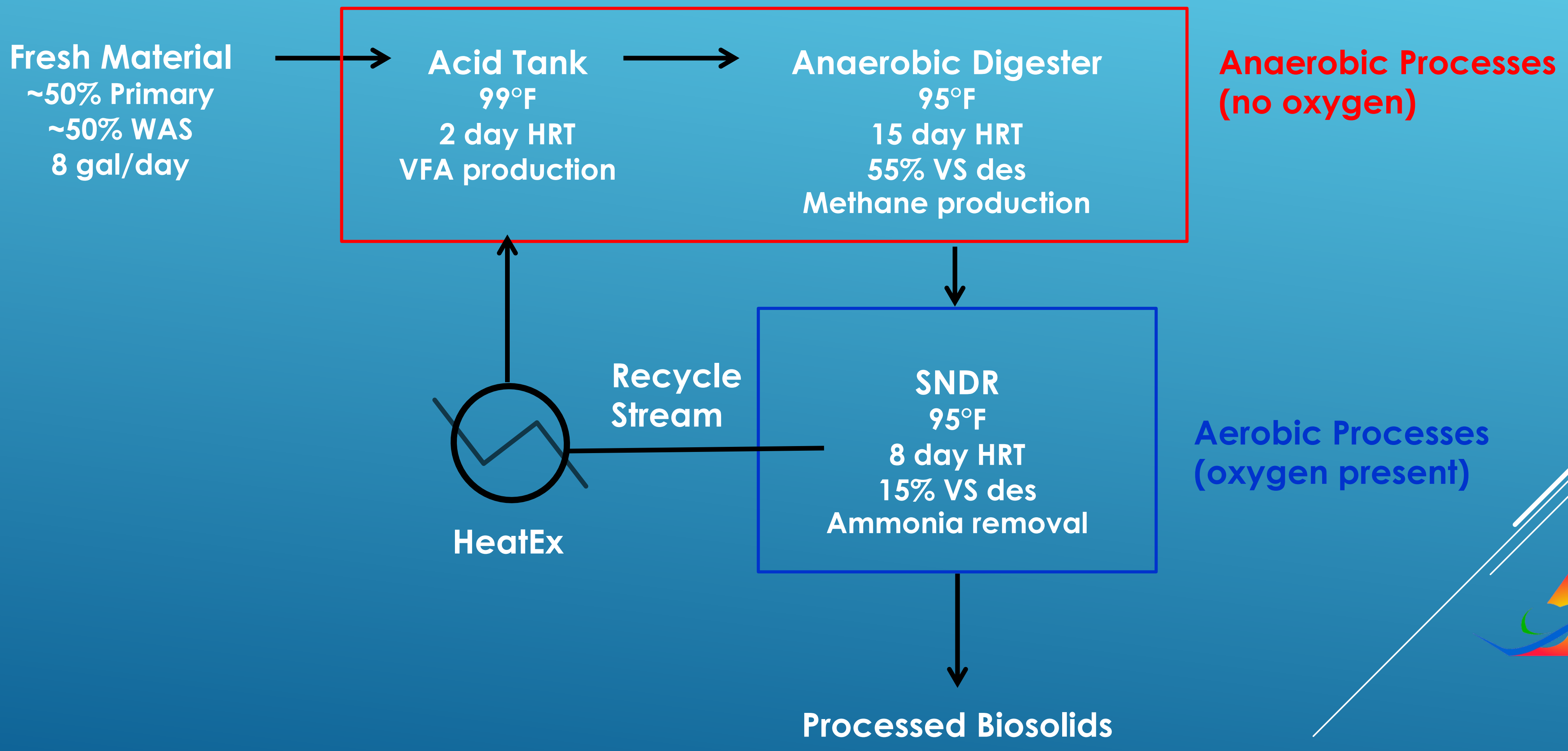
ANAER PILOT STUDY

Overall Goals

- Effectively combine anaerobic and aerobic digestion
- Create optimal environments for each of the different bacterial cultures
- Implement process control parameters to balance VFA production and conversion in the AD
- Decrease the overall HRT for the anaerobic digestion process with improved solids destruction and biogas production

