Emerging Technologies for Nutrient Removal

Puget Sound Nutrient Forum

November 3, 2020

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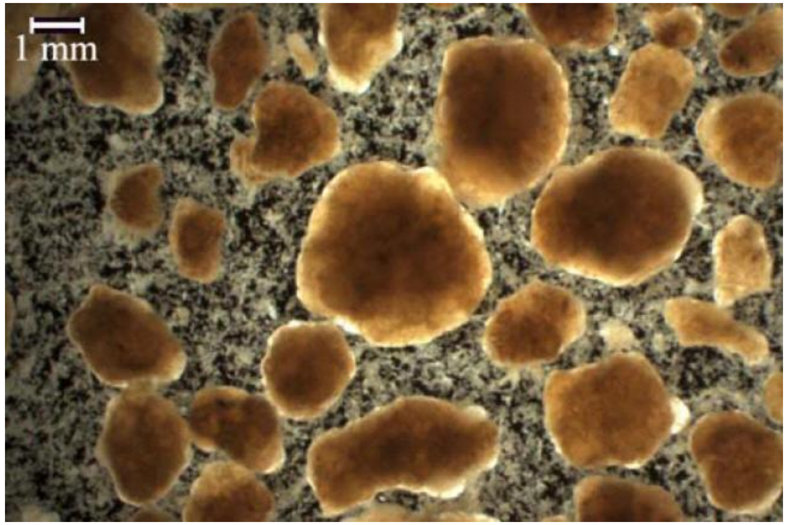
Topic outline

- Aerobic granular activated sludge (AGS) characteristics and advantages
- AGS in existing wastewater treatment facilities
- UW/King County AGS Bioaugmentation pilot plant study
- Promoting AGS growth in continuous flow systems

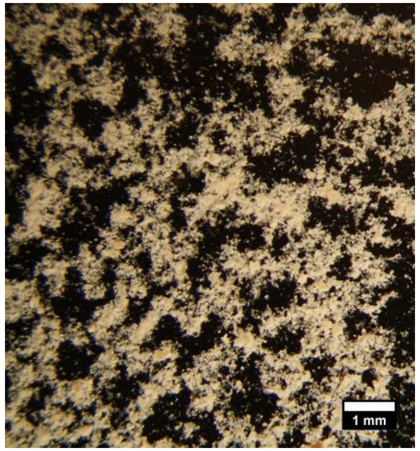
What are aerobic granules?

- Microbial biofilms without carrier media
- Larger and faster-settling than flocs
  - Particle size >200 um
  - SVI_{30min} 30-40 mL/g,
  - SVI_5/SVI_{30} ~1.0



Aerobic granules
2000-2010

"Flocs"



