Selecting the Best Technology for Water Reuse: Overview of the MBR Process

April 10, 2019

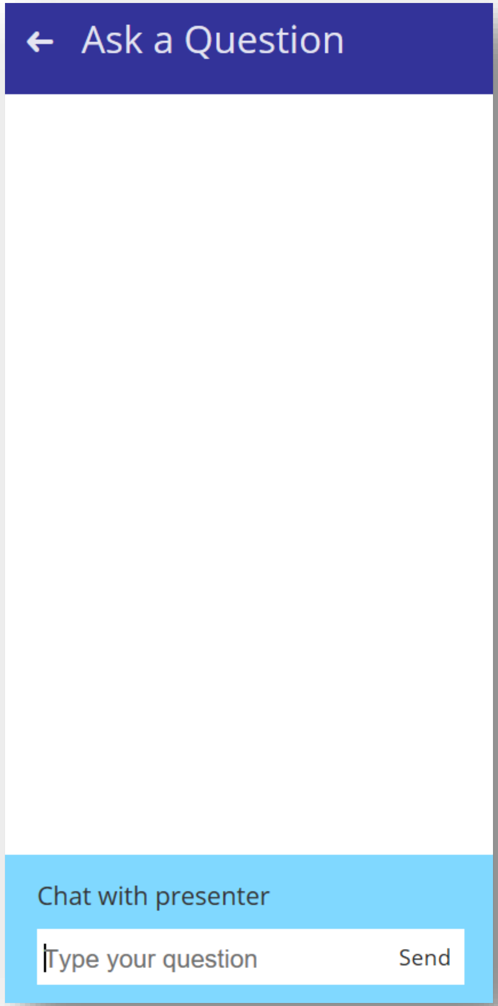
WATEREUSE

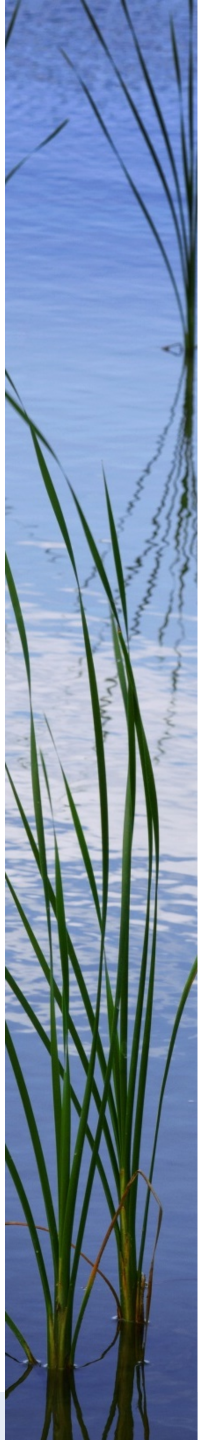
AMTA
American Membrane Technology Association

WateReuse Webcast Series

A Few Notes Before We Start…

- Today's webcast will be 60 minutes.
- There is one (1) Professional Development Hour (PDH) available for this webcast.
- A PDF of today's presentation can be downloaded when you complete the survey at the conclusion of this webcast.
- If you have questions for the presenters please send a message by typing it into the chat box located on the panel on the left side of your screen.





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Today’s Presenters

Harold Fravel (Moderator)
Executive Director
AMTA

Sean Carter, P.E.
Product Manager, UF, MF, and MBR for the Americas
Toray Membrane USA, Inc.

Size	0.001 µm	0.01 µm	0.1 µm	1 µm	10 µm

Separation materials

- Ions, Low molecule weight organics
- High molecular weight polymer
- Colloid
- Clay
- Trihalomethane
- Agricultural & Organic Material
- Na+ Cl-
- Ca2+ Mg2+
- Bacteria
- Coliform
- Cryptosporidium

Types

RO/NF Membrane | Low Pressure Membrane

Reverse Osmosis [RO]	Nanofiltration [NF]	Ultrafiltration [UF]	Microfiltration [MF]

Membrane products

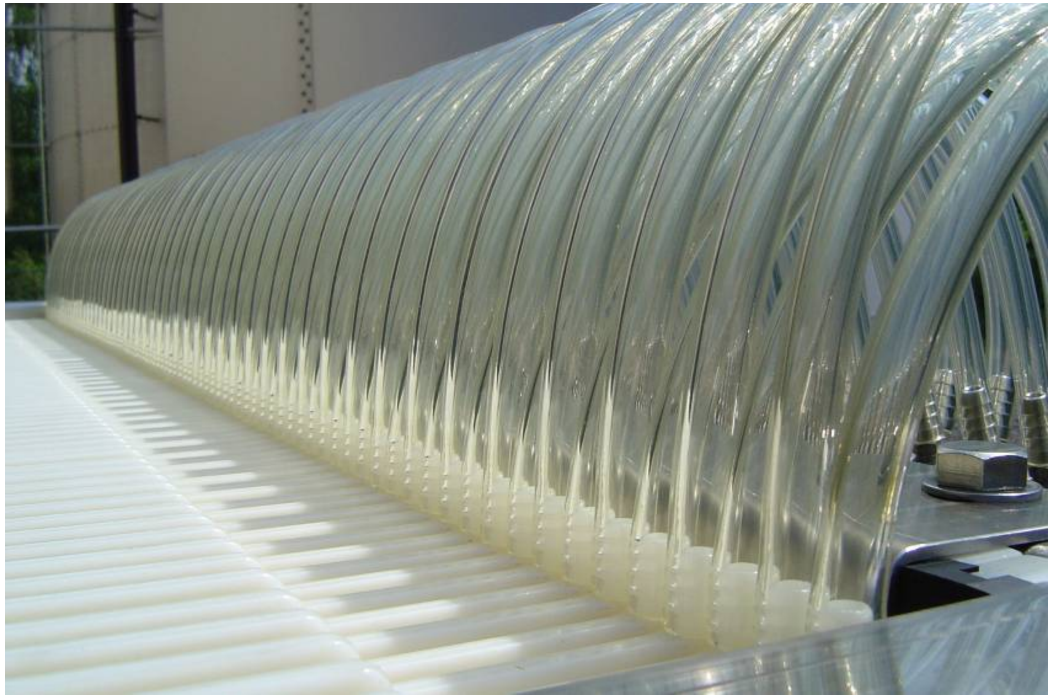
Ultrapure Water, Seawater Desalination, Advanced Water Treatment	Softening, Removal of Toxic substance	Municipal Drinking Water, Reuse of Wastewater, Pretreatment for RO Process	Sewage Water Treatment