ANAER PROCESS OVERVIEW

Flow Schematic



LAB RESULTS

Steady-State VS Destruction		
AD	SNDR	Total
57.7%	15.3%	64.3%

- Continued operation of the AD came with an increase in VS destruction
- Recycle maintained VFA/ALK under 0.3
- No spikes in VFA concentration or foaming events
- Low NH_3 and H_2S in biogas
- Biogas production is in upper end of literature values

AD VFAs and Alkalinity	
VFAs (mg/L)	938
ALK (mg/L)	3372
VFA/ALK	0.28
VFA Conversion	57%

AD Biogas Averages	
Hydrogen Sulfide (ppm)	21.0
Ammonia (ppm)	6.06
Carbon Dioxide (%)	38.1%
Methane (%)	61.9%
Biogas produced (ft^3/lb VS)	13.47

DEWATERING RESULTS

Sample	Total Solids (%)	Coagulant (mL Ferric Sulfate)	Flocculant (mL Polymer)	Cake Solids (%)	Coagulant (active lb/dry ton)	Flocculant (active lb/dry ton)
Pilot SNDR	1.90	0	5	28.7	0	10

- Fully mesophilic system yielded superior dewatering results
- Eliminated coagulant demand and significantly reduced polymer requirement
- High TS reduction and high cake solids lower amount of material to haul considerably
- AnAer system provides major benefits to dewatering operations

CURRENT OPERATION

Increased SNDR recycle from 60% to 200% of daily feed

- Consistent VS destruction & biogas production
- H_2S in biogas has lowered to <1ppm
- Ammonia decreased from 1500 mg/L to 500 mg/L
- Maintaining lower NH_3 keeps pH slightly lower; 7.2 → 6.7
- Lower ammonia and pH both decrease struvite potential

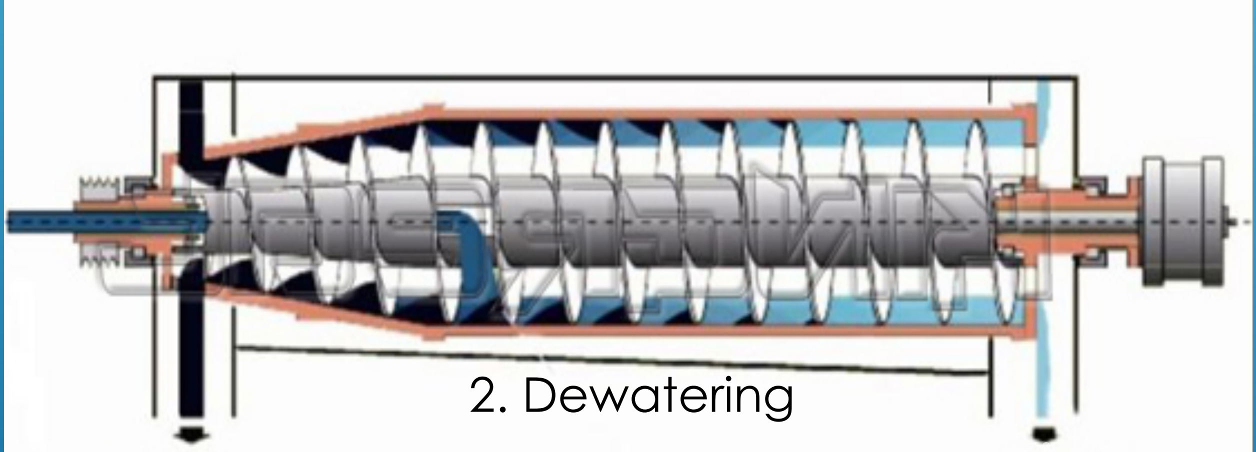
TARGETED PHOSPHORUS RECOVERY
A NEW APPROACH TO P MANAGEMENT

- Researching new methods for biosolids dewatering
- Begins with digestion – “solids conditioning”
- Address multiple issues negatively affecting dewatering
- Reduce chemical costs
- Form a product

