Innovative Process for Granulation of Continuous Flow Conventional Activated Sludge

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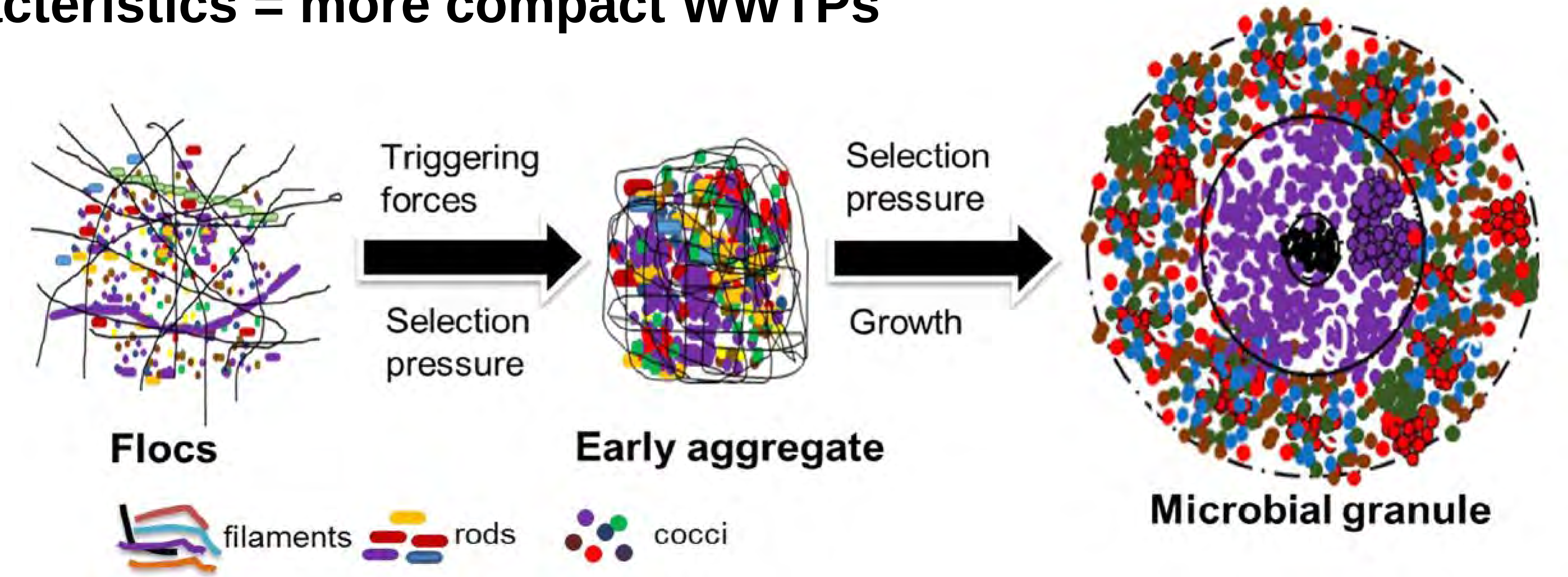
Introduction

- **The objective of this presentation is to:**
- **Introduce Aerobic Granular Sludge (AGS), including mechanisms for formation and benefits**
- **Discuss “conventional” application of AGS**
- **Review the development of a continuous-flow granular sludge process for BNR**

What is Granular Sludge?

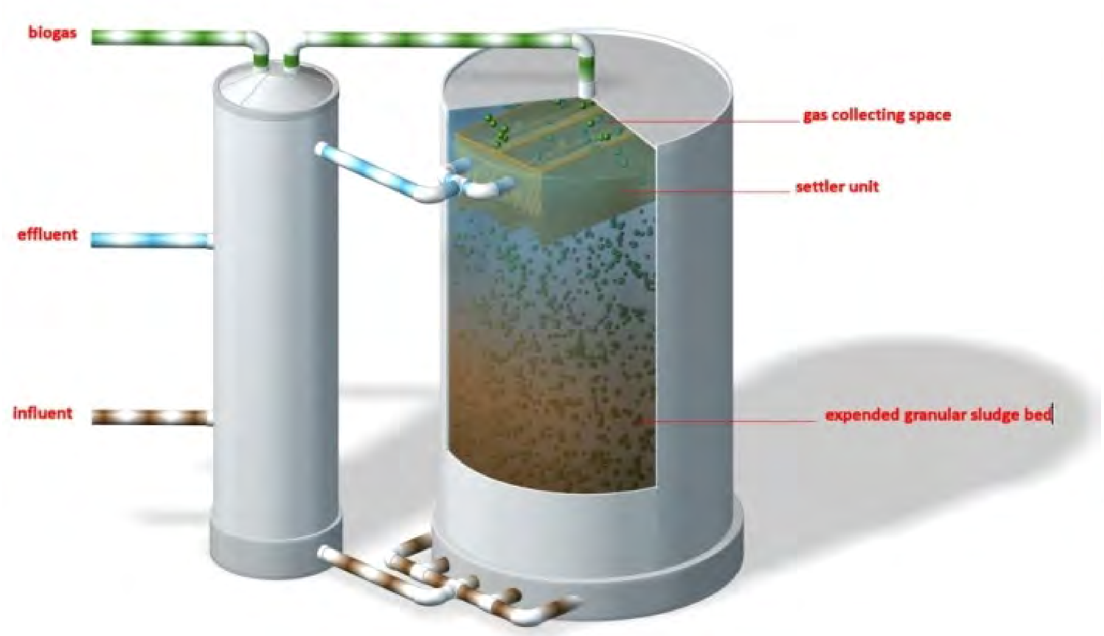
- Sludge granule is a tightly aggregated mass of microorganisms in a matrix of extra polymeric substances (EPS)
- A cross between floc and fixed film growth
- Their large size (> 0.2mm) and density allow for excellent settling characteristics = more compact WWTPs

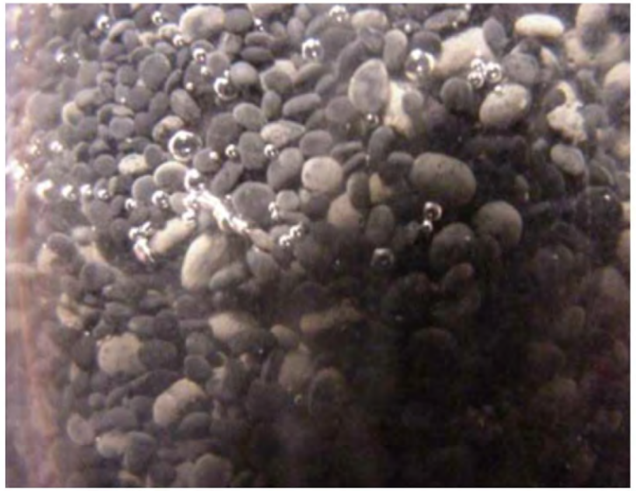


Reference: Sarma, S.J. et al., 2017. Finding knowledge gaps in aerobic granulation technology

Granular Sludge Relies on Dominance Slow Growing Microorganisms

- Treatment processes that rely on slow-growing bacteria are better at granulation
- Anaerobic systems were the first granular sludge processes developed (Biothane™, Biobed™) to treat high strength soluble COD waste



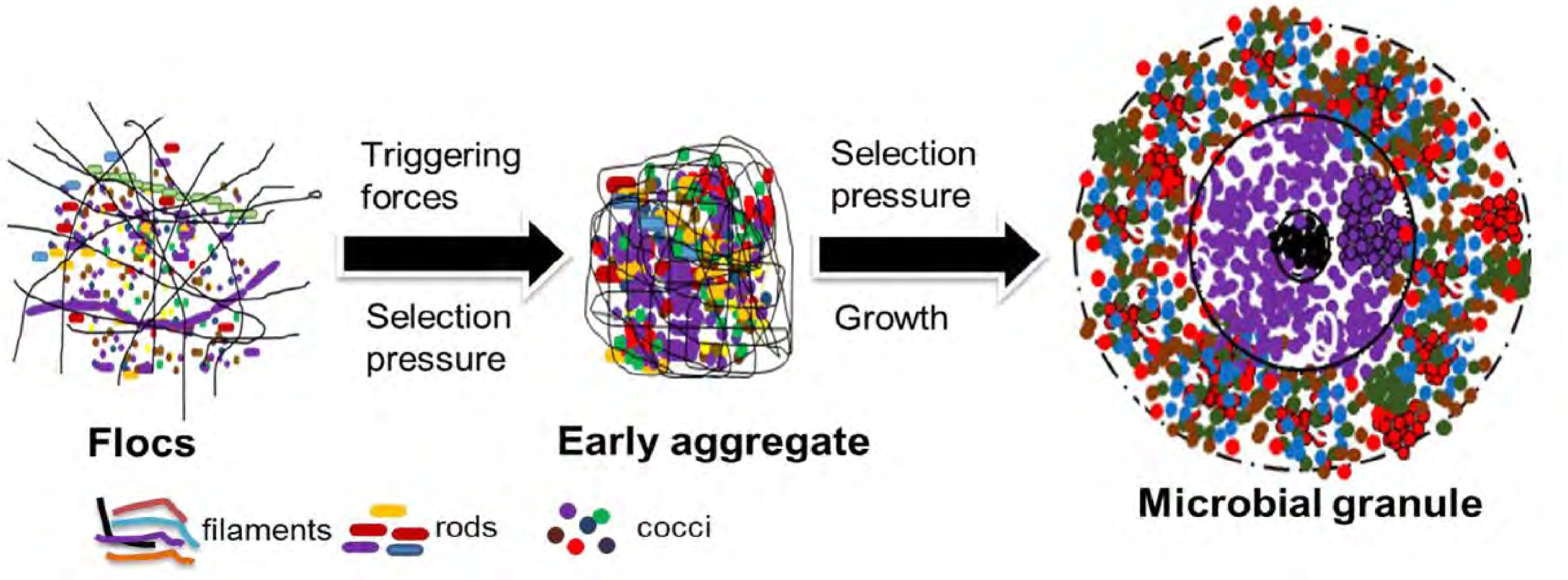


Anaerobic granules supporting acid formers & methanogen growth

Reference: van Lier, J.B. et al., 2015. Celebrating 40 years anaerobic sludge bed reactors for industrial wastewater treatment

Aerobic Granular Sludge

- Developing aerobic granular sludge (AGS) for treating domestic wastewater has been more challenging
- Growth from floc to granule in an aerobic environment more complex

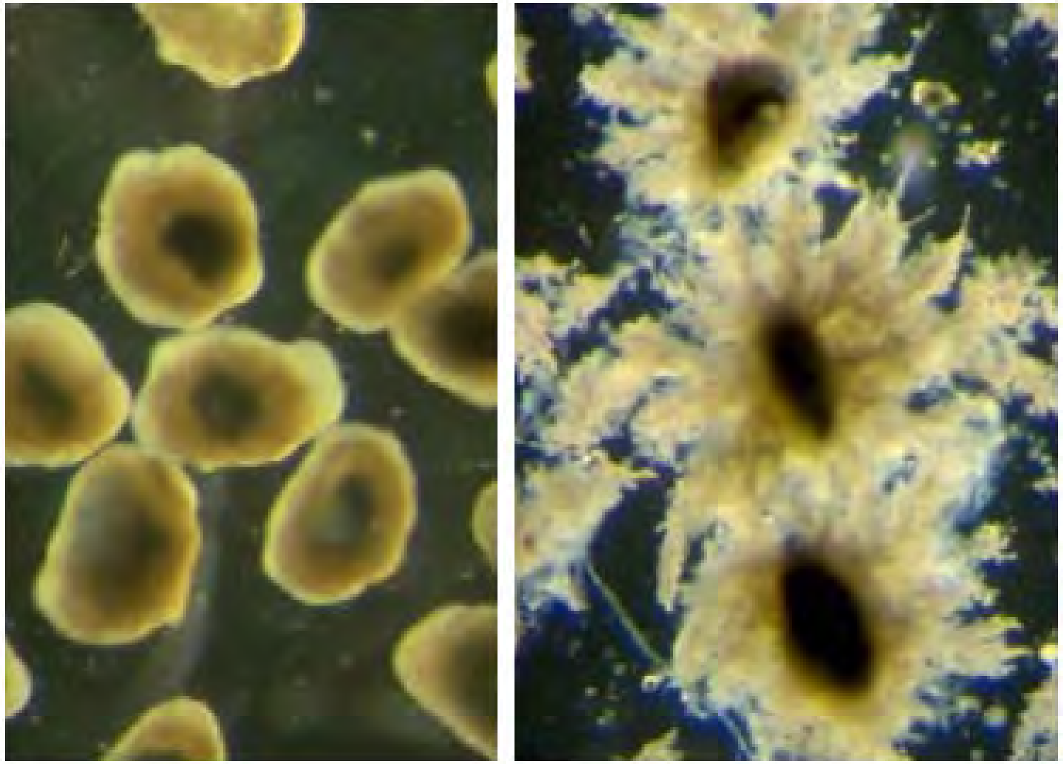


Reference: Sarma, S.J. et al., 2017. Finding knowledge gaps in aerobic granulation technology