RO membrane | NF membrane

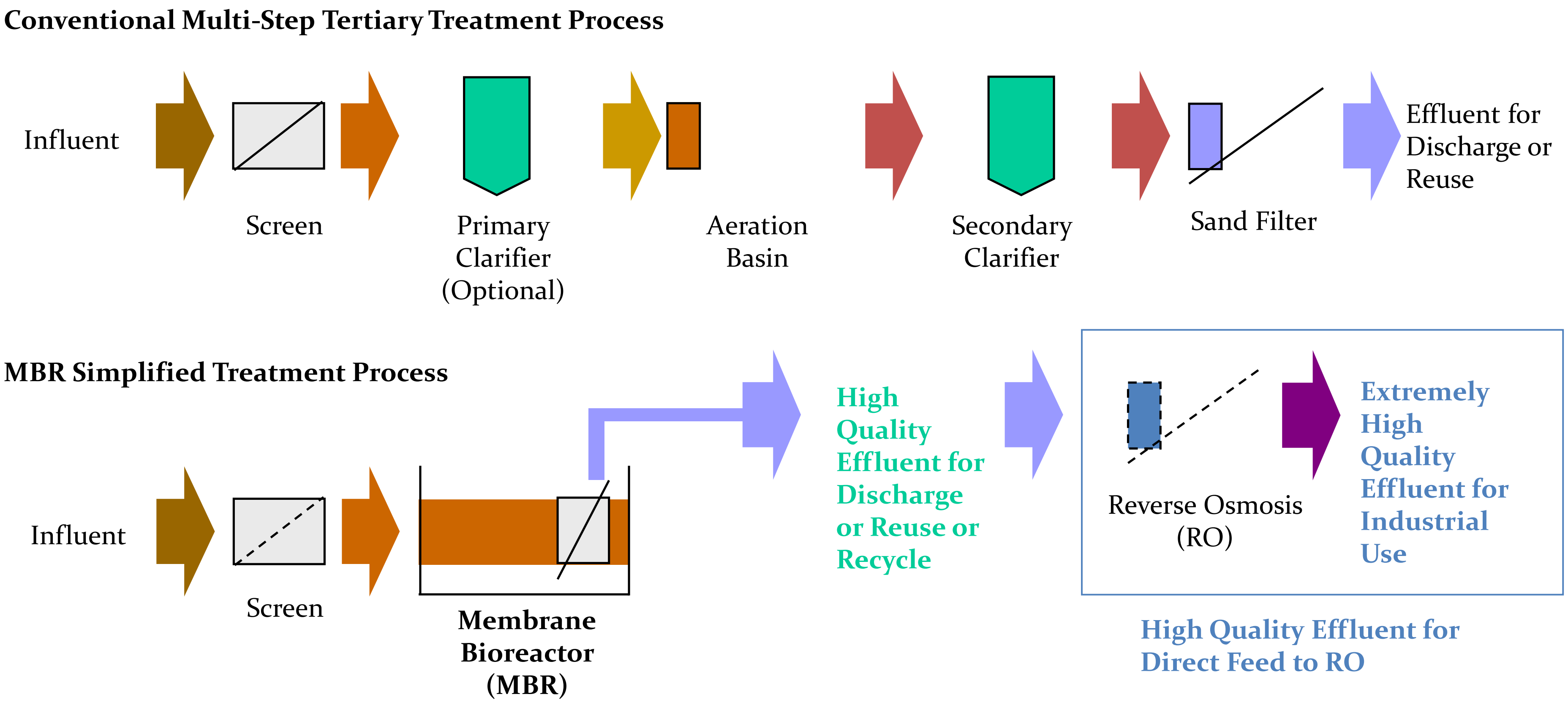
UF membrane (PVDF Hollow Fiber) | MF membrane (PVDF Hollow Fiber)

PVDF Immersed membrane for MBR

MBR TECHNOLOGY



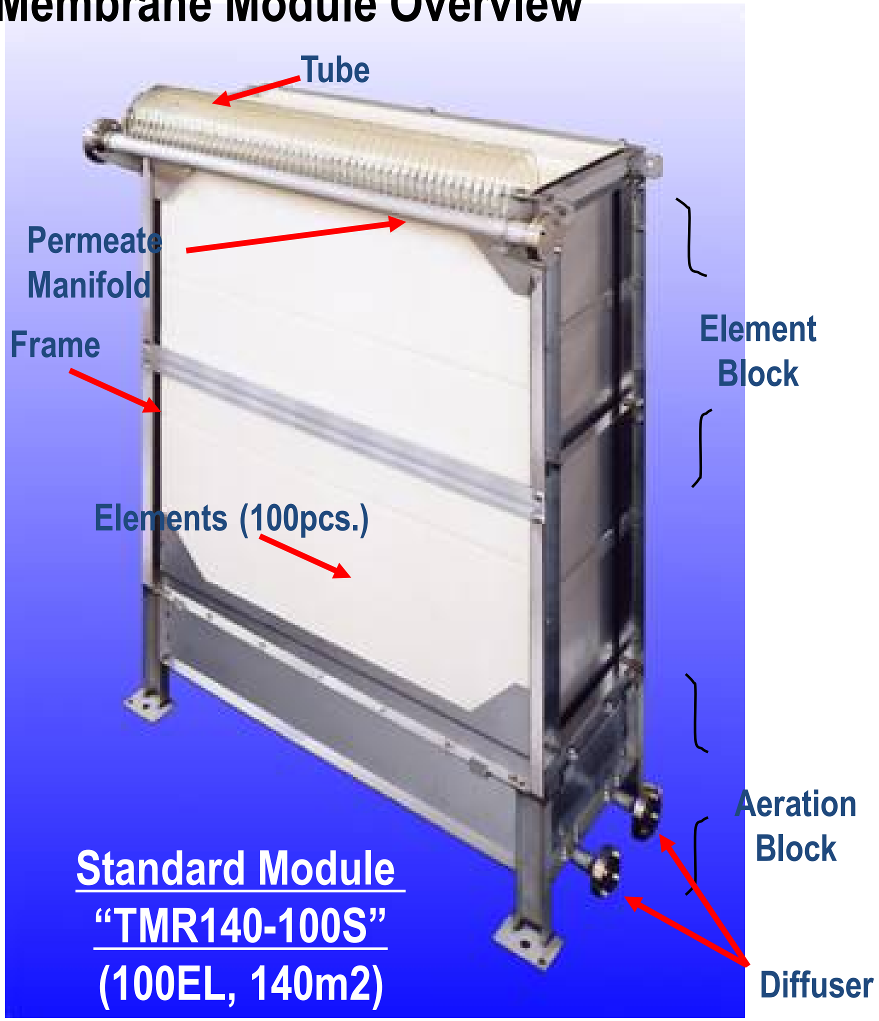
Membrane Bioreactor (MBR)



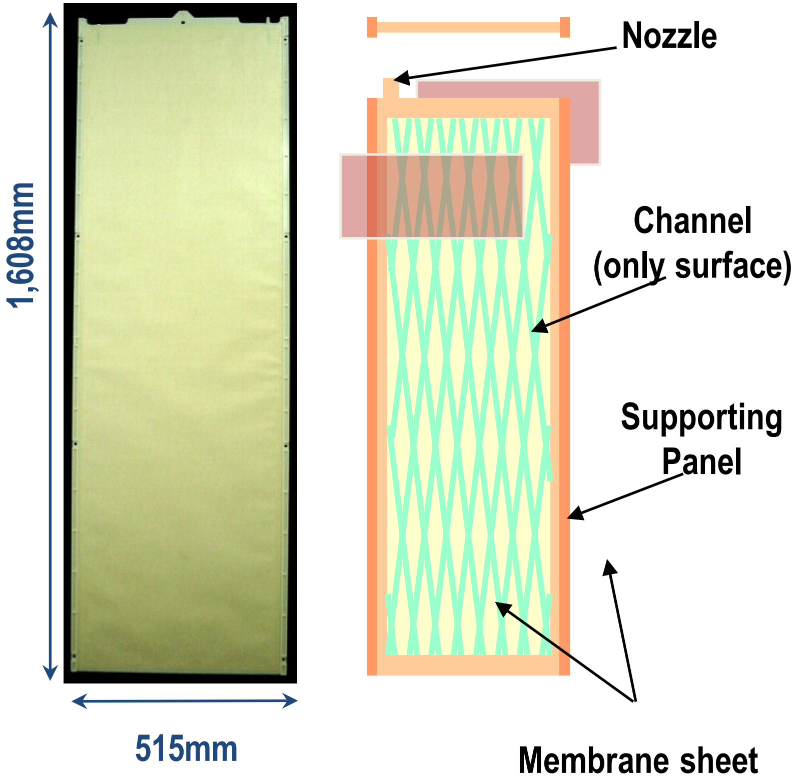
- **Combines membrane technology with biological treatment**
- **Replaces conventional clarification, aeration and filtration into a single step**