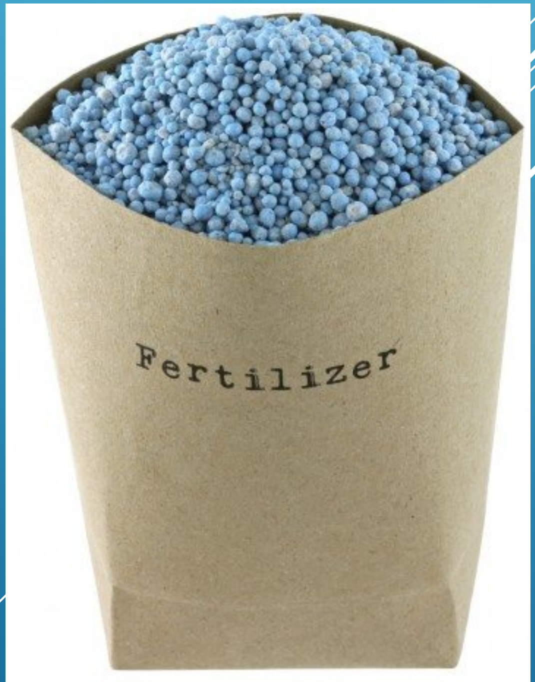
A NEW APPROACH

SNDR
~2.25 TS

1. Conditioning



2. Dewatering



3. P Recovery

SOLIDS CONDITIONING

Storage Nitrification/Denitrification Reactor (SNDR)

- Developed to remove ammonia during digestion
- Also efficient at removing soluble COD, VFAs, proteins, and carbohydrates
    - Breaking up proteins and carbohydrates (polysaccharides) disrupts the production of EPS that negatively affects dewatering
- Reduces alkalinity through nit/denit cycles
- Effective when following ATAD or anaerobic digester

DEWATERING

SNDR following anaerobic digestion

- Pilot research shows elimination of coagulant requirement
- Low polymer dose → ~10 active lbs/dry ton

SNDR following ATAD

- Cell lysis in the ATAD creates strong emulsion
- Coagulant is needed to break the emulsion
- 10-20% reduction in polymer demand

DEWATERING

Replacement of coagulant with strong acid

- Acid acts as a coagulant through charge neutralization
  e.g., H_2SO_4 vs $Fe_2(SO_4)_3$ & $Al_2(SO_4)_3$
- Acid hydrolysis ruptures cells, releasing stored P
- Lowers pH which prevents precipitates from forming
  Mg^{2+} and Ca^{2+} remain soluble → lower M/D
- Lower alkalinity = less acid required → SNDR is key