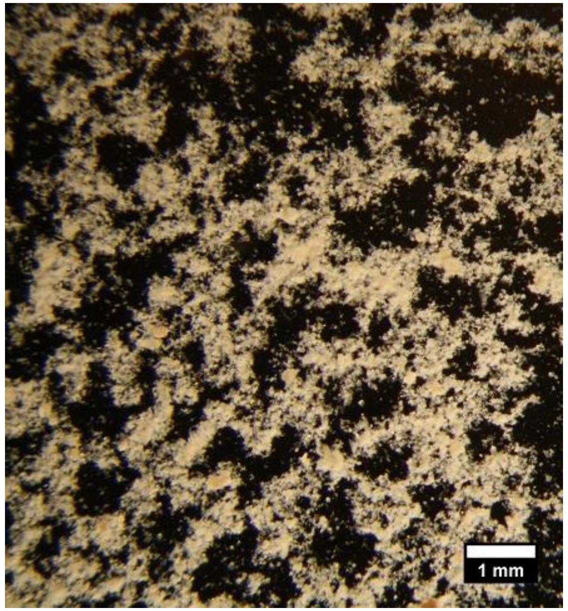
Flocculent Activated sludge
Since 1914

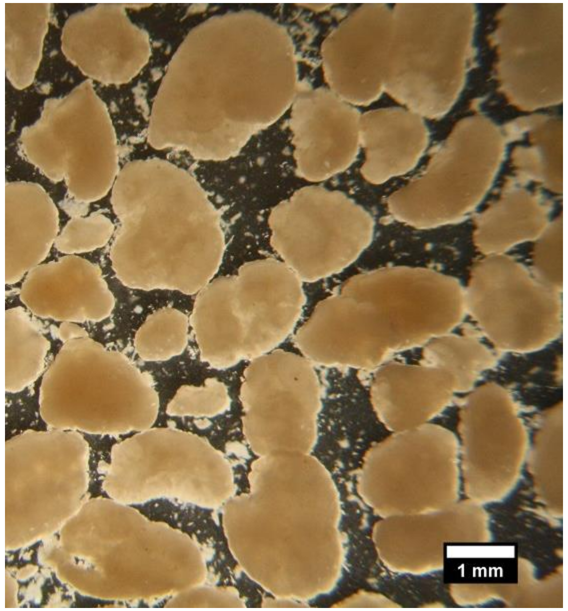
Anaerobic granules
Late 1970s

Anammox granules
~1995-2000

Anammox granules Sidestream nitrogen Removal W/O carbon
$NH_4 + NO_2 = N_2$

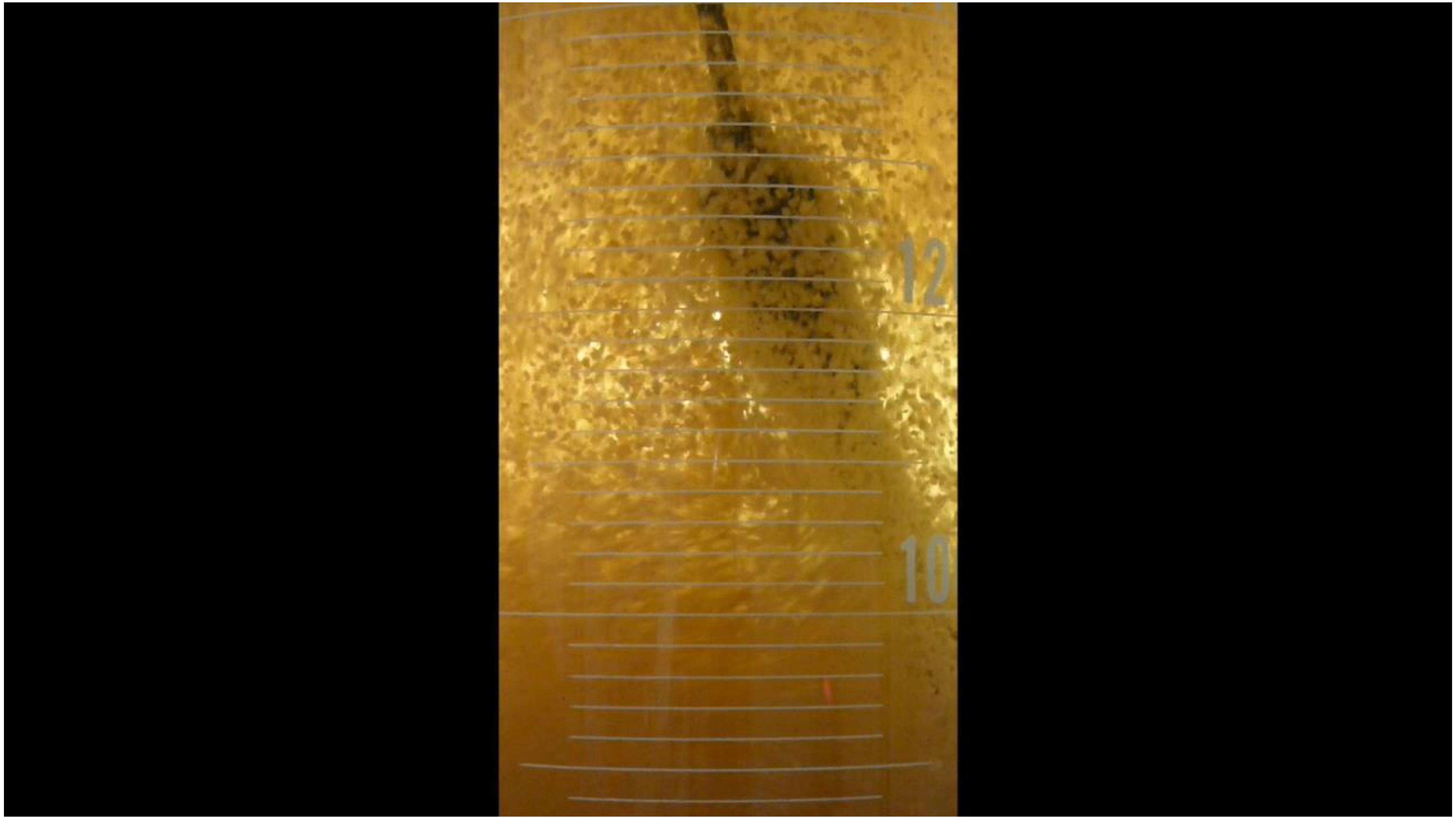
Advantage #1: AGS has lower SVI, settles and thickens faster than flocculent sludge
Higher MLSS and Process Intensification



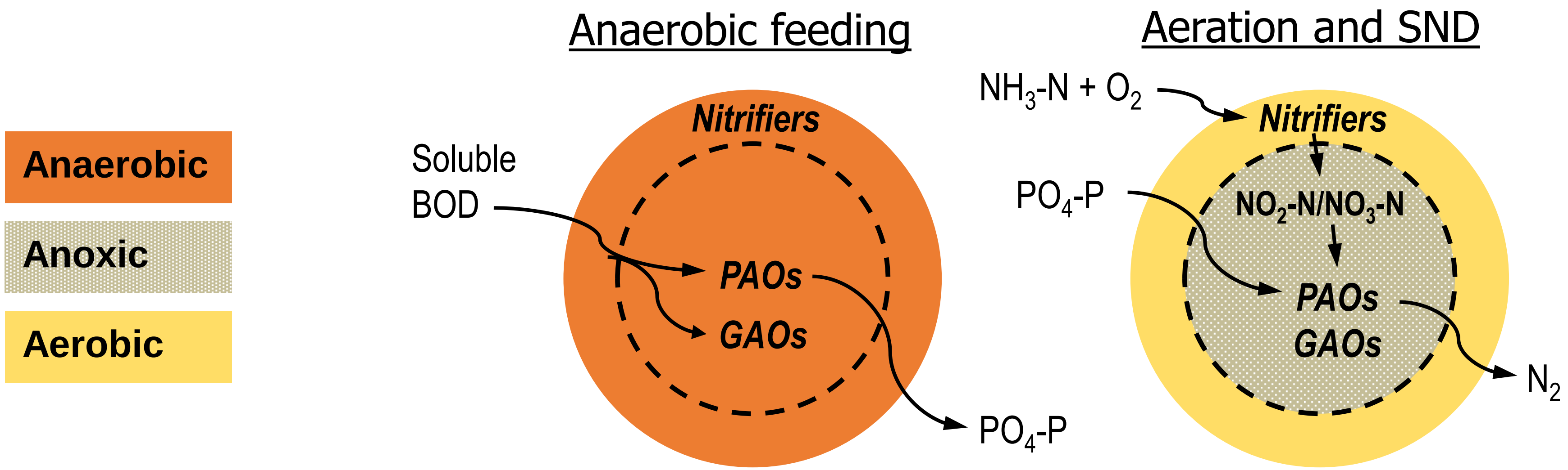


Parameter	Flocs	Granules
Morphology	Loose, irregular	Regular, compact, smooth
Particle size	Small (<400 um)	Large (0.5 - 3 mm typical)
Sludge Vol. Index (SVI)	~120 mL/g	20-40 mL/g
Settling velocity	Slow (~1 m/hr)	Fast (>10 m/hr)
SVI_{5min} / SVI_{30min}	~2.0 (slow thickening)	1.0 - 1.1 (rapid thickening)
MLSS, mg/L	2,000 – 3,500	6,000 – 10,000

Aerobic granules settle and thicken much faster!



Advantage #2: Anaerobic-aerobic operation provides granules with Enhanced biological phosphorus removal (EBPR) and simultaneous nitrification/denitrification (SND)