Slow Growing Organisms Enhance Granule Morphology

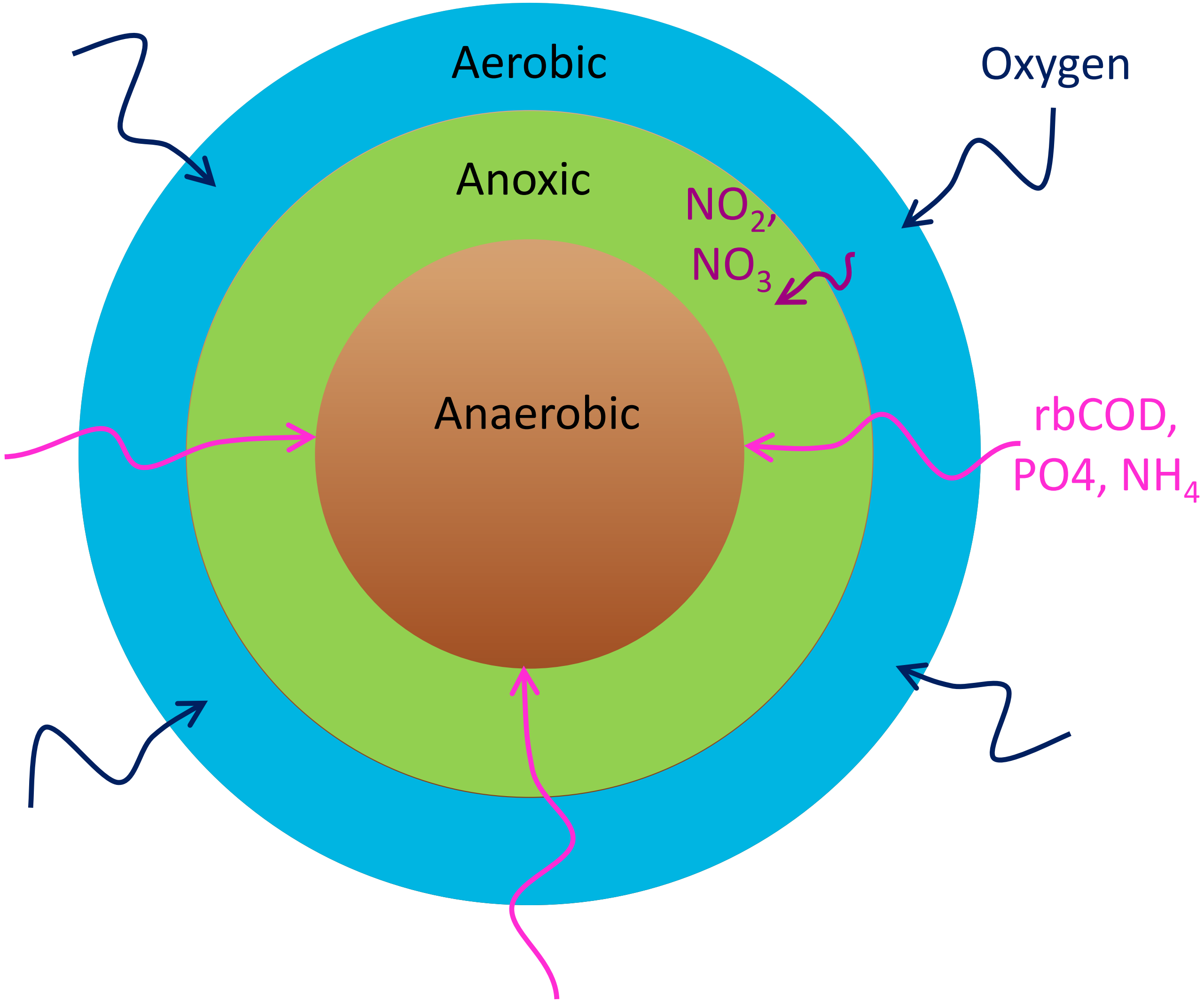
– **Feeding PE under anaerobic conditions selects for organisms that outcompete filamentous aerobic heterotrophs**

– **PAO's & GAO's do not have a filamentous morphology and allows for a reliably stable granule**



Reference: adapted from van Loosdrecht, M., 2013. Advances in Aerated Granular Sludge Technologies (WEF presentation).

Granule Porosity Both a Strength and a Vulnerability



- Porosity allows for diverse ecological niches and biological conversions
- Porosity a strength & vulnerability

Reference: adapted from Nancharaiah, Y.V. et al, 2018. Aerobic granular sludge technology: Mechanisms of granulation and biotechnological applications

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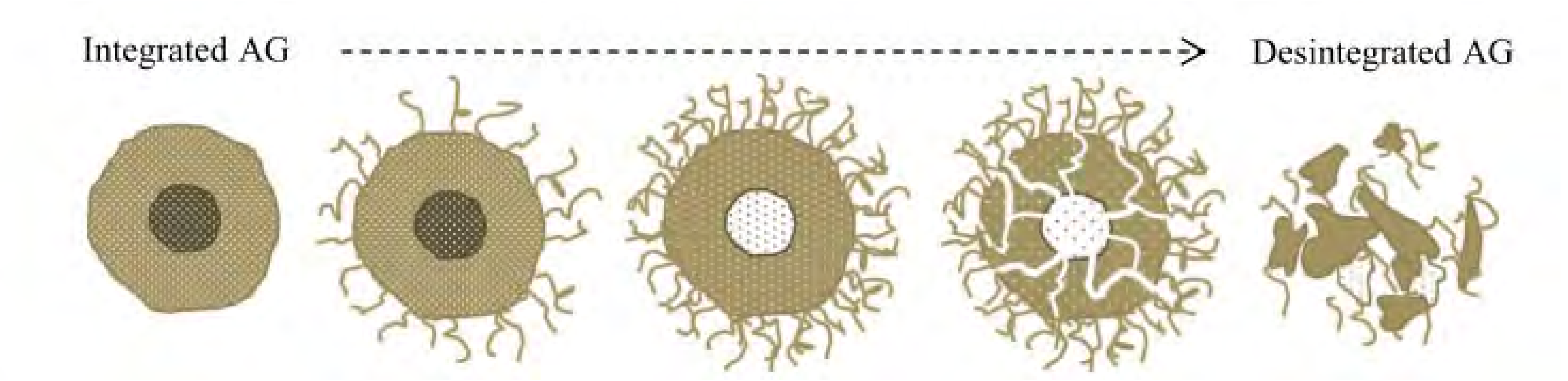
Granules Vulnerable with excessive attachment of fast growing organisms

– **Pores can be clogged by overgrowth of filamentous bacteria on the outer layer when rbCOD is present under aerobic conditions.**

– **Reduction of porosity reduces mass transfer, internal core is consumed & granule disintegrates**

– **Need to control fast growing bacteria typically found in activated sludge systems**



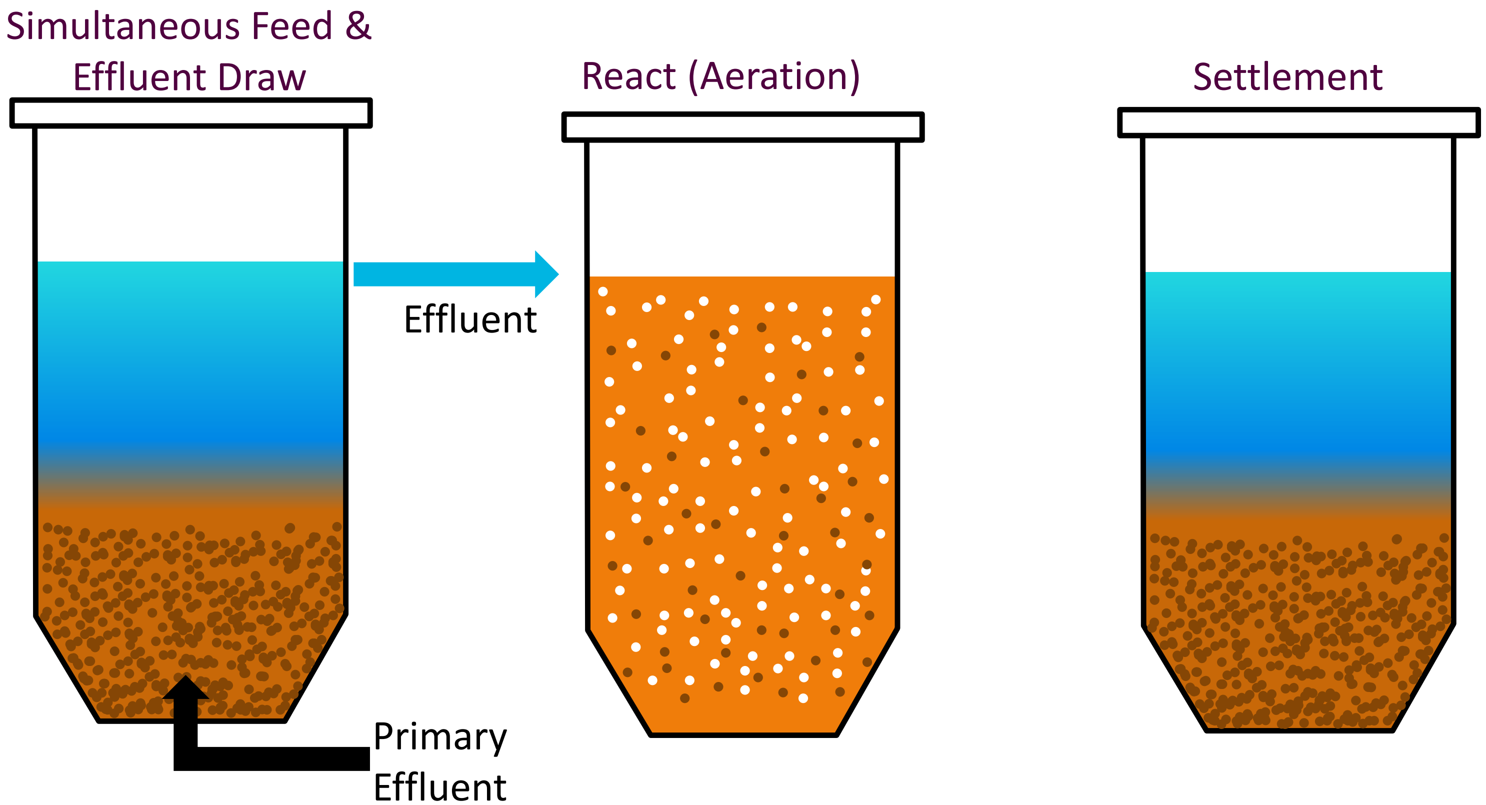
Reference: Franca, R.D.G. et al. 2018. Stability of aerobic granules during long-term bioreactor operation.

