The Annamox Process Application at DC Water

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dc Process ENGINEERING

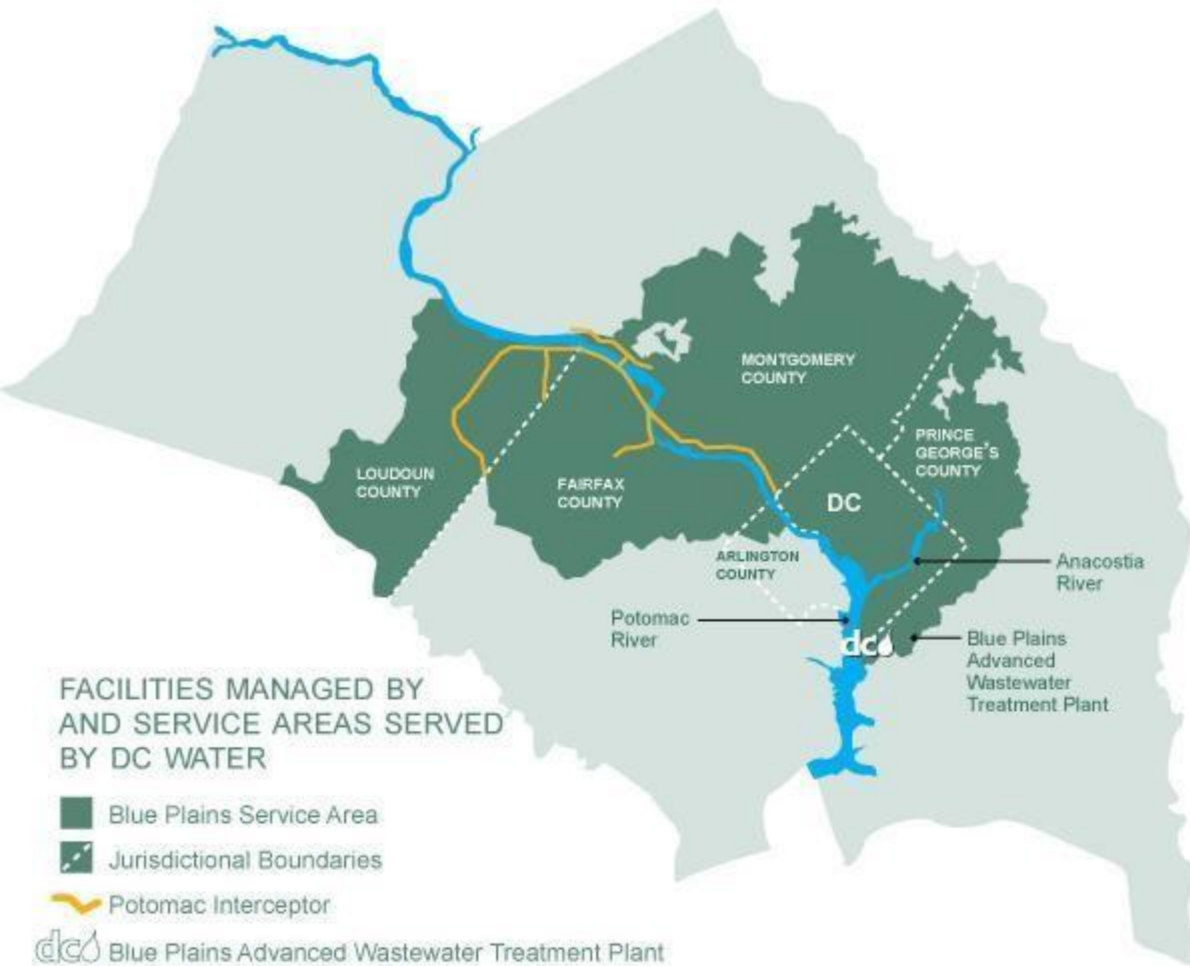
Filtrate Treatment Facility Startup

Presented by: Miguel E Miranda and Shawna Martinelli Gill

Objective and Schedule

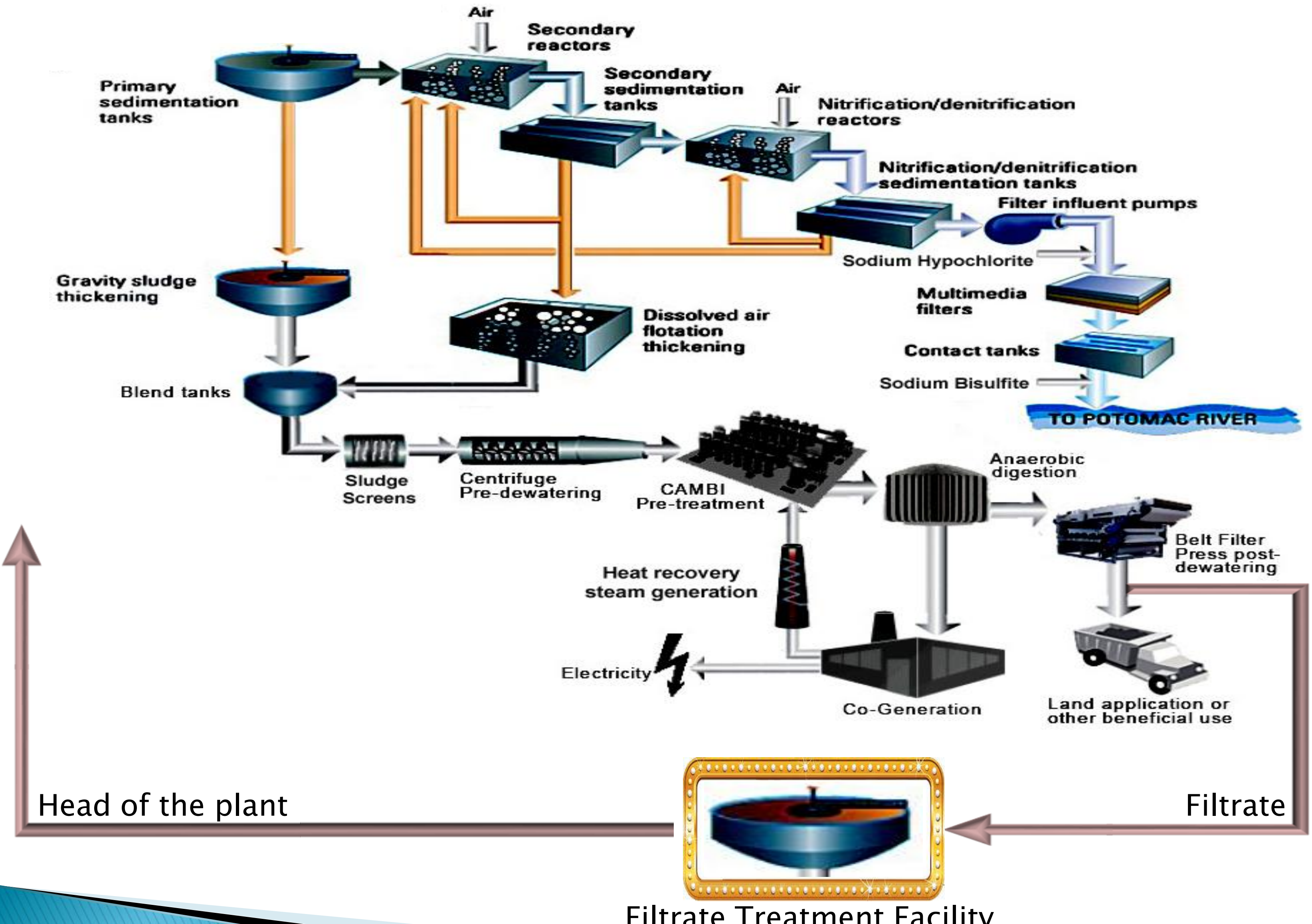
- Who is DC Water and why Annamox?
- Project timeline
- Contract Structure
- Equipment overview
- Control strategy development
- Ramp up performance
  - Pros and cons of our unique methods
- Operational Demonstration (OD) 1 and OD 2
- Lessons Learned

Flow and Service Overview



- Treats wastewater for a population of 2.1 million over a 725 mi^2 service area
- 384 MGD design average flow
- 555 MGD complete treatment during wet weather
- Produces Class A biosolids

Plant Flow Diagram

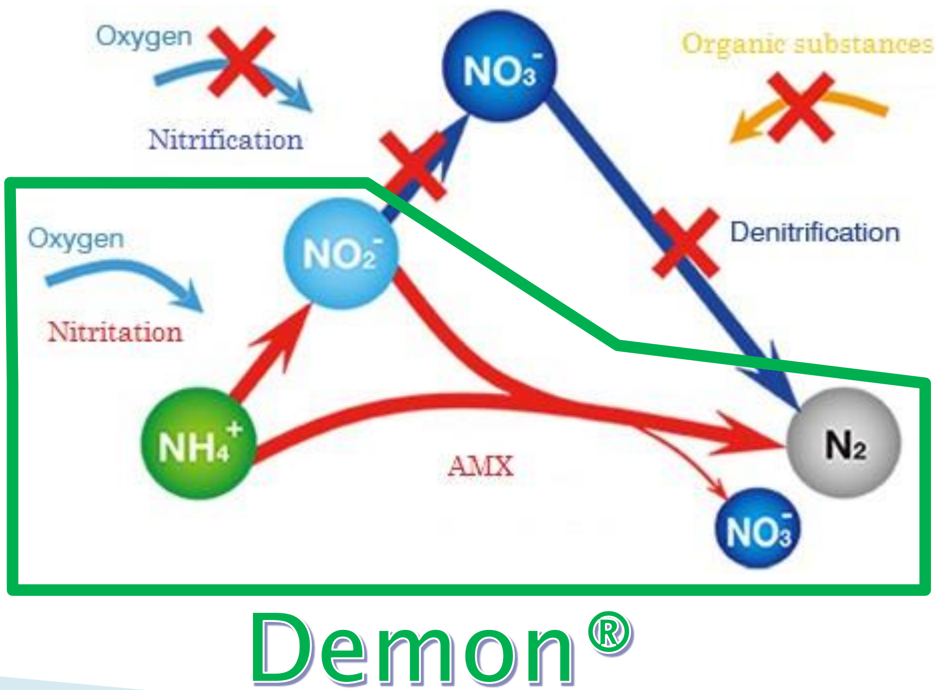


What is Anammox and the Demon$^{(R)}$ System?

- Anammox are a group of anaerobic ammonium oxidizing bacteria that do not require oxygen or methanol to transform NO_2 to Nitrogen gas

- The Demon® System is a process that uses ammonia oxidizing bacteria (AOB) and Anammox to efficiently remove Ammonia (NH_3/ NH_4^+)

- Reduces operational cost of high aeration of oxygen (blowers cost) and methanol demand



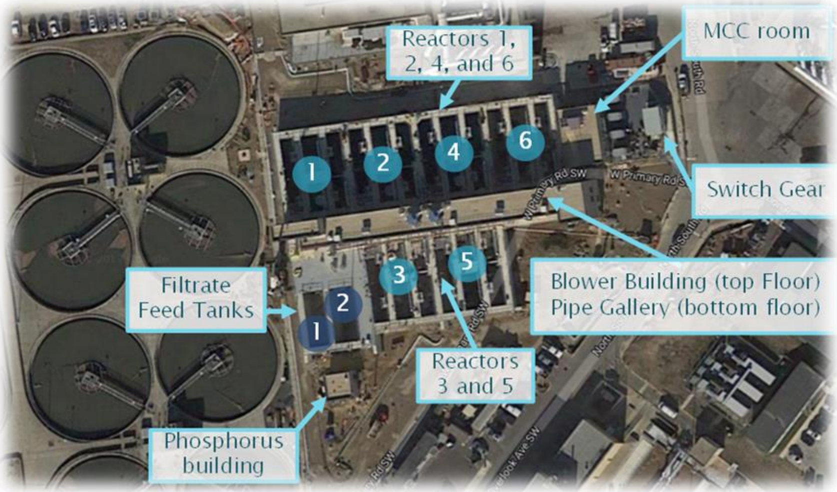
Why use Annamox and DEMON[(R)]?

- Due to Anaerobic Digestion we have an additional 30%-40% Ammonia load
  - During Dewatering at the Belt Filter Presses we generate a concentrated filtrate side stream (~1,600 mg/L of Ammonia)
- Demon can treat Ammonia concentrations of approx. 2,000mg/L, unlike mainstream biology which treats concentration of about 100 mg/L or less

Project Timeline

2009 – 2013	• Preplanning occurred concurrently with THP and Anaerobic Digestion in 2009-2012 • Detail design with B&V was 2012-2013
2014	• Bidding Process • Control strategy developed Emerson/WWW/DCW
2015-early 2017	• Construction and Control Strategy FAT
Mid-2017	• Final Loop testing • Clean Water Testing for oxygen transfer efficiency • Mech. Wet Testing with PC Construction
Late 2017-2018	• Initial Reactor 5 seeding and ramp up • Seeding reactors 1-4
2019-Mid 2020	• Operational Demonstration 1 • Reactor 2 and 5 ramp up • Operational Demonstration 2
Late 2020-now	• Operational optimization • Process Transfer to Operations

