Kubota's Online Operator Workshop

Basics

TODAY'S AGENDA

- Basics
- Break
- Case Study
- Break
- Case Study
- Quiz

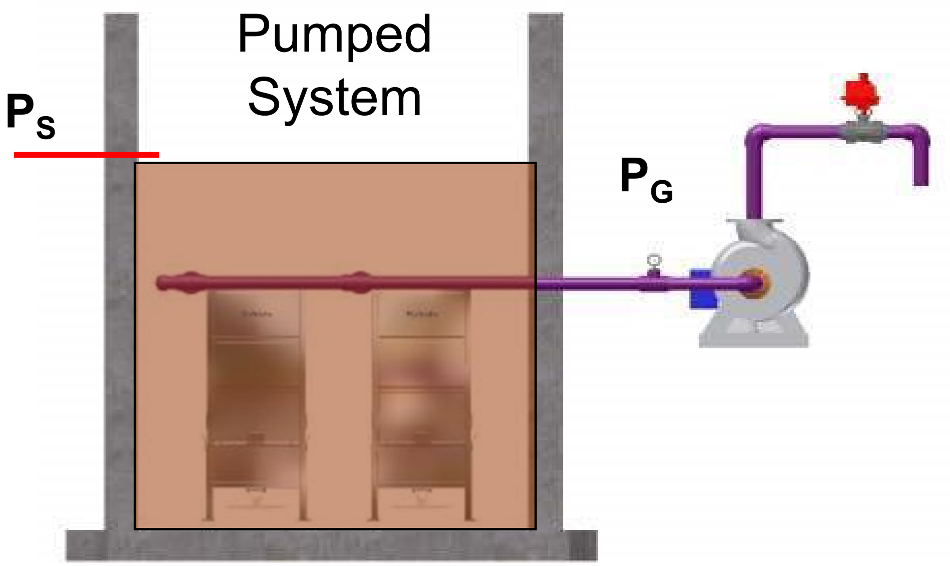
Basics

- Terms, Definitions
- Submerged Membrane Unit Structure and Function
- System Components
- Managing MBR System Performance
- Biofilm Management
- Controls
- Biological Nutrient Removal

Terms and Definitions

- The rate of filtration per unit area of membrane material is called flux. Defined here in the U.S. as gallons per square foot.
  - Typical value 12 gfd at 10°C
  - 14 at 15°C
  - 17 at 20°C
- The water that is produced during filtration is called permeate
- The pressure difference across a membrane during filtration is called transmembrane pressure (TMP)
  - Typical TMP at design flux rates 0.5-1.0 psig
  - Maximum TMP 3.0 psig
- Air Scour
  - Determined by number of membranes and flux rate
- The ratio of flux to TMP is referred to as permeability
  - Permeability=Flux/TMP
- Biofilm is a complex dynamic matrix comprised of microorganisms, EPS/SMP, non-biological solids, substrates, metabolites, interior pores and channels
- The interdependency between biological process conditions and membrane hydraulic performance through a biofilm is termed *BioHydraulics*

Measuring TMP



$P_G = P_S - P_P - TMP$

$TMP = P_S - P_P - P_G$

TMP = Membrane & biofilm pressure losses

P_P = Piping friction losses (fittings, piping, etc.)

P_G = Gauge reading during filtration

P_S = Static pressure reading at zero filtration

Terms and Definitions

- **Production Capacity**: The net permeate flow rate over a given period of continuous operation accounting for CIP procedures and relaxation.
  - **Average Daily Flow (ADF):** The net daily flow requirement generally occurring during dry weather conditions and lasting nine (9) months.
  - **Maximum Monthly Flow (MMF):** The net daily flow requirement generally occurring during wet weather conditions and lasting three (3) months.
  - **Peak Daily Flow (PDF):** The net daily flow required during peak daily flow conditions and lasting 24hr.
  - **Peak Hourly Flow (PHF):** The net peak hourly flow requirement generally occurring during wet weather flow conditions and lasting 4hr.

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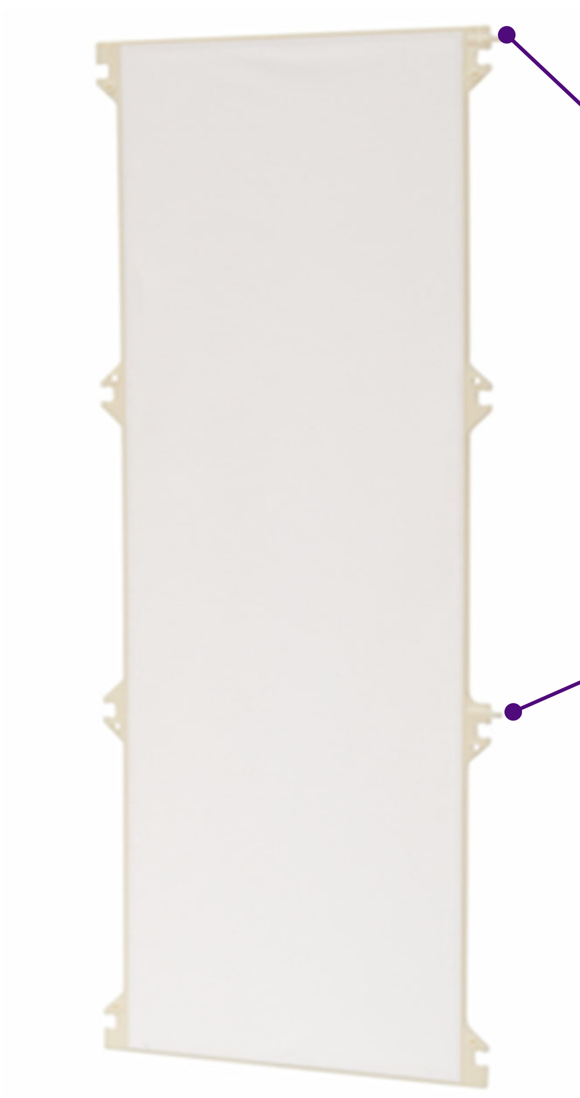
Submerged Membrane Unit (SMU) Structure and Function



Type 515

-1.64ft x 4.92ft

-15.61ft^2 Area

Cartridge Anatomy

-ABS plate

-Chlorinated polyethylene membrane

-Thermal weld process

-Polyester plenum material

-0.4 m mean pore size

-<0.2 m effective pore size

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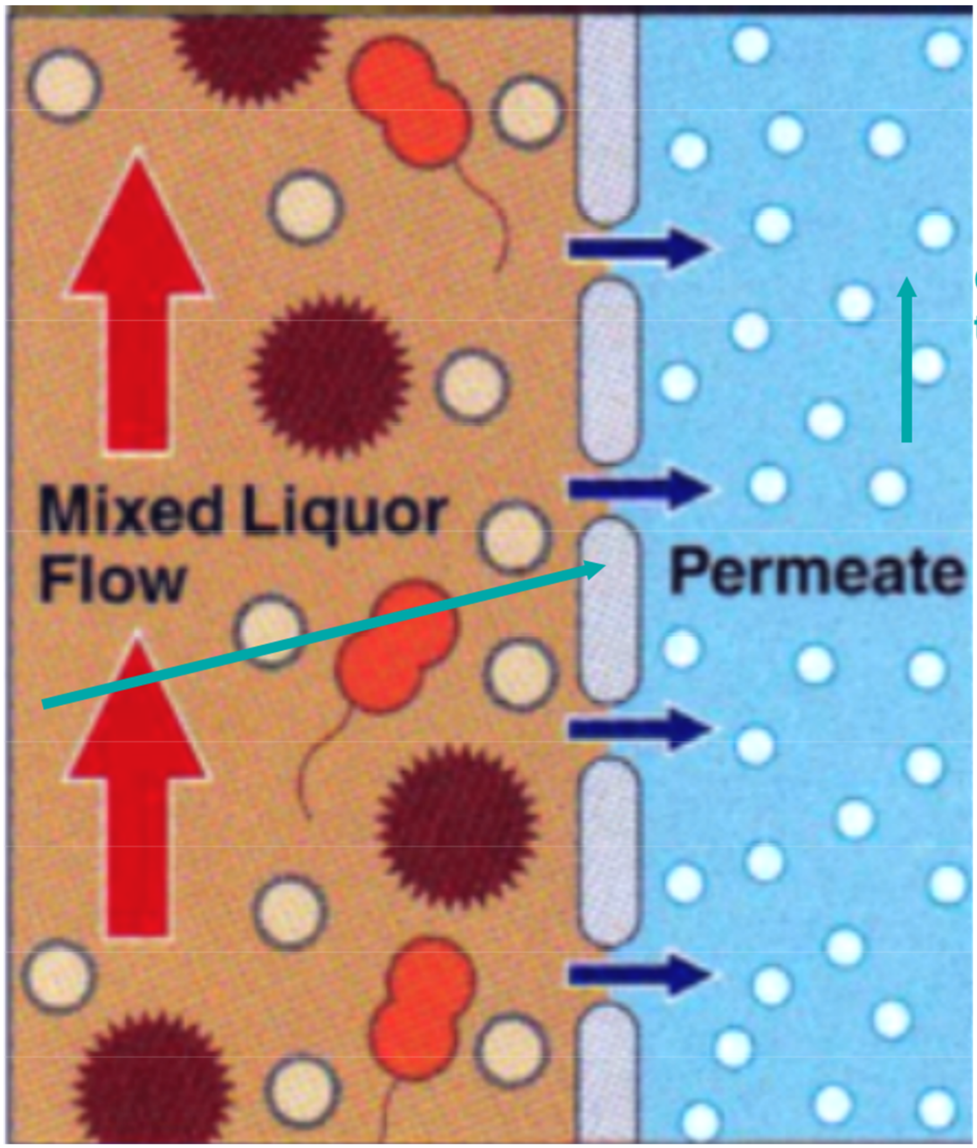
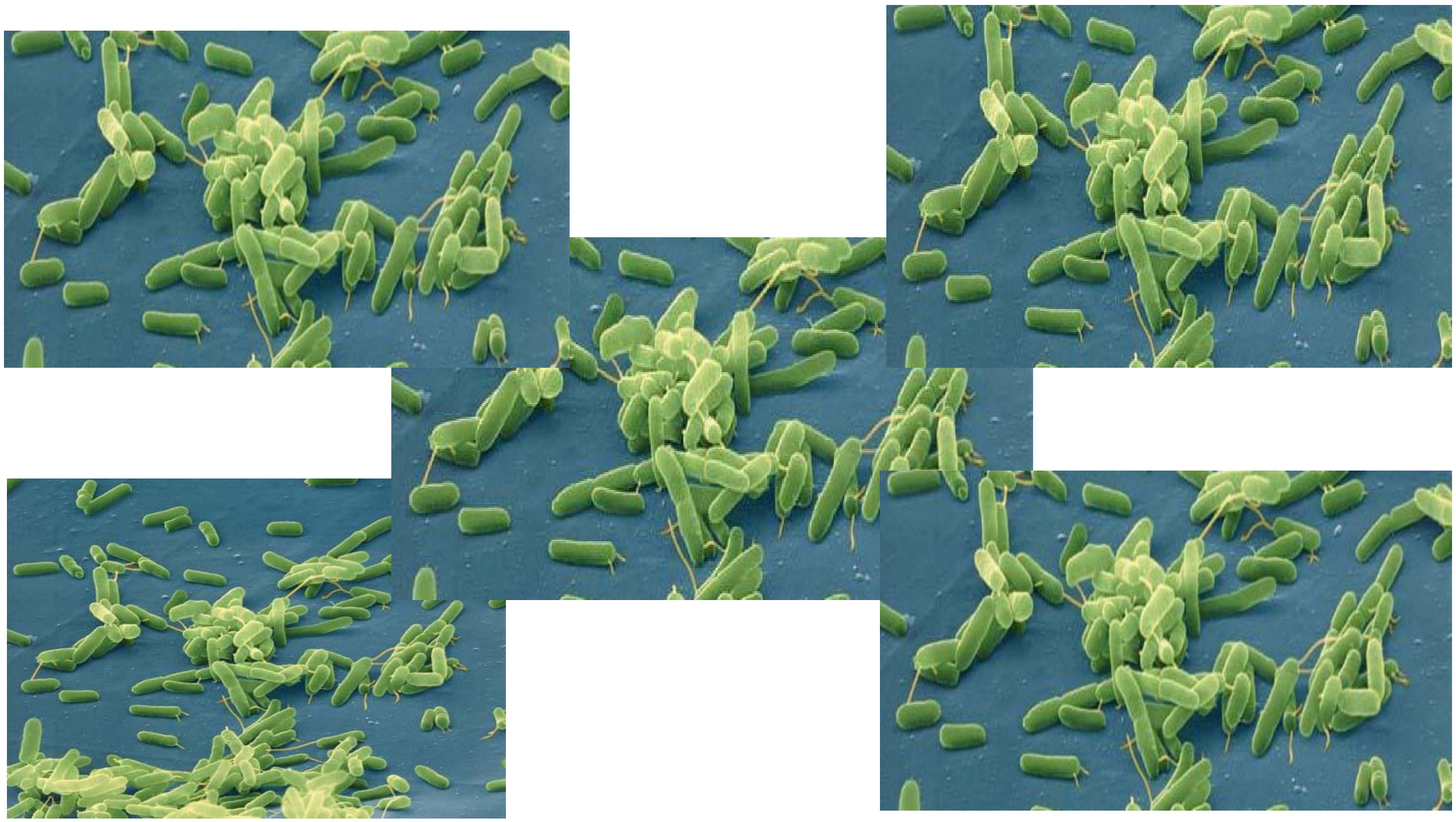
Submerged Membrane Unit (SMU) Structure and Function