Structure of the Membrane Module

Membrane Module Overview



Membrane Element



Membrane area = 1.4 m2 / Element

…and assembled into a rugged, space-efficient module

Membrane Element

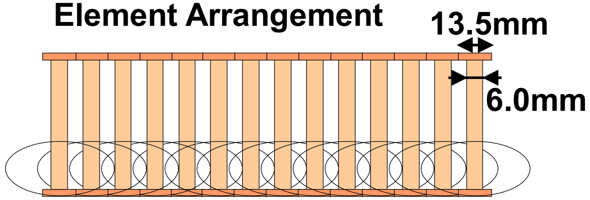
Element Block

Module

Element Frame

Aeration Block

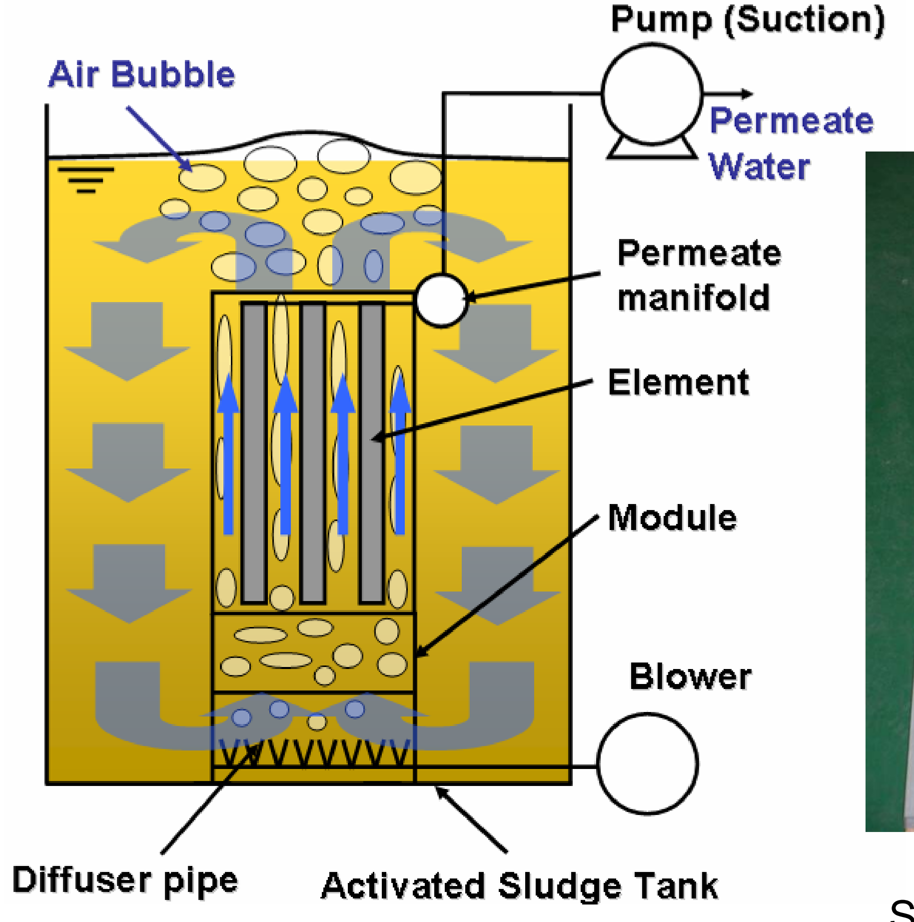
Element Arrangement



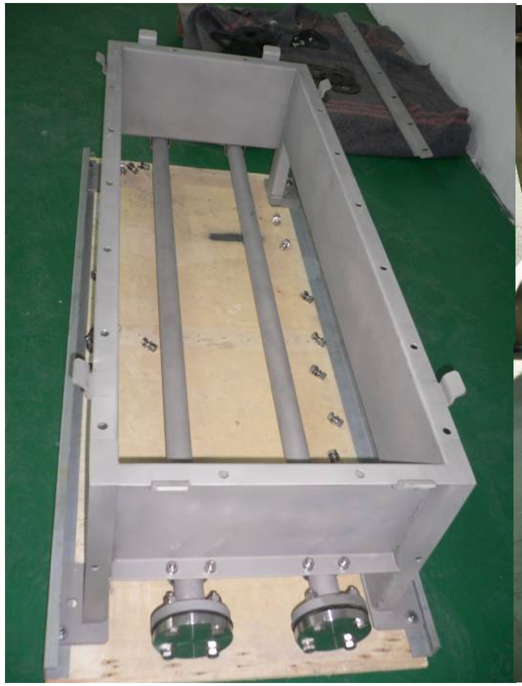
Membrane surface Clearance: 7.5mm

Efficient & effective

MBR Module – AERATION BLOCK



TMR140-Series



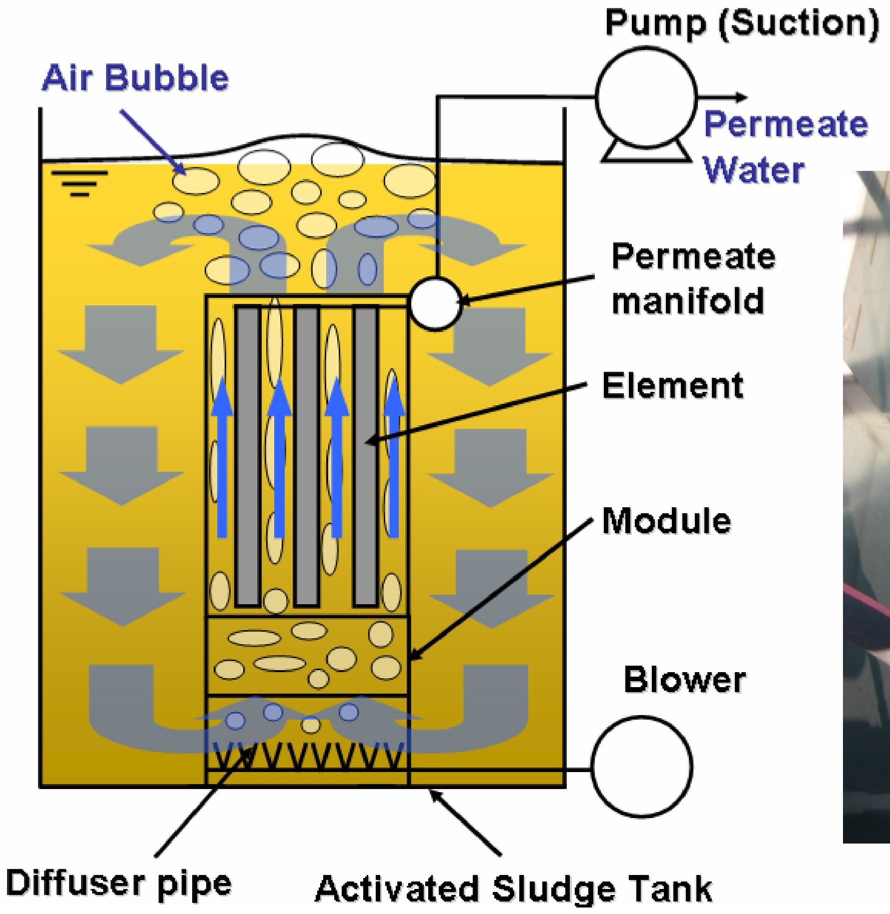
Stainless steel coarse bubble diffuser

TMR090-Series

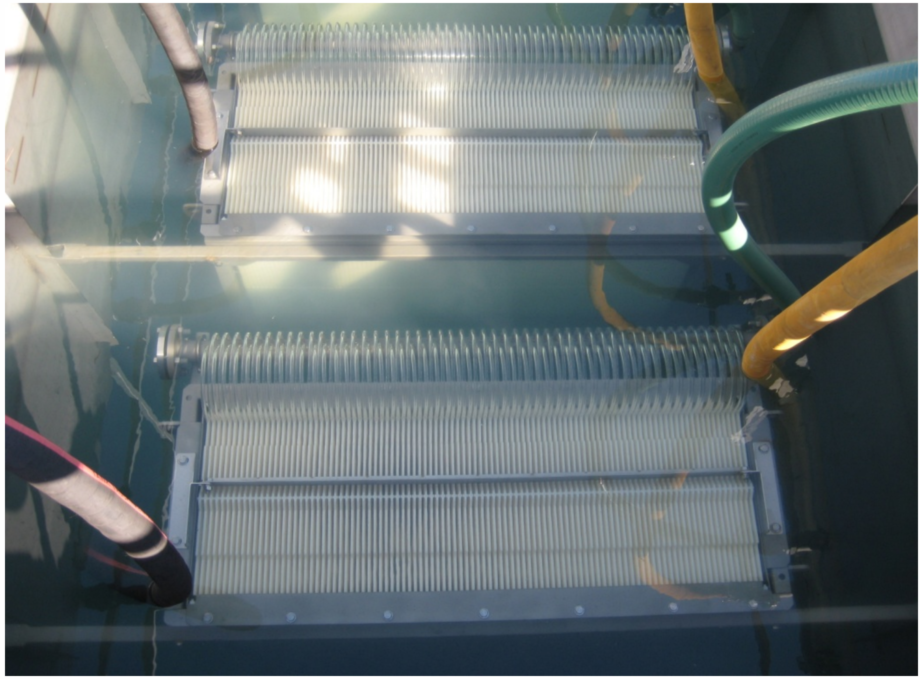
Membrane medium bubble diffuser