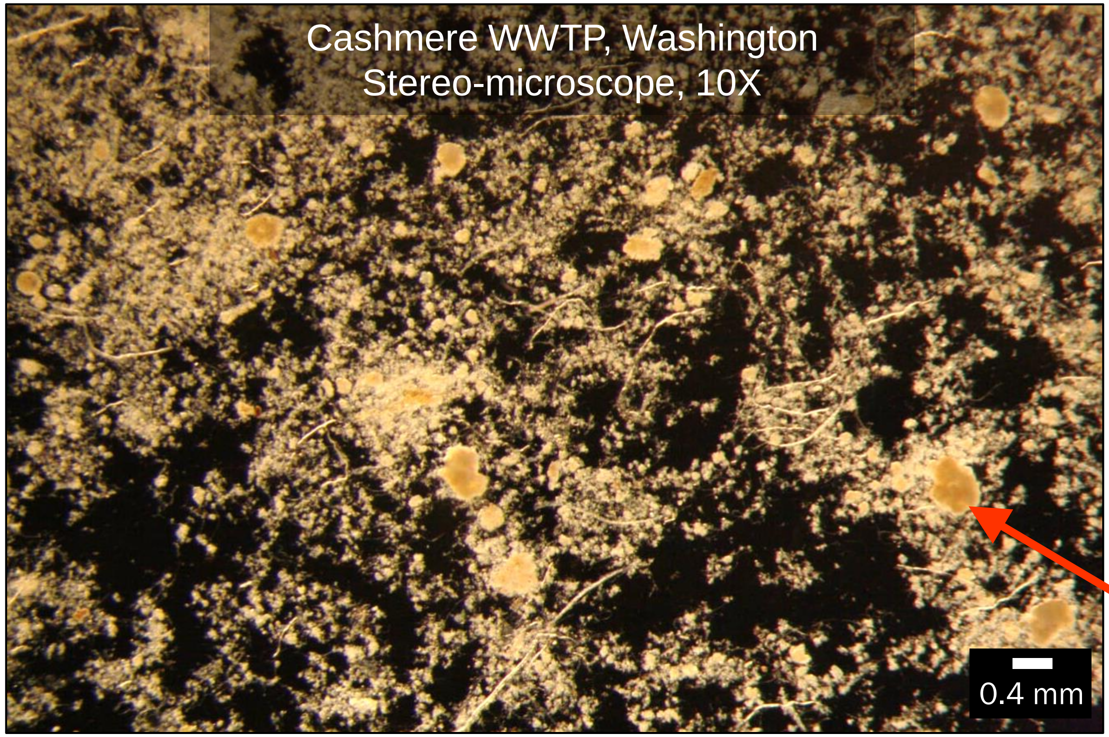


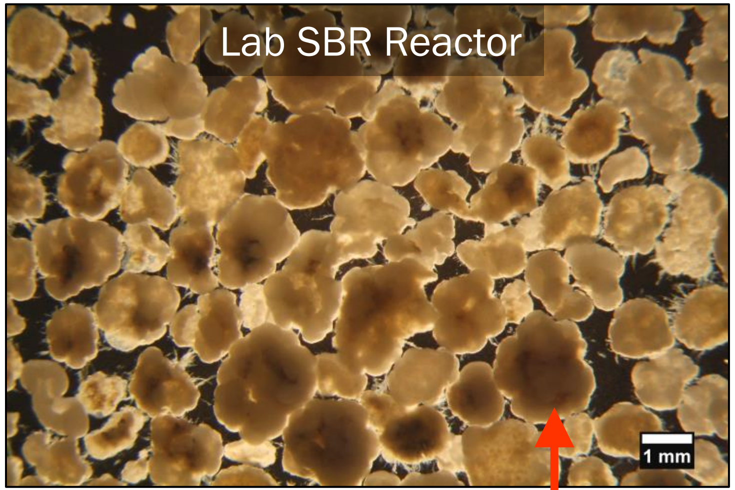
PAOs = phosphorus-accumulating organisms
GAOs = glycogen-accumulating organisms

- Same carbon used for PAO/GAO growth and denitrification
- DO controlled to provide simultaneous nitrification/denitrification
- Denitrification provides alkalinity for pH control

Granules have been out there for a long time!

Observations of Baby Granules at Cashmere, WA Enhanced Biological Phosphorus Removal (EBPR) Plant led to field survey study by UW (~2015)





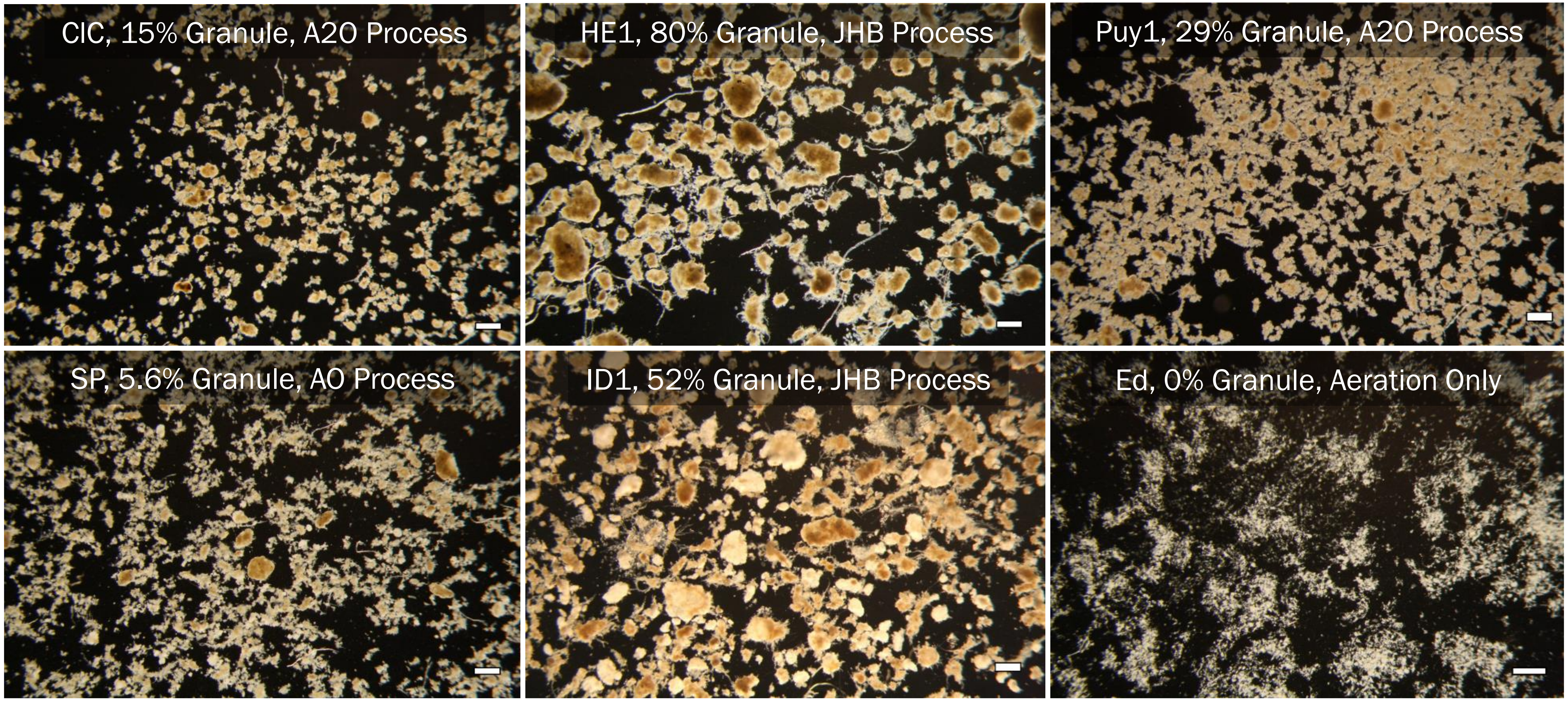
Larger Granules
(0.5 – 5 mm)

Smaller Granules
- Size 0.2 – 0.6 mm
- Granular morphology

We asked: Do other plants have these granules?