Only requires 0.5 to 3 psi TMP

Avg. pore size 0.20 micron

Submerged Membrane Unit (SMU) Structure and Function



MBR has 4X to 5X the bacteria concentration

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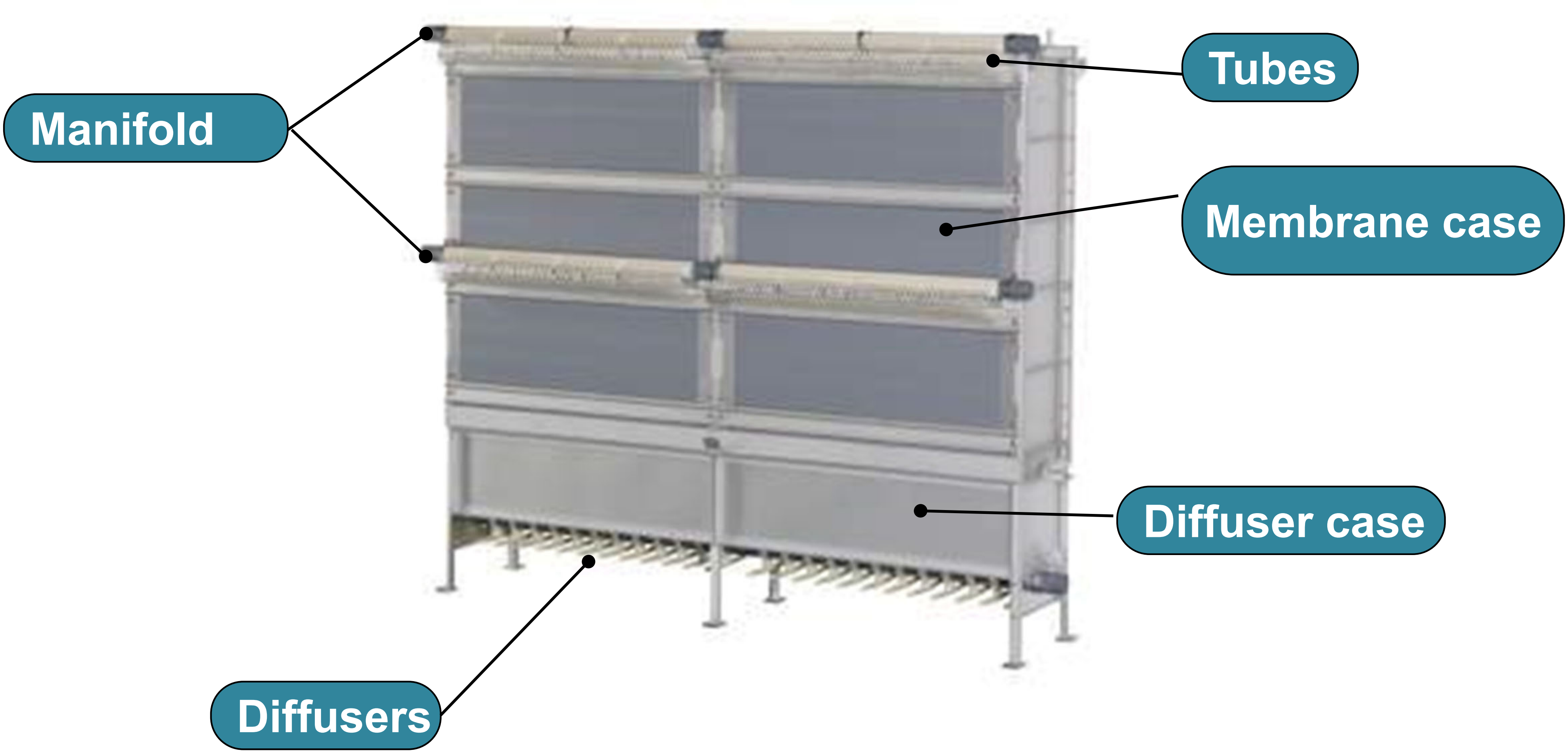
Submerged Membrane Unit (SMU) Structure and Function



Submerged Membrane Unit (SMU) Structure and Function

- Flat Plate Geometry Matters
  - Fixed spacing between cartridges (8 mm)
  - Very little for "solids" to hang up on
  - Airlift pump action keeps sludge moving between cartridges

Submerged Membrane Unit (SMU) Structure and Function

- Acts like an airlift pump
  - Continuous coarse bubbles at the bottom
  - Fully enclosed
  - Air scour in constant contact with the membranes
  - Continuous movement of mixed liquor keeps tank contents well mixed and in suspension

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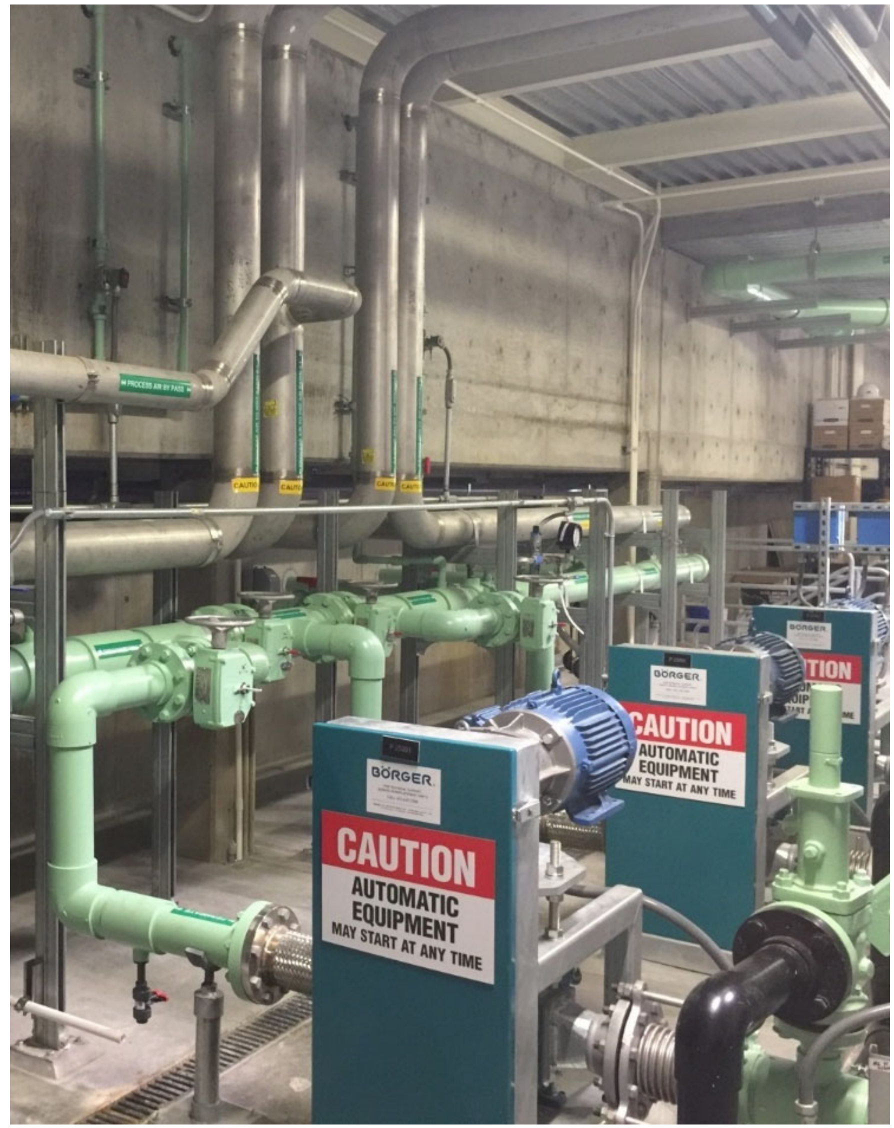
System Components

- Fine Screen
  - Achilles heel of all MBRs
  - Ideal to have duty/standby
  - Ensure there is no bypass
  - Outdoor installations may require heat tracing

System Components

- Permeate Pumps
  - Ideal to have dedicated pumps for each MBR basin with a common standby
  - Make sure there aren’t high points in the suction piping that can lead to air binding



System Components

- Blowers
  - MBR tanks and pre-air basins should have separate blowers (though they can share a common standby)
  - Make sure you have spare parts such as belts or filters on hand at all times