TECHNOLOGY

MBR Module – MEMBRANE BLOCK



TMR140-Series



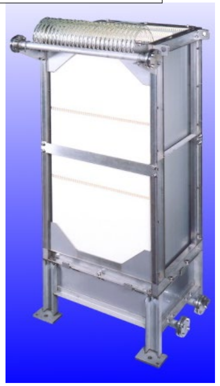
With Stainless Steel Coarse Bubble Diffuser

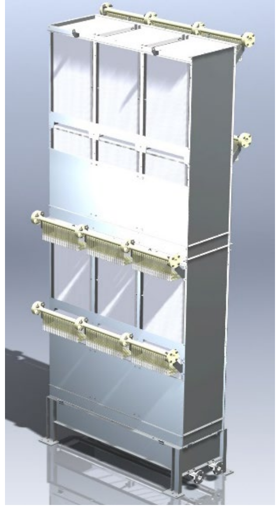
TECHNOLOGY

Differing MBR platforms

Module Type	No. of Elements	Membrane Area (m2)	Permeate Flow* (m^3/d)	Dimensions (mm) W x L x H
TMR 090-050S	50	45	30	711 x 1016 x 1474
TMR 090-100S	100	90	60	711 x 1719 x 1474
TMR 140-050S	50	70	53	810 x 950 x 2100
TMR 140-100S	100	140	105	810 x 1620 x 2100
TMR 140-200W	200	280	210	810 x 3260 x 2100
TMR 140-200D	200	280	210	810 x 1620 x 4160

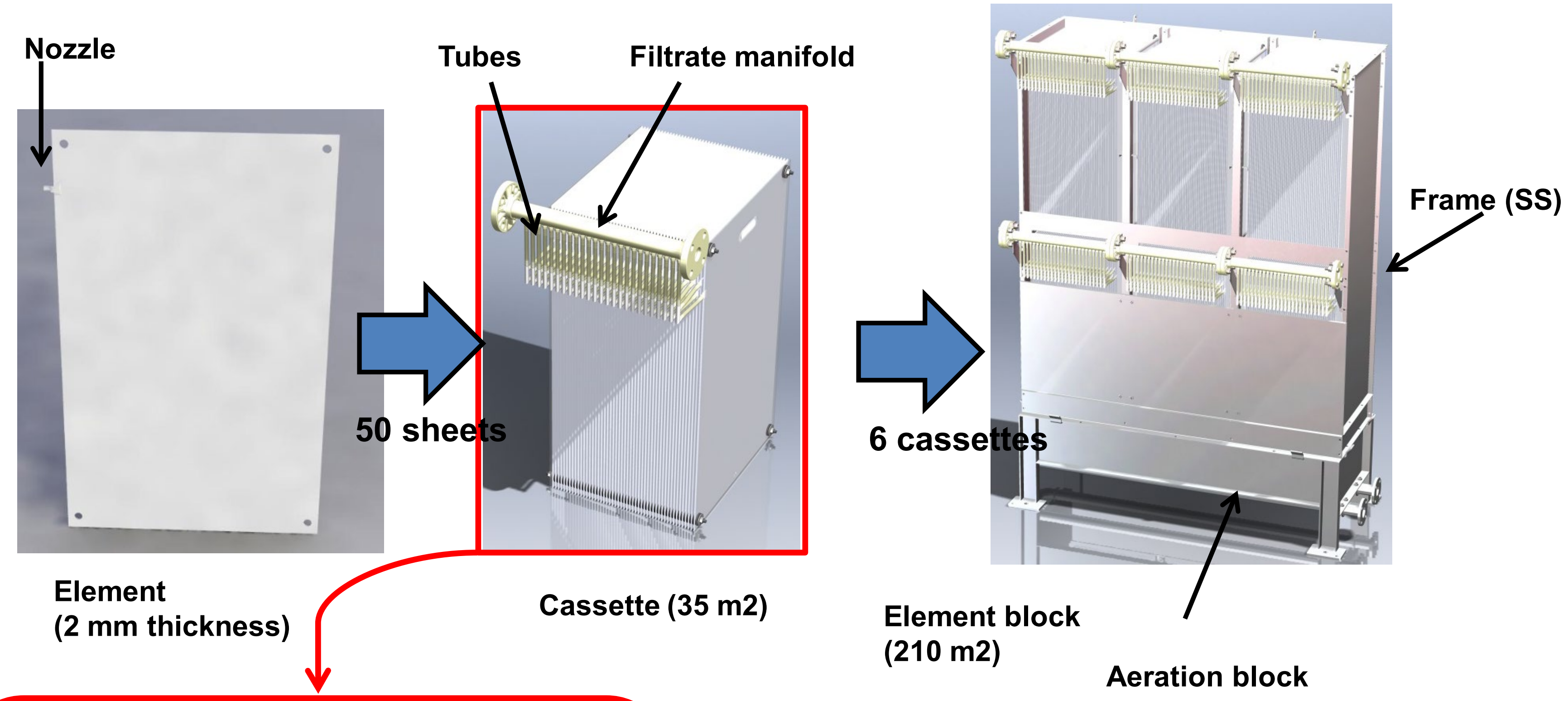
* Under standard conditions @ T > 15oC & flux of 31 LMH