Nereda® - Batch "SBR" Granular Sludge

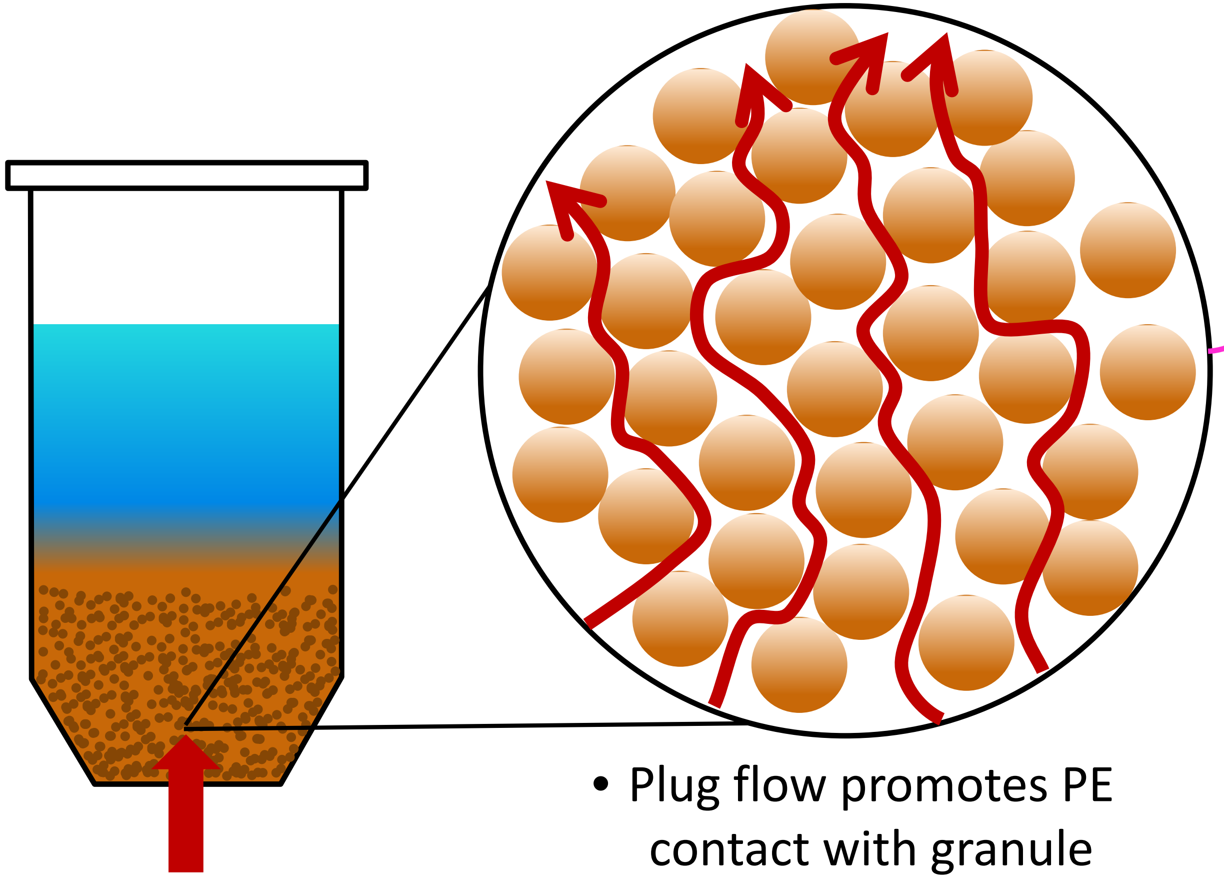
– **An important milestone in the development of AGS was adding an anaerobic selector – the 'Feast' stage**

– **Nereda®, the first commercialized AGS, uses a batch process**

– **After the aeration phase and sludge settles, PE is fed to the reactor**

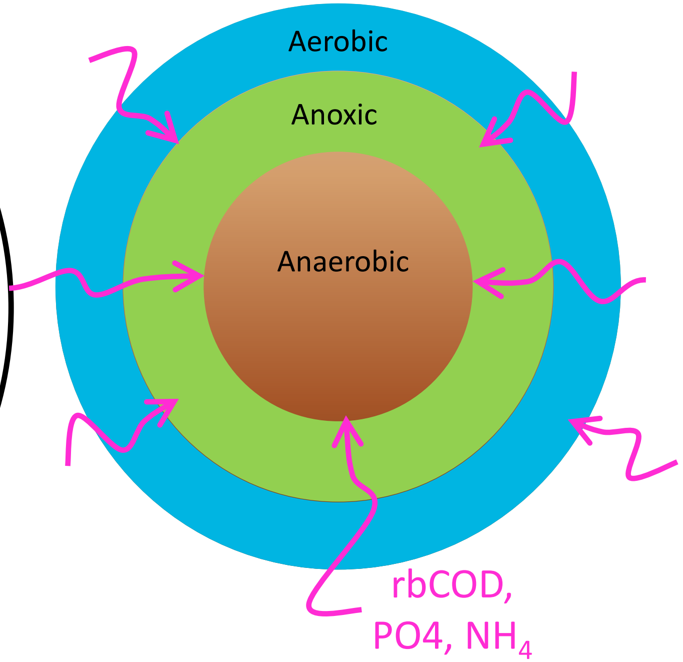


Promotes High rbCOD Concentration Contact with Granules to Overcome Diffusion Gradient & Feast Condition



Raw Influent or Primary Effluent

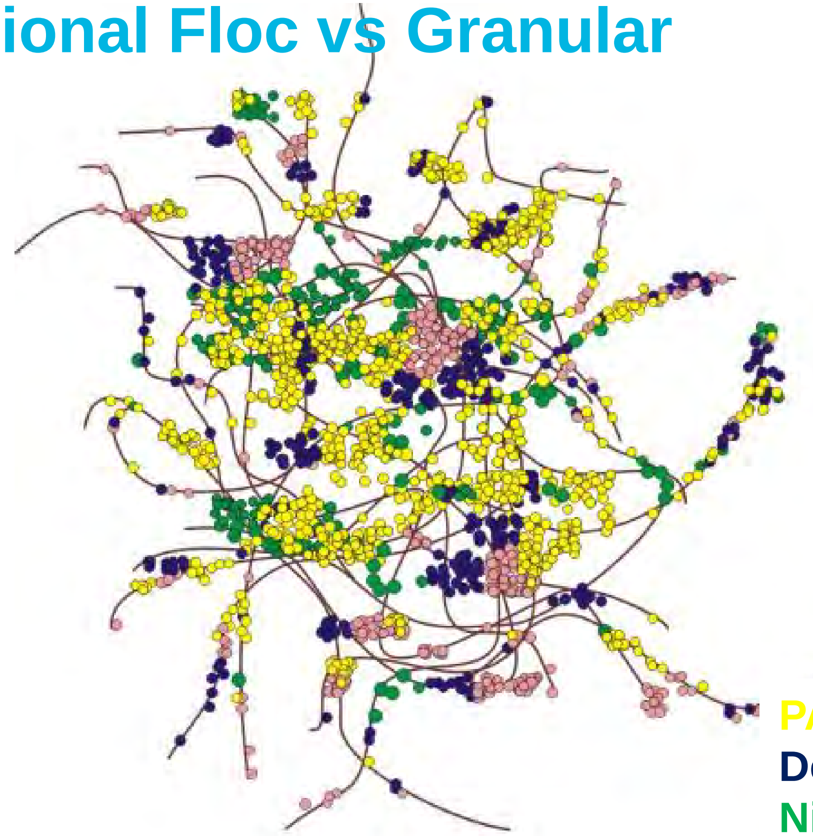
- Plug flow promotes PE contact with granule

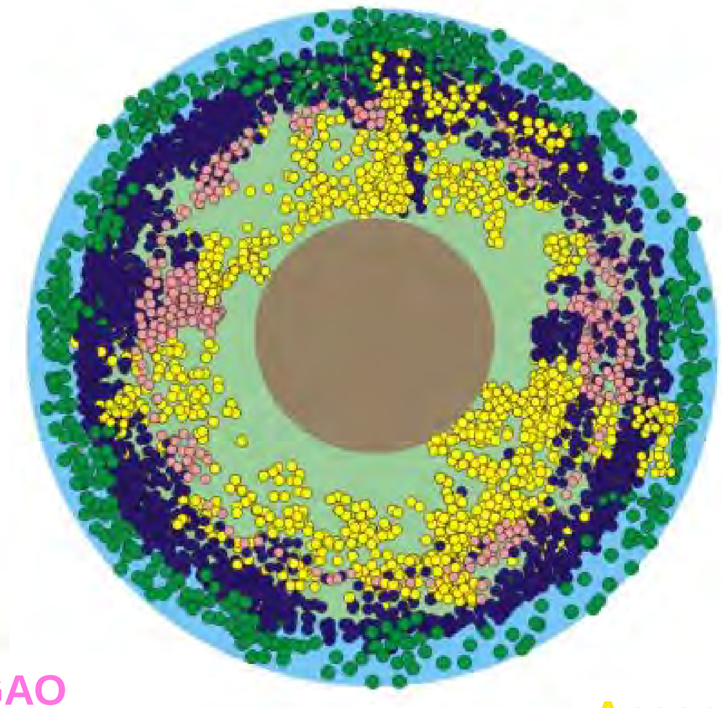


- PE contact overcomes any diffusion gradient

Reference: adapted from van Loosdrecht, M., 2013. Advances in Aerated Granular Sludge Technologies (WEF presentation).

Conventional Floc vs Granular





Characteristic	Floc	Granule
Settling	Compression	Discrete
Settling Velocity (m/h)	±1.0	5 – 50
Size	na	> 0.2 mm
SVI, 30 minutes	100 -150	< 60

Picture Courtesy Delft Technical University

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Nereda® Aerobic Granular Sludge

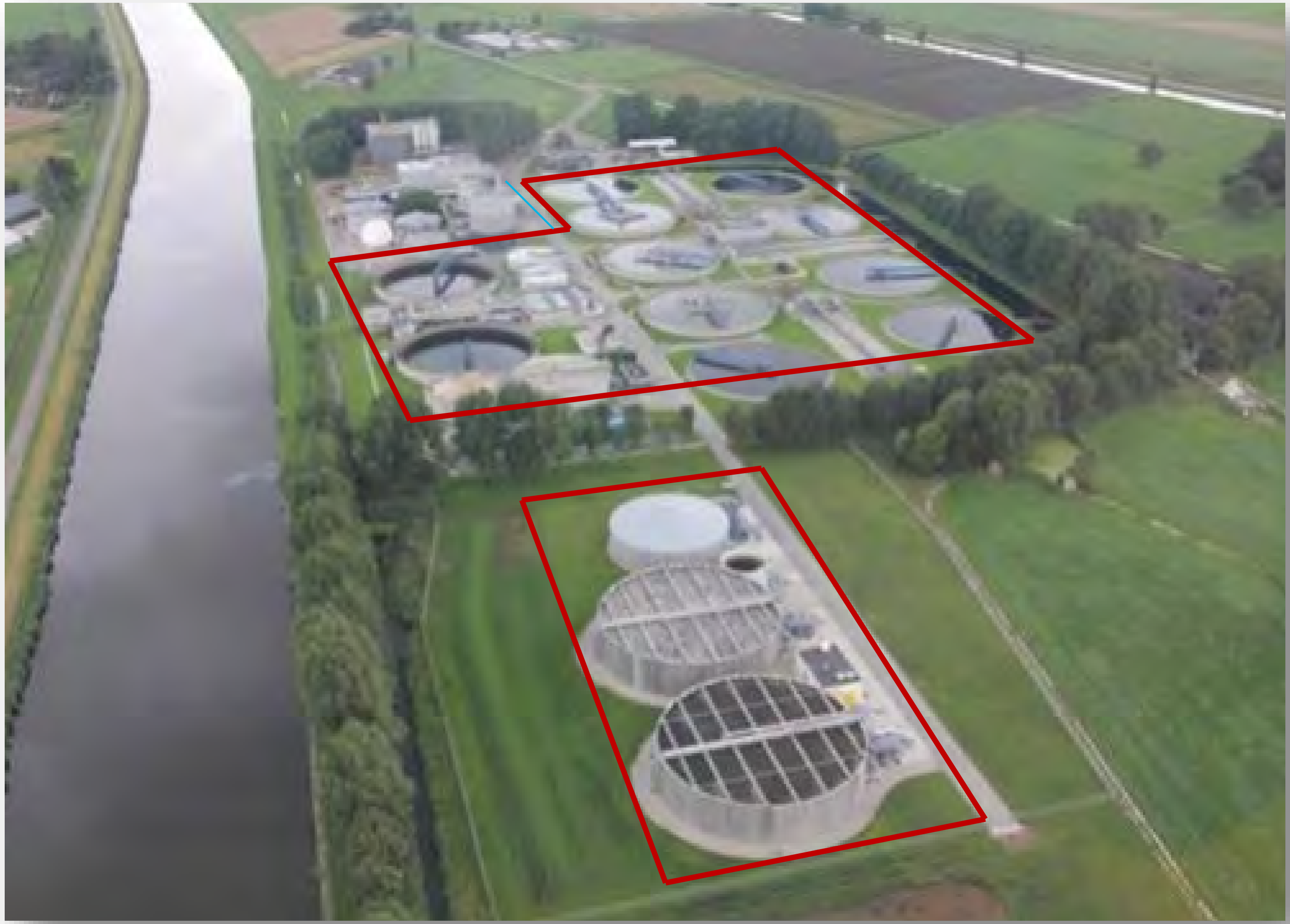
Nereda®
a product of Royal HaskoningDHV

- The settled volume of sludge after 5 minutes is similar to that after 30 minutes
- SVI 5 / SVI 30 ≈ 1.0

Dense Granules = Settle in 5 mins

Conventional Activated Sludge

Benefits of Aerobic Granular Sludge



Garmerwolde, NL WWTP Nereda
Footprint Advantage – 75% Footprint Reduction

<u>Garmerwolde STP</u>

– Nerada add-on designed for 40% of total plant flow .