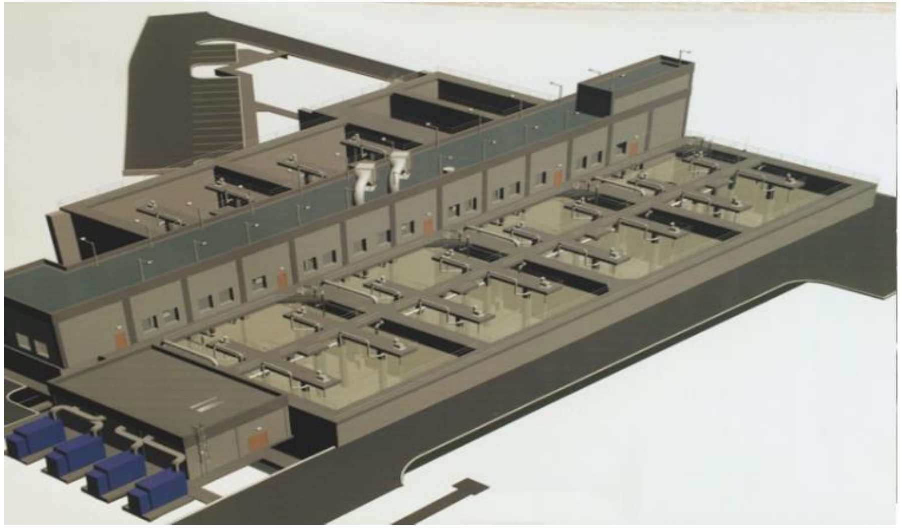
Start Here

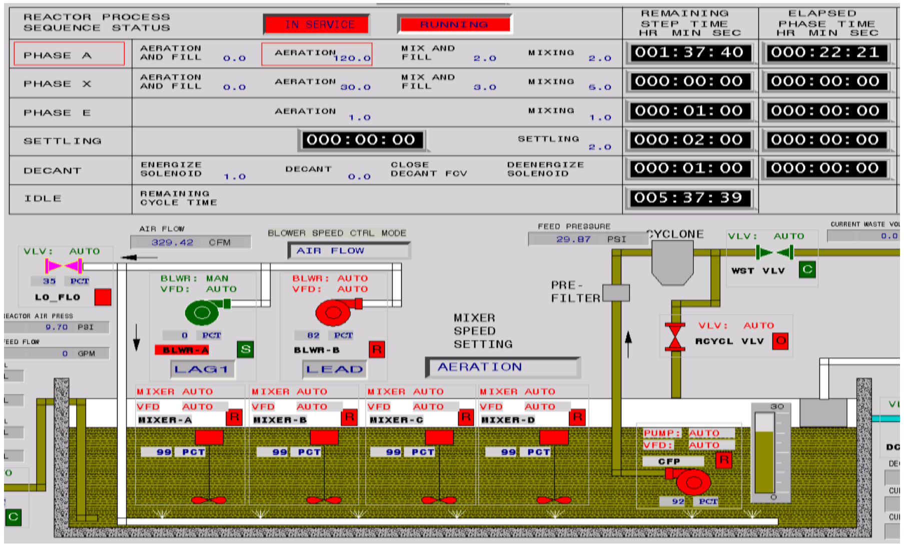


Unique Contract Structure

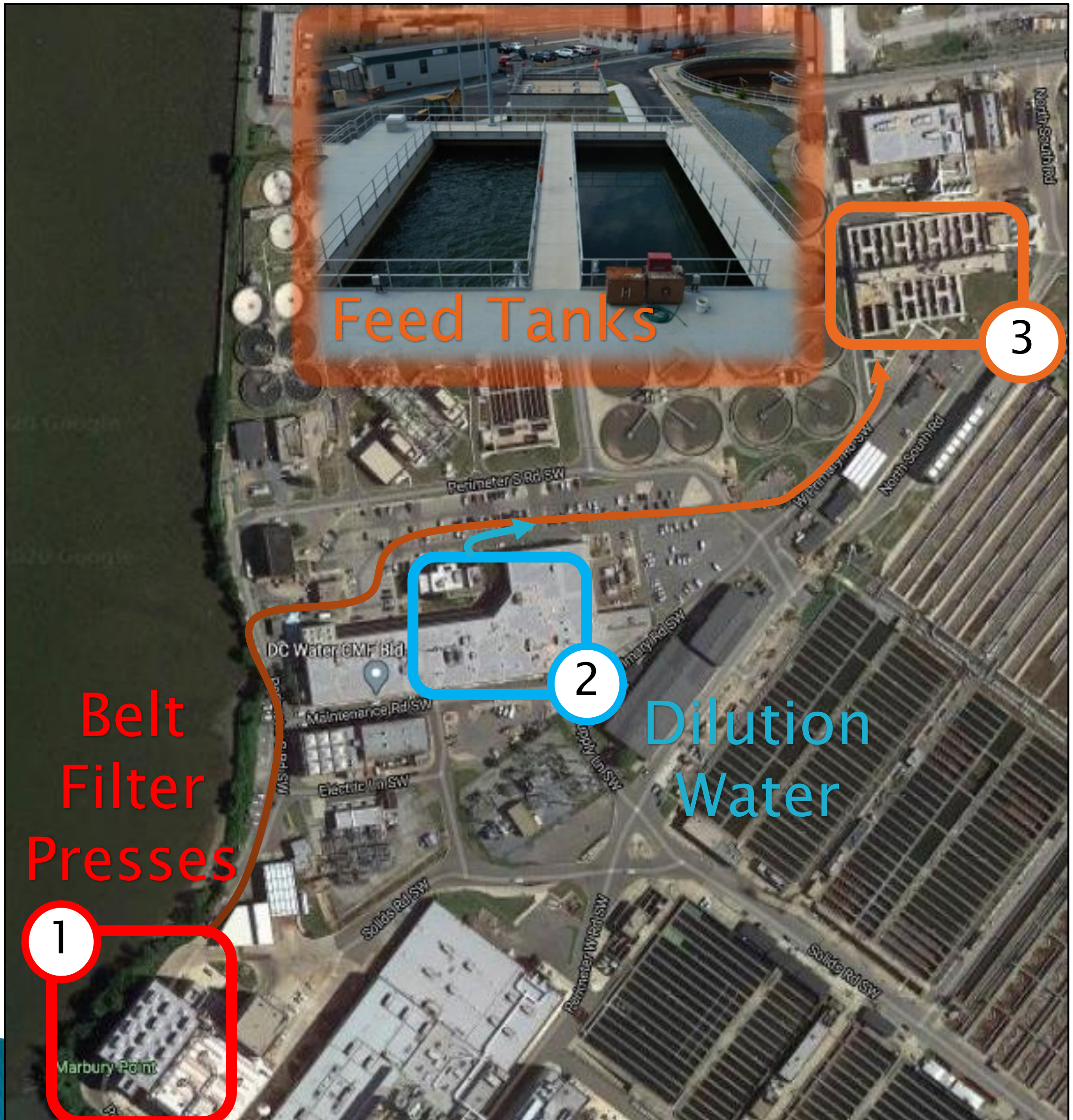
- "Design-Bid-Build"
  - Commissioning team involved in the development of the control strategy and contract structure

- Focused on integrating the system controls with our existing system instead of purchasing a vendor control package
  - We were able to tailor the system to what we wanted





Feed Tanks and Feed System



- Filtrate is pumped from the Belt filter presses to FTF
  - Dilution water is added along the way
- Two tank @0.5 MG
- Feed pumps that maintain pressure in feed loop
- Actuated valves draw from loop to feed reactors

Reactors

- Six Basins
  - Volume = ~1MG
  - 30ft deep
    - Hi operational level – 27 ft
    - Low operational level – 22.5 ft

- Two blowers per basin (Lead/Lag)
- Four mixers per basin
- One Hydrocyclone per basin

Neuros Blowers

*Note that these blowers are designed to Start/Stop frequently

- Has internal PI Controller but is operated via PCS
- Variable Speed blower
  - To achieve lower airflows a blow off valve is used
- Three operating mode
  - DO, Airflow, Constant speed
- Operates by trying to match operator input DO or Air flow values

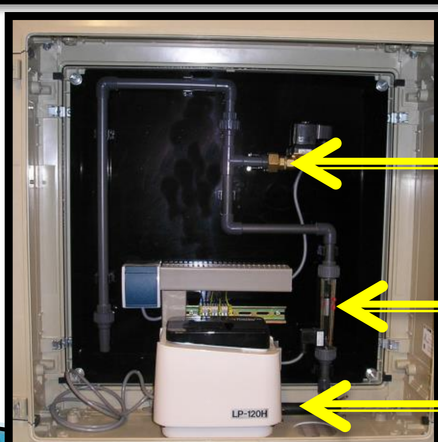
Invent Mixers/Aerators

- Used in tandem with Neuros blowers to create fine bubbles

- Variable speed motors to be able to adjust speed
  - Initially we were varying our mixer speeds during aerating vs mixing (operator input)

- High level protection at 27ft
- Low level protection at 5ft

Decanter SDK 450



- No in tank mechanical parts
- Pneumatic Air Cabinet provides protection from loss of MLSS
- Decant Effluent goes to Raw Waste Water Pumping Station #1

Hydrocyclone System

Overflow: AOB/NOB/OHO(Ordinary Heterotrophic Organisms) Recycled or Wasted

Waste Valve

Pre-Screen

Recycle Valve

Cyclone Pump

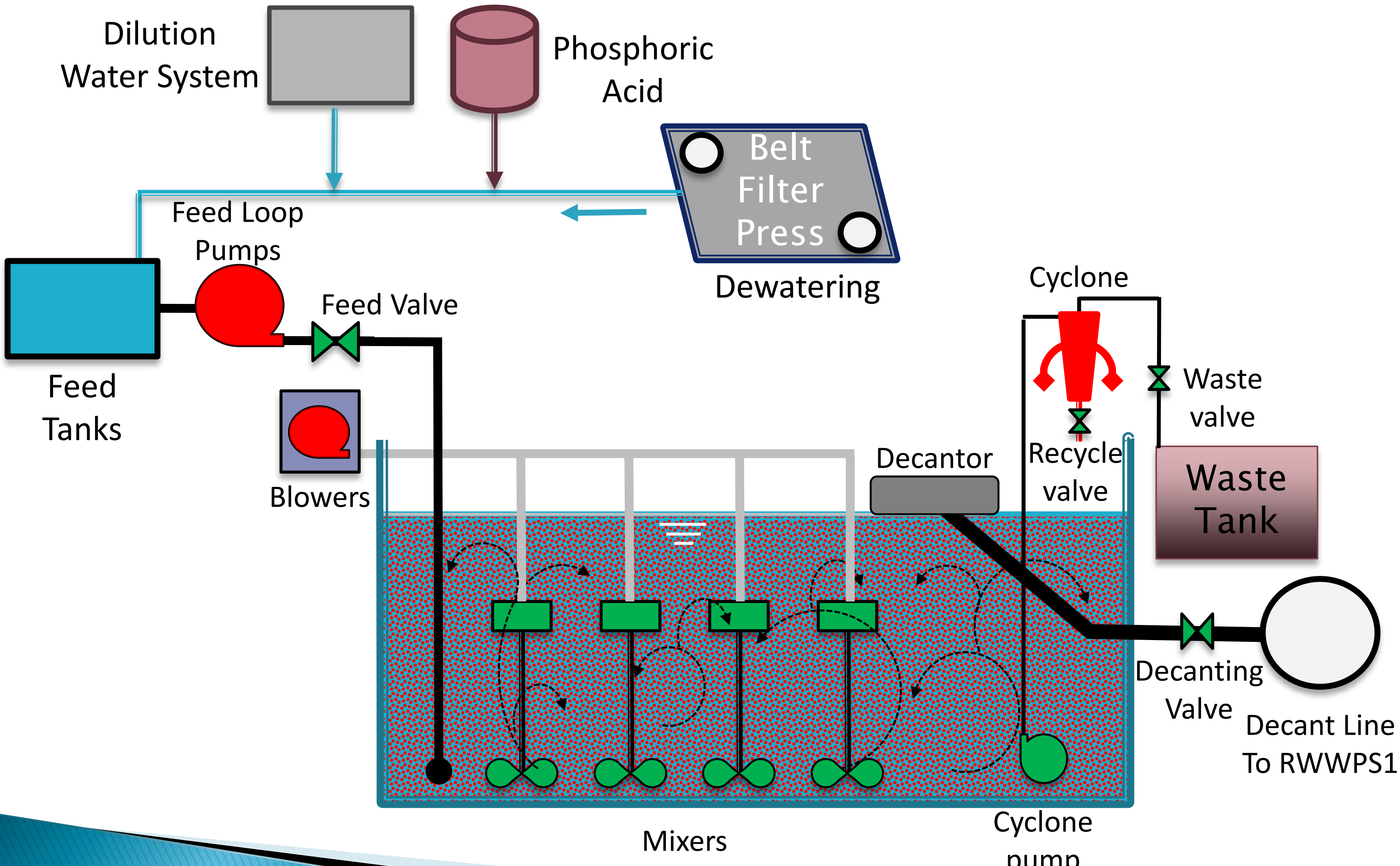
Underflow: Anammox returned to Process

Instrumentation

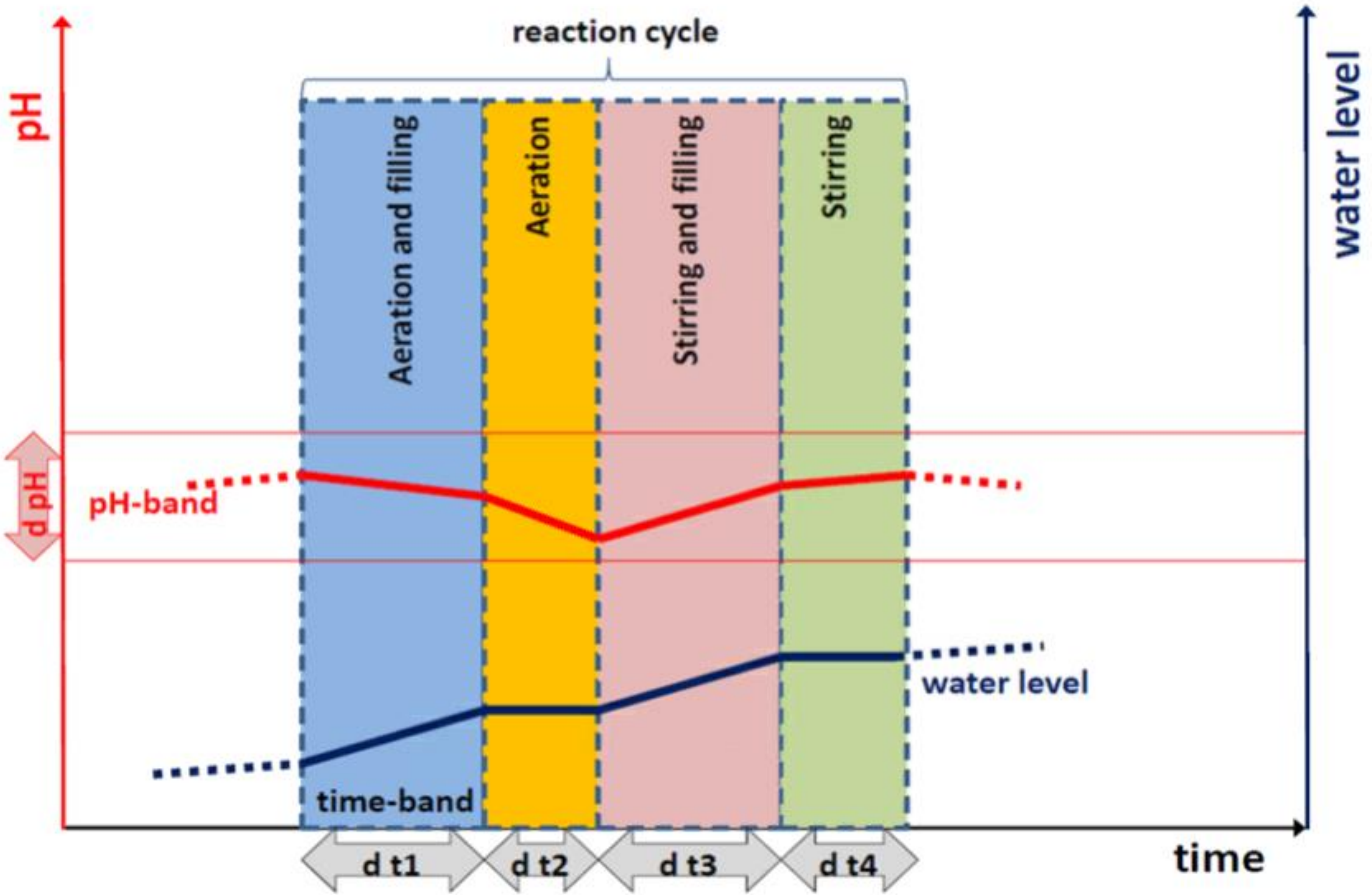
- Sc1000 meter
  - HACH pH/Temperature probe
    - pH range: 6.6-6.8
  - HACH Dissolved Oxygen Probe
    - DO range: 0-1 mg/L