DEWATERING

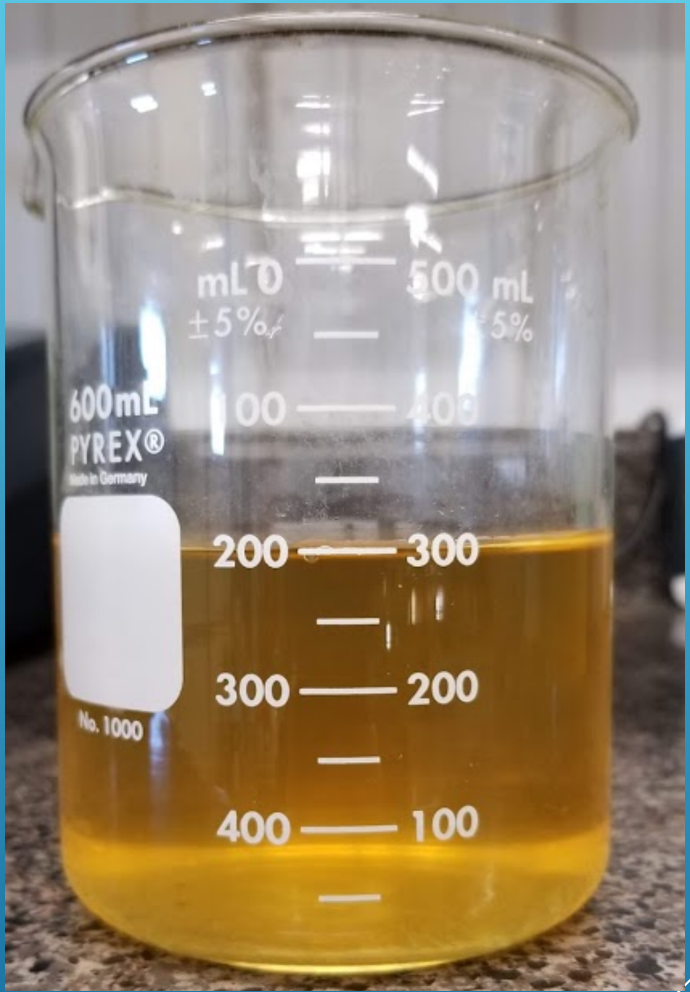
- Ensure pH is at safe level for dewatering equipment
- Smaller H^+ ions coagulate solids without forming large precipitates that add to cake weight
- Less material to bind → less polymer
- Balances cake N/P ratio
- Lab testing shows >30% decrease in cake weight
- Centrifuge dewatering achieved >35% cake solids

TPR Ferric

DEWATERING

Filtrate

- Liquid-solid separation results in P rich filtrate, centrate, etc.
- Minimal alkalinity and biological activity remaining
- Absence of solids removes "contaminants" that lower P recovery efficiency