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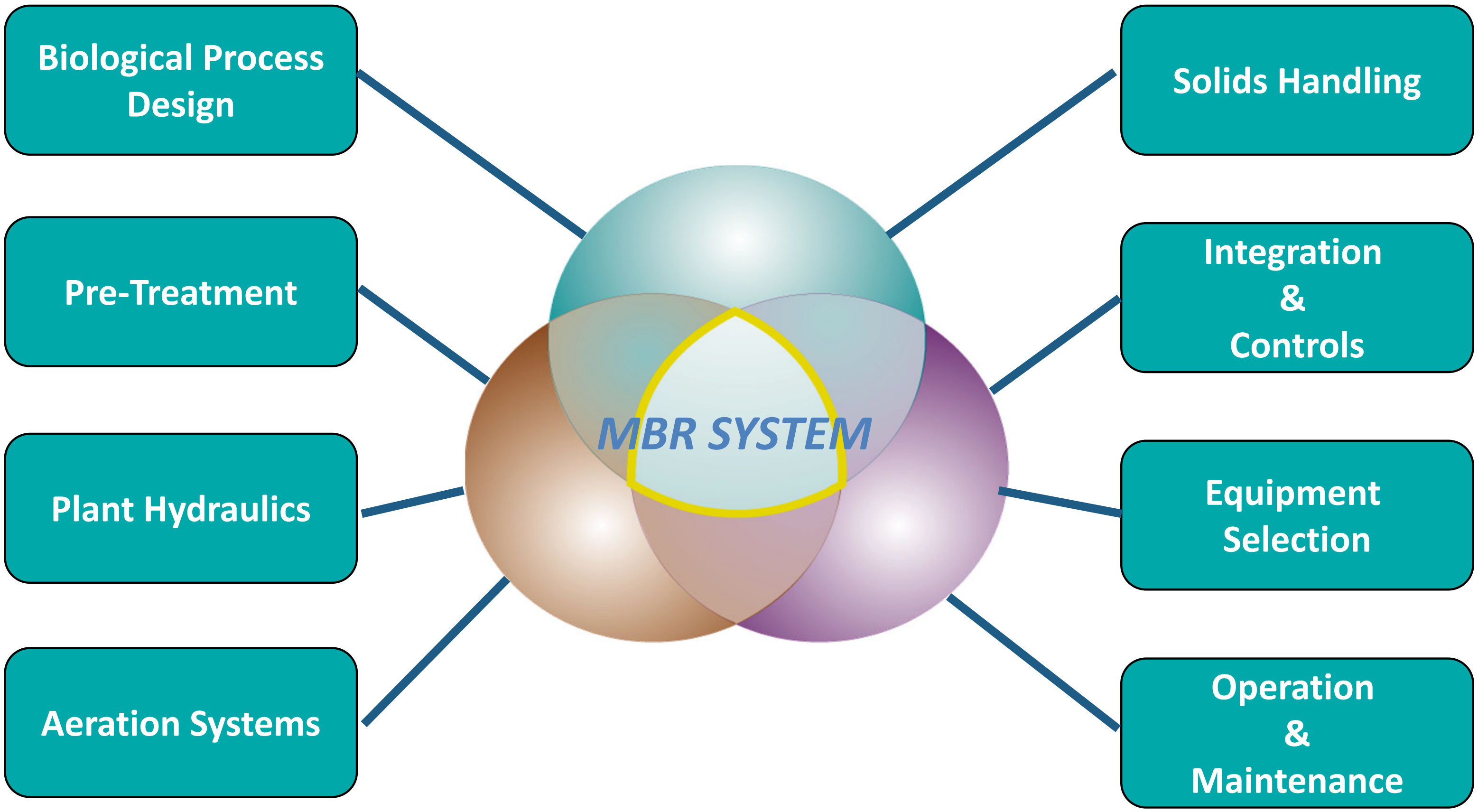
System Components

- Clean in Place
  - Semi-automatic
  - Pumped or Mazzei injector
  - Become familiar with isolation valves, especially the vent valve

Managing MBR System Performance



Managing MBR System Performance

- Think MBR system <u>not</u> membranes

Process Condition	Impact on MBR
Screenings Bypass	Debris Accumulation ⟶ Reduced Scour⟶ Localized Dewatering Membrane Damage ⟶ High Turbidity
Insufficient Aeration	Fouling ⟶ CIP frequency
Air leaks / Air Lock in Permeate Pipe	False 'High' TMP ⟶ Reduced Capacity
Unrecognized Flow/Loading Changes	Poor Sludge Quality ⟶ Increased Fouling
Flow Splitting	MLSS Imbalance ⟶ High MBR Solids ⟶ Increased Fouling
Poor Air/Permeate Control Improper Relaxation	Non-ideal Biofilm Thickness → Increased Fouling, Increased CIP Frequency
Lower Than Design Temperature	Increased TMP ⟶ Decreased Capacity
Unmanaged SRT/MLSS	Poor Sludge Quality Low MBR Solids ⟶ Increased Fouling High MBR Solids ⟶ Increased Fouling

Managing MBR System Performance

- The Basics:
  - TMP/Permeability
  - Air Scour Rate
  - Permeate flow rate
  - Air scour bubble pattern/Diffuser clean cycles
  - MLSS
  - Filterability

Biofilm Management

- All submerged membranes have them, managing them is key
- Biofilm, what is it?
  - A complex dynamic matrices comprised of microorganisms, EPS/SMP, non-biological solids, substrates, metabolites, interior pores and channels.
  - Create a dense secondary membrane that can allow for enhanced nutrient removal and degradation of refractory organics
  - As soon as filtration starts and biological solids are brought to the membrane surface, biofilm formation occurs.
  - Biofilm serves as the secondary dynamic filter and represents a changing resistance to filtrate flow.

Biofilm Management

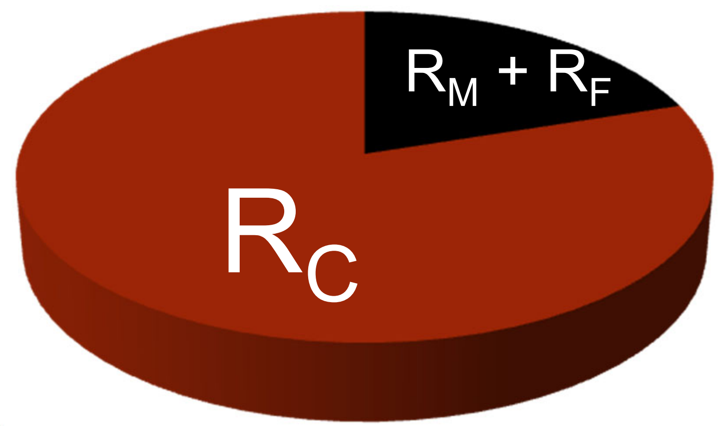
- Membrane Air Scour
- Relaxation
- Sludge Quality Control
  - SRT/MLSS
- Maintenance Cleaning

Biofilm Management

Total Flow Resistance Through Membranes:

$$R_T = (R_M + R_F) + R_C$$

- R_M = Membrane Resistance
- R_F = Membrane Pore Clogging & Adsorption
- R_C = Cake Resistance (Biofilm)



Directly Impacts Hydraulics and Cleaning (TMP)