Evaluated design, performance, and mixed liquor of 16 activated sludge facilities
i.e. <u>Stereo microscopic</u> pictures, SVI, % granules in ML

Granules found only in plants with anaerobic/aerobic process with EBPR**
% granules in mixed li2our (ML) varied between plants



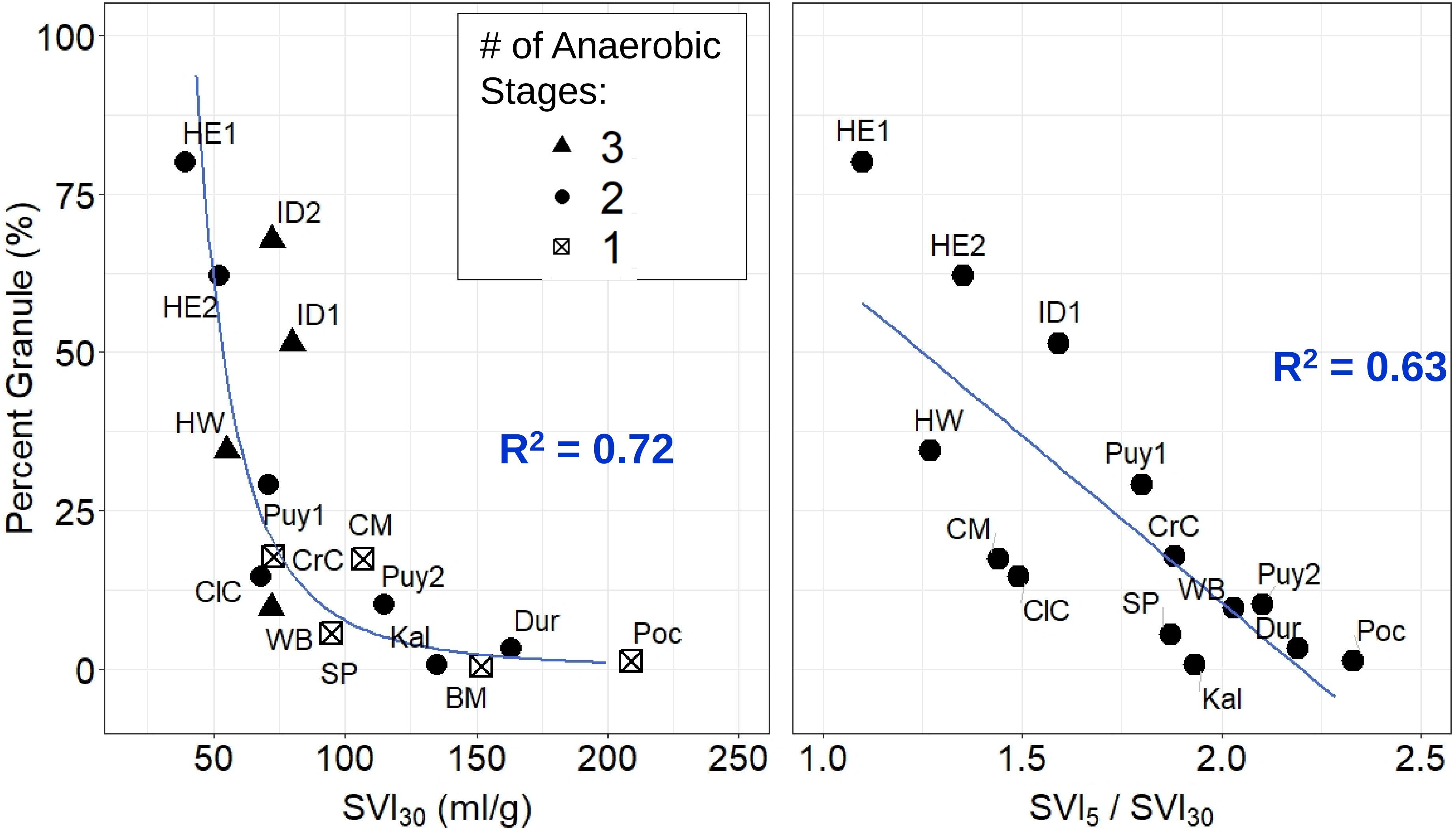
Scale bar = 0.5 mm

**Note: other aerobic granules have also been grown in lab without EBPR by UW and others

Lower SVI and SVI_5/SVI_{30} with Higher Granule Abundance

% granules varied from 5 – 75% of mixed liquor

At > 10-15%, SVI < 60 mL/g possible



HE-Henderson, NV
ID - Idaho Falls, ID
PUY - Puyallup, WA
CM - Cashmere, WA
CIC - Clark County, NV
SP - King Cty South plt

Why Higher Granule production and lower SVI in some plants?

-EBPR (PAOs make more extracellular polymeric substances (EPS)

-Higher biodegradable soluble COD F/M loading in first anaerobic stage biodegradable soluble COD in influent or by UMIF in anaerobic

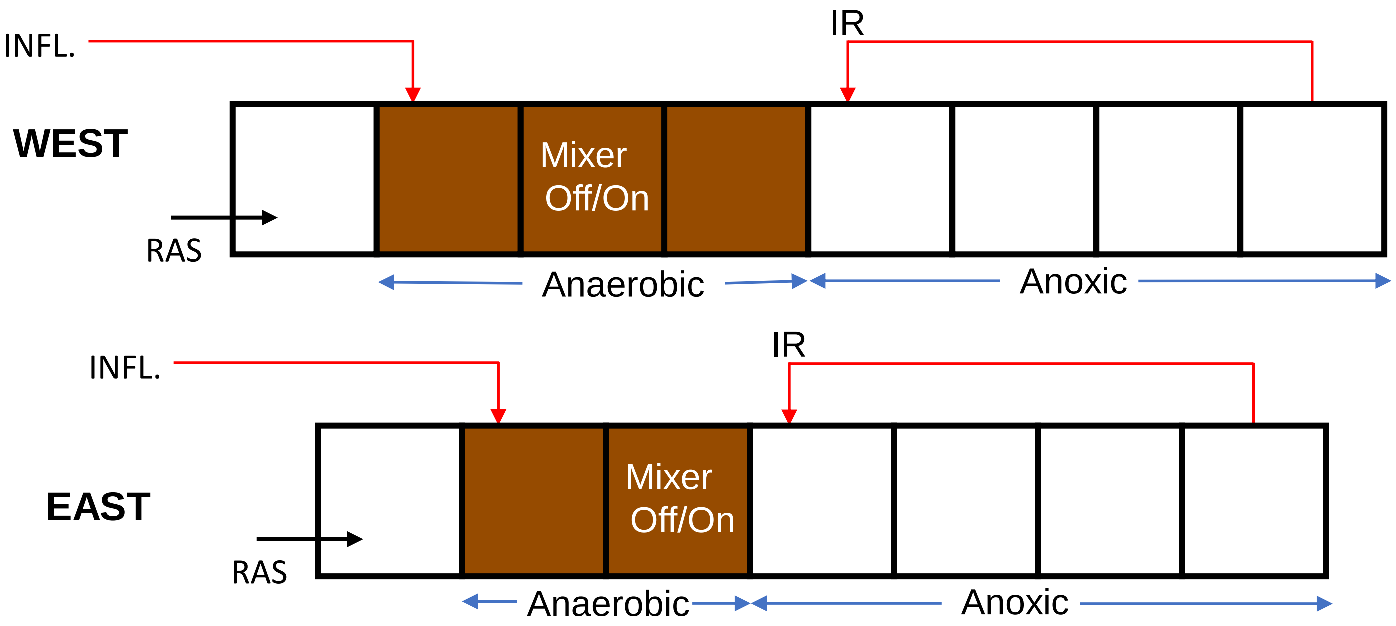
Plant	Process	%Granules	Anaerobic Stages	Anaerobic F/M, gBOD/gVSS·d	Mixing
CrC, Puy, SP, Poc, BM*	AO/A2O	0.5 - 18	1	0.8 – 4.9	Conventional
WB, CIC, Dur	JHB/A2O	10 - 15	2 - 3	3.5 – 4.8	Conventional
CM	A2O	17	1	0.7	Invent
Idaho Falls	JHB	50 - 60	3	2.0 – 2.4	Invent
Henderson East	JHB	60 - 80	2	10 – 14	UMIF, Conventional
Henderson West	JHB	35	3	14	UMIF, Conventional