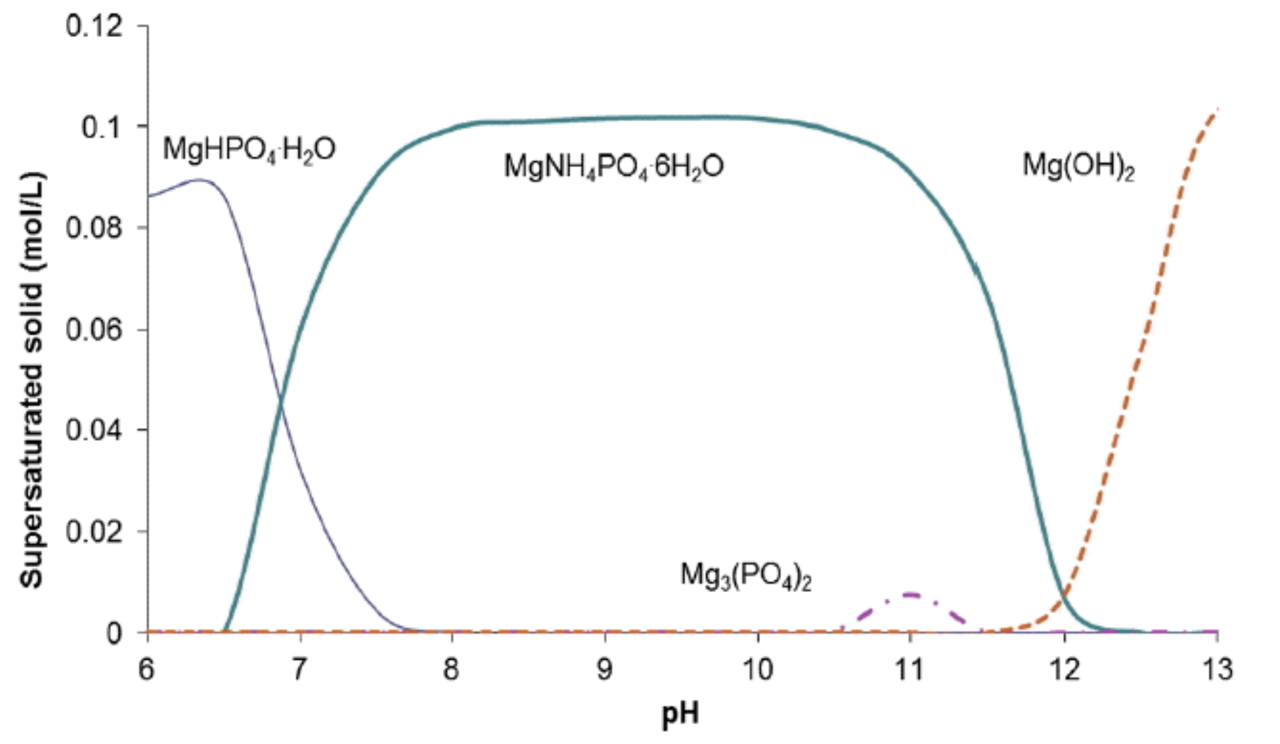


Phosphorus rich filtrate

PHOSPHORUS RECOVERY

Chemical Precipitation

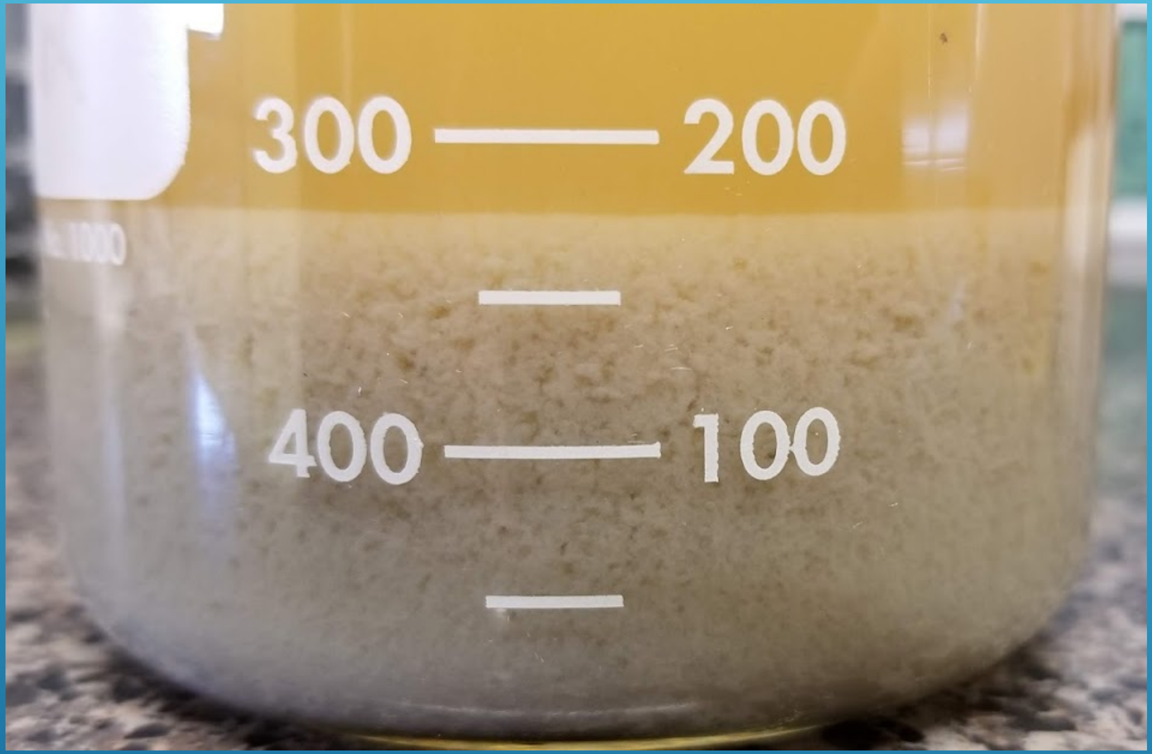
- High P liquid stream with little pH buffer
- Target either brushite or struvite formation
- Precipitate readily forms at right conditions
- Soluble Ca^{2+} and Mg^{2+} already present reduce chemical demand