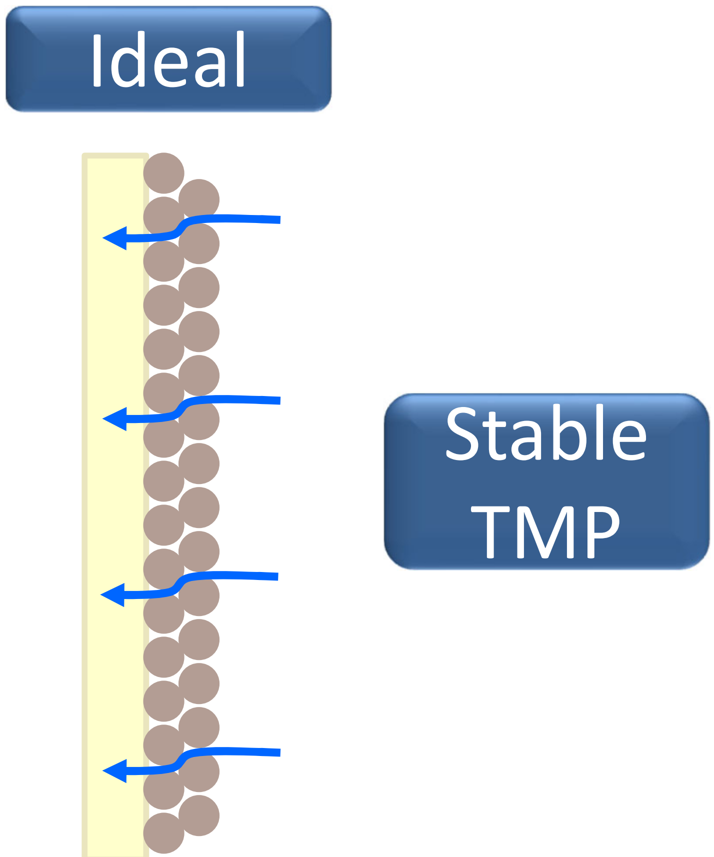
Biofilm Management

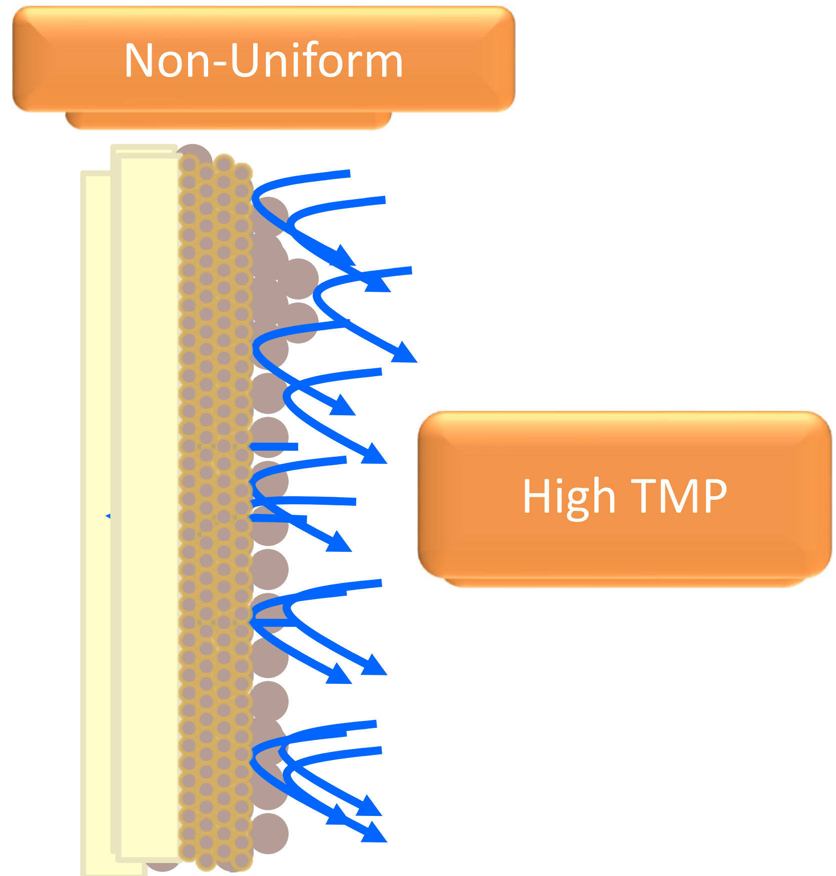
- Good

Biofilm Management

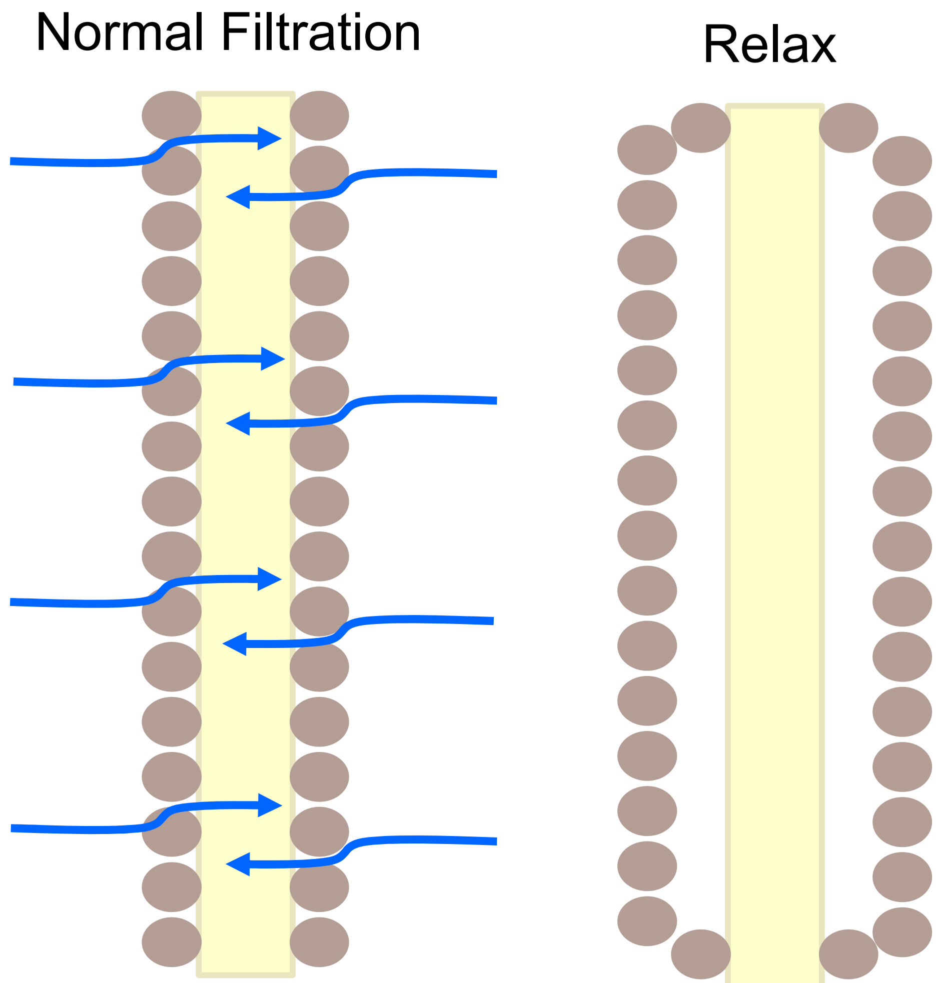
- BAD

Biofilm Management





Biofilm Management



Biofilm Management

Improving Sludge Quality

- 12 days < SRT < 54 days
- 8,000 mg/l < MLSS < 18,000 mg/l
- MPE50™ for upsets & operations outside design conditions

Biofilm Management

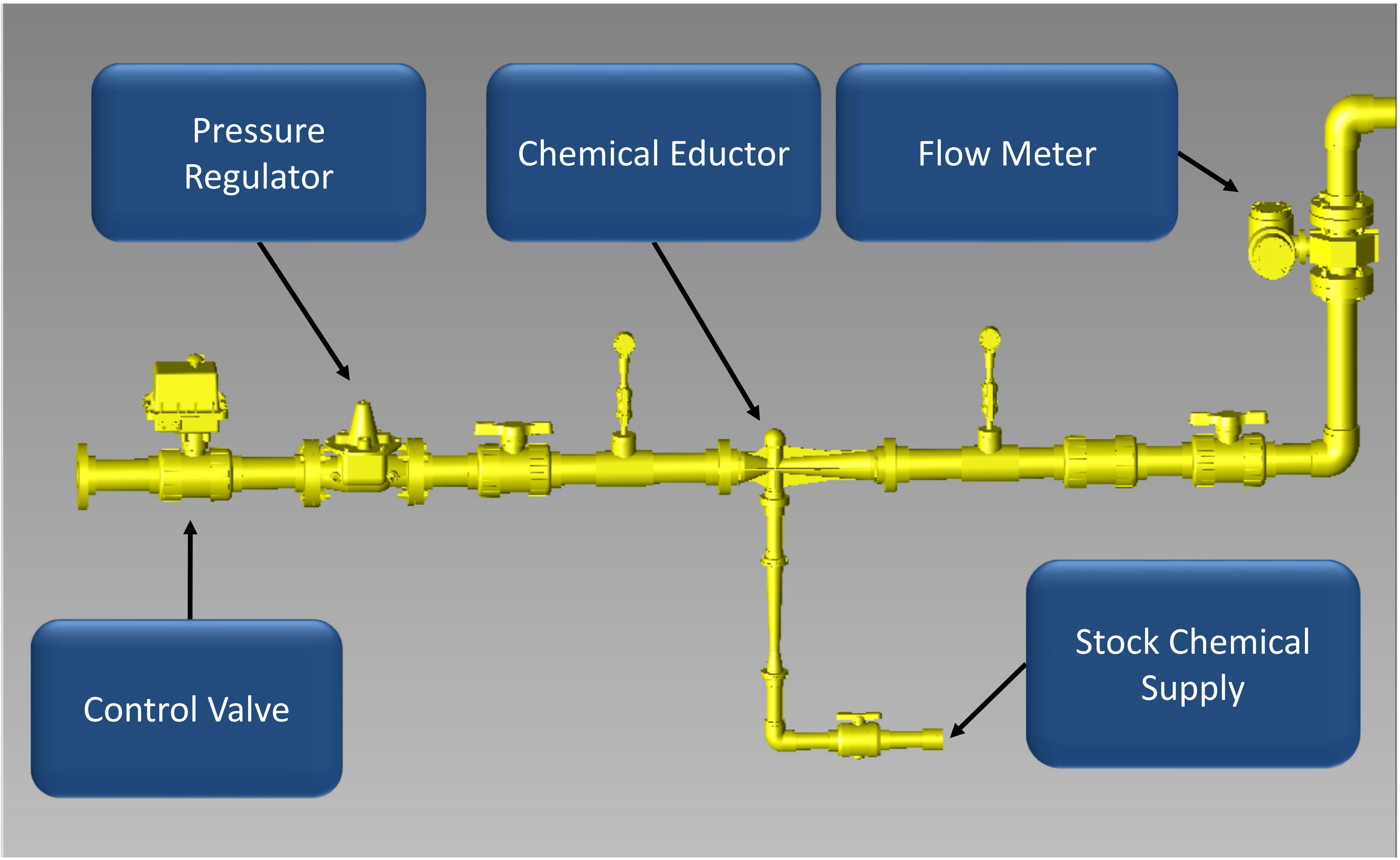
Maintenance Cleaning

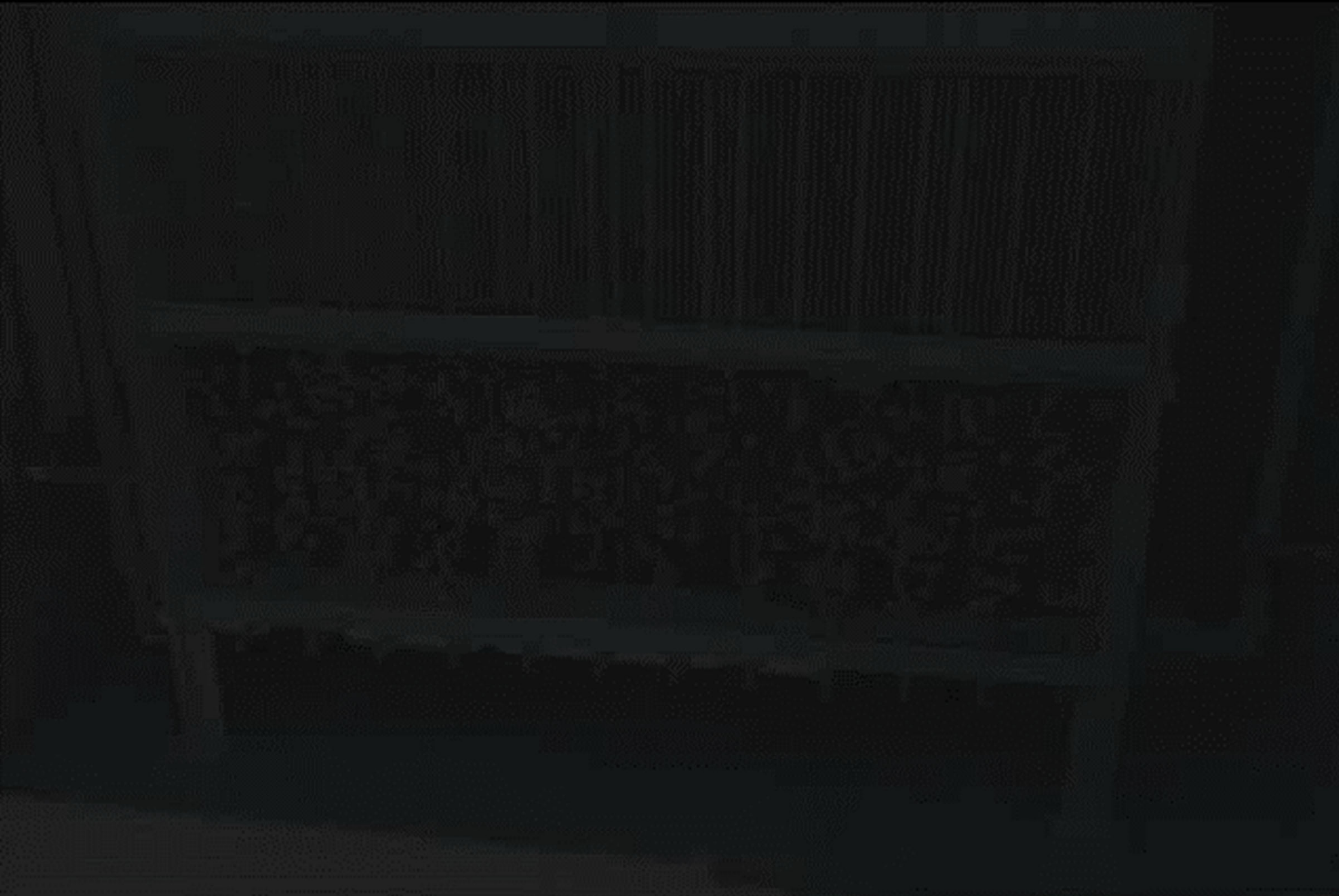
- Intended to remove surface (biofilm or cake) fouling.[1]
- Does not involve taking tanks out of service for extended periods of time (~1-4hr)
- Routine procedure
- Can return to MBR filtration mode in ~15 minutes

Recovery Cleaning

- Intended to "dislodge particles from membrane microstructure."[1]
- May take from >4-24hrs.
- Requires that membranes be soaked in concentrated chemical solution.
- Generally a non-routine procedure for flat plate systems

Biofilm Management





Biofilm Management

Suspected Fouling Material	Recommended Cleaning Chemical	Alternate Cleaning Chemical	Cleaning Solution Weight Percent	Cleaning Duration
Organic	Sodium Hypochlorite (Bleach)	Hydrogen Peroxide	0.5% or 1/3*MLSS[d]	1.0 - 2.0 hrs
Aluminum Oxide[a]	Oxalic Acid[c]	Citric Acid	0.5% to 1.0%	0.5 - 1.0 hrs
Ferric Oxide[a]	Oxalic Acid[c]	Citric Acid	0.5% to 1.0%	0.5 - 1.0 hrs
Calcium Carbonate[b]	Hydrochloric Acid	Citric Acid	2%	0.5 - 1.0 hrs