– Treating 8-10 mgd on average in two 2.5 MG reactors.

– 55% of total plant flow in fraction of footprint.

– Achieving TN <=7 and TP<= 1

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Aerobic Granular Sludge for Other Process Configurations?

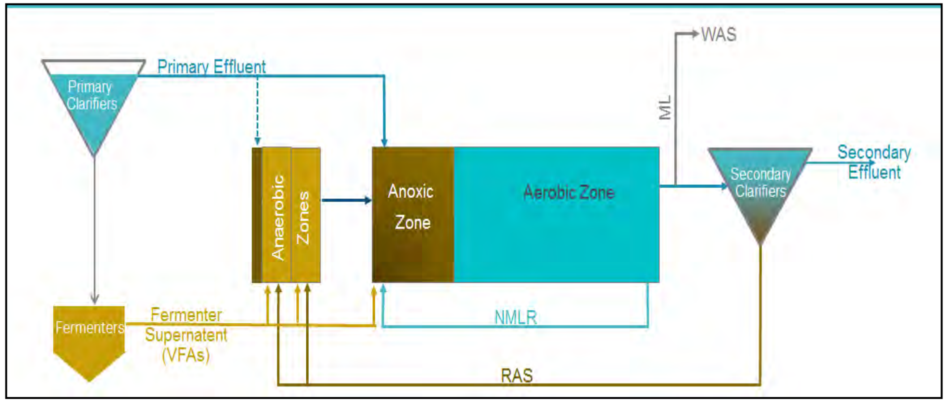
– **SBR Nereda® Aerobic Granular Sludge**

- Batch process, well established at >30 plants
- Not easily amenable to upgrading existing conventional activated sludge process
- Preferred Min. SWD = 18’ (5.5m)

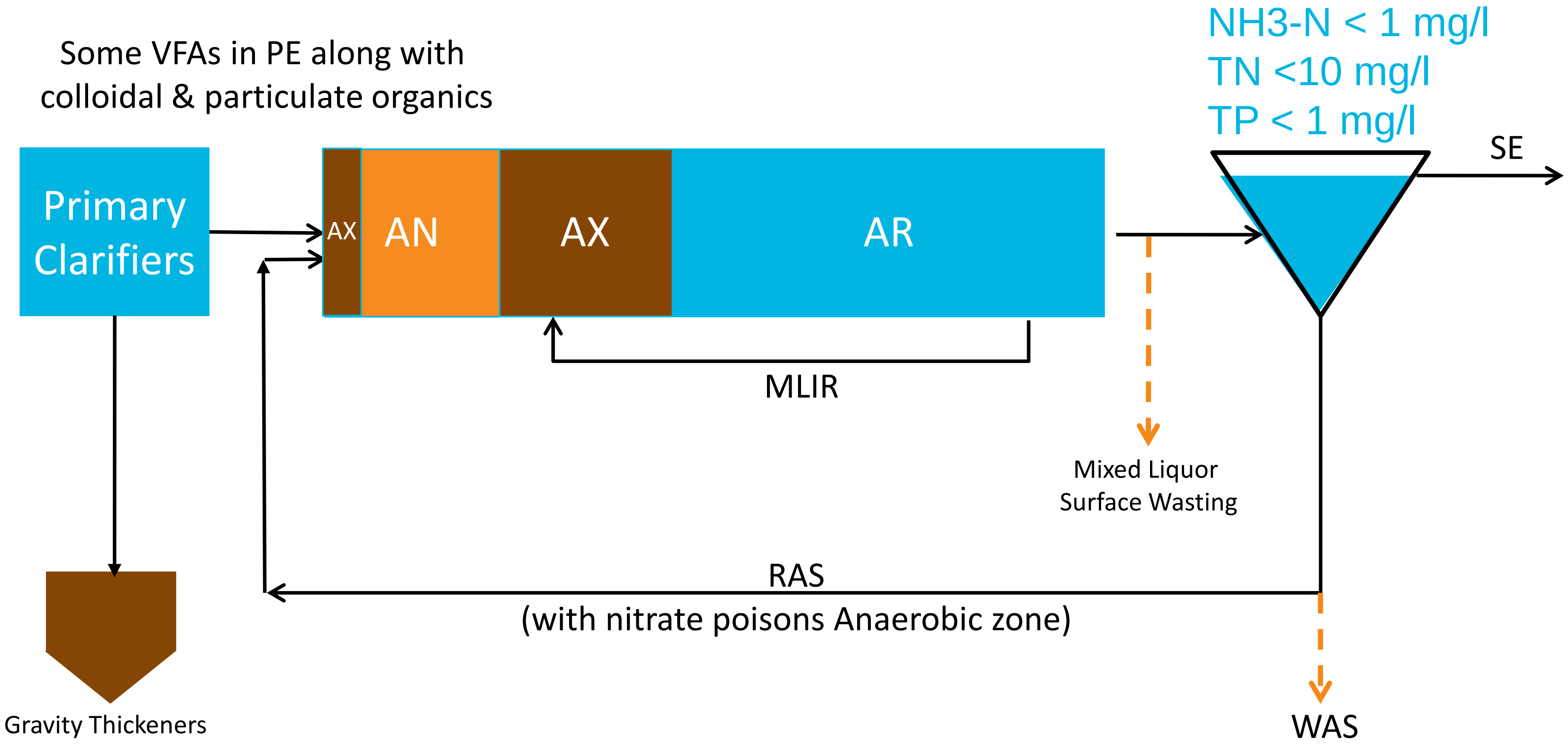
Nereda®

– **Continuous Flow Granular Activated Sludge – R&D**

- Adapting conventional activated sludge BNR to produce granular sludge



Conventional Activated Sludge Enhanced Biological Phosphorus Removal (EBPR) Systems – A2O



1. Anaerobic zone - VFA formation (Fermentation) & Uptake (Phosphorus Release)
2. Anoxic Zone - RAS and MLIR Nitrate Reduction
3. Aerobic zone – ammonia oxidation to NOx & Luxury Phosphorus Uptake
4. Remove Phosphorus in the WAS

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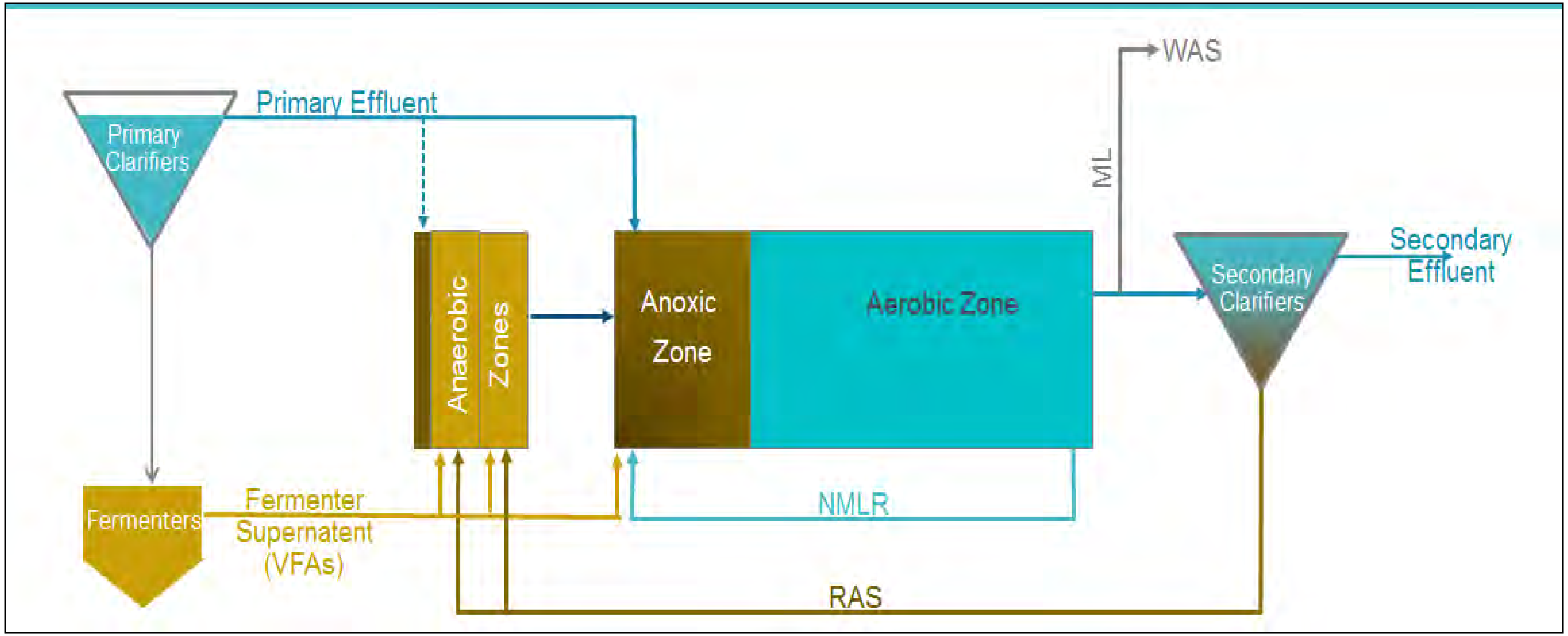
Adapting Activated Sludge For Smaller, Simpler Phosphorus Removal System - Westbank Process



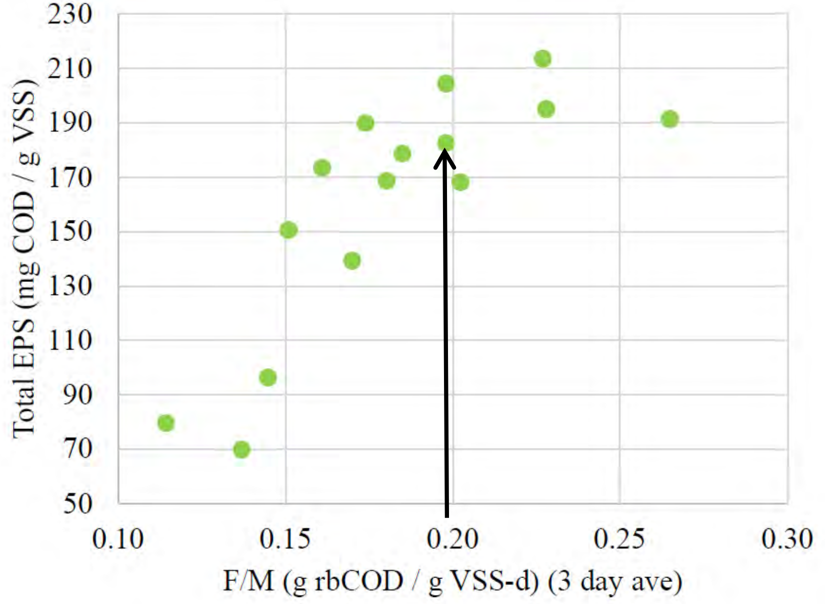
1. Smaller Concentrated Anaerobic zone – 33% less volume – less cost & space
2. Organics fermented to VFA in fermenter – less volume, cost, space
3. Stable Low ORP – Less / No NOx DO intrusion – More Reliable Performance
4. More diverse & stable population of Phosphorus Accumulating Organisms

Why Is Westbank A Good Baseline For Mainstream Granulation?