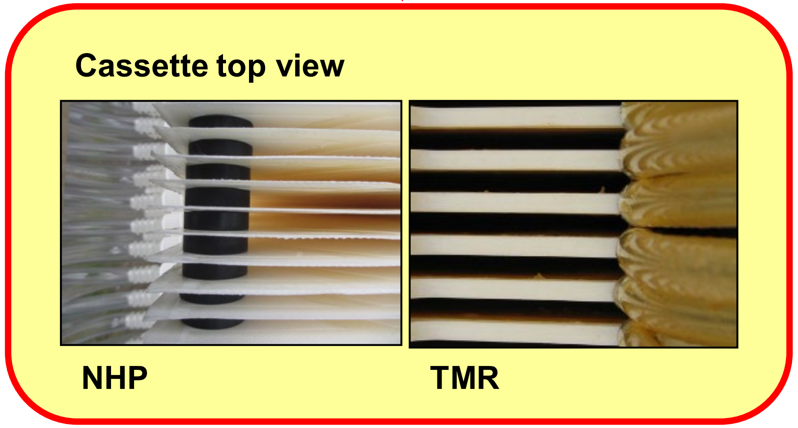




Robust, reliable, compact, flexible & affordable technology

Higher Area Designs

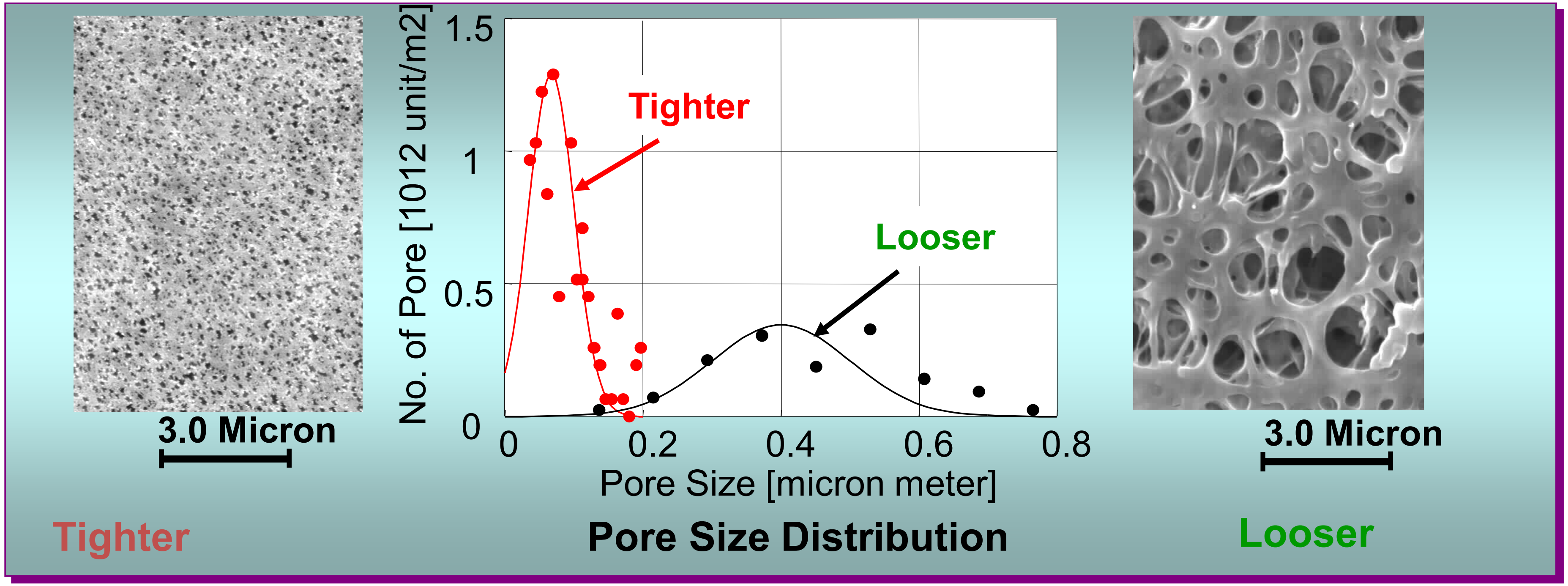


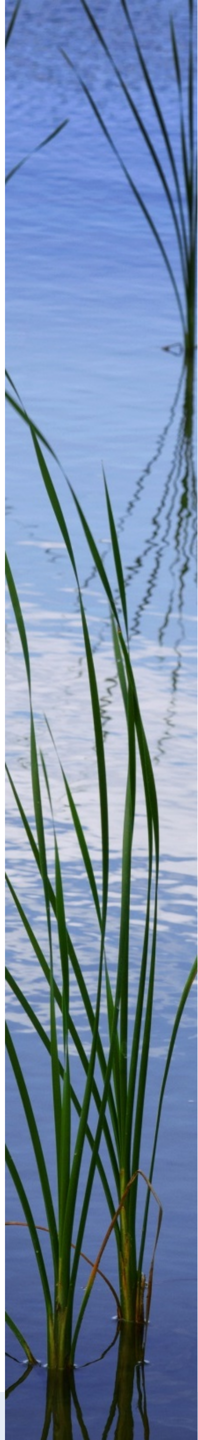


*Module is compatible with TMR140-100S

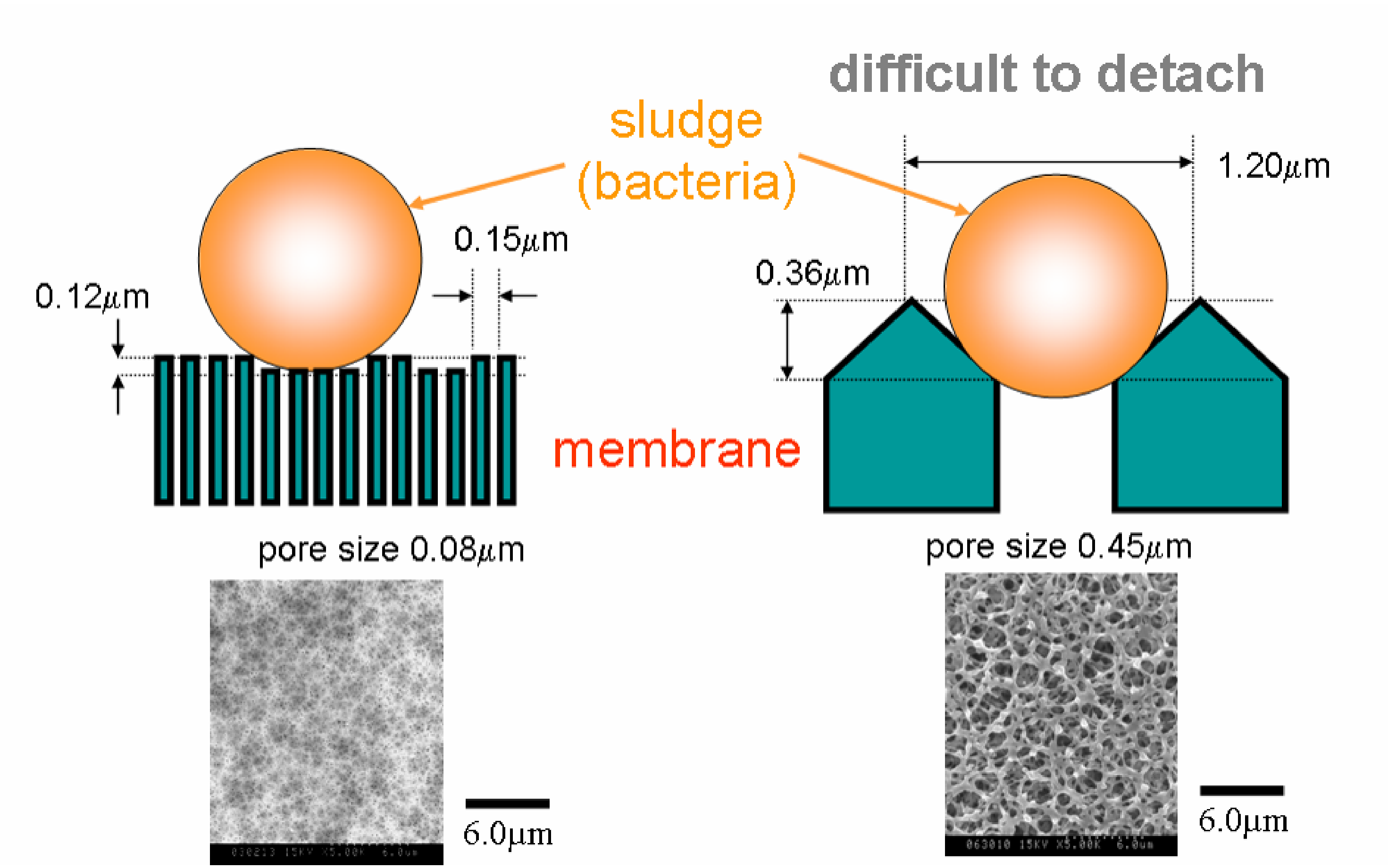