Biofilm Management

Calculate the amount of cleaning solution (V_{CS}) required to clean one bank of membranes (uppers or lowers in one MBR basin):

$$V_{CS} = \#SMU \cdot \frac{\#Cartridges}{SMU} \cdot \frac{1.35 gal}{Cartridge}$$

# of SMUs = 3

# of Cartridges = 200

Biofilm Management

Calculate the approximate concentration of the cleaning solution (C_{CS}) that should be used at the given MLSS concentration

$$C_{CS} = MLSS \cdot \frac{1}{3}$$

$$C_{CS} = 15{,}000 mg/l \cdot \frac{1}{3} = 5{,}000 mg/l \approx 0.5\%$$

Calculate the dilution factor (f_D) given the concentration of the stock chemical and the cleaning solution weight percent calculated above

$$f_D = \frac{wt\%StockChemical}{wt\%CleaningSolution} \qquad f_D = \frac{12.5\%}{0.5\%} = 25$$

Biofilm Management

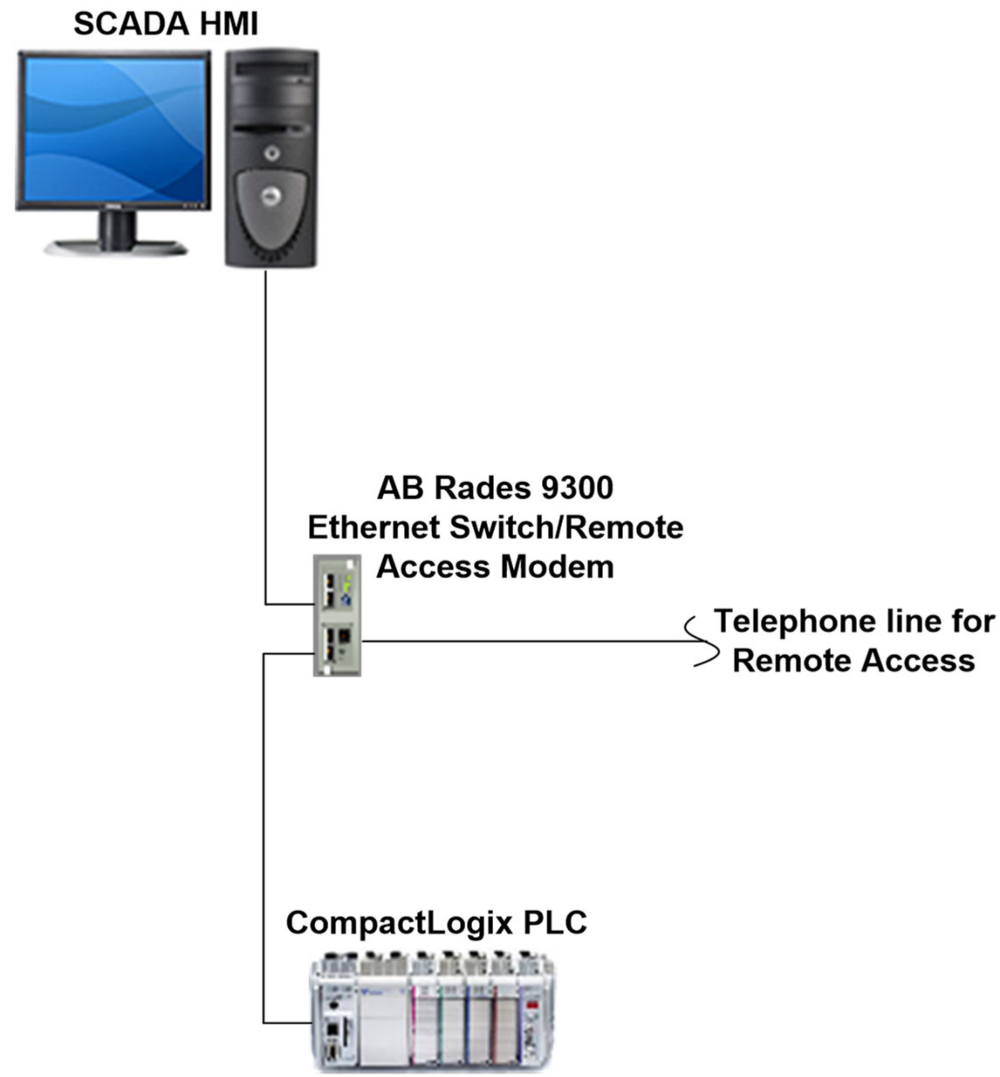
Calculate the amount of stock chemical (V_{SC}) required to perform the Maintenance Cleaning

$$V_{SC} = \frac{V_{CS}}{f_D} \qquad V_{SC} = \frac{800\,gal}{25} = 32\,gal$$

Therefore, only 32 gallons of 12.5% bleach are required to makeup the cleaning solution

Controls

- Control System Architecture
  - PC and PLC networked via Ethernet
  - Remote access gained through dial-up modem or VPN



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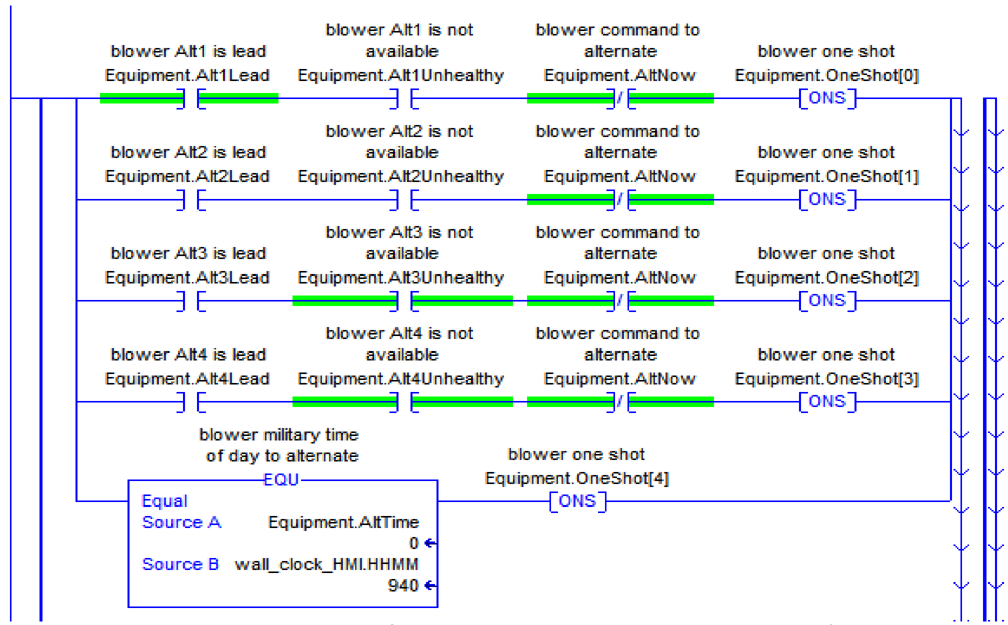
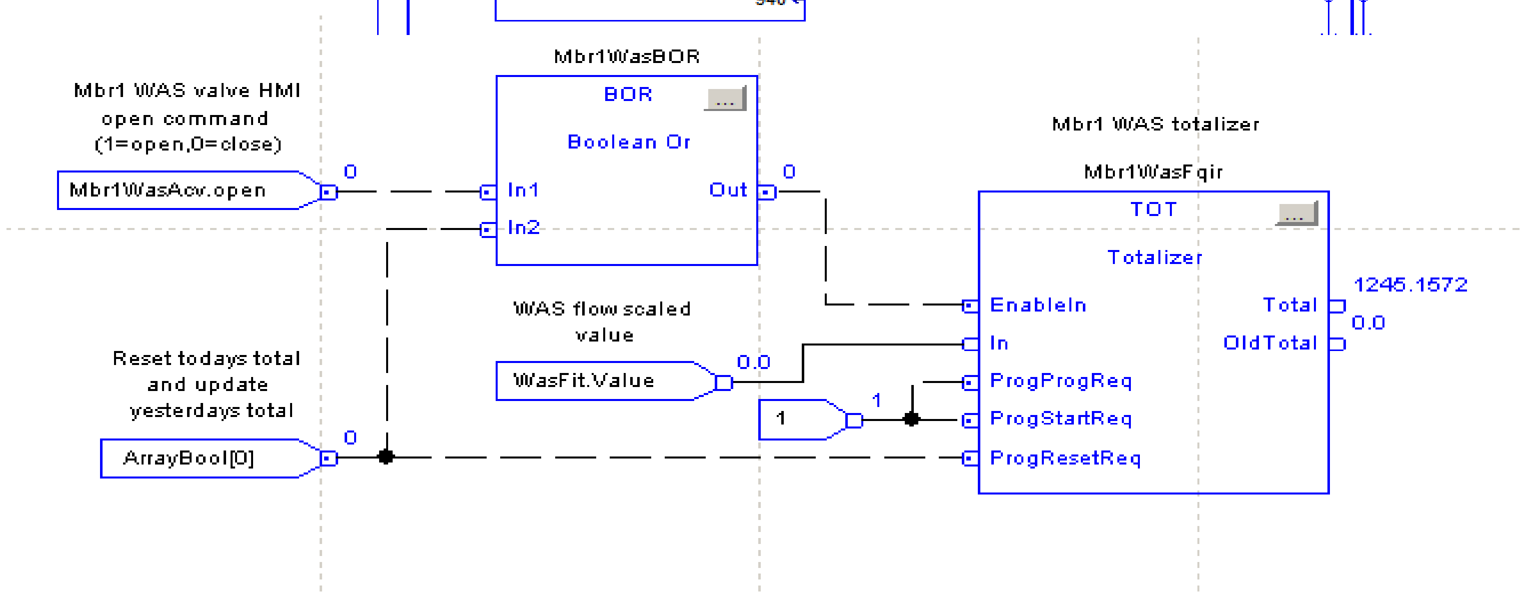
Controls

- The Plant's Brain





Controls

- The Brain is Dead

Controls

- Manual Operation (becoming the brain)
- Think logically about how flow comes into the plant
- Concentrate on the absolute basics
  - Screens
  - Recycle
  - Air scour
  - Permeate flow
  - Achieve a good balance

Biological Nutrient Removal

- Nitrogen
  - Raw Wastewater contains nitrogen in the form of:
    1. Organic nitrogen
    2. Ammonia-N (NH3-N)
    3. Nitrite (N02-N)
    4. Nitrate (NO3-N)

  - TKN = 1 + 2
  - TIN = 2 + 3 + 4
  - TN = 1 + 2 + 3 + 4

  Inert nitrogen = 2% of TN

Biological Nutrient Removal

- Autotrophic Bacteria
  - Known as Aerobes or Producers
  - Use carbon dioxide as their sole source of carbon
  - Perform Nitrification
    - Nitrosomonas convert ammonia to nitrite
    - Nitrobacter convert the nitrite to nitrate
    - Together they break down ammonia into nitrates
  - Use dissolved oxygen to oxidize ammonia
  - Thrive in the aeration basin and can survive in anoxic
  - Very sensitive to pH changes and toxins