- Sc200 meter
  - HACH Conductivity Sensor
    - Range: 2,000-6,000 uS

DEMON® Process Flowchart



Control Strategy



Control Strategy

DEMON Control Modes	Description	Tabular Representation
Intermittent Feed Mode	-Feeding and Aerating occurs separately -Aeration time is predetermined -Maximize denitrification by using high COD -Used during start-up	see table 1 below
Timed Mode	-Feeding and Aerating occur at the same time -Aeration time is predetermined -Used during ramp up -Very hands-on (sampling)	see table 2 below
pH Control Mode	-pH and DO probes to control Feeding and Aerating -Blower starts when pH reaches upper setpoint and stops when pH drops to the lower setpoint -Feed occurs when above the lower pH setpoint and stops when upper setpoint is reached	see table 3 below

Intermittent Feed Mode

REACTOR PROCESS SEQUENCE STATUS — IN SERVICE — RUNNING

	AERATION AND FILL	AERATION	MIX AND FILL	MIXING
PHASE A	0.0	120.0	2.0	2.0
PHASE X	0.0	30.0	3.0	5.0
PHASE E		1.0		1.0

Timed Mode

REACTOR PROCESS SEQUENCE STATUS — IN SERVICE — RUNNING

	AERATION AND FILL	AERATION	MIX AND FILL	MIXING
PHASE A	15.0	0.0	8.0	0.0
PHASE X	15.0	0.0	8.0	0.0
PHASE E		13.0		20.0

pH Control Mode

REACTOR PROCESS SEQUENCE STATUS — IN SERVICE — RUNNING

	AERATION AND FILL	AERATION	MIX AND FILL	MIXING
PHASE A	13.0	0.0	8.0	0.0
PHASE X	600.0	0.0	0.0	0.0
PHASE E		13.0		20.0

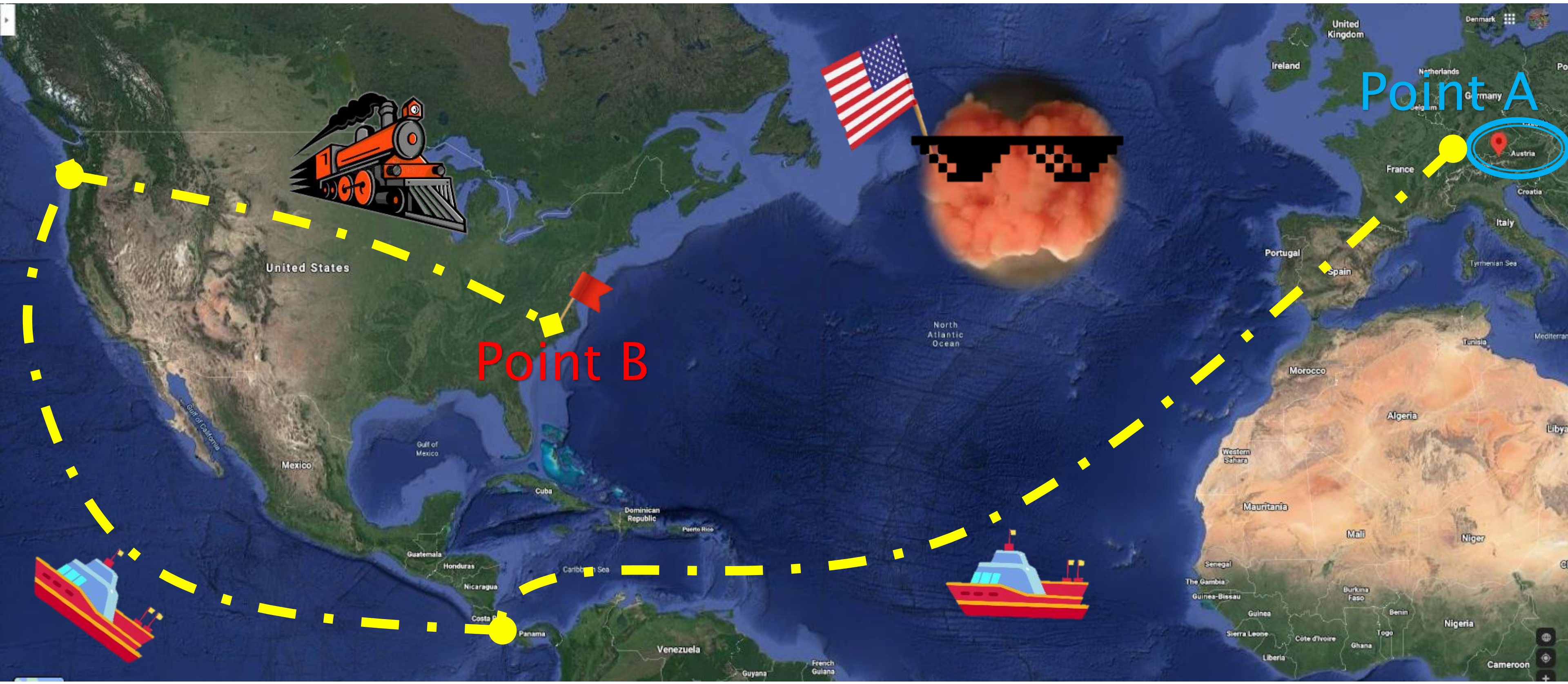
FTF Start-Up Events

- First shipment of Annamox seed was delivered from Strass, Austria in Late 2017
  - They can remain dormant over long periods of time

- Seed sludge had a layover before its final destination in FTF Reactor 5!

Seed Sludge

FTF Start-Up Events



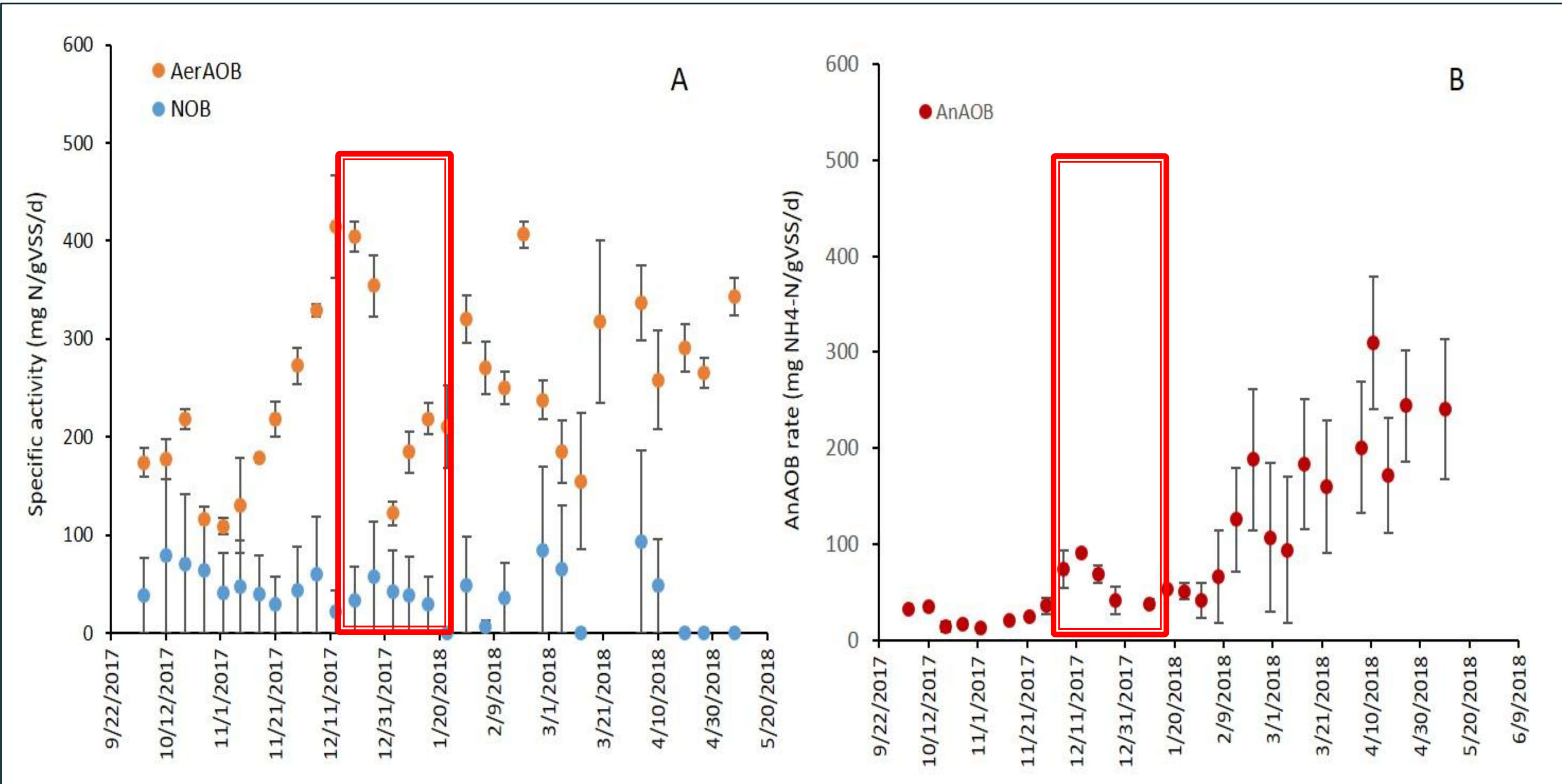
Unique Start Up Modes

- **Nitritation/Denitritation (N/dN) Mode** – develop acclimated AOBs and Heterotrophic bacteria prior to seeding
- **Nitritation Only Mode (N)** – develop a high NO_2 environment prior to seeding as well as some treatment benefits
- In both Mode NOBs were quickly out selected prior to seeding

2A – Modes of Reactor Operation							
Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Rx-1	-	-	N	N	N	N	N
Rx-2	-	-	-	N	N	N	D
Rx-3	-	N/dN	N/dN	N/dN	N/dN	D	D
Rx-4	-	-	-	N/dN	N/dN	N/dN	N/dN
Rx-5	N/dN; D	D	D	D	D	D	D
Rx-6	CT	CT	CT	CT	CT	CT	CT

D = operation for deammonification
N/dN = operation for nitritation and denitritation to low NO2-N
N = operation for nitritation only
CT = controls system testing (variable modes)

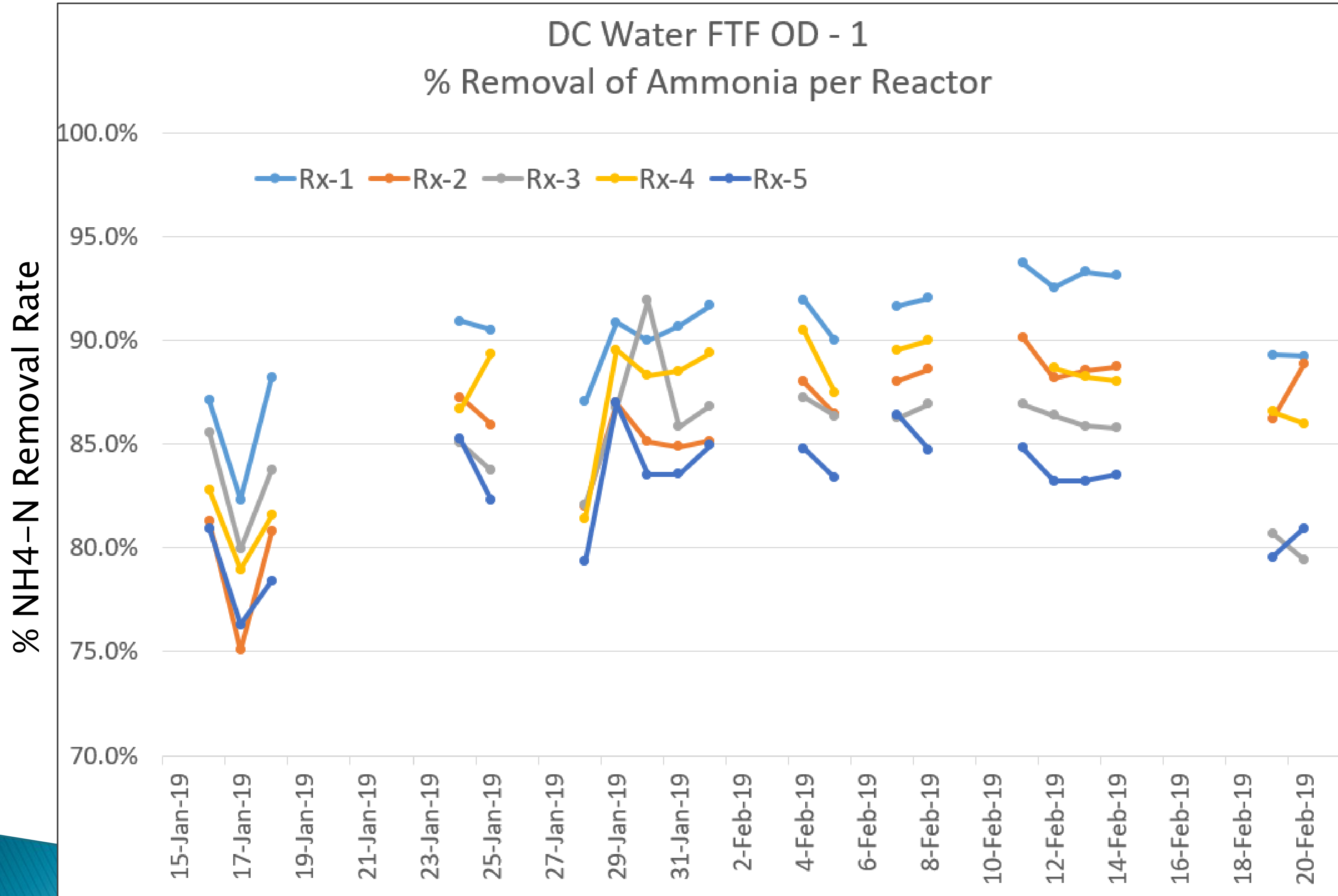
Unique Start Up Modes



Process Performance: OD1

- 30 Day Operation Demonstration
- Treating all incoming load
- No operational changes allowed
- Design Load for Rx1-5 were 0.35 to 0.4 kg/m3-day
- Filtered decant Samples (and duplicate) were taken to an external lab