*5-stage Bardenpho with MBR

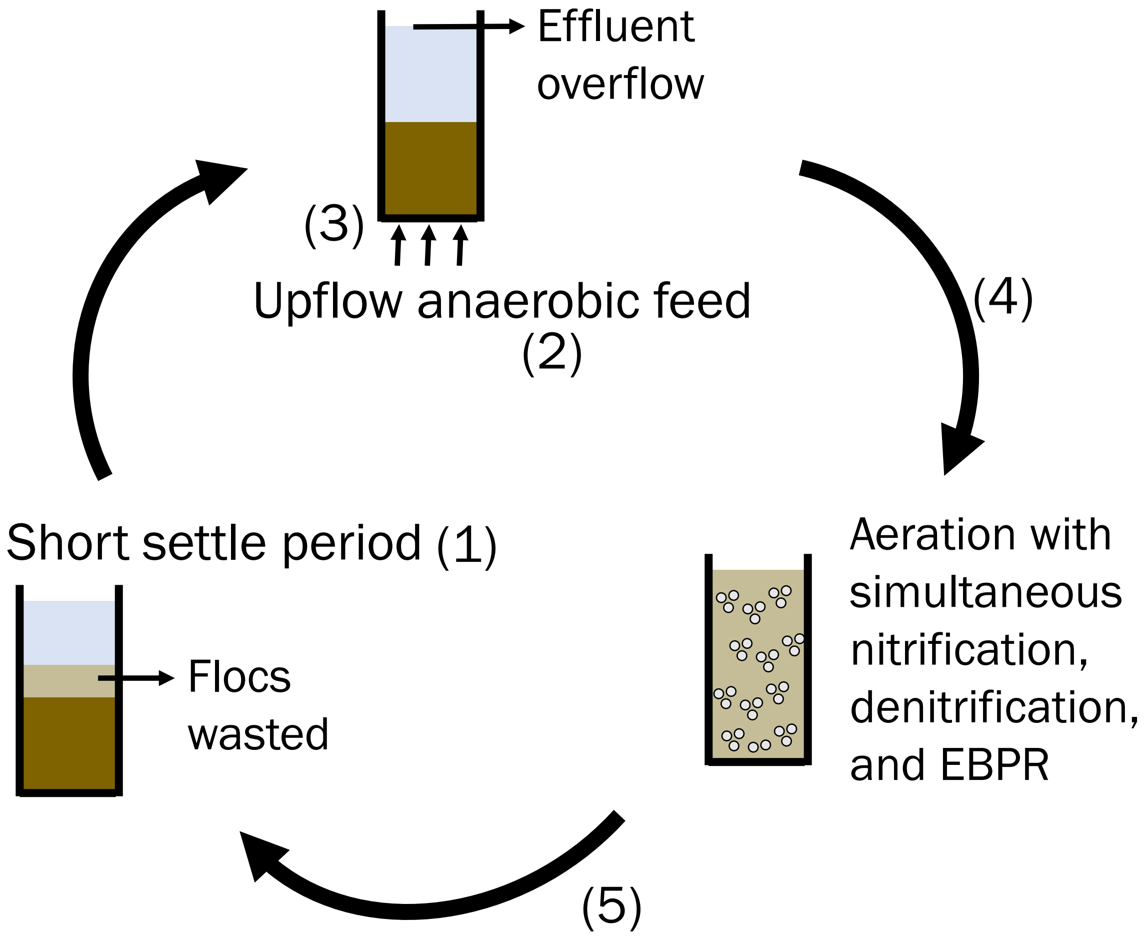
High soluble COD fraction, sCOD/COD = 44 - 82%

UMIF = Unmixed In-Line Mixed Liquor Fermentation in Anaerobic Stage

Henderson Water Reclamation Facility (50-80% granules



What conditions select for granules?
Patented Vendor AGS SBR (Nereda®) System Cycle Selects for Granules



Key selection pressures

1. Short batch settling keeps mainly fast Settling granules (0.5 – 3 mm typical)

2. Anaerobic feed for PAOs

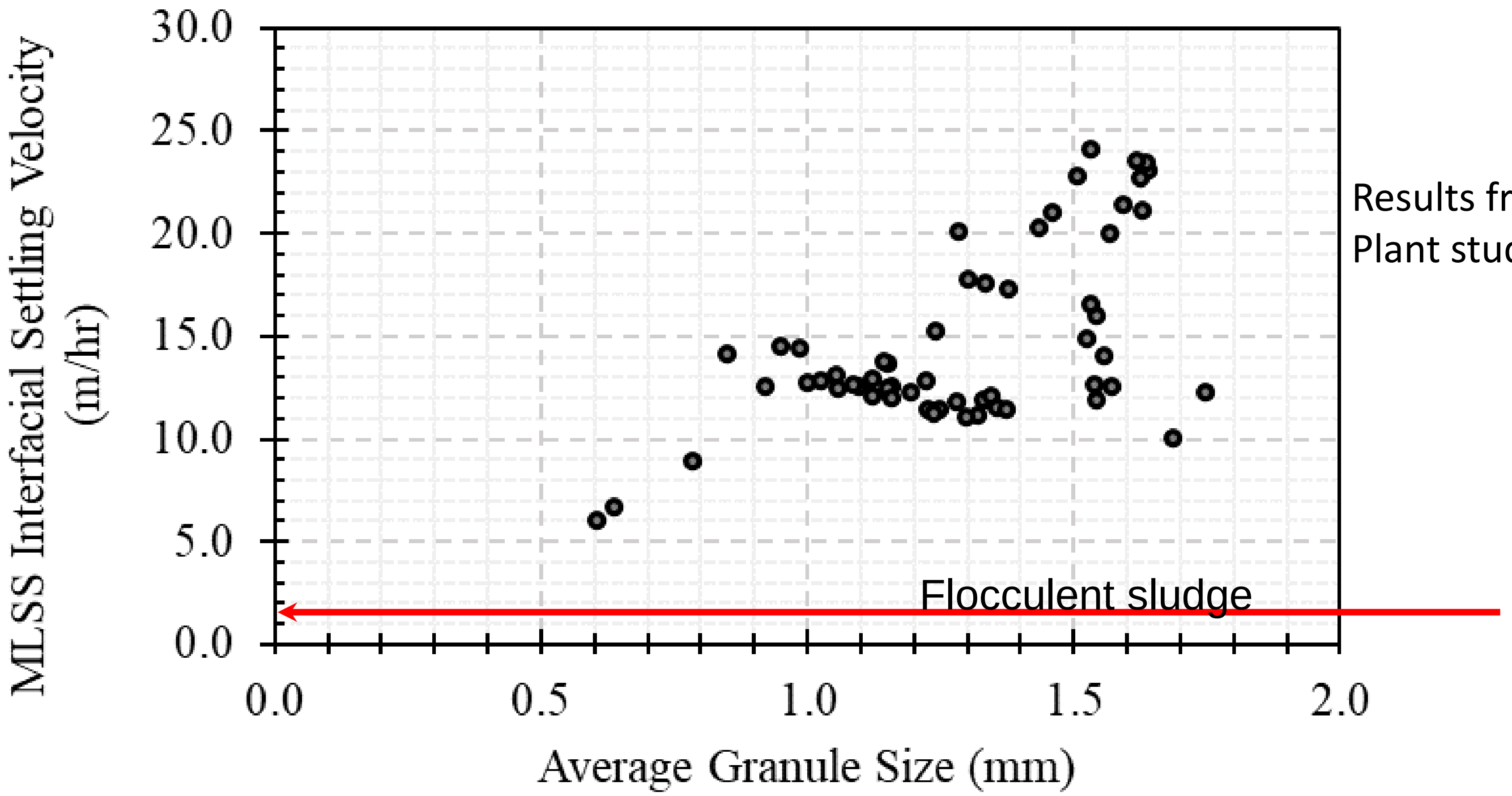
3. Feed flow through settled bed has very high localized F/M to grow larger granules