Biological Nutrient Removal

- Nitrification
  - Presence of oxygen
  - Occurs in Pre-Air and MBR basins
  - Autotrophic bacteria are slow growing. Longer SRT
  - Nitrification consumes alkalinity @ 7.14 g alkalinity/g NH_3-N
- <u>Nitrification</u> (NH_3 to NO_3) 4.57 gO_2/gNH_3
  - *Nitrosomonas*
    - *NH_3 to NO_2* *3.43 gO_2/gNH_3*
  - *Nitrobacter*
    - *NO_2 to NO_3* *1.14 gO_2/gNO_2*
  - *Electron Acceptor: Oxygen*

Biological Nutrient Removal

- Denitrification
  - Absence of free oxygen
  - Occurs in Anoxic basin
  - Heterotrophic bacteria
  - Denitrification recovers 50% alkalinity lost in nitrification @ 3.57g alkalinity/g NO_3-N
- <u>Denitrification</u> (NO_3 to N_2 gas)
  - *Alcaligens, Pseudomonas*
    - *NO_3 to N_2* *2.86 gO_2/gNO_3*
  - *Oxygen Equivalent of NO_3*
  - *Electron Acceptor: Nitrate*
  - *BOD:TN ratio greater than or equal to 4*

Biological Nutrient Removal

Heterotrophs also known as Anaerobes or Consumers

- They use BOD as their principle source of carbon
- 80-90% of the overall population
- In the right environment, they perform Denitrification
  - They are facultative
  - They can use dissolved oxygen to oxidize BOD
  - Or they can use oxygen from Nitrates to oxidize BOD
- Thrive in the aeration basin and thrive in the anoxic basin
- Compared to autotrophs, they are less sensitive to pH changes and toxins

Biological Nutrient Removal

Characteristics or Traits	A	H
Perform Nitrification	★	
Perform Denitrification		★
Require a long SRT	★	
Require a short SRT		★
More sensitive to pH	★	
Less sensitive to pH		★
Make up 10-20% of the MLSS population	★	
Make up 80-90% of the MLSS population		★
Thrive in the aeration basin	★	★
Thrive in the anoxic basin		★
Use free oxygen when metabolizing	★	
Use oxygen found in nitrate when metabolizing		★

Biological Nutrient Removal

- **100:1**

For every 100 Pounds of BOD coming into the plant: a minimum of 1 Pound of Phosphorous is needed to promote cell growth

- **20:1**

For every 20 Pounds of BOD coming into the plant: a minimum of 1 Pound of Nitrogen is needed to promote cell growth

- **7:1**

For Every 1 Pound of Ammonia that is oxidized in the process: 7.14 Pounds of Alkalinity (as CaCO3) is consumed

- **4.6:1**

For every 1 Pound of Ammonia Nitrogen that is oxidized to Nitrate: 4.57 Pounds of Oxygen is utilized.

- **4:1**

For every 1 Pound of Nitrate to be reduced: 4 Pounds of BOD must be available

- **3.5:1**

For every 1 Pound of Nitrate that is reduced in the system: 3.57 Pounds of Alkalinity (as CaCO3) is recovered

Biological Nutrient Removal

- Phosphorus
  - Raw wastewater contains phosphorus in the form of:
    1. Orthophosphate
    2. Polyphosphate

Biological Nutrient Removal

- Phosphorus Accumulating Organisms (PAOs)
  – Store carbon as an energy source in anaerobic environments
  – Burn polyphosphorus during this process and release orthophosphate
  – Convert carbon to energy and uptake phosphorus in aerobic environments for cell growth, known us luxury uptake

Conclusions

- Flux is critical to proper operation of your Kubota membranes
- Kubota SMUs are designed specifically for wastewater treatment
- MBRs are a system of components including the membrane
- Biofilm management is key to preventing premature fouling
- Plants can be operated manually in emergencies
- Autotrophs, heterotrophs and PAOs allow us to remove nutrients biologically

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MBR System Upgrade and Replacement

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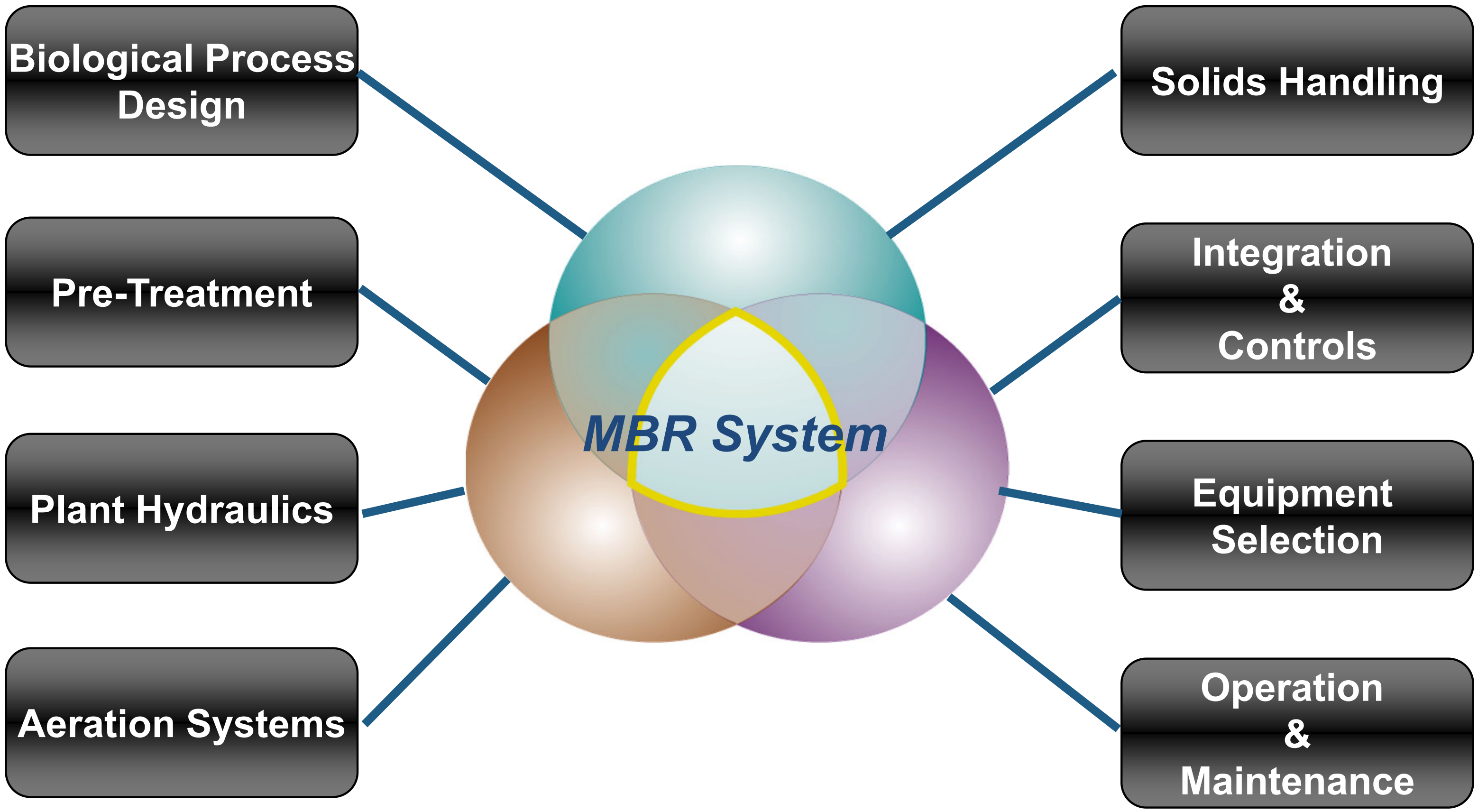
The Focus

- Operators
  - Sticking with our customers
  - Reconnect with those who have slipped away
- Process
  - Ensuring plants are consistent with current standards
  - Improving plants that are below standards
- Equipment
  - Membrane Units
  - Pumps and blowers
  - Instrumentation
- Controls
  - Proactive Tools

Operators

- You are our greatest asset
- Process Improvements
- Equipment, instrumentation, control philosophy
- Validation
    - You will let us know what works and what doesn’t
- TRAINING
    - Determine their comfort level
    - Provide refresher training as our product evolves
    - Identify new operators requiring training. The outgoing guy probably didn’t do a good job.
    - Annual operator’s workshop
    - Schedule periodic regional training sessions
    - Operator conferences

Evaluating MBR Subsystems



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To Ensure Proper Performance

- TMP / Permeability
- Air scour rate
- Permeate flow rate
- Process aeration requirements
- MLSS
- Filterability
- CSS testing

Process

- Improving plant performance through analysis and optimization
  - Determine the most efficient points for MLSS, aeration rates, flux rates, etc.
- Plant configurations
  - Add zone bypass options to assist with process adjustments
  - Hydraulic improvements
  - System turndown conversion
- Chemical dosing
  - Polymers for emergencies
  - Nutrient removal (carbon source, phosphorus)
- Energy Optimization
  - Continue development of tools to determine most energy efficient design

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Equipment Improvements

- New fine screens
  - Poor performance leading cause of problems
- New Pumps and Blowers
  - 15-30% less energy than older equipment
- Added Benefits
  - Integrated instrumentation
  - Much quieter
  - Smaller footprint
  - Reduced O&M

Method of Air Flow Delivery and Control is Critical

- Carefully choose the type of blower
  - Positive displacement
  - Hybrid
  - Turbo
- Connection method
  - Independent, direct coupled blower to each service
  - Common header approach with multiple flow control valves
- Avoid varying water levels in aerated zones

Equipment Upgrades

- Upgrade to our current standards for reliability or to reduce nuisance alarms
    - Electrical actuators
    - Flow meters
- Additional instrumentation for additional protection and operator aid
    - MLSS probes
    - NH3/NO3 analyzers
- Spare parts for critical items
    - Electrical actuators
    - Level transmitters
    - Pressure transmitters

Membrane Unit Upgrade/Replacement

Original Cartridge
8.61 Ft²/Cart

510 Cartridge
(10-400 cartridges / unit)

Larger Cartridge
15.61 Ft²/Cart

515 Cartridge
(150-400 cartridges / unit)

'Lego Block'
Module
108 Ft²/Mo

SP Series
(20-80 modules / unit)