Pore Distribution

Item	Tight	Loose
Average Pore Size [micron meter]	0.08	0.4
Clean Water Permeability [$10^{-9}m^3/m^2/Pa/s$]	40	30





HIGH SURFACE SMOOTHNESS



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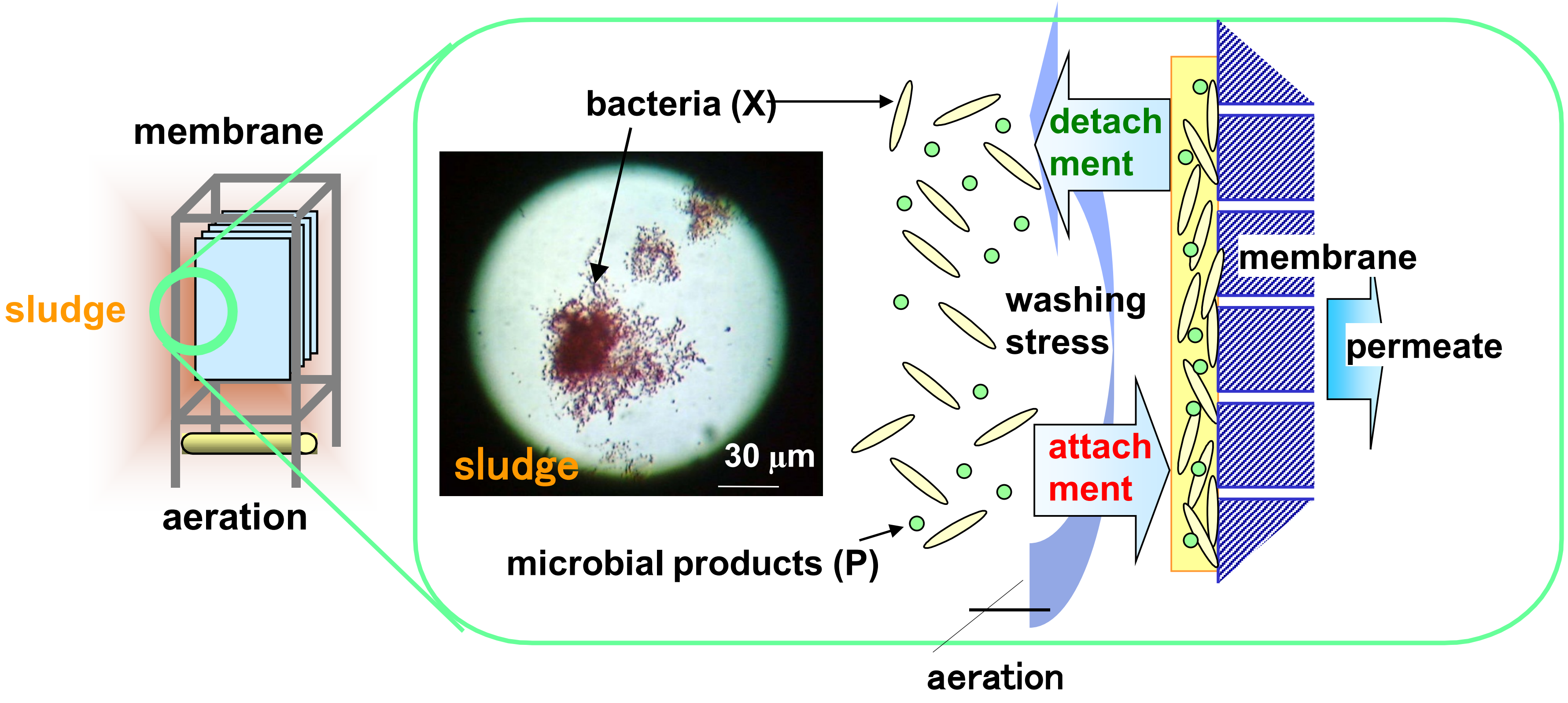
MBR Simulation