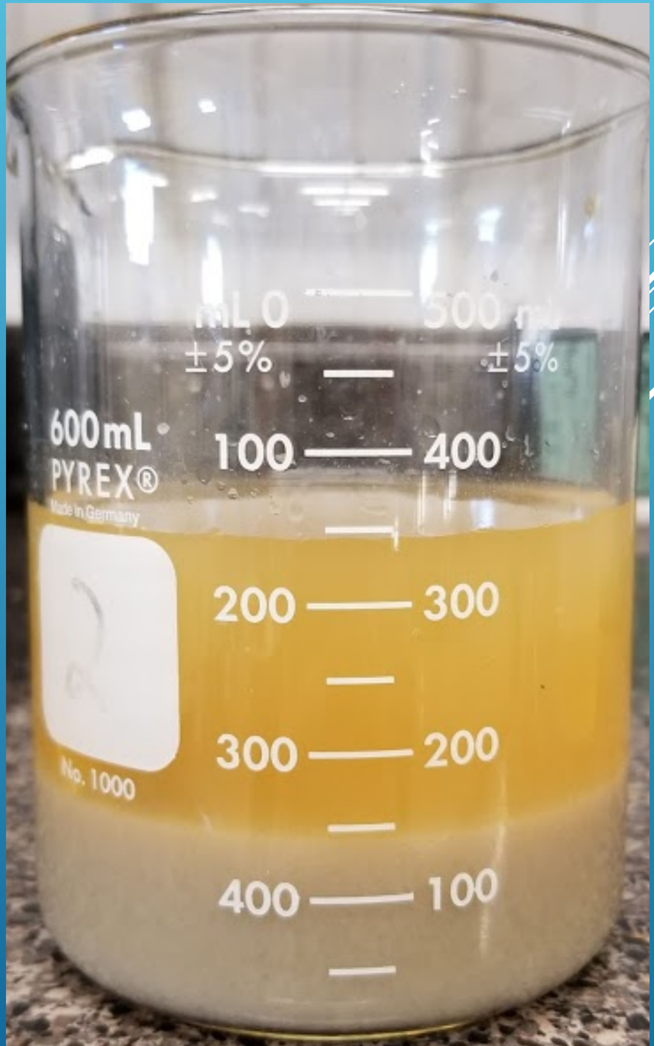


Struvite Solubility Curve
Source: Kim, 2016

PHOSPHORUS RECOVERY

Chemical Precipitation



TARGETED PHOSPHORUS RECOVERY

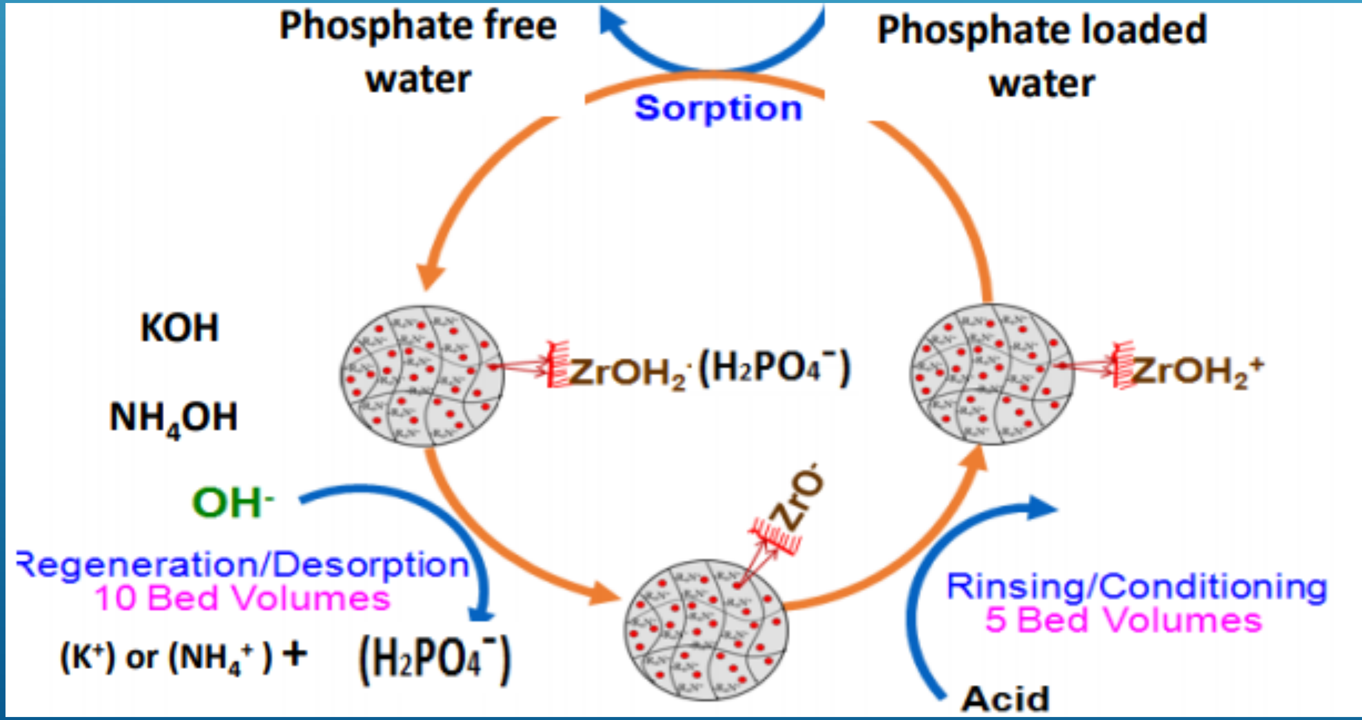
Lab Testing Results

	Low	High	Average
Total Phosphorus Solubilized	74%	96%	83%
Soluble Phosphorus Precipitated	91%	93%	92%
Total Phosphorus Removed	72%	89%	79%

PHOSPHORUS RECOVERY

Ion Exchange

- Liquid centrate can be passed through an ion exchange column
- Hybrid Ion Exchange Nano-Absorptive Media (HIX-Nano)
  Utilizes iron or zirconium oxides for ortho-P affinity
- More effective at lower pH