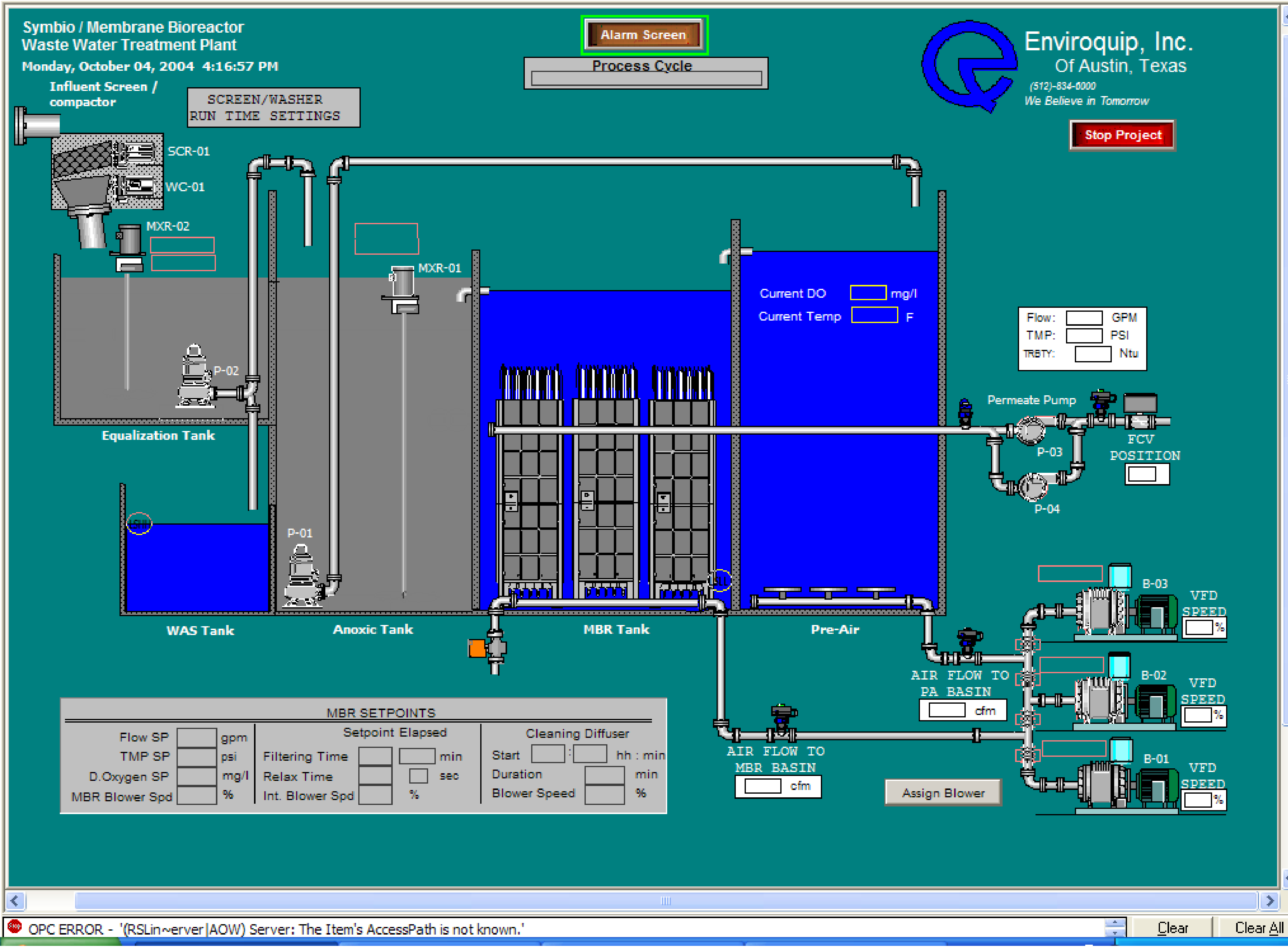
- Different models are available with various types of Membrane Cartridge and Module.
- ES-EK, with original 510 Membrane Cartridge is the long standing workhorse.
- RM-RW, with larger 515 Membrane Cartridge, same footprint, more capacity.
- SP, with 'Lego Block' Membrane module, more compact, energy efficient, diffuser options.

When to Replace Your Membranes

- Damaged
  - Identify root cause
- Age
  - Forensic testing can determine strength and flow capacity
- Plant expansion
- Desire more efficient operation
- System turndown
  - Handling more flow with fewer membranes leads to energy efficiency
- Other types of membranes not working as advertised

Controls

- Bring all plants up to our current standards
  - We now provide more information, trends, etc. allowing operators to be more proactive
  - Eliminate known glitches
  - Analyze alarm settings to eliminate nuisance alarms and spurious callouts
  - Equipment / instrument overrides
  - Increase remote access capability


Symbio / Membrane Bioreactor
Waste Water Treatment Plant
Monday, October 04, 2004 4:16:57 PM
Alarm Screen
Process Cycle
Enviroquip, Inc.
Of Austin, Texas
(512)-834-6000
We Believe in Tomorrow
Stop Project
Influent Screen / compactor
SCREEN/WASHER RUN TIME SETTINGS
SCR-01
WC-01
MXR-02
MXR-01
P-02
Equalization Tank
Current DO mg/l
Current Temp F
Flow: GPM
TMP: PSI
TRBTY: Ntu
Permeate Pump
P-03
P-04
FCV POSITION
P-01
WAS Tank
Anoxic Tank
MBR Tank
Pre-Air
B-03
VFD SPEED %
B-02
VFD SPEED %
B-01
VFD SPEED %
AIR FLOW TO PA BASIN
cfm
AIR FLOW TO MBR BASIN
cfm
Assign Blower
MBR SETPOINTS
Flow SP gpm
TMP SP psi
D.Oxygen SP mg/l
MBR Blower Spd %
Setpoint Elapsed
Filtering Time min
Relax Time sec
Int. Blower Spd %
Cleaning Diffuser
Start hh : min
Duration min
Blower Speed %
OPC ERROR - '(RSLin~erver|AOW) Server: The Item's AccessPath is not known.'
Clear
Clear All

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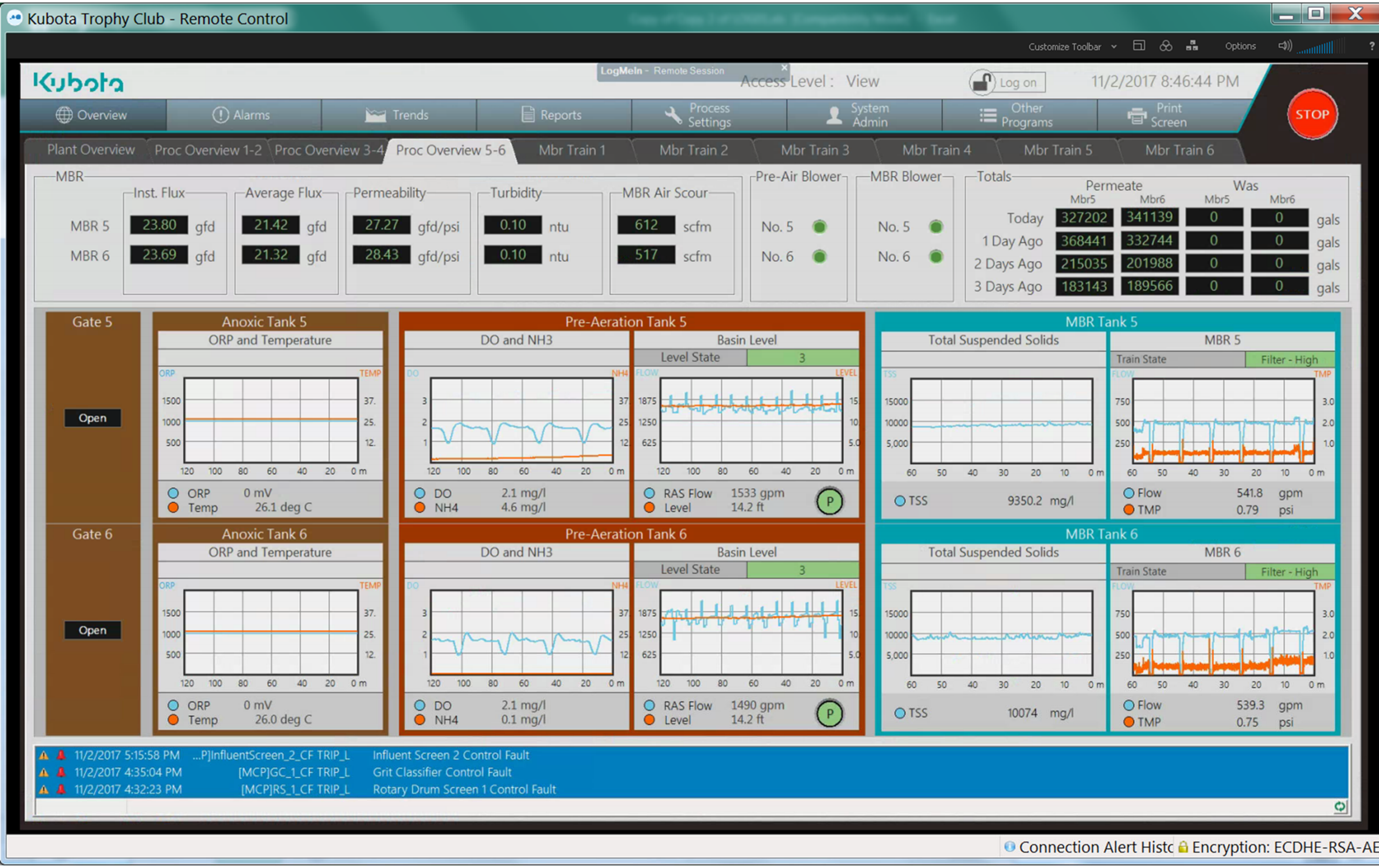

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Improving the Performance and Increasing the Capacity of Existing and Older MBR Systems

Small Plant

- 80,000 GPD MBR facility installed in 2011
- History of operational issues (2011 to 2015)
  - Failure to meet hydraulic capacity
  - Sludging
  - Over flow events
  - Short circuiting
    - All of the above blamed on the membranes
- Owner wanted to fix operational issues and expand to a capacity of 100,000 GPD
- Engineer wanted to replace with another type of membrane

Issues Form Perceptions

- Inability to meet hydraulic demand
- Sludging
- Over flows
- Short Circuiting
- “It’s the membranes”

Fundamental Issues

- Fine Screening
  - Existing 2-mm bar screen is inadequate
  - Replace with a 2-mm internally-fed drum
- Hydraulics
  - Uneven RAS returns
  - Reconfigure the plant
- Permeate Pumps
  - Issues with cavitation and air lock
  - Replace pumps and reconfigure piping
- Control System
  - Existing system uses unsupported, proprietary architecture
  - Replace the control system

Construction

- Construction tasks
  - Install new equipment including fine screens, permeate pumps, and SMUs
  - Reconfigure the plant hydraulics
  - Change the control system
- And do all this while keeping the plant online