4. Feast (anaerobic), famine – long aerobic
5. No granular recycle pumping minimal granule shear

Selection of Granules:
Comparison of granular SBR process versus continuous flow activated sludge (CFAS)

Parameter	Vendor patented SBR	EBPR CFAS Selector
Settling time	Short, 8-10 min	Long, 1 hr+
Anaerobic feed	Yes	Yes
High F/M in anaerobic feed	Yes	Not as High
Feast/famine	Yes	Yes
Minimize granule shear	Yes	No

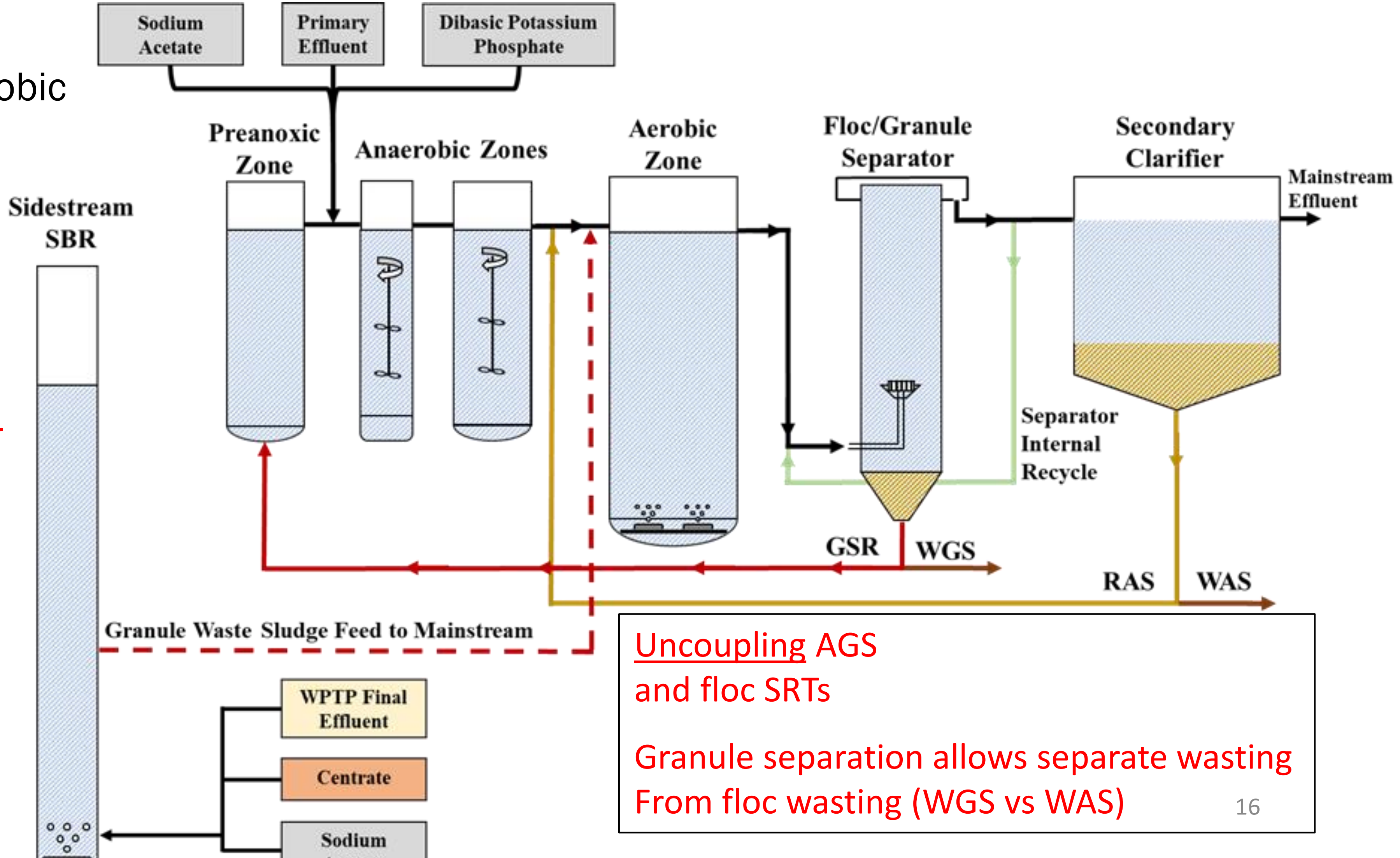
Shorter settling times result in larger size granules with high settling velocity in batch hydraulic separator



Results from UW pilot
Plant study with King County

UW/King County AGS Sidestream Bioaugmentation Pilot Plant (1.5 gpm)

- PAO-NDN granules grown in sidestream SBR treating anaerobic digestion centrate
- Granule fed to mainstream
- Hydraulic separator retains granules
- Light floc is wasted from clarifier underflow
- SRTs uncoupled gives higher AGS content and higher MLSS
    - 20+ d for AGS
    - 5-6 d for floc



Uncoupling AGS and floc SRTs

Granule separation allows separate wasting From floc wasting (WGS vs WAS)

Pilot Plant Sidestream Centrate Treatment Granular Growth SBR

1-ft diameter
8-ft liquid depth
50% decant depth
6-hour cycle
fine bubble diffuser