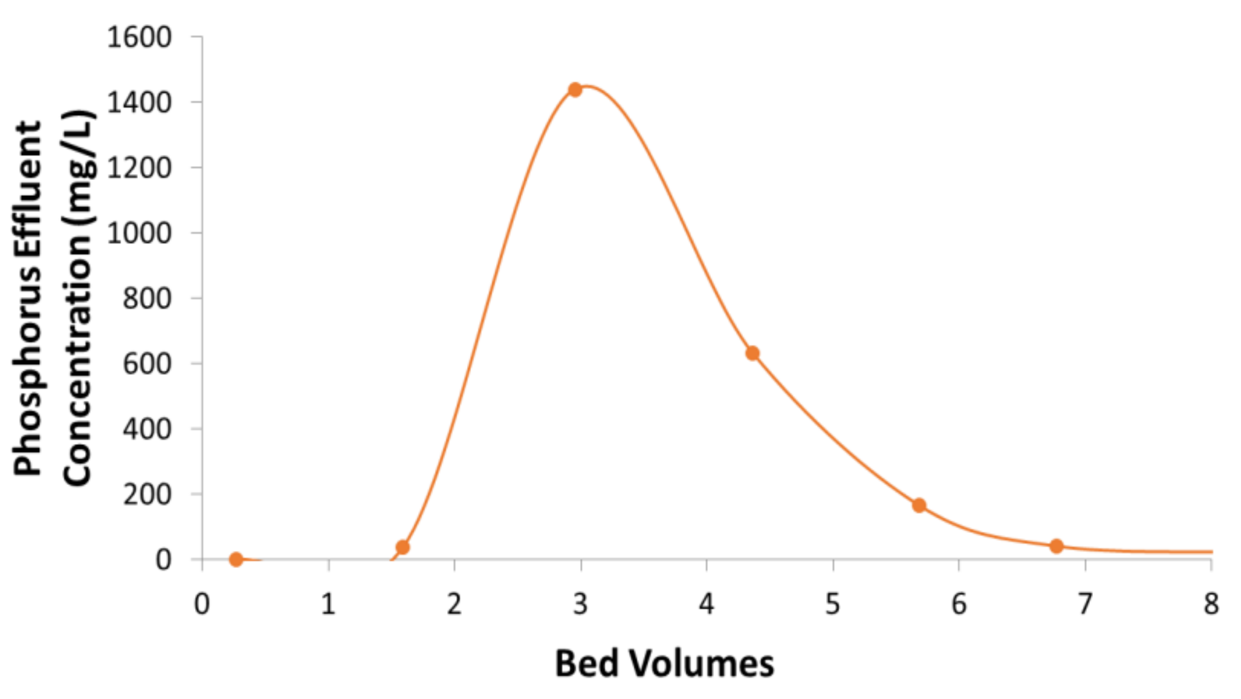


Phosphate sorption and release
Source: Weinberg, 2017

PHOSPHORUS RECOVERY

Ion Exchange

- HIX(Fe)-Nano captures ortho-P and releases a concentrated solution to storage tank
- Ortho-P selectivity removes contaminants from effluent
- Concentrated P solution is ideal for making valuable products
  - Hydroponic fertilizers
  - Fluidized catalytic cracking catalysts
  - Lithium-ion battery cathode material



Source: Weinberg, 2017

IDEAL TPR SYSTEMS

Enhanced Biological Nutrient Removal
Phosphorus uptake by bacteria

Low P Return

Low P Return

Acetic Acid

Acid Phase Digester
Acid hydrolysis
Phosphorus Release

Anaerobic Digester
VS & COD Destruction

SNDR
Nitrification/Denitrification
EPS Reduction
Alkalinity Reduction

TPR
Dewatering

Low P Cake

P Product

ATAD
Thermal hydrolysis
Phosphorus Release
VS & COD Destruction

SNDR
Nitrification/Denitrification
EPS Reduction
Alkalinity Reduction

TPR
Dewatering

Low P Cake

P Product

IDEAL TPR SYSTEMS

SNDR after Anaerobic Digester

- SNDR recycle helps prevent formation of EPS in AD
- Biosolids don’t require coagulant to dewater
- Lowering P return to headworks begins to “cycle down” plant
- Combines with lower NH_3 and pH in AD to significantly reduce precipitation potential

SNDR after ATAD

- SNDR greatly improves dewatering of ATAD material
- Lowering P return to headworks begins to “cycle down” plant

SUMMARY

Phosphorus in Wastewater

- EBNR moves P from water effluent to bacteria
- P and micronutrients are released during digestion
- Increases in P result in decline in dewatering performance

AnAer Pilot Study

- Implements effect process control for anaerobic digestion
- Demonstrated significant reduction in material hauling
- Reduces precipitation potential

Targeted Phosphorus Recovery

- Conditioning material is critical to providing a “cleaner chemistry”
- “Target” P to remain soluble through dewatering
- Removes expensive standard coagulants
- Improves dewaterability of biosolids
- Multiple routes for recovering P after dewatering

WHAT'S NEXT?

AnAer

- Complete steady-state operation
- Install & operate on-site pilot
- Continue patent-approval process

Targeted Phosphorus Recovery

- Continue lab research to optimize current process
- Install & operate on-site pilot at ThermAer™ facility
- Continue patent-approval process

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Thank you!

Questions/Comments?

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