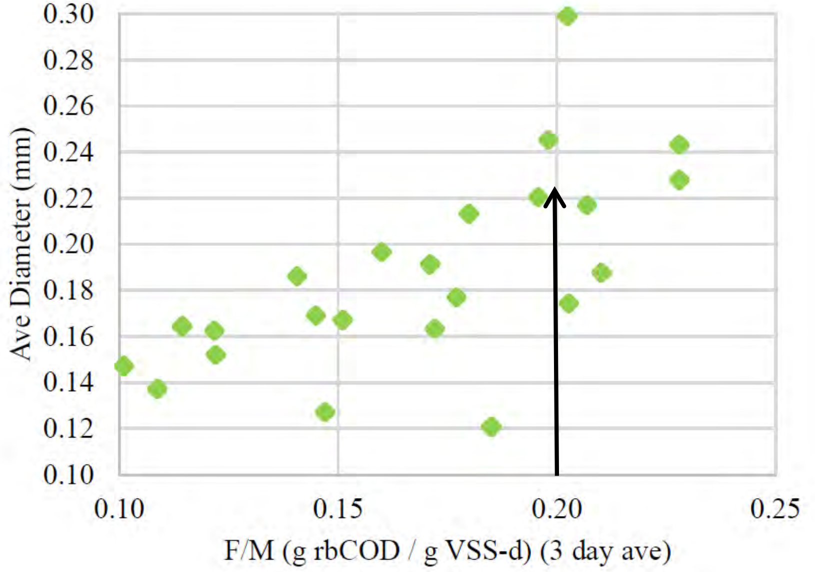
– **High F:M Using The Fermentate**

– **Ability To Step-feed The RAS In Westbank to control the F:M in the feast stage**

EPS formation relative to F:M



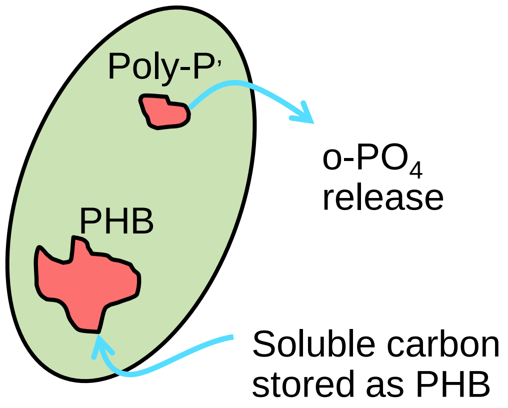
Granule formation relative to F:M



The Impact Of Applying An Internal Substrate Selection Strategy To Improve Aerobic Granular Sludge Formation. Rasha Faraj, Theresa Amante, Jennifer Warren, Mariela Mosquera, And Belinda Sturm. The University Of Kansas.

Adapting the Westbank BNR Process to AGS

- **In BNR fermenter supernatant is high in VFAs (e.g. acetate) and is the ideal carbon source for PAOs**



Parameter	Fermenter Supernatant (Kelowna WWTF)
VFA Total, mg/L	226
VFA, % acetate	56%
pH	6.4
Alkalinity, mg/L (as $CaCO_3$)	260
COD soluble, mg/L	644
TSS, mg/L	203
Ammonia, mg N/L	27
Phosphate, mg P/L	10

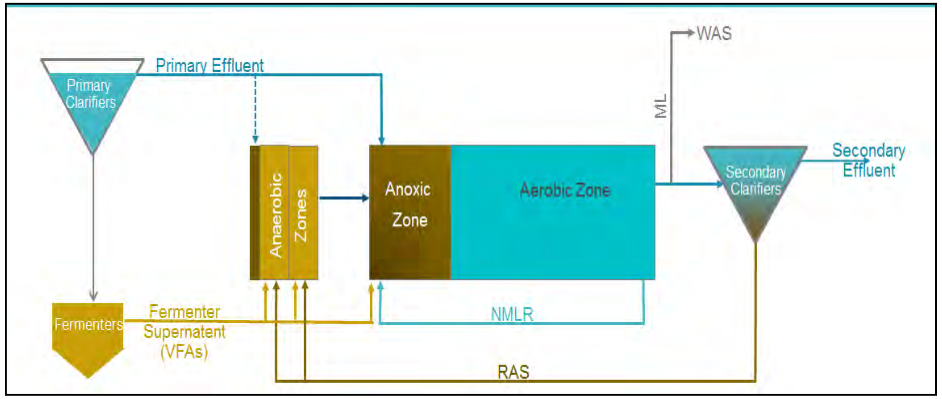
AECOM / City of Penticton AWWTP Granular Sludge Full Scale Demonstration

– **Existing influent flow = 2.9 mgd**

– **Two independent trains with PE equally split just upstream of the bioreactor inlet**

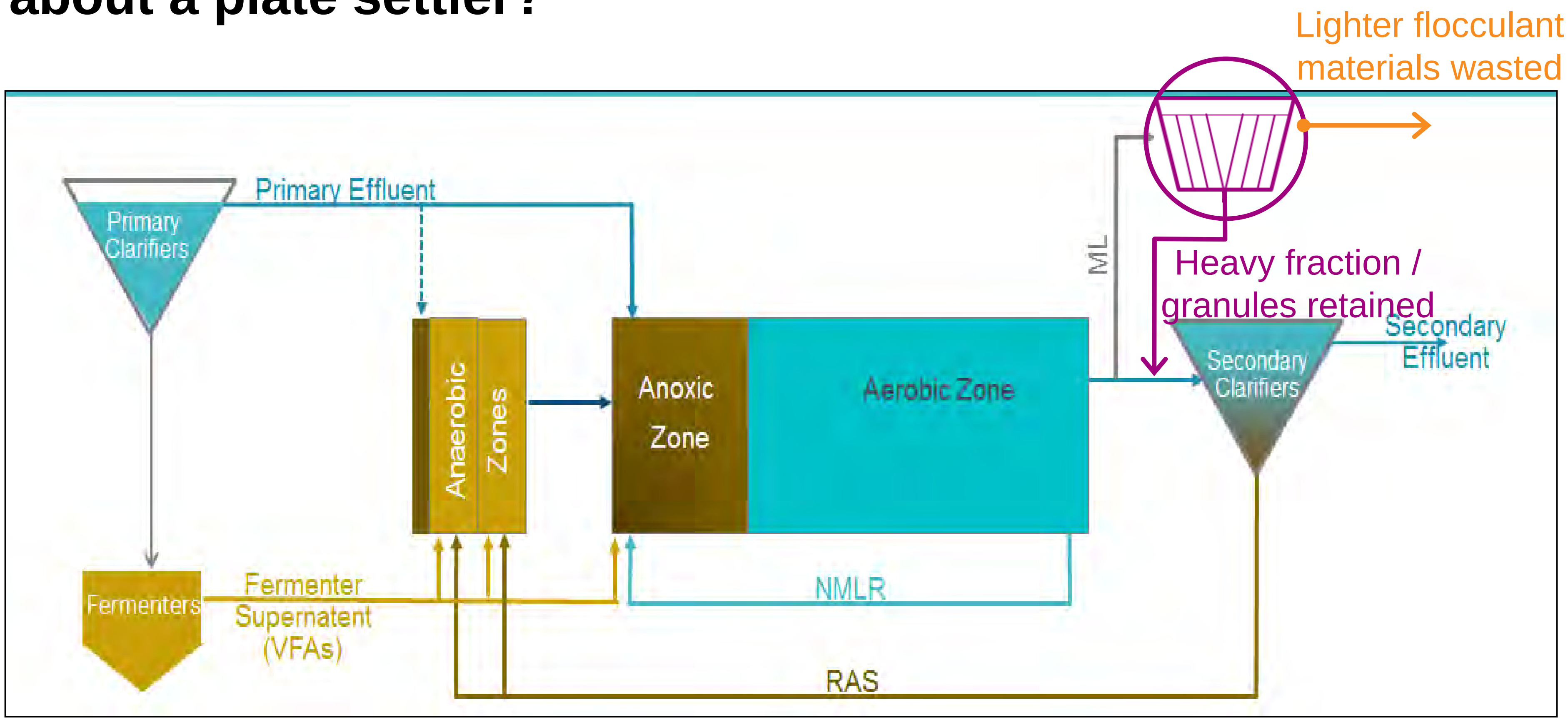
– **Final effluent discharged to nearby river with TP < 0.20 mg P/L and TN < 6.0 mg/L (based on annual average)**

– **Existing decommissioned digester converted to fermenter**

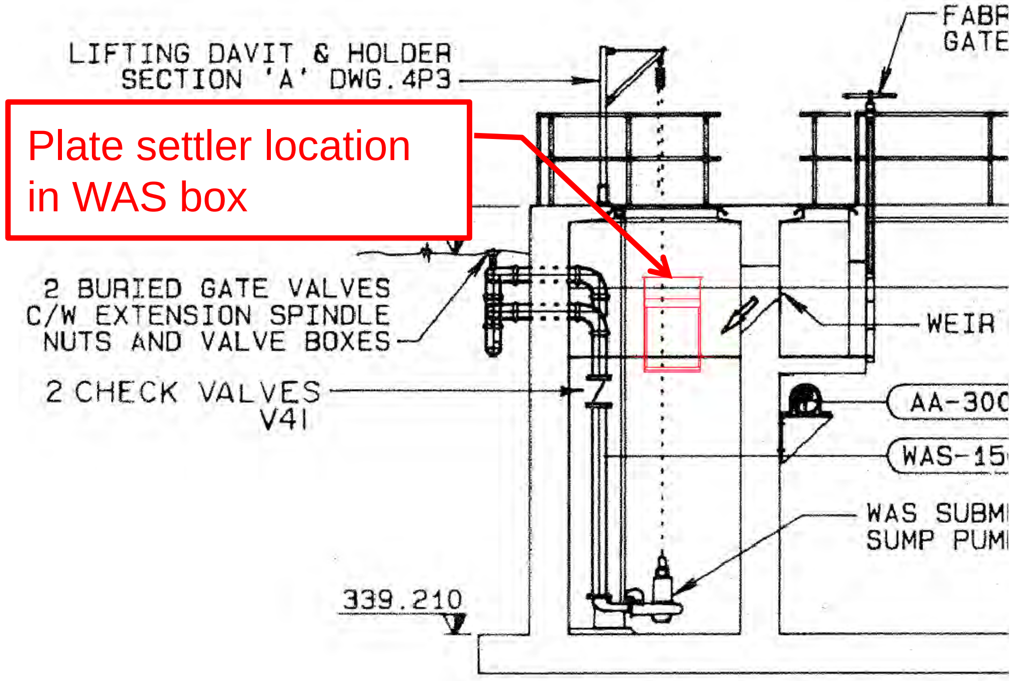


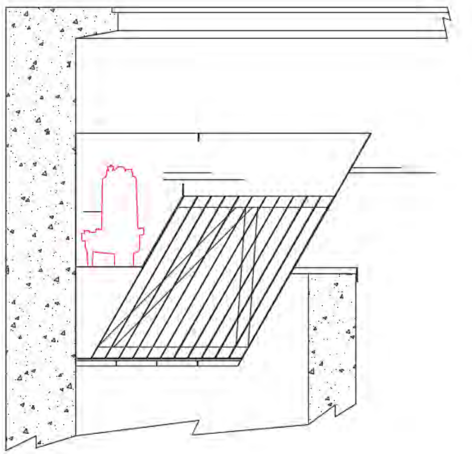
Adapting the Westbank BNR Process to AGS

- Westbank BNR process provides the right conditions for AGS
- Just need a way to select for the heavier particles and waste lighter floc
- How about a plate settler?