Process Performance: OD1

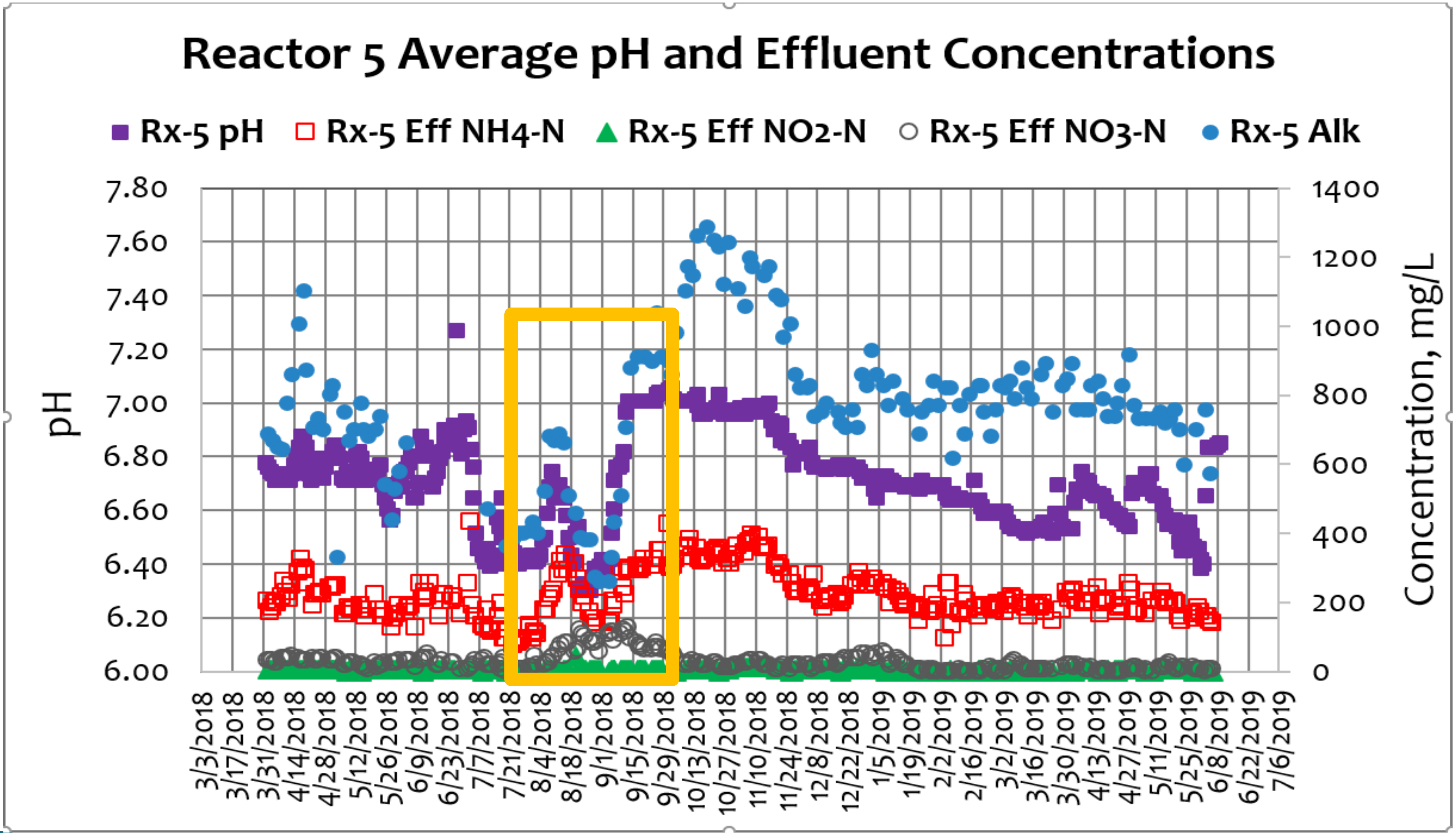


OD1 Results & Lessons Learned

- When stable, biology is self-sufficient and resilient
  - When troubleshooting reactors can be put offline until issues are resolved
- Importance of Chemical Balance
  - Low pH can lead to high NOB population
- Need to waste excess biology to assist with settling
  - Excessive AOB can prevent Annamox from settling

OD1 Results & Lessons Learned

- Important of chemical balance



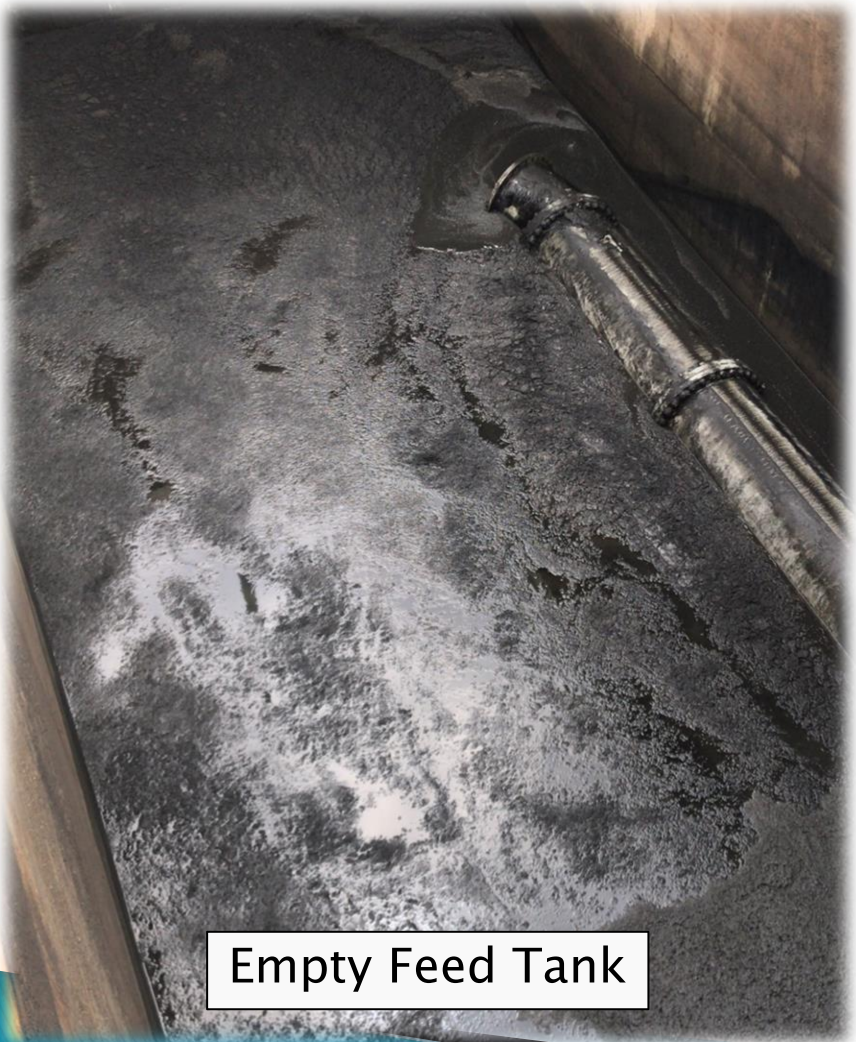
OD1 Results & Lessons Learned

- Important of chemical balance

	pH												
Ammonia	6.80	6.90	7.00	7.10	7.20	7.30	7.40	7.50	7.60	7.70	7.80	7.90	8.00
50 mg/L	0.25 mg/L	0.32 mg/L	0.40 mg/L	0.50 mg/L	0.63 mg/L	0.79 mg/L	0.99 mg/L	1.24 mg/L	1.55 mg/L	1.94 mg/L	2.42 mg/L	3.01 mg/L	3.73 mg/L
60 mg/L	0.30 mg/L	0.38 mg/L	0.48 mg/L	0.60 mg/L	0.76 mg/L	0.95 mg/L	1.19 mg/L	1.49 mg/L	1.86 mg/L	2.33 mg/L	2.90 mg/L	3.61 mg/L	4.47 mg/L
70 mg/L	0.35 mg/L	0.45 mg/L	0.56 mg/L	0.70 mg/L	0.88 mg/L	1.11 mg/L	1.39 mg/L	1.74 mg/L	2.18 mg/L	2.72 mg/L	3.39 mg/L	4.21 mg/L	5.22 mg/L
80 mg/L	0.40 mg/L	0.51 mg/L	0.64 mg/L	0.80 mg/L	1.01 mg/L	1.27 mg/L	1.59 mg/L	1.99 mg/L	2.49 mg/L	3.10 mg/L	3.87 mg/L	4.81 mg/L	5.96 mg/L
90 mg/L	0.46 mg/L	0.57 mg/L	0.72 mg/L	0.90 mg/L	1.13 mg/L	1.42 mg/L	1.79 mg/L	2.24 mg/L	2.80 mg/L	3.49 mg/L	4.35 mg/L	5.41 mg/L	6.71 mg/L
100 mg/L	0.51 mg/L	0.64 mg/L	0.80 mg/L	1.00 mg/L	1.26 mg/L	1.58 mg/L	1.98 mg/L	2.48 mg/L	3.11 mg/L	3.88 mg/L	4.84 mg/L	6.01 mg/L	7.46 mg/L
110 mg/L	0.56 mg/L	0.70 mg/L	0.88 mg/L	1.10 mg/L	1.39 mg/L	1.74 mg/L	2.18 mg/L	2.73 mg/L	3.42 mg/L	4.27 mg/L	5.32 mg/L	6.62 mg/L	8.20 mg/L
120 mg/L	0.61 mg/L	0.76 mg/L	0.96 mg/L	1.20 mg/L	1.51 mg/L	1.90 mg/L	2.38 mg/L	2.98 mg/L	3.73 mg/L	4.66 mg/L	5.80 mg/L	7.22 mg/L	8.95 mg/L
130 mg/L	0.66 mg/L	0.83 mg/L	1.04 mg/L	1.31 mg/L	1.64 mg/L	2.06 mg/L	2.58 mg/L	3.23 mg/L	4.04 mg/L	5.05 mg/L	6.29 mg/L	7.82 mg/L	9.69 mg/L
140 mg/L	0.71 mg/L	0.89 mg/L	1.12 mg/L	1.41 mg/L	1.76 mg/L	2.21 mg/L	2.78 mg/L	3.48 mg/L	4.35 mg/L	5.43 mg/L	6.77 mg/L	8.42 mg/L	10.44 mg/L
150 mg/L	0.76 mg/L	0.95 mg/L	1.20 mg/L	1.51 mg/L	1.89 mg/L	2.37 mg/L	2.98 mg/L	3.73 mg/L	4.66 mg/L	5.82 mg/L	7.26 mg/L	9.02 mg/L	11.18 mg/L
160 mg/L	0.81 mg/L	1.02 mg/L	1.28 mg/L	1.61 mg/L	2.02 mg/L	2.53 mg/L	3.17 mg/L	3.97 mg/L	4.97 mg/L	6.21 mg/L	7.74 mg/L	9.62 mg/L	11.93 mg/L
170 mg/L	0.86 mg/L	1.08 mg/L	1.36 mg/L	1.71 mg/L	2.14 mg/L	2.69 mg/L	3.37 mg/L	4.22 mg/L	5.28 mg/L	6.60 mg/L	8.22 mg/L	10.22 mg/L	12.67 mg/L
180 mg/L	0.91 mg/L	1.14 mg/L	1.44 mg/L	1.81 mg/L	2.27 mg/L	2.85 mg/L	3.57 mg/L	4.47 mg/L	5.59 mg/L	6.99 mg/L	8.71 mg/L	10.83 mg/L	13.42 mg/L
190 mg/L	0.96 mg/L	1.21 mg/L	1.52 mg/L	1.91 mg/L	2.40 mg/L	3.01 mg/L	3.77 mg/L	4.72 mg/L	5.90 mg/L	7.37 mg/L	9.19 mg/L	11.43 mg/L	14.17 mg/L
200 mg/L	1.01 mg/L	1.27 mg/L	1.60 mg/L	2.01 mg/L	2.52 mg/L	3.16 mg/L	3.97 mg/L	4.97 mg/L	6.22 mg/L	7.76 mg/L	9.67 mg/L	12.03 mg/L	14.91 mg/L
210 mg/L	1.06 mg/L	1.34 mg/L	1.68 mg/L	2.11 mg/L	2.65 mg/L	3.32 mg/L	4.17 mg/L	5.22 mg/L	6.53 mg/L	8.15 mg/L	10.16 mg/L	12.63 mg/L	15.66 mg/L
220 mg/L	1.11 mg/L	1.40 mg/L	1.76 mg/L	2.21 mg/L	2.77 mg/L	3.48 mg/L	4.36 mg/L	5.47 mg/L	6.84 mg/L	8.54 mg/L	10.64 mg/L	13.23 mg/L	16.40 mg/L
230 mg/L	1.16 mg/L	1.46 mg/L	1.84 mg/L	2.31 mg/L	2.90 mg/L	3.64 mg/L	4.56 mg/L	5.71 mg/L	7.15 mg/L	8.93 mg/L	11.13 mg/L	13.83 mg/L	17.15 mg/L
240 mg/L	1.21 mg/L	1.53 mg/L	1.92 mg/L	2.41 mg/L	3.03 mg/L	3.80 mg/L	4.76 mg/L	5.96 mg/L	7.46 mg/L	9.31 mg/L	11.61 mg/L	14.43 mg/L	17.89 mg/L
250 mg/L	1.26 mg/L	1.59 mg/L	2.00 mg/L	2.51 mg/L	3.15 mg/L	3.95 mg/L	4.96 mg/L	6.21 mg/L	7.77 mg/L	9.70 mg/L	12.09 mg/L	15.04 mg/L	18.64 mg/L

OD1 Results & Lessons Learned

- Sinking and Floating Solids



OD1 Results & Lessons Learned

- Sinking and Floating Solids: Part 2

OD1 Results & Lessons Learned

- Excess Polymer and Coating

Operational Demonstration 2

- 30 Day Operation Demonstration
- Two Reactors selected by DC Water to challenge with sustained peak Nitrogen loading rate of 0.6 kg NH_3-N/d/m^3
- Minimum 72% ammonia removal and minimum of 65% total nitrogen removal
- Filtered decant and feed tank Samples (and duplicate) sent to external lab(s) and DC Water lab and Hach used to validate results