Existing Tank Layout

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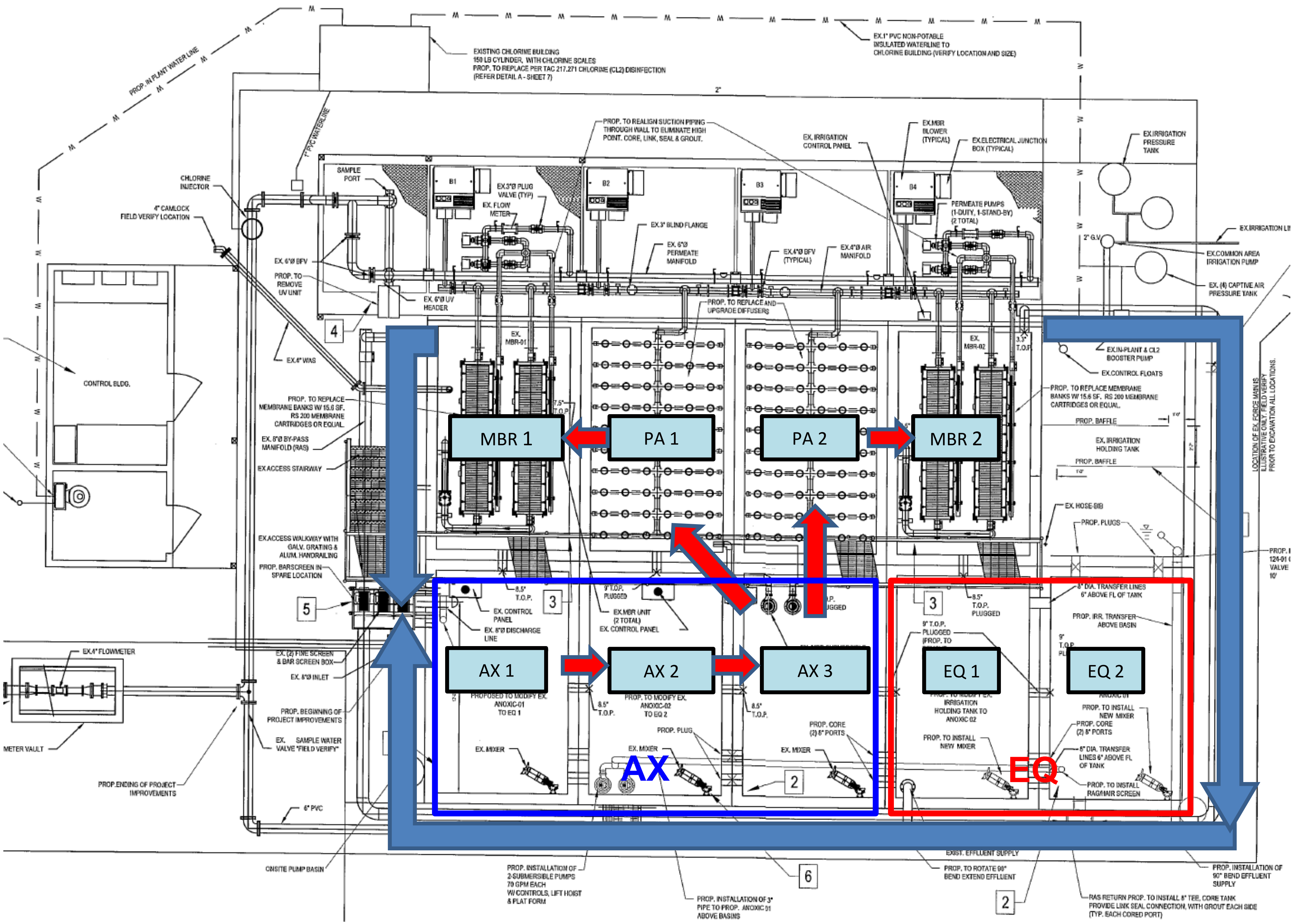

Retrofit plan Proposed by KMU

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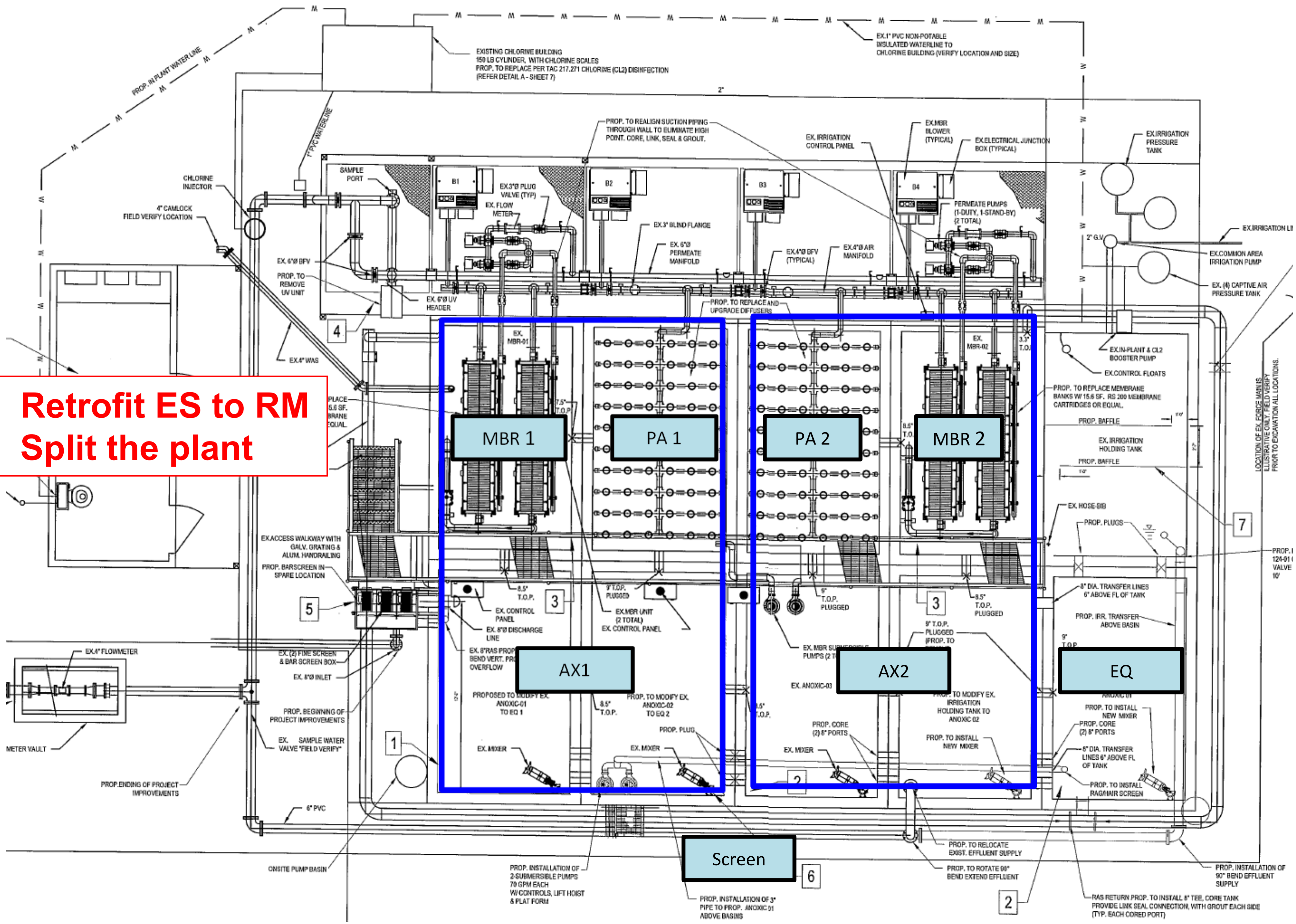
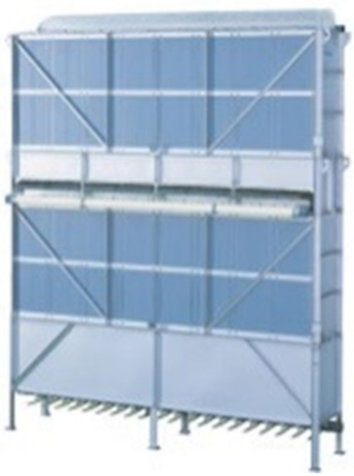


- Retrofit ES to RM
- Split the plant

Medium Sized Plant

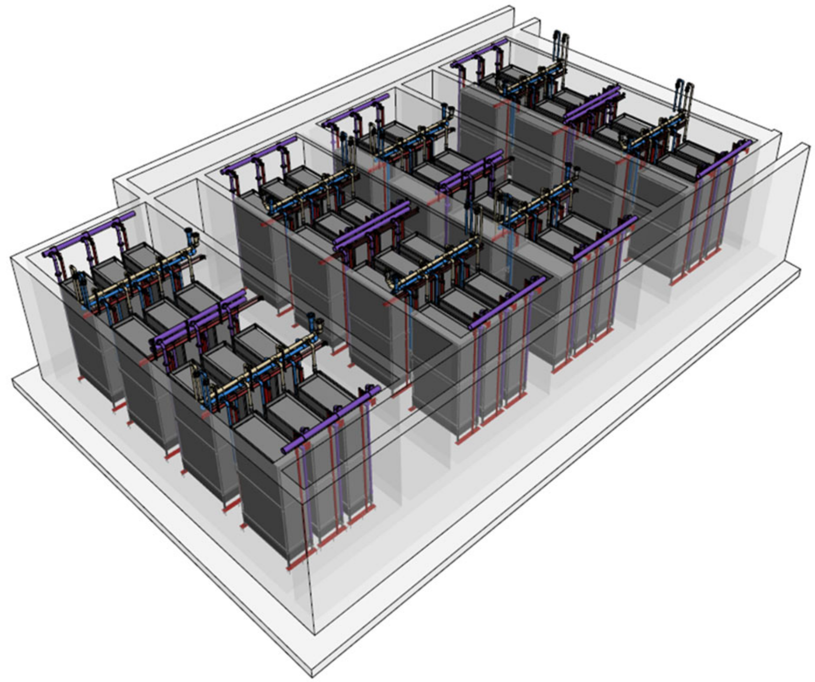
- 2 MGD MBR facility installed in 2004
- History of operational issues
  - Poor screening
  - Sludging
  - Frequent foaming events
  - Limited instrumentation and control
  - Permeate pumps cross connected across two tanks (upper and lowers on separate pumps)
- Owner wanted to fix operational issues and prepare for future expansion

SMU Upgrade



Old Units
EK-400
3,444 ft²
surface area

New Units
SP-600
6,459 ft²
surface area
88% more in
same footprint



Construction

- Construction tasks
  - Install new fine screens and SMUs
  - Reconfigure the plant hydraulics
    - Changed permeate piping to one pump aligned to one tank arrangement. More flexibility
  - Change the control system
    - Added air scour control and monitoring
    - Added ability to rotate membrane basins as needed
- And do all this while keeping the plant online

Replacing Other Membrane Types

- 0.6 MGD MBR facility installed in 2016 with Microdyn Membranes
- History of operational issues
  - Not capable of meeting flux and MLSS design points
    - Very sensitive to low temperatures
    - Plant had to be de-rated
    - Heavy requirements for additional chemicals for flux and TP removal
  - Sheets sticking together
    - Reduced surface area
    - Faster fouling, more chemical cleans
    - Sludging
- Replaced Microdyn with Kubota SP450 summer 2021
  - Work limited to in-basin
  - Connect to existing air and permeate headers

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SP450 Installation

Kubota Advantages

- Microfiltration membrane.
  - Allows for higher sustained flux and mixed liquor concentrations.
  - Virus removal testing has shown Kubota microfiltration membranes can achieve the log removal rates at ultrafiltration membranes.
- Ease of use. Simple cleaning procedures.
  - Weak chemical solutions injected inside the membranes via the permeate piping under atmospheric pressure, so no pressurized back pulsing is required.
  - Membranes and MLSS stay in the tank.
- Kubota membranes are rigid plates with fixed spacing.
  - This provides an open flow path between membranes to minimize the accumulation of debris or mixed liquor.
  - Prevents membrane material that is adjacent to each other from sticking together, which is common with hollow fiber and flexible sheets. The sticking together of membrane material reduces the available surface area, which in turn reduces hydraulic capacity and requires more frequent and intensive chemical cleaning procedures.
- Superior strength and durability with the use of chlorinated polyethylene as compared to PVDF.
- Membrane zones can be used as an active part of the biological process, and membrane air scour can contribute to the process oxygen demand.
  - This results in an overall smaller plant footprint and greater process flexibility.

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And in Conclusion!

- Our Goals for Plant Improvements
  - Keep operators engaged
  - Open conduits for information sharing
  - Identify problems and resolutions
  - Maintain and/or upgrade plants as our systems continue to evolve and improve
  - Ensure each plant is a great resource for all involved

Thank you

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