Installation of Lamella Plate Settler for Surface Wasting





Section

Lamella plate settler installed (without pump)

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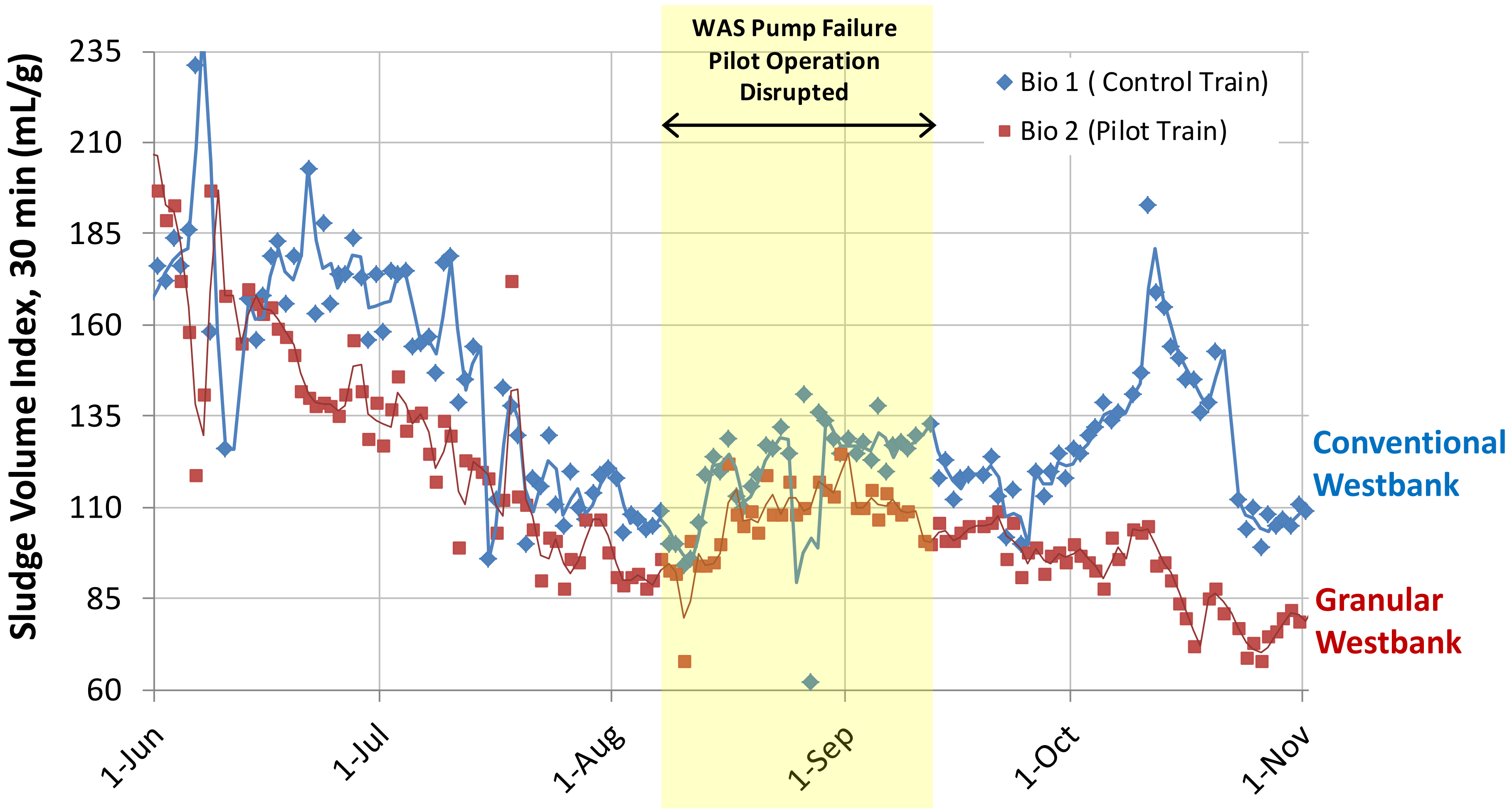
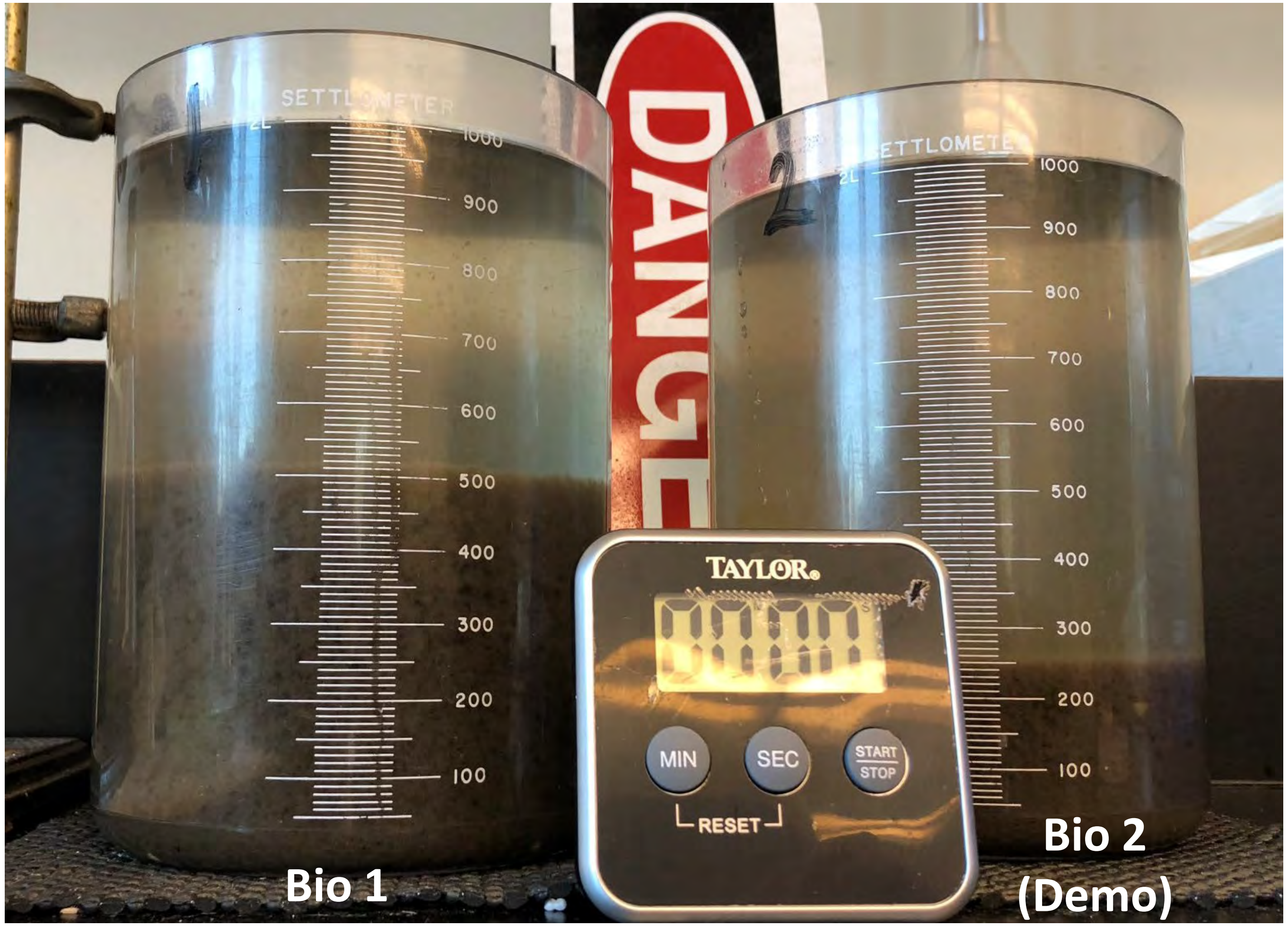
AECOMs Continuous Flow Granular Sludge Process Proves to be Very Successful In Full Scale Demonstration



Penticton AGS Pilot – Settling Comparison

- Sludge in Demo Train settles faster

Sludge settlement after 5 minutes (SVI 5) at same MLSS



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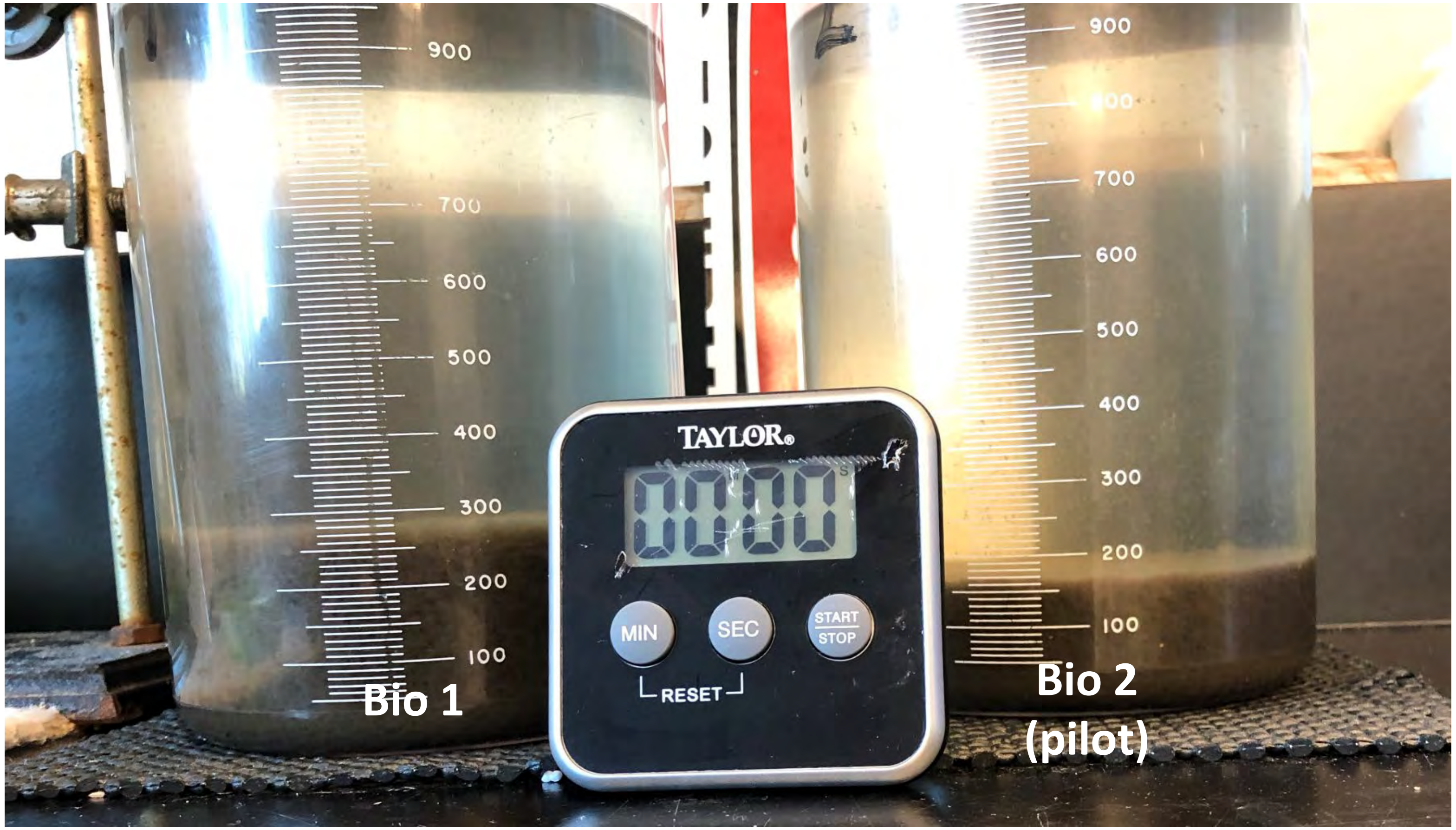
Penticton AGS Pilot – Settling Comparison

- SVI 30 significantly lower in the pilot train (Bio 2) compared to the control train (Bio 1)

Sludge settlement after 30 minutes (SVI 30) at same MLSS



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Settling Video

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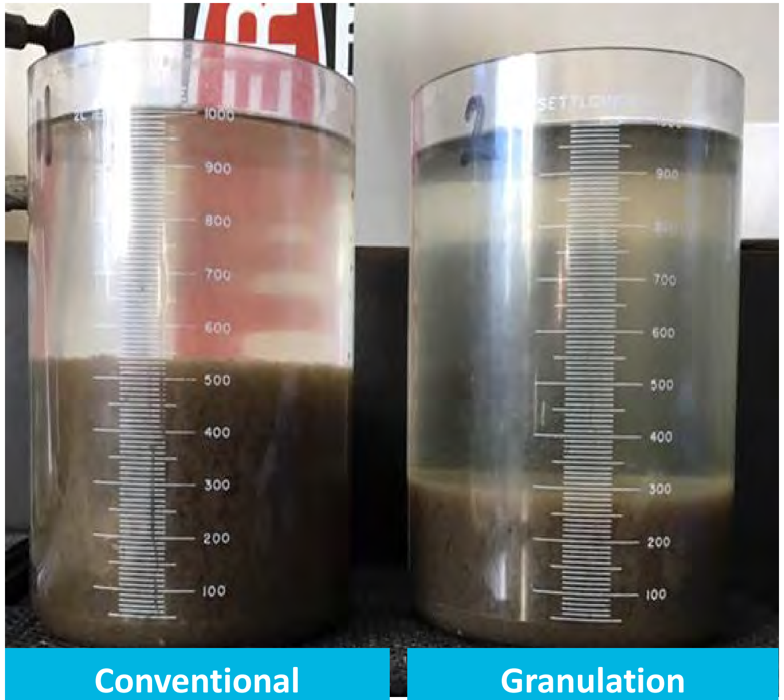
Improved settling - 5 min settling almost equal to 30 min settling in AECOM Mainstream Granulation Demonstration Test Train