OD2 Results & Lessons Learned

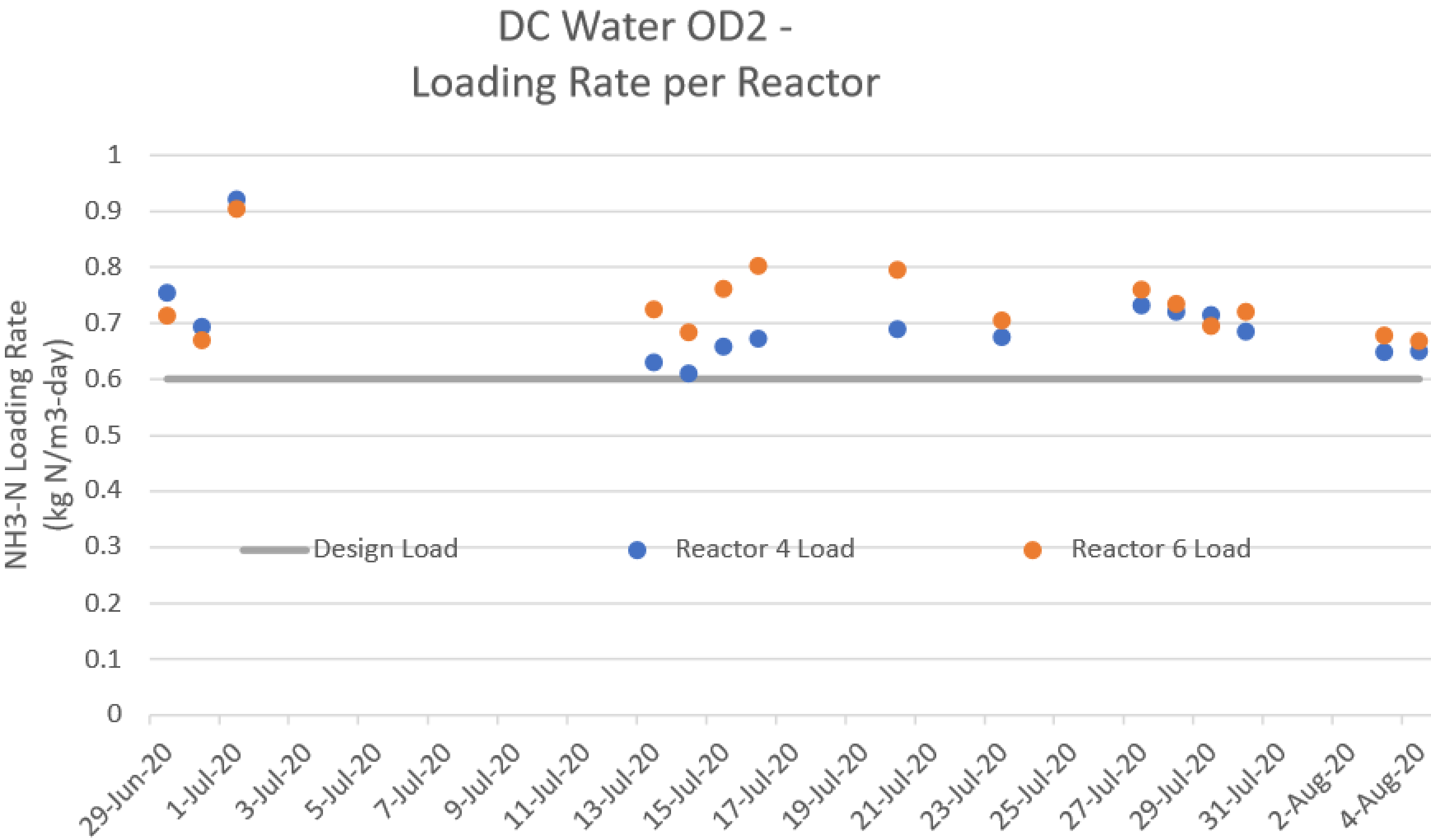
OD2 % Removal for Reactors 4 & 6 Combined

	NH_3-N	TIN
Contract Requirement	>72%	>62%
Average	86.8%	83.3%
Minimum	80.5%	78.9%
Maximum	92.8%	90.2%

OD2 % Removal for Reactors 4 & 6 Separately

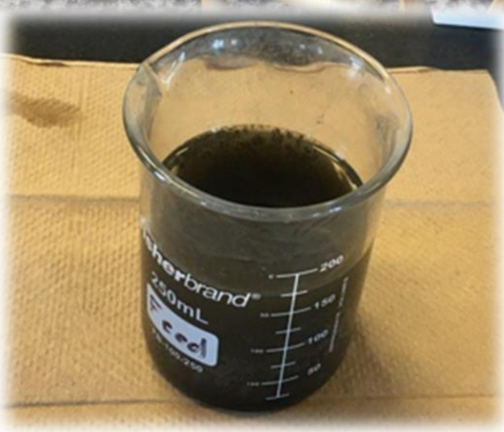
	FTF #4 NH_3-N	FTF #4 TIN	FTF #6 NH_3-N	FTF #6 TIN
Contract Requirement	>72%	>62%	>72%	>62%
Average	86.6%	81.6%	87.0%	84.9%
Minimum	80.5%	73.7%	83.0%	80.1%
Maximum	91.4%	89.5%	92.8%	91.0%

OD2 Results & Lessons Learned



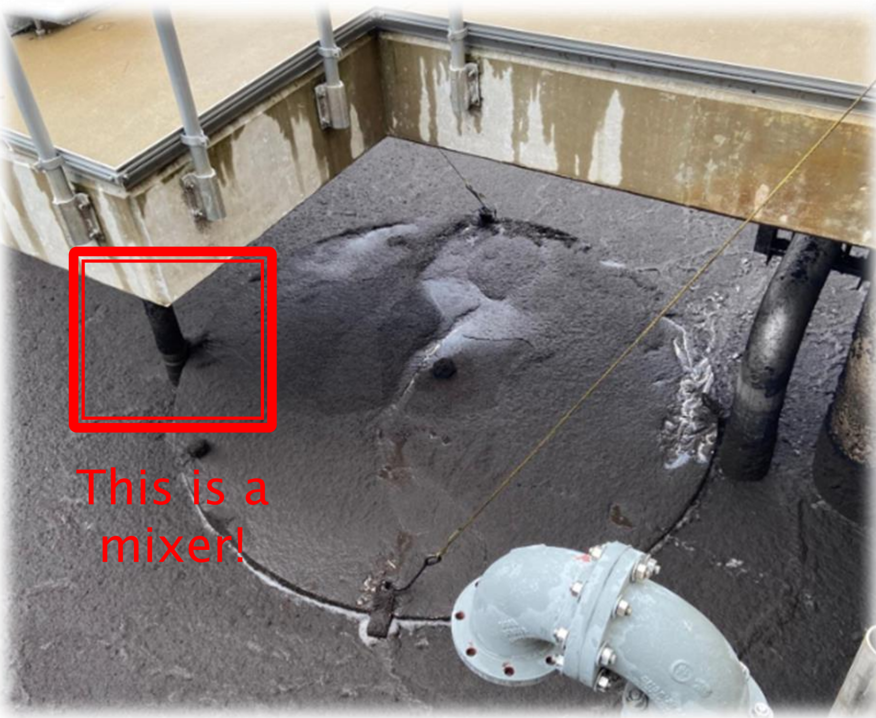
OD2 Results & Lessons Learned

- Excessive Foaming in feed tank and reactors
- Immediate impact on reactor performance and TSS when poor filtrate quality occurs due to belt operation or polymer efficiency



Decanter Failure (OD1&2)

- Decanter Failure in Reactor 5 originally, Reactors 2 & 3 at conclusion of OD1, and failure of Reactors 4 and 6 conclusion of OD2



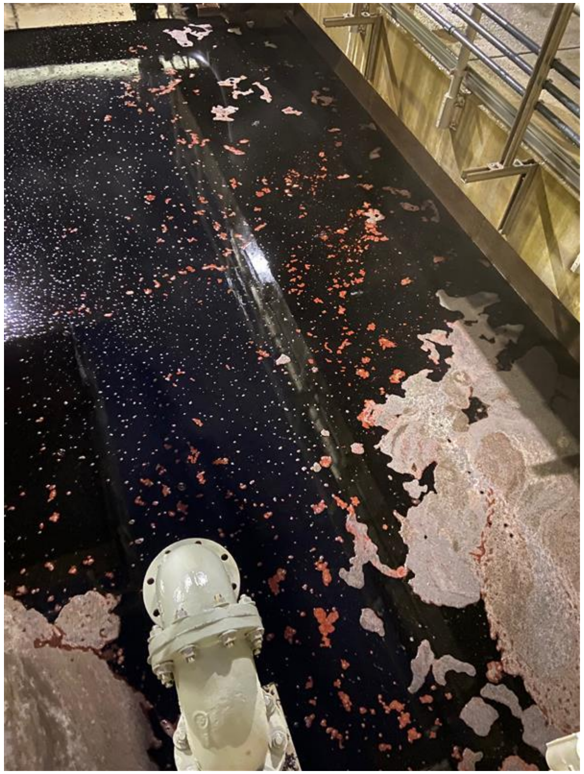
Ops Optimization

- Decanter Removal and short term riser modifications

- Quickest solution but with big consequences
  - Biological lost
  - Limited feed

Ops Optimization

- Loss of Biology through wasting or supernatant



Ops Optimization

- Ongoing feed quality issues
  - Feed Tank emptying and solids removal
- Installation of a Cerlic to determine baseline versus process upset
- Create bypass of feed tank to flush

Ops Optimization

- Long term intent : modify one reactor to continuous overflow with a baffle wall configuration

- DCW currently working with specialty firm on Computational Fluid Dynamics (CFD) model of baffle wall with invent aerator mixers

- If pending simulations are agreeable will try full scale pilot in one of the 6 reactors

- In meantime modifying 2 of the decanters to be robust enough to treat load of FTF in interim

Hindsight 20/20

- Process Champion
  - Requires a level of attention and understanding beyond typical continuous flow operations
- CFD of unique equipment combination; contribution of blowers and invent mixer/aerators to decanter
- Lack of adequate buffer or equalization before feeding
  - Ability to remove solids from reactor and feed tanks (Sinking and Floating)
  - Ability to Bypass FTF or flush feed tank
- Individual sample lines for each reactor (combined overflow of reactors and feed tanks to common decanter line)

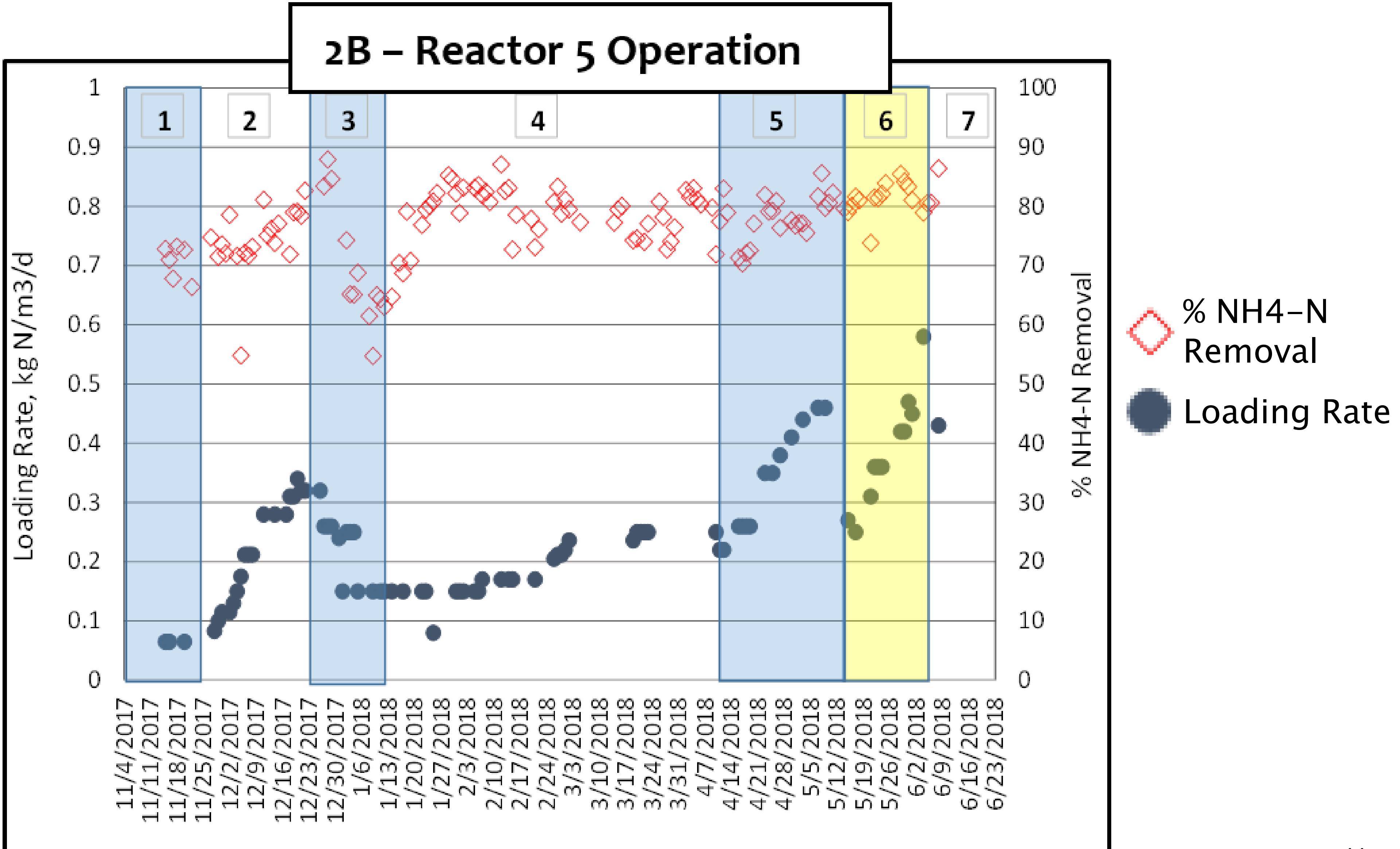
Questions?