Quick Summary of Project

- Sidestream operated for 2 years treating West Point centrate
    - 95% granules
    - Average size 1.5 mm
    - 90-94% Simultaneous nitrification-denitrification at DO = 2.0-2.2 mg/L
    - SVI_{30} = 27-35 mL/g
    - SVI_5/SVI_{30} = 1.0 – 1.05
    - MLSS = 9,000 – 12,000 mg/L

Project Activities

- Mainstream and bioaugmentation operation only for 31 days before Covid 19 shut down
  - Granular growth occurred in mainstream
  - Nitrification and N removal via bioaugmentation occurred
  - Separator efficiency poor so $SRT_{granules}/SRT_{floc}$ = 1.5, not 4-5
  - Larger granules broken to 0.212 to 0.425 mm granules

- Modifications if we could have continued
  - Add waste sludge from mainstream to sidestream SBR for batch settling and lose light floc in decant
  - Start up with lower flow and mixed liquor to build up granules/floc ratio
  - Have higher F/M in first anaerobic stage

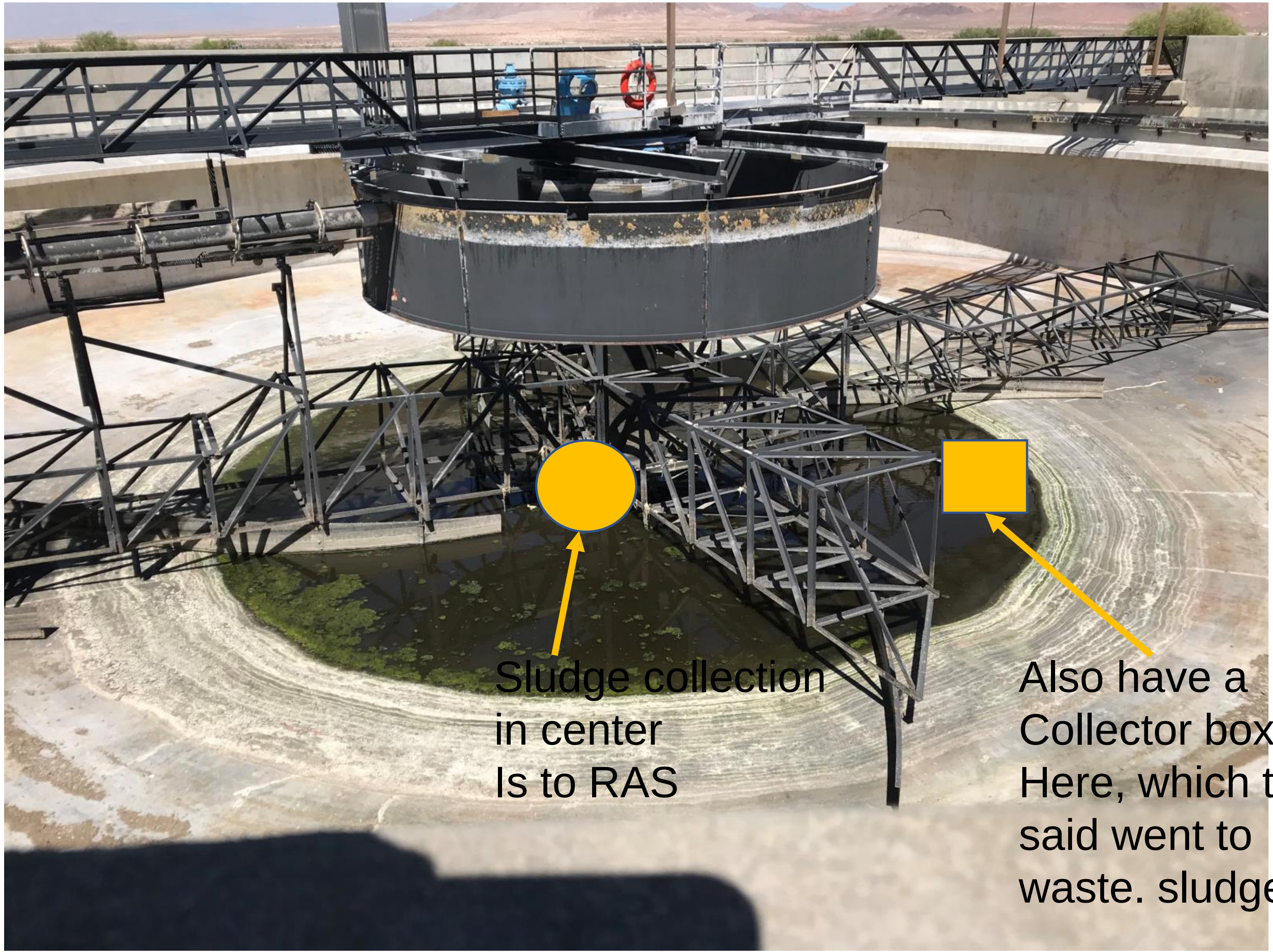
AGS Intensification Process
Applying what we have learned
to convert continuous AS to hybrid granular/floc process

- EBPR process
- High F/M biodegradable soluble COD (bSCOD) in 1st anaerobic
  - Short anaerobic first stage
  - Create more bSCOD
    - Anaerobic contact on/off mixing
    - Primary sludge fermentation

- Minimize granule shear – use different type of recycle pumping

- Selective wasting of floc over granules
  - Sidestream centrate treatment per King County pilot
  - Sidestream hydraulic separator
  - Modify secondary clarifier to separate floc/granules

Use two sludge withdrawal points for secondary clarifier
feed center RAS with AGS to anaerobic contact, other to anoxic or aerobic tanks