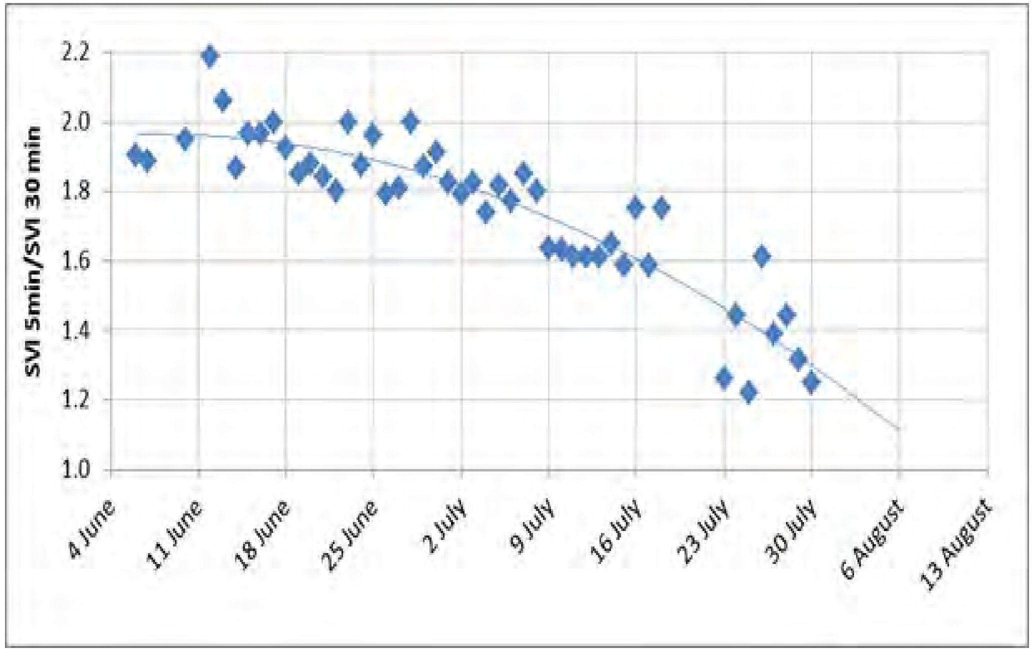
SVI 5 Results (13-Jul-18)



Conventional Westbank Process Train

Granulation Demonstration Train

SVI 5/ SVI 30 in Granulation Train



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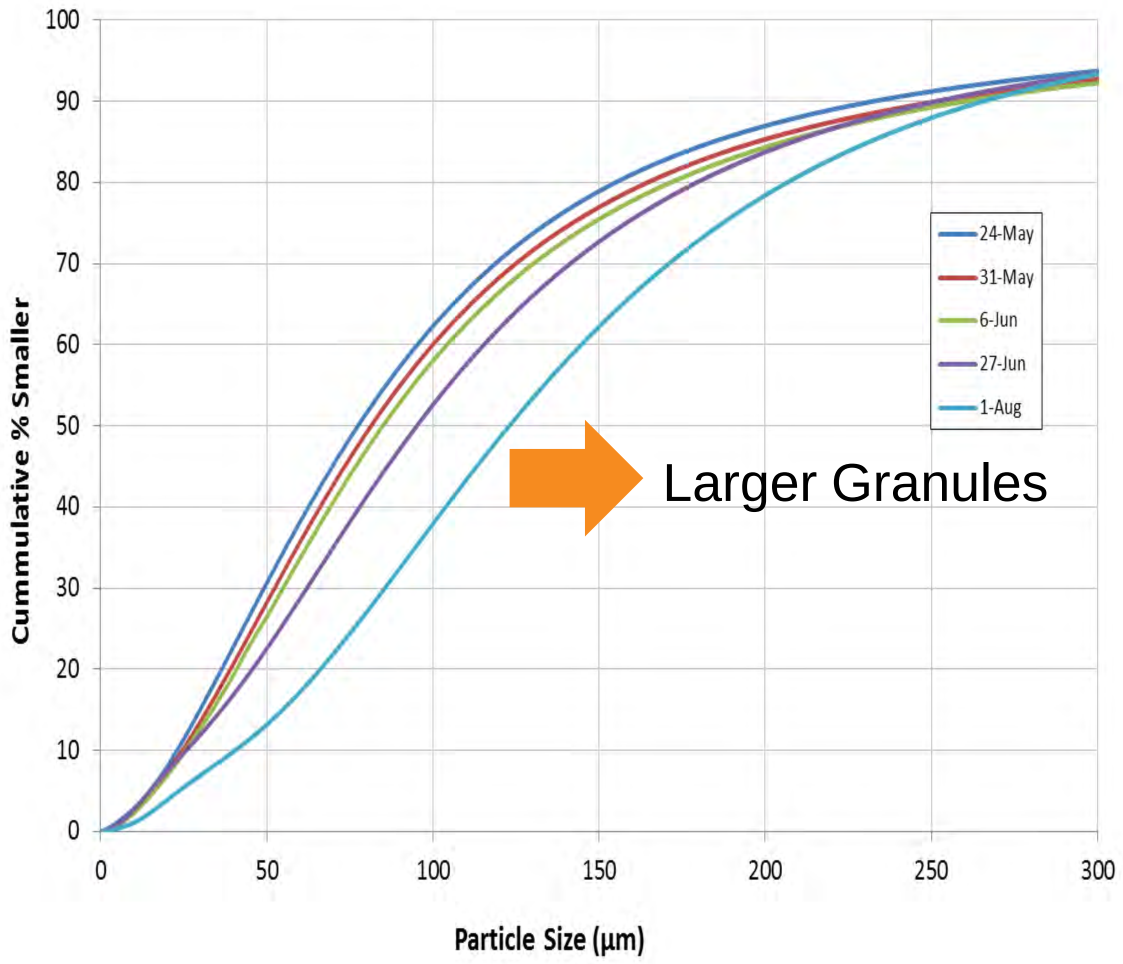
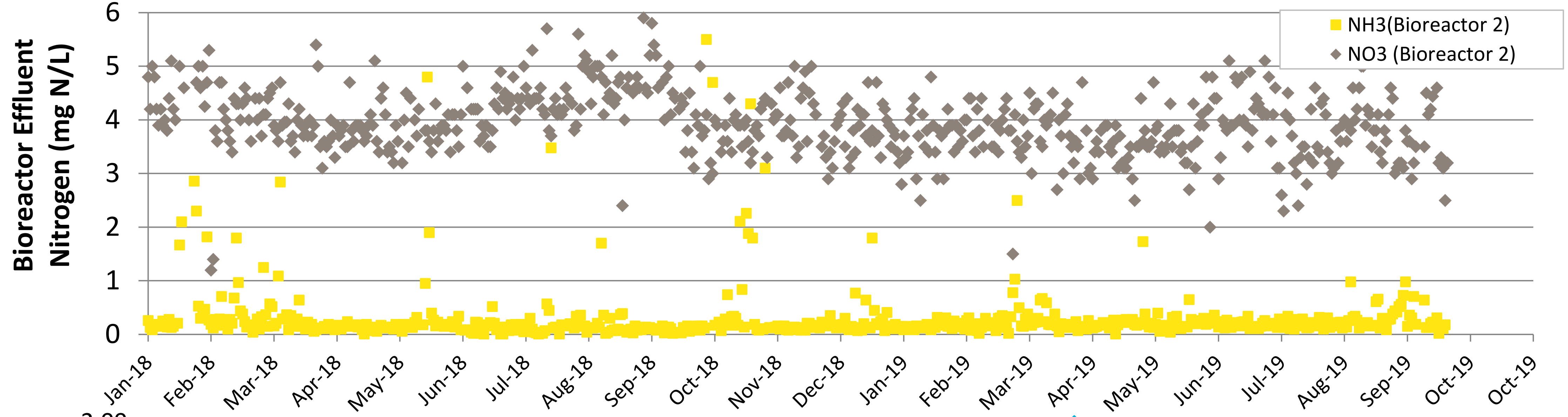
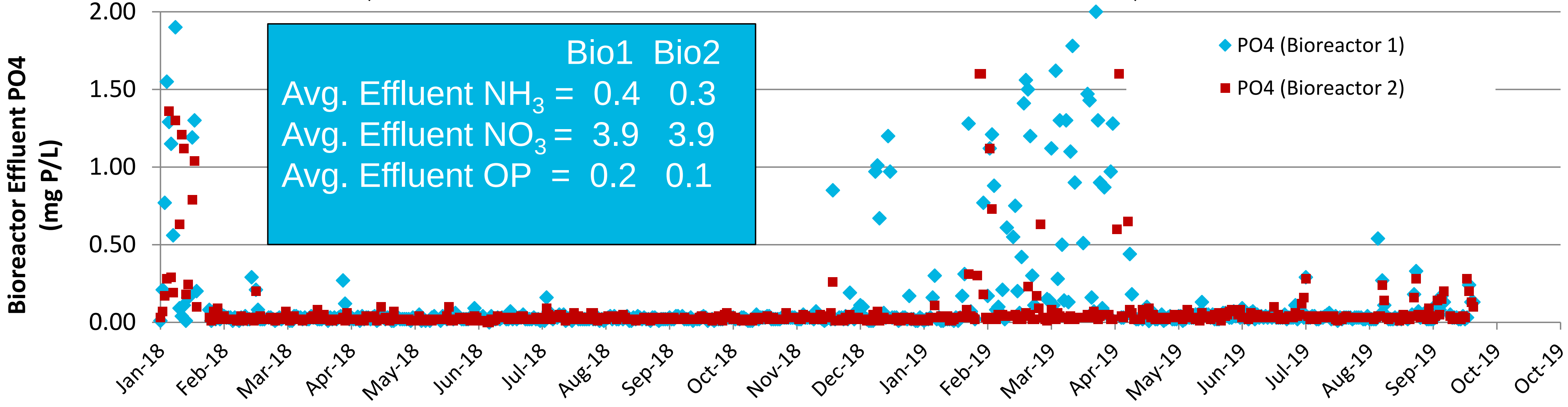
Sludge Size Characteristics



- Particle size in the pilot granulation train continues to increase
- Microscopy shows agglomerations that have granular features

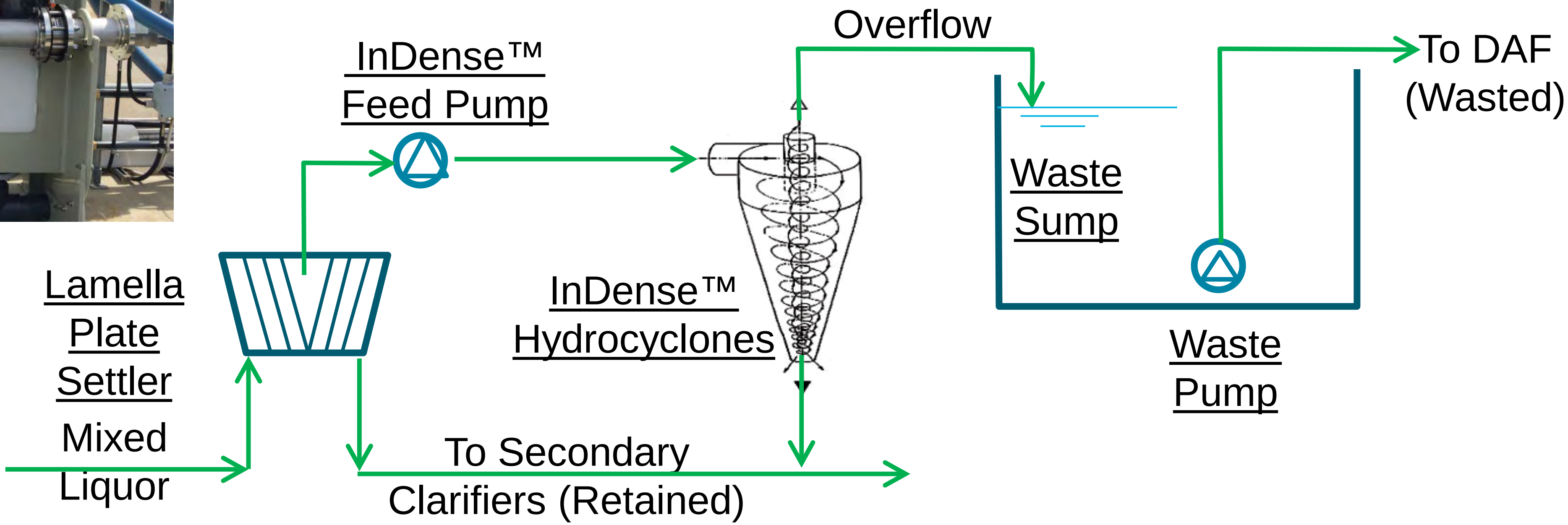
Nutrient Removal Performance





	Bio1	Bio2
Avg. Effluent NH_3 =	0.4	0.3
Avg. Effluent NO_3 =	3.9	3.9
Avg. Effluent OP =	0.2	0.1