Contact

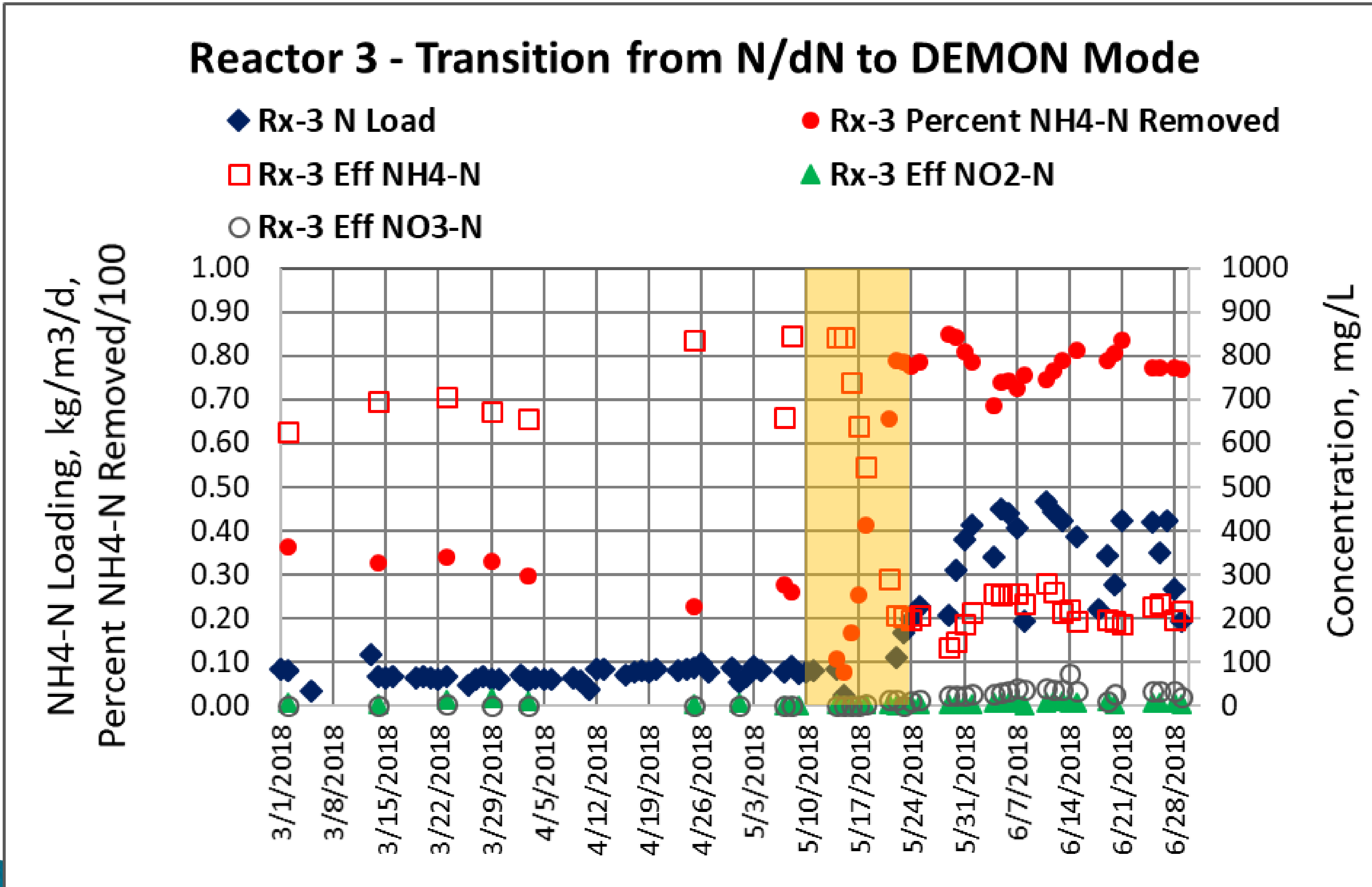
Miguel Miranda – mmiranda@dcwater.com
Shawna Martinelli – smartinelli@dcwater.com

Supplemental info

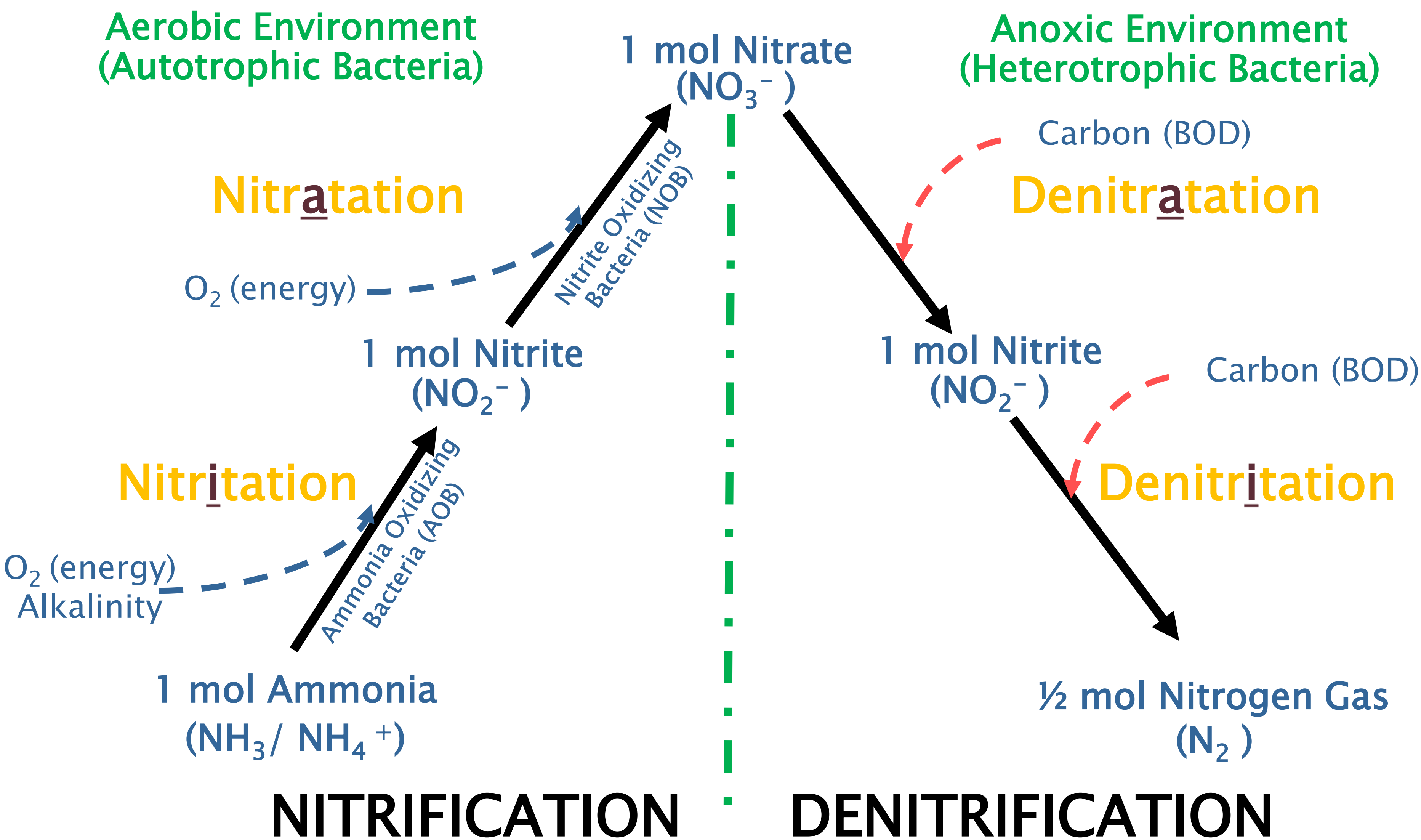
Unique Start Up Modes



Unique Start Up Modes



Standard Nitrification / Denitrification



DEMON (R) (Anammox) Process

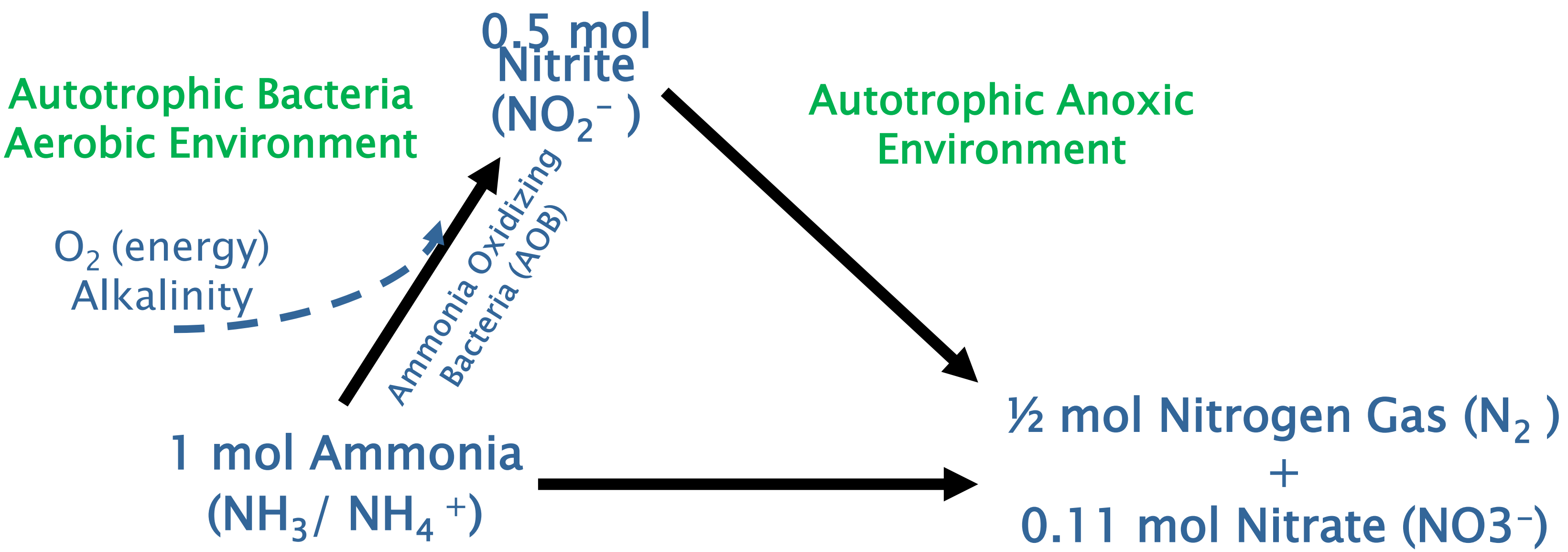
$$NH_4^+ + 1.32\ NO_2^- + 0.066\ HCO_3^- + 0.13\ H^+$$

$$\downarrow$$

$$0.26\ NO_3^- + 1.02N_2 + 0.066\ CH_2O_{0.5}N_{0.15} + 2.03\ H_2O$$

Advantages

- 63% reduction in oxygen demand (energy)
- Nearly 100% reduction in carbon demand
- 80% reduction in biomass production
- No additional alkalinity required



Typical Demon[(R)] Effluent Quality

- Standard Effluent Performance
  - 90% removal of ammonia-nitrogen

$$NH_4\,removal = \frac{NH_4inf - NH_4eff}{NH_4inf}\;x\,100$$

  - 10-15% production of nitrate-nitrogen

$$NO_3\,production = \frac{NO_3eff - \;NO_3inf}{NH_4\,inf - \;NH_4\,eff}\;x\,100$$

  - 80% removal of total nitrogen (could increase in with influent carbon)

  - Typical Guidelines:
    - Residual alkalinity 250 – 300 mg/L as CaCO3
    - Residual NH3-N of 100 – 300 mg/L
    - Nitrite concentration below 15 mg/L

Full Scale Operational Requirements

- Sampling
  - Steady State – 2-3 x per week analysis of influent / effluent
  - Measurements of NH_3-N, NO_3-N, NO_2-N and TSS
- Sensors
  - pH, DO, Conductivity and optional NH_3-N
- Regular Operation
  - DO range of 0.3 – 0.5 mg/L (normal COD); 1 mg/L (excess COD)
  - pH typically around 7.0
  - Hydrocyclone – 1 hr per cycle; increasing NO_3-N, Inc. time

NO_2–N Rise

Target: <3 mg/L, > 3 to 15 mg/L ok for start up,15 to 35 mg/L take measures to reduce, >35 mg/l put the system in OFF-LINE (manual mix overnight) to allow anammox to consume the NO2.

- Cause: Limited diffusion
- Action: Longer shearing time

- Cause: Over Aeration
- Action: Reduced Blower VFD, if severe increase mixing time

NO_3-N Rise

(Target: < 12 % for NO3-N/ NH_3-N removed)

- Cause: NOB proliferation
- Action: SRT should be 1.5 days until the NO3 concentrations are normal, if needed reduce tank volume (by lowering decanter height) to achieve this

NH_3–N Rising

Target: Target > 82% of Influent Ammonia removal ~100 to 300 mg/L (residual requirement of 100–300 mg/L)

- Cause: Deficient O_2
- Action: Increase aeration volume (Blower % VFD)

- Cause: AOB SRT too low
- Action: Reduce sludge wasting

- Cause: Inhibition/Toxicity
- Action: Troubleshoot individual possibilities

dc Process ENGINEERING

Most Common Issues

- The most common in a DEMON system for AMX:
  - High NO2 level (>100 ppm for >2 days)
  - High level (>1.0mg/L) dissolved oxygen – for long periods of time
  - High level of TSS (heavy TSS not wanted due to competition in cyclone)
  - Overdosing Polymer – causes layering effect on granules which needs to be removed

Foam

- Causes:
  - Over dosage of polymer – minimal foaming is tolerable
  - Biomass die off – OHO/AOB/NOB
  - Toxic event

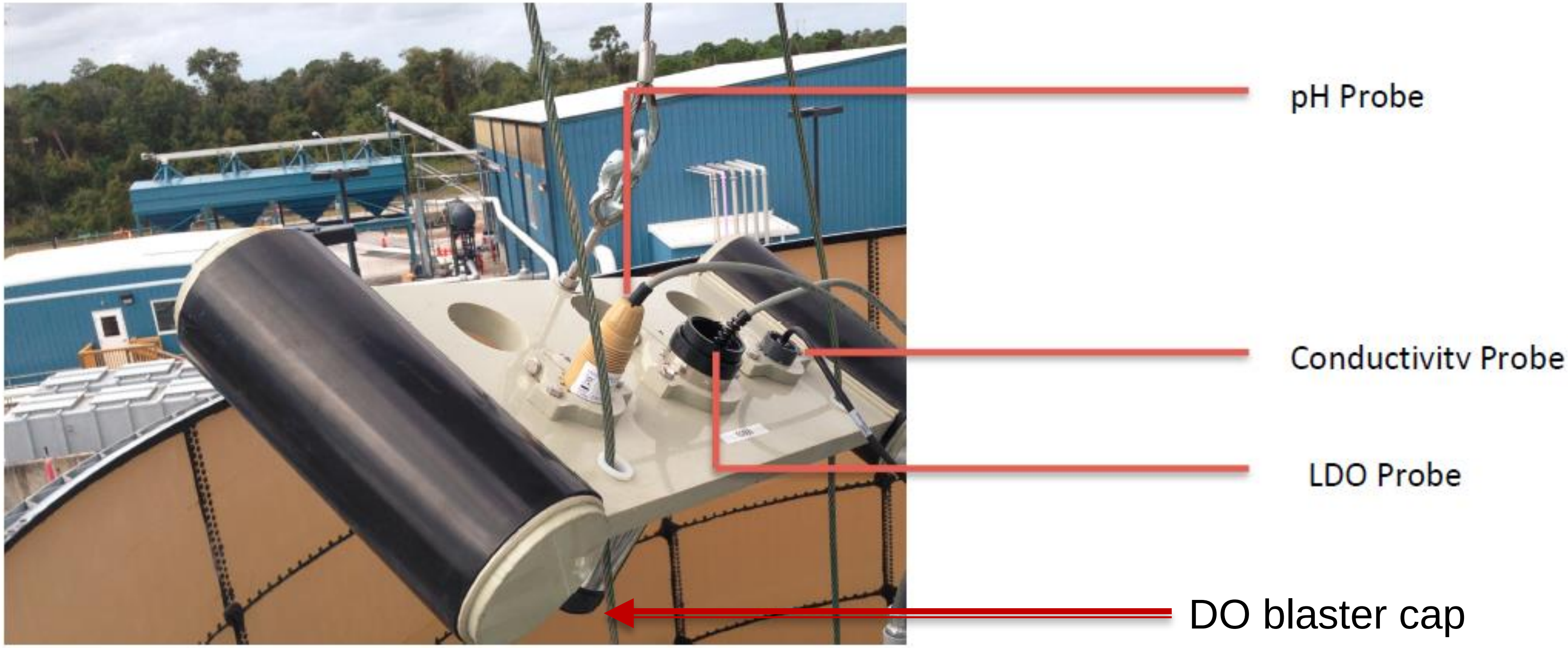
- Actions:
  - If a >10% reduction of Ammonia removal is seen, reduce or stop feed until problem is identified
  - Check polymer dosing and adjust if over dosage