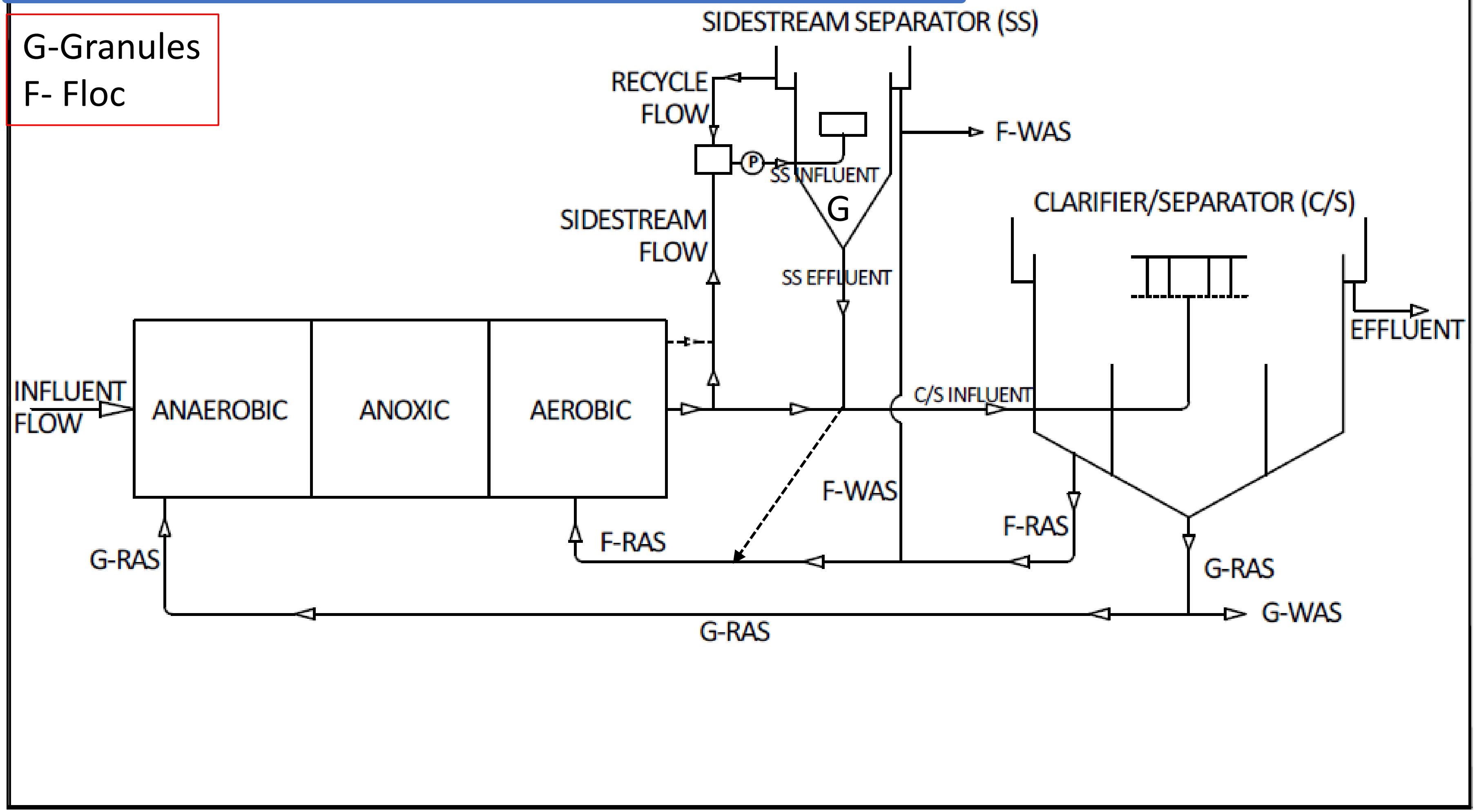
Henderson, Nevada
Secondary Clarifiers

HENDERSON
SECONDARY
CLARIFIER
FEED
WELL

Faster Settling
Sludge falls out near center

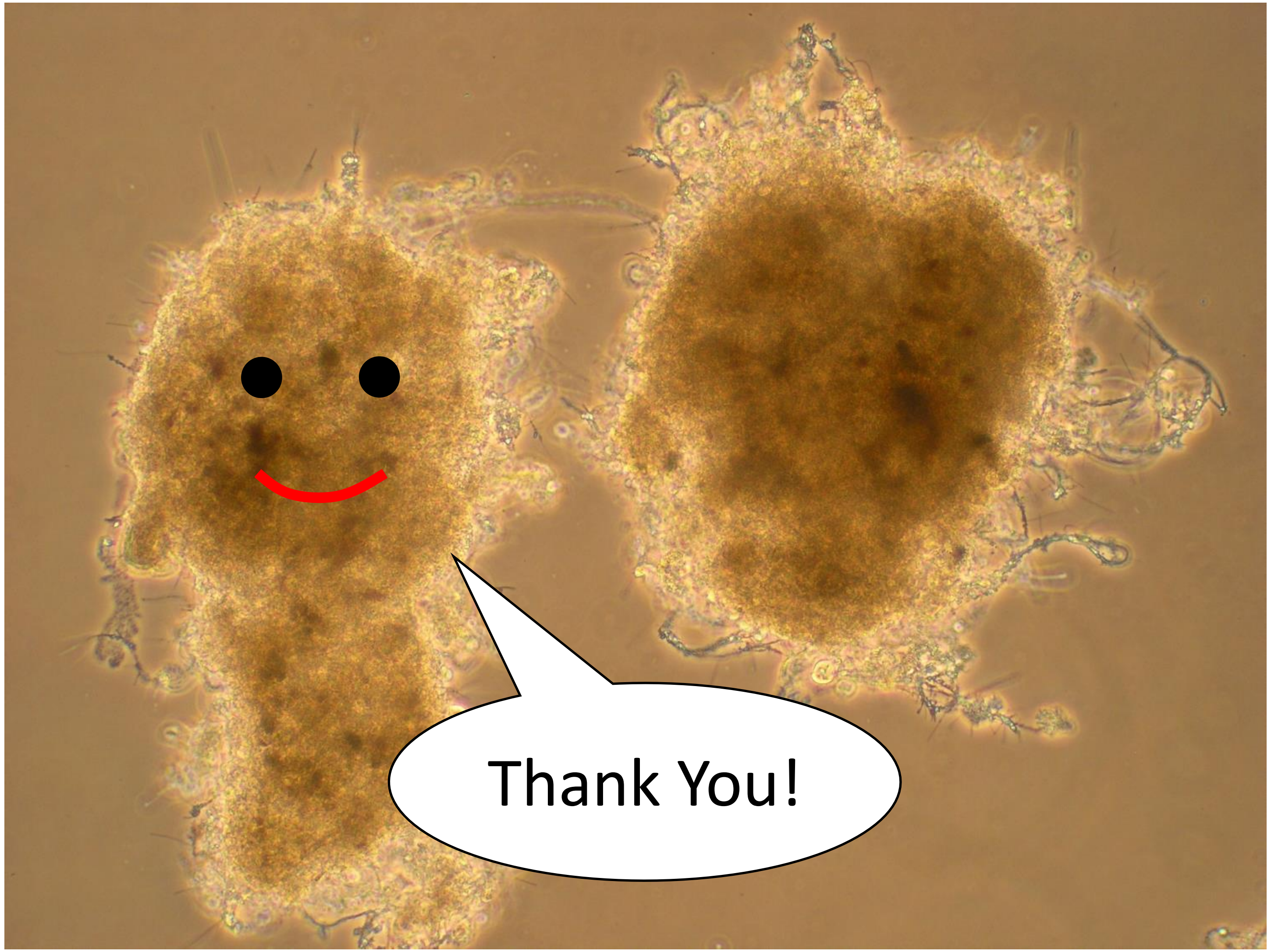
Hydraulic Granule Separation in waste sludge and in secondary clarifier for uncoupled SRTs

G-Granules
F- Floc



Other methods for uncoupling SRTs

- Batch settling of aeration tank effluent
  - Requires multiple batch settlers
  - Overflow to clarifier
  - Underflow with granules to 1st anaerobic contact
- Hydrocyclone for waste sludge
  - Lighter solids wasted
  - Heavier to mainstream
  - Densification process


Thank You!