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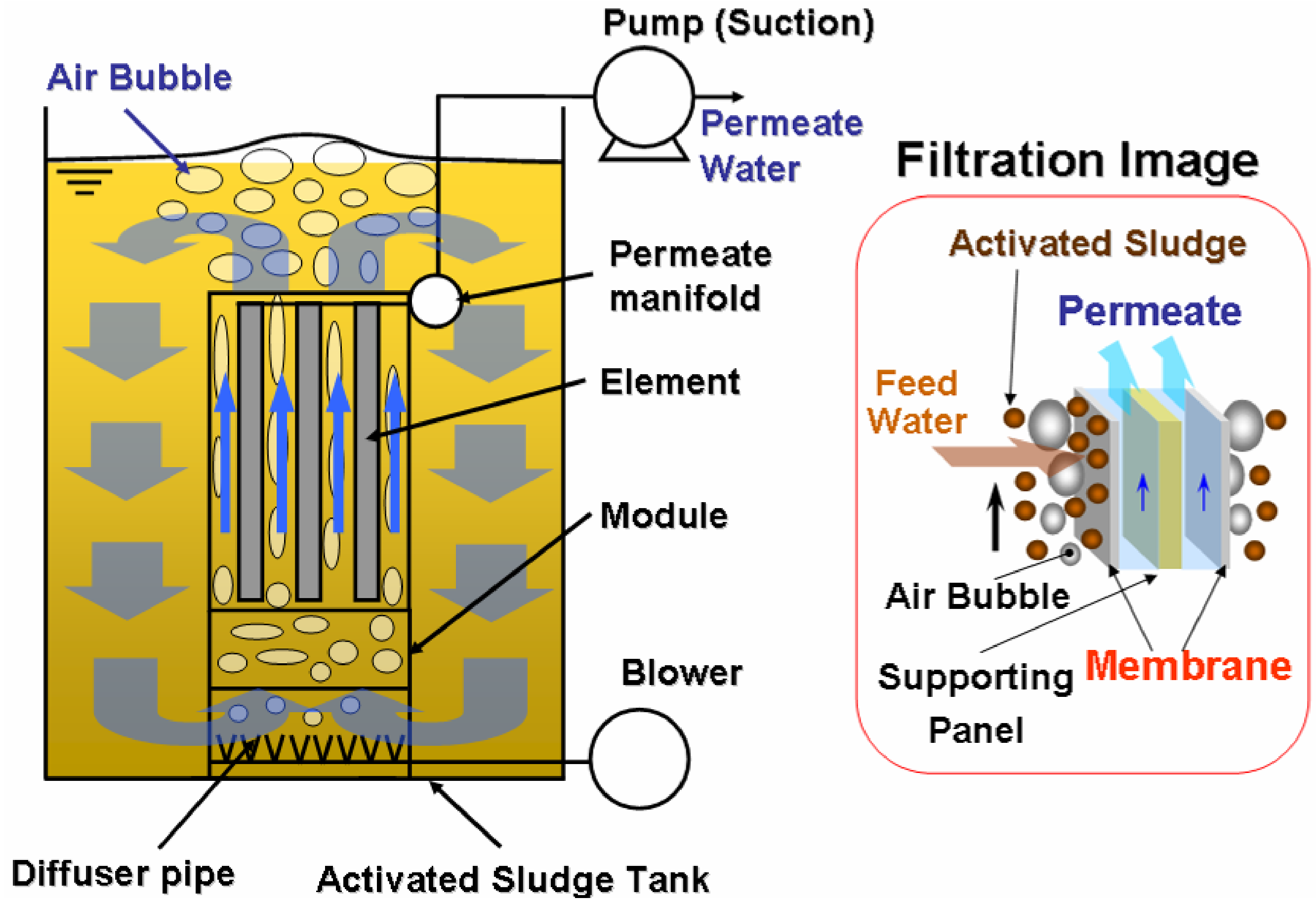
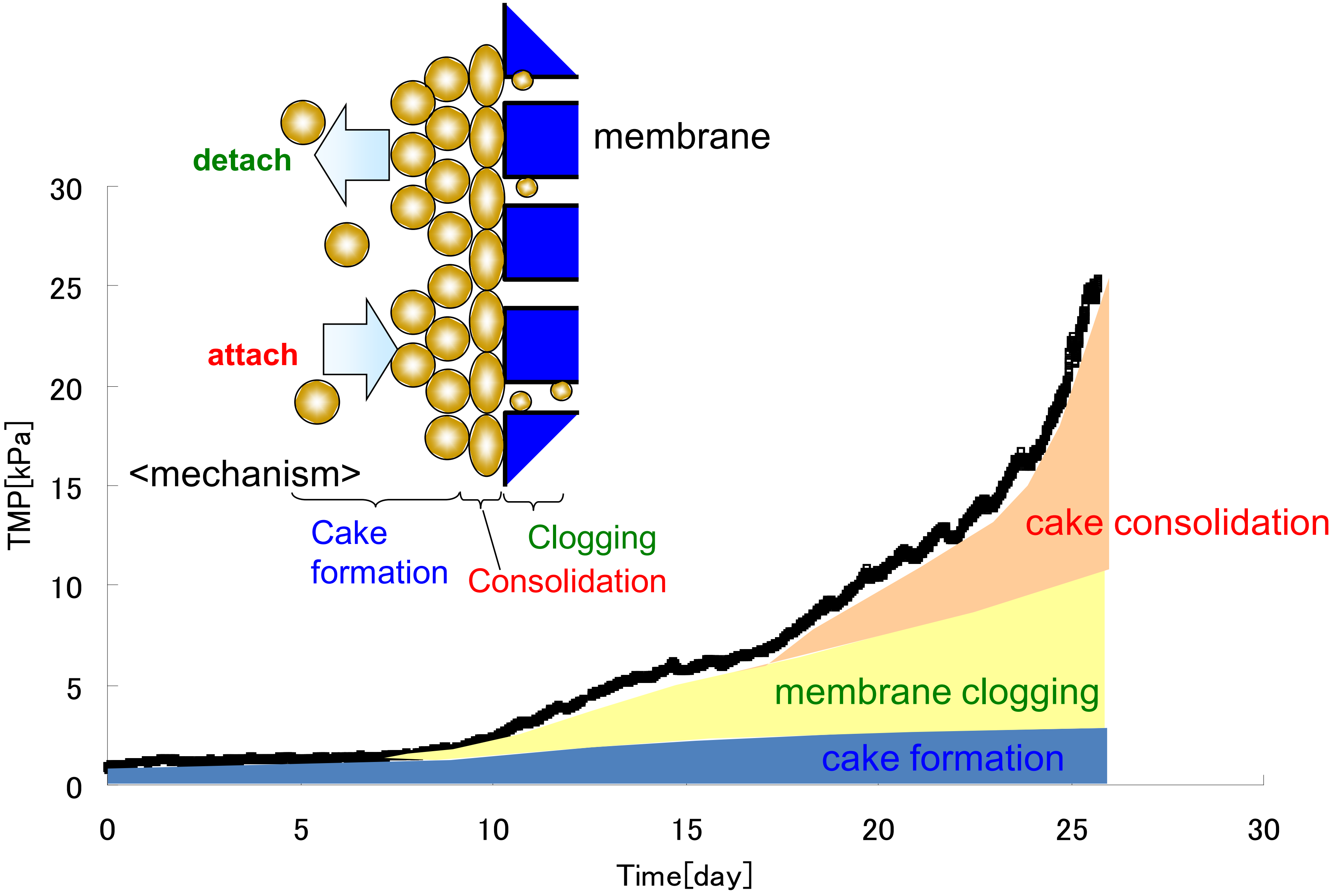
SCOURING AIR FLOW