Instrumentation

- Sc1000 meter
  - HACH pH/Temperature probe
  - HACH Dissolved Oxygen Probe
- Sc200 meter
  - HACH Conductivity Sensor
- DO Blaster

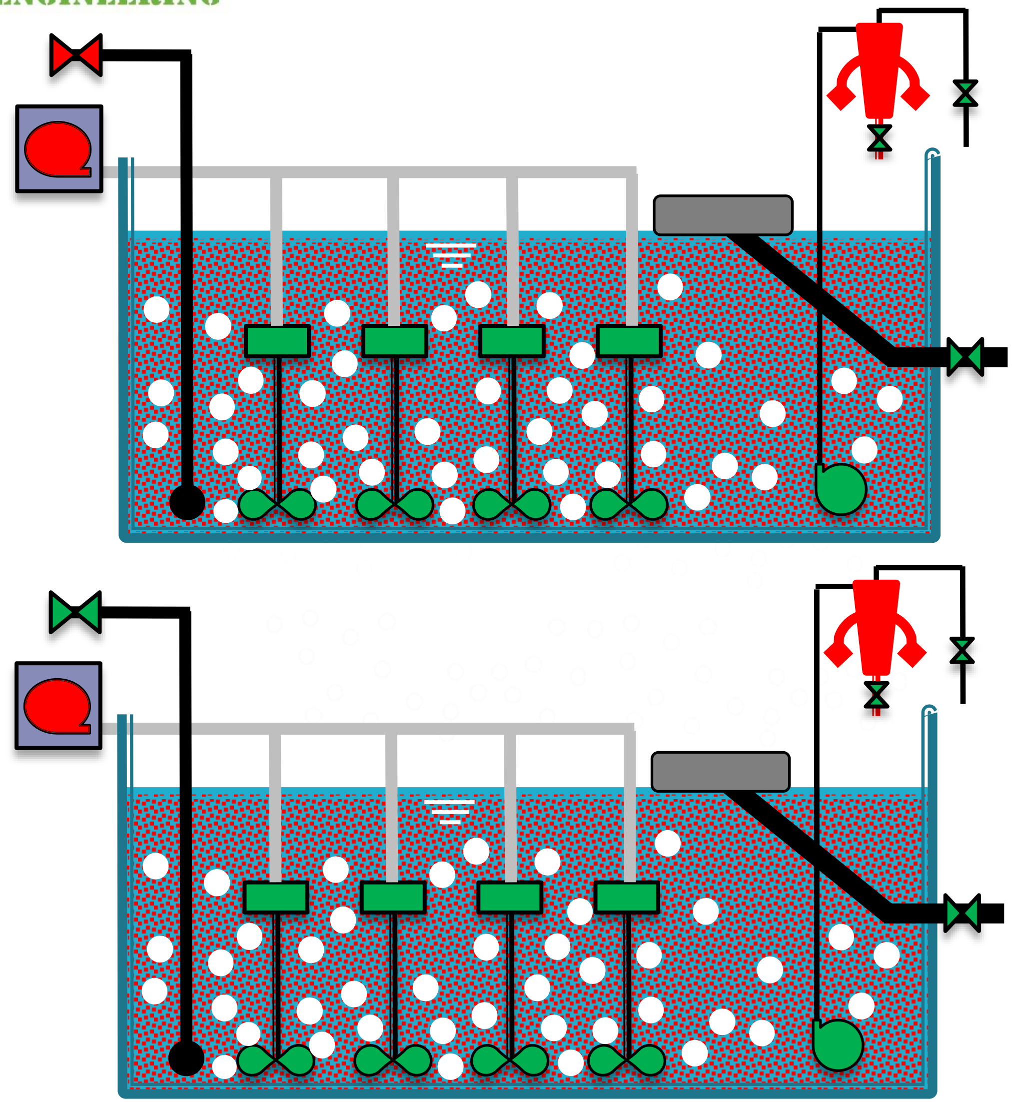
- Operating range:
  - Temperature- 20 to 38 C (ideal 30 C), 68 to 100 F (ideal 86 F)
  - DO- 0.3 - 0.5 mg/L, 0.5 - 1.0 mg/L (excess COD)
  - pH- 6.5 to 7.5
  - Conductivity- 2,500 to 4,500 mg/l

Instrument float probe identification



- The Instrument float seats on top of the water surface
- Wipe build up with a disposable wipe and rinse probes with DI water

Control Strategies' Operational phases

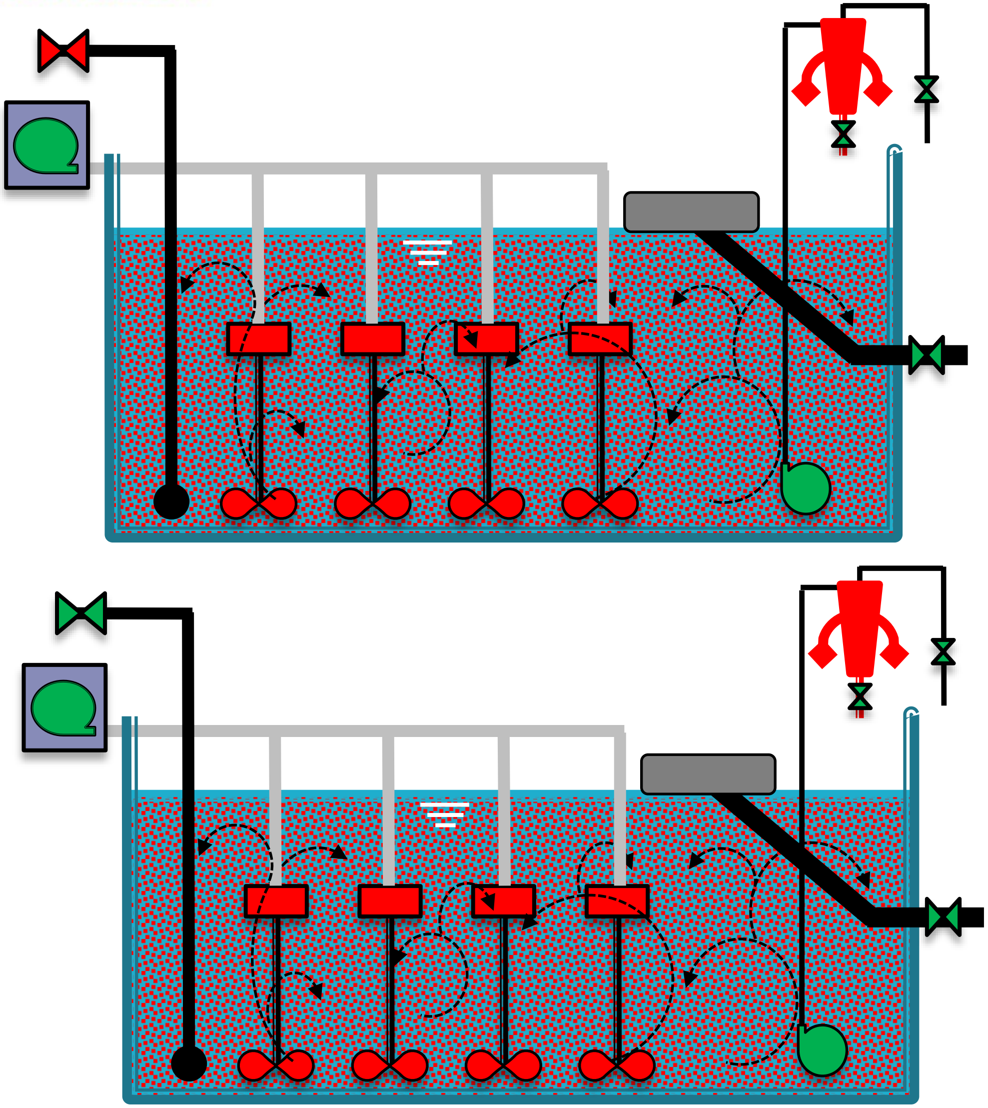


Aeration/Fill (A / X) or Aeration phase (A / X / E)

Equipment status

- Blowers – ON
- Feed pump/valve – ON/Open (Aeration/Fill only)
- Mixers – ON
- Decant Valve – Close
- Hydrocyclones – ON or OFF

Control Strategies' Operational phases

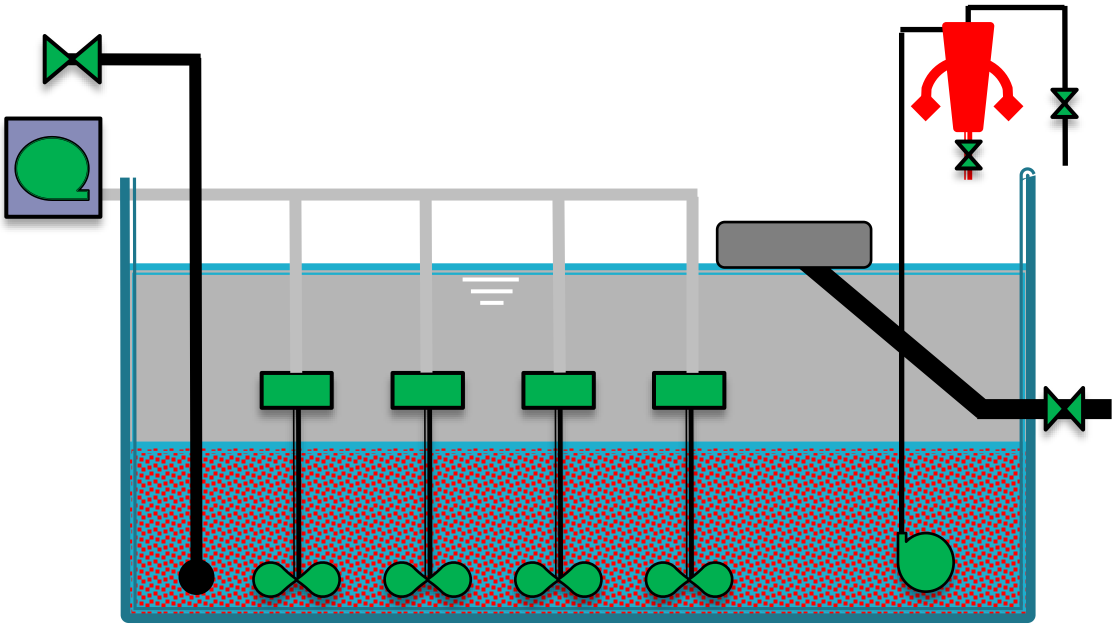


Mix/Fill (A / X)
or Mix (A / X / E)

Equipment status

- Blowers – OFF
- Feed pump/valve – ON/Open (Mix/Fill only)
- Mixers – ON
- Decant Valve – Close
- Hydrocyclones – ON or OFF

Control Strategies' Operational phases



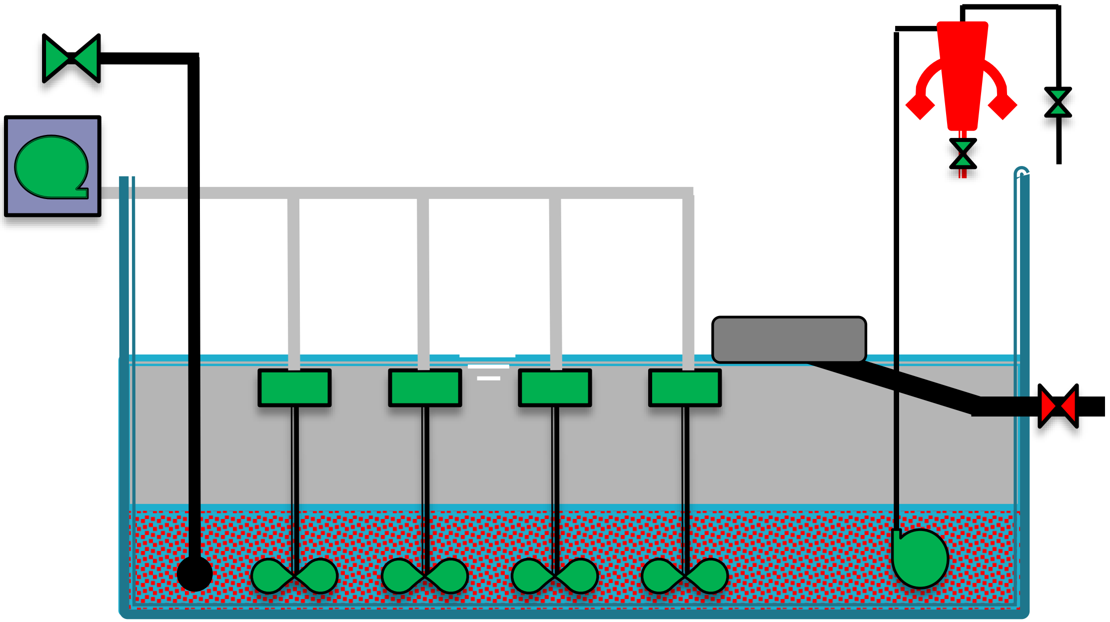
Settling phase

Equipment status

- Blowers – OFF
- Mixers – OFF
- Feed pump/valve – Off/Close
- Decant Valve – Close
- Hydrocyclones – OFF