Two-stage Solids Separation To Enhance Recovery



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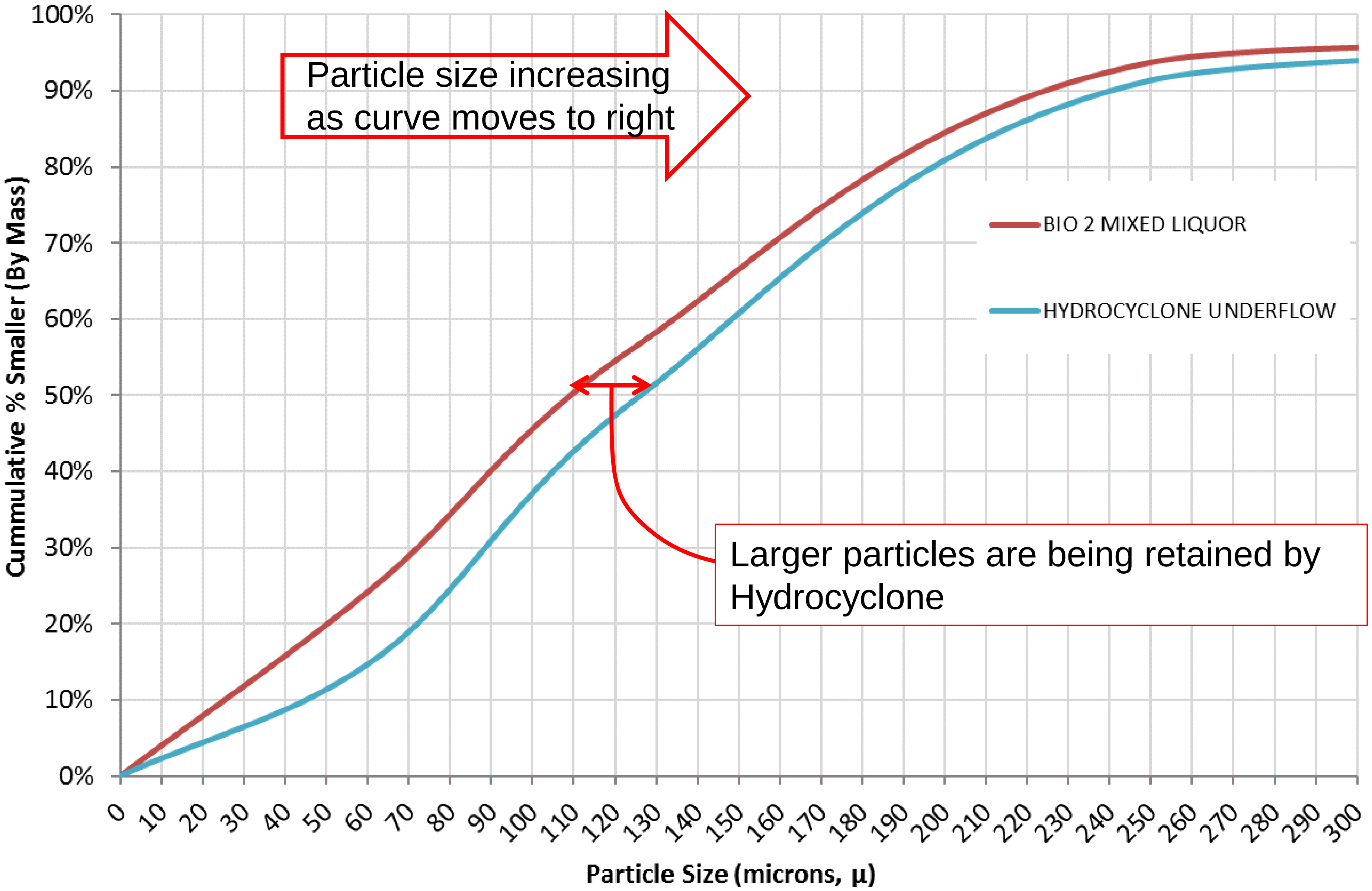
Granule Size Testing Completed On June 25, 2019

Particle Testing (June 25)



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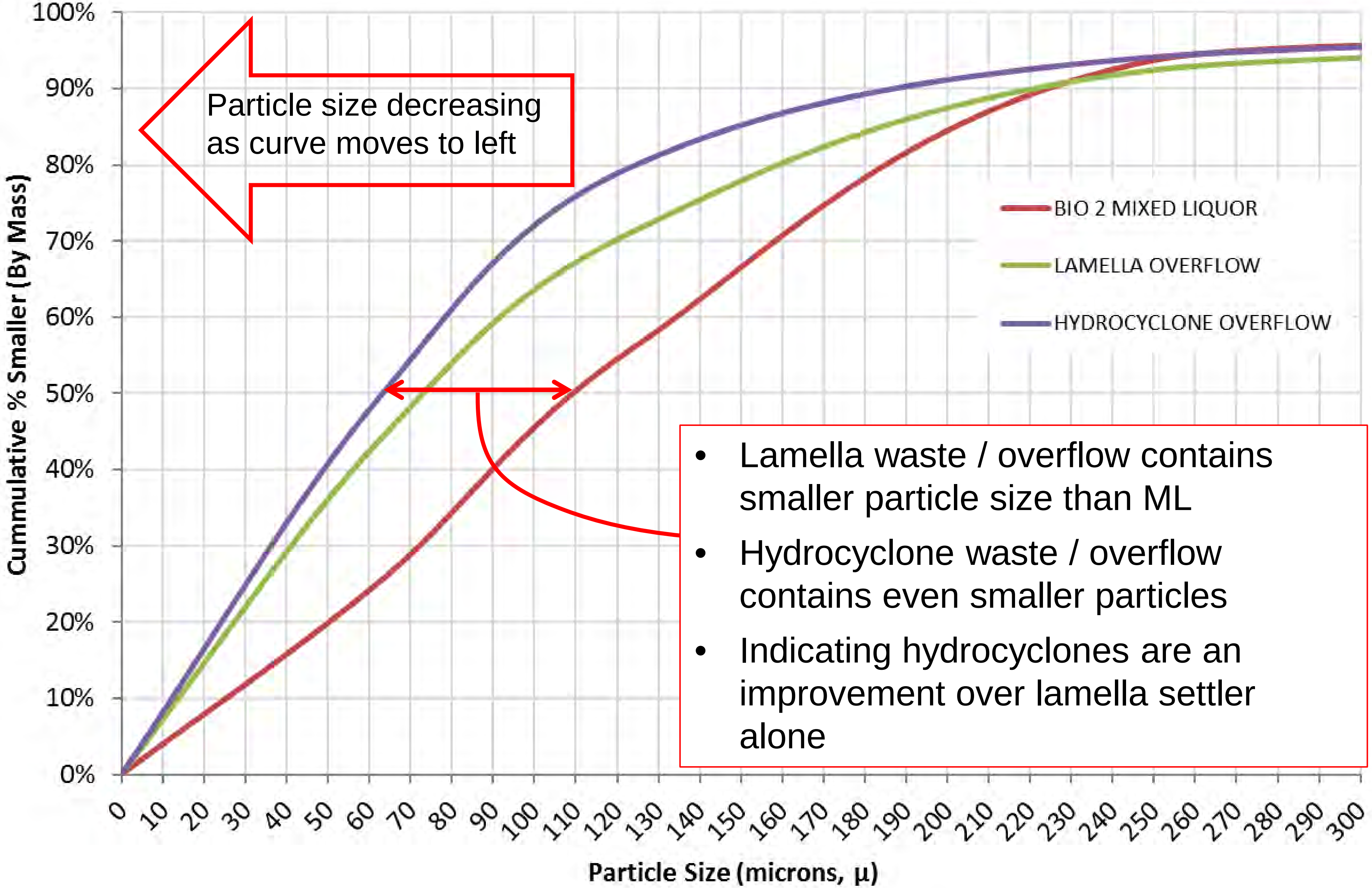
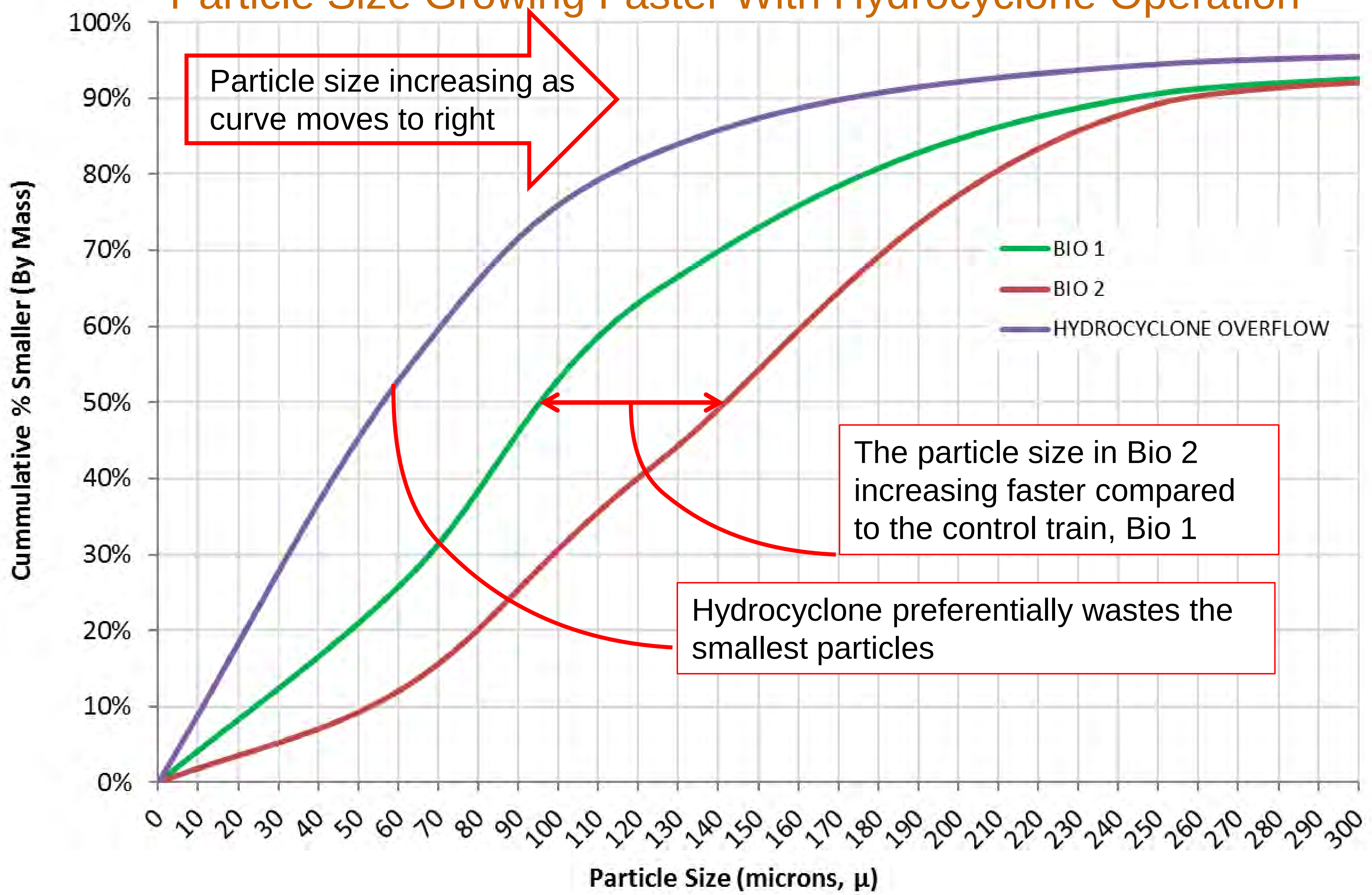


- Lamella waste / overflow contains smaller particle size than ML
- Hydrocyclone waste / overflow contains even smaller particles
- Indicating hydrocyclones are an improvement over lamella settler alone

Granule Size Testing Completed On July 2, 2019

Particle Size Growing Faster With Hydrocyclone Operation

Particle Testing (July 2)



Next Steps

- Continue monitoring performance and particle size distribution of both trains through the winter of 2019/2020
- Evaluate two-stage separation Lamella + InDense Hydrocyclones vs. only InDense Hydrocyclones
- Conduct microbial analysis and structure of granulated sludge particles
- Stress Test the Granulated BioReactor with increased flows and loads to assess “Infrastretching” concept

DISCUSSION