Control Strategies' Operational phases

Decant phase

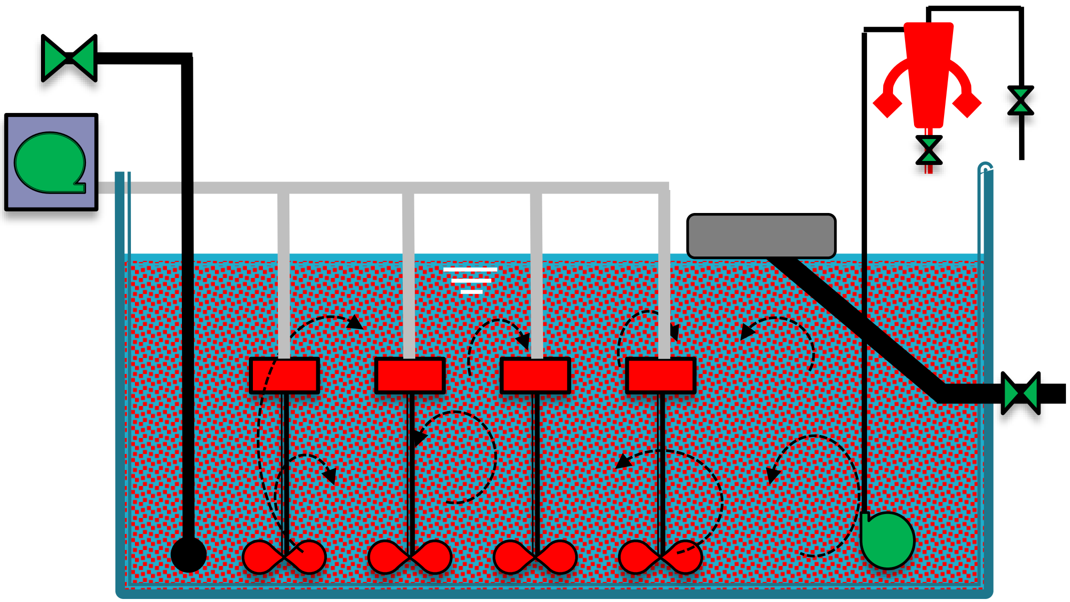


Equipment status

- Blowers – OFF
- Mixers – OFF
- Feed pump/valve – Off/Close
- Decant Valve – Open
- Hydrocyclones – OFF

Control Strategies' Operational phases

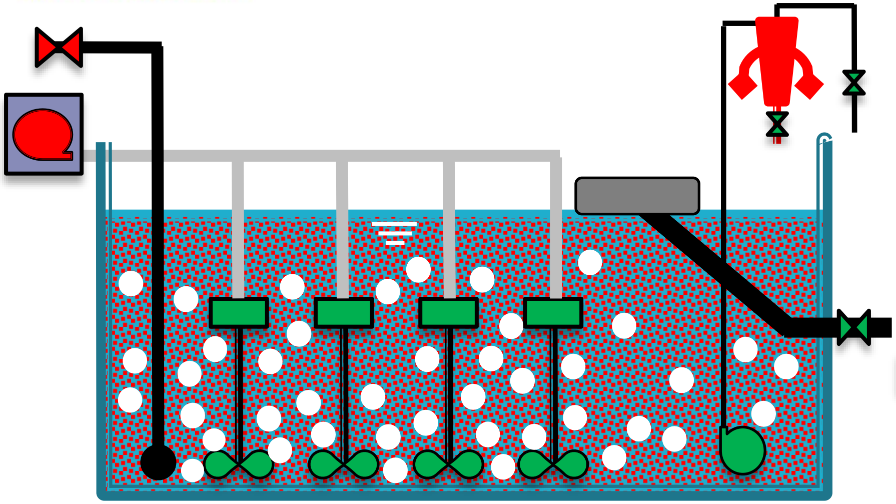
Pause



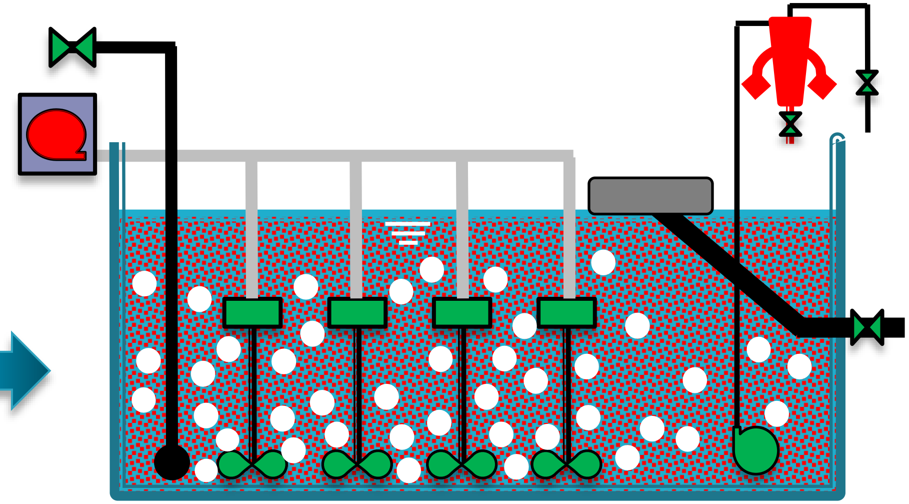
Equipment status

- Blowers – OFF
- Mixers – ON
- Feed pump/valve – Off/Close
- Decant Valve – Close
- Hydrocyclones – OFF

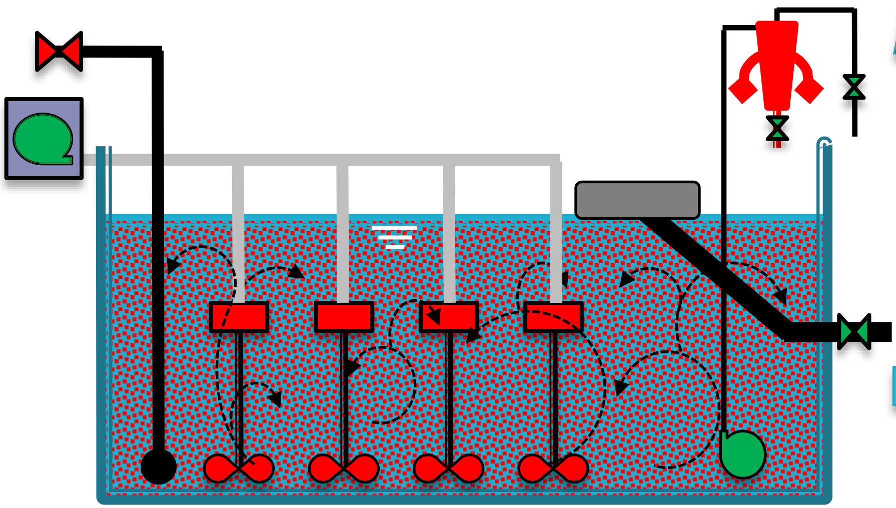
Operational Phases



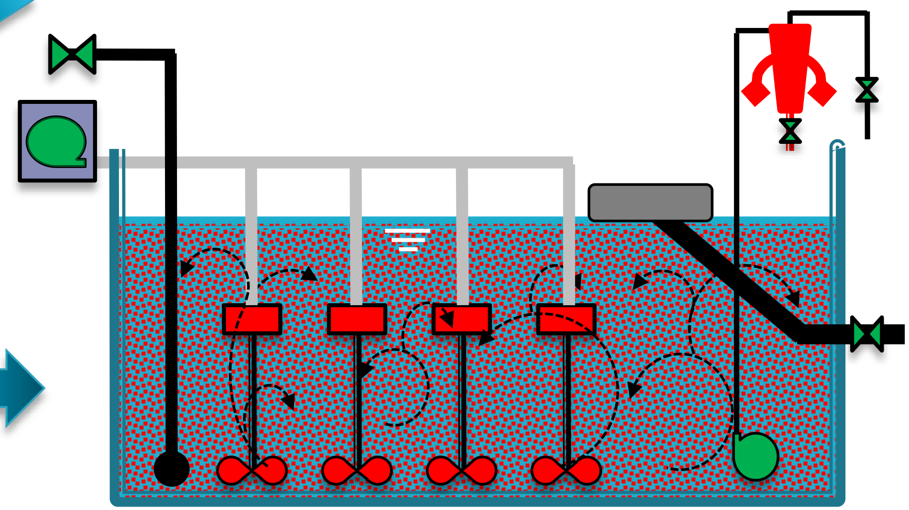
Aeration/Fill (A / X)



Aeration (A / X / E)

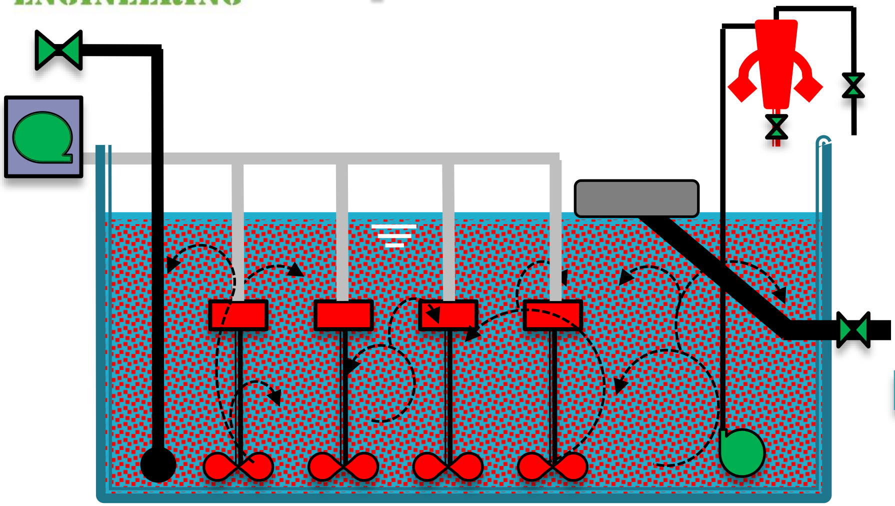


Mix/Fill (A / X)

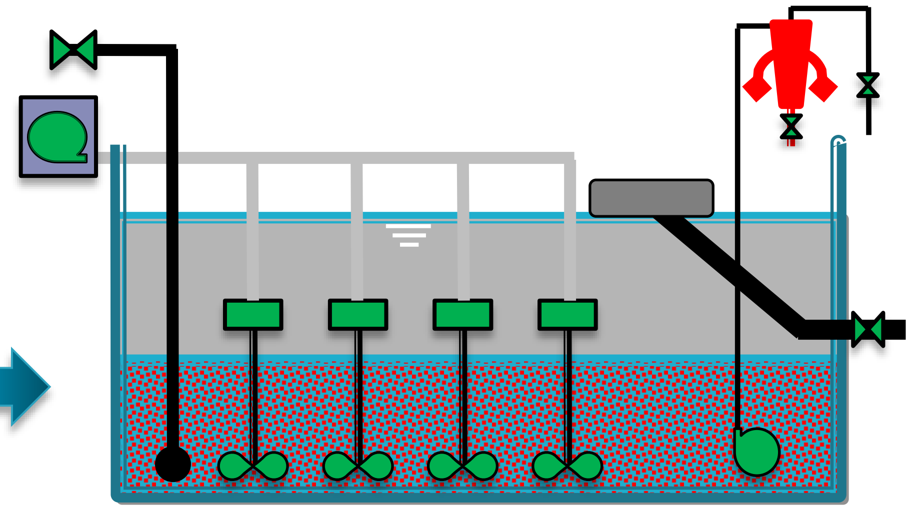


Mix (A / X / E)

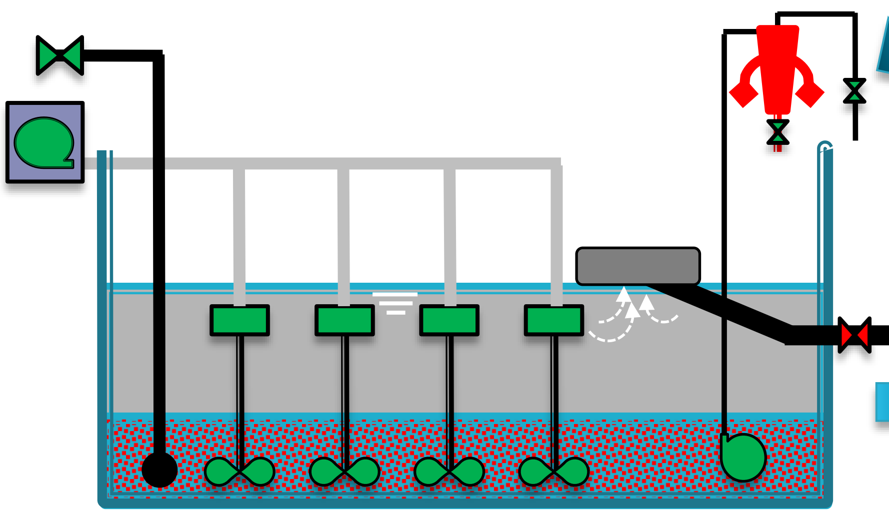
Operational Phases



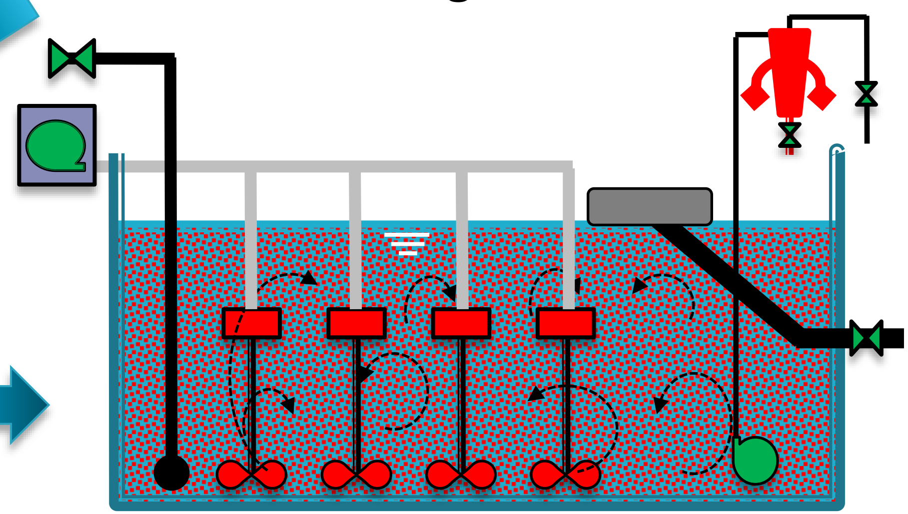
Phase X's Final Mixing



Settling Phase



Decant Phase



Pause

Operational Modes

- **In Service**- allows PCS to run system after pressing "Start." Is only available when all appropriate equipment is in AUTO.
- **Pause**- can be initiated when running the process, will freeze the active timer while continuing the elapse timer. All components shall stop, mixers will run at "Mixer" speed. After 60 minutes and alarm shall activate. Intended for short periods of time
  - Resume- Return you from pause to whatever phase you were at
  - Extend-Add another 60 minutes to the allowable time
- **Suspend**- similar to Pause but for a few days, will occasionally feed and aerate
- **Off-line**- stop the sequence, turns off all equipment besides the mixers, removes the reactor from the queue, and mixers are in "Mixer" speed.
- **OOS**- used when you want to stop mid-sequence, also when the reactor needs to be drained for larger maintenance

Control Strategy