SCOURING AIR FLOW – 0.5 to 0.7 scfm per Element

Mechanism of Filtration Resistance



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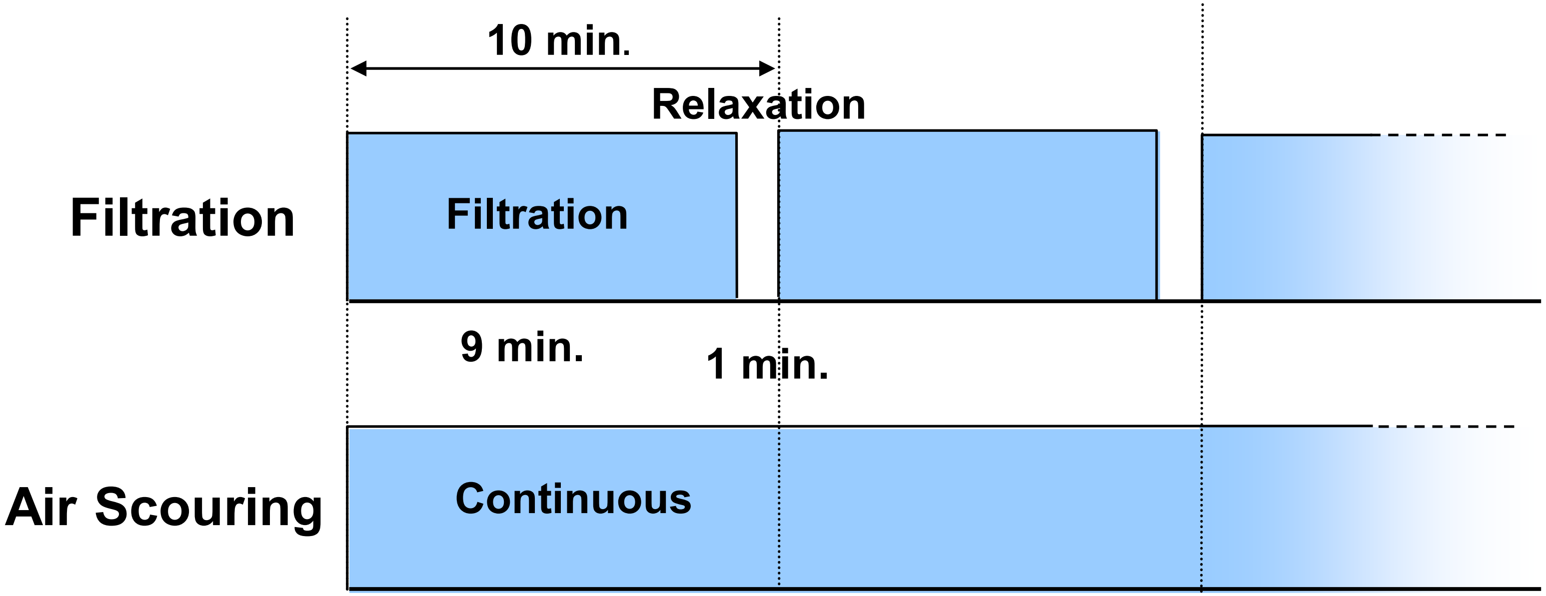
Production Cycles

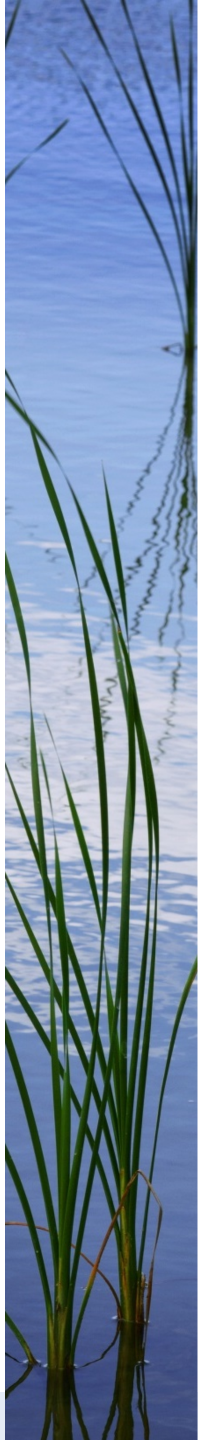
- **Production Cycle**
  - **Production cycle time (t_p) is typically 10 min**
  - **Membrane is operated at the instantaneous flux (J_i)**
- **Relaxation Cycle**
  - **Membrane is relaxing for 60 - 120 sec with no permeation, but ongoing aeration**



TYPICAL FLUX DESIGN GUIDELINES

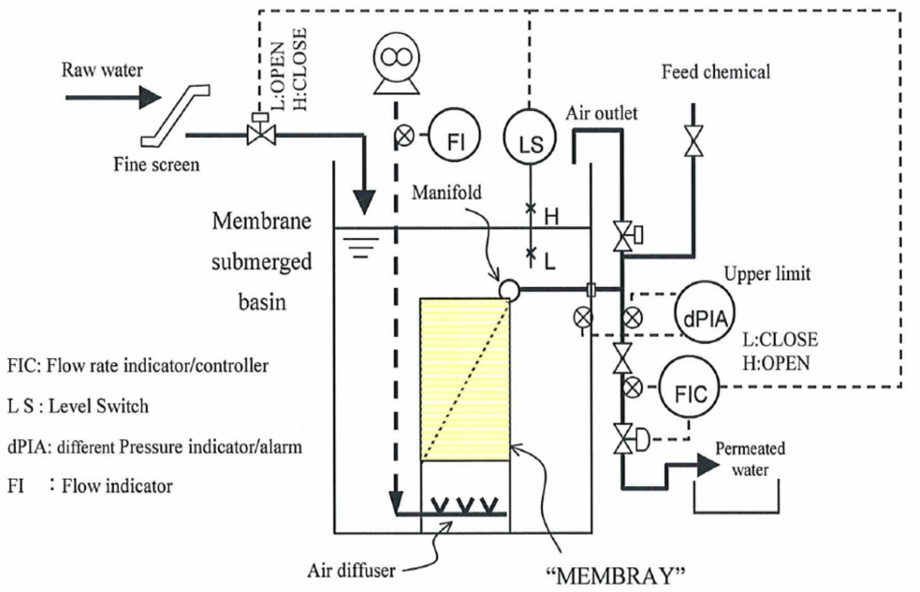
Application MLSS: 8 – 20 g/l		Daily average	Daily Peak max. duration 24h	Weekly Peak max. duration 7 days
Municipal	< 15°C	< 21 l/m^2.h < 12.5 gfd	< 25 l/m^2.h < 15 gfd	<23 l/m^2.h <13.7 gfd
	> 15°C	< 25 l/m^2.h < 15 gfd	< 30 l/m^2.h < 17.6 gfd	< 27.5 l/m^2.h < 16.2 gfd
Food Processing	< 15°C	< 17.5 l/m^2.h < 10 gfd	not available	
	> 15°C	< 21 l/m^2.h < 12.5 gfd		
Industrial	< 15°C	< 12 l/m^2.h < 7.5 gfd		
	> 15°C	< 16.0 l/m^2.h < 10 gfd		

TYPICAL OPERATING TMP – 0.5 to 1.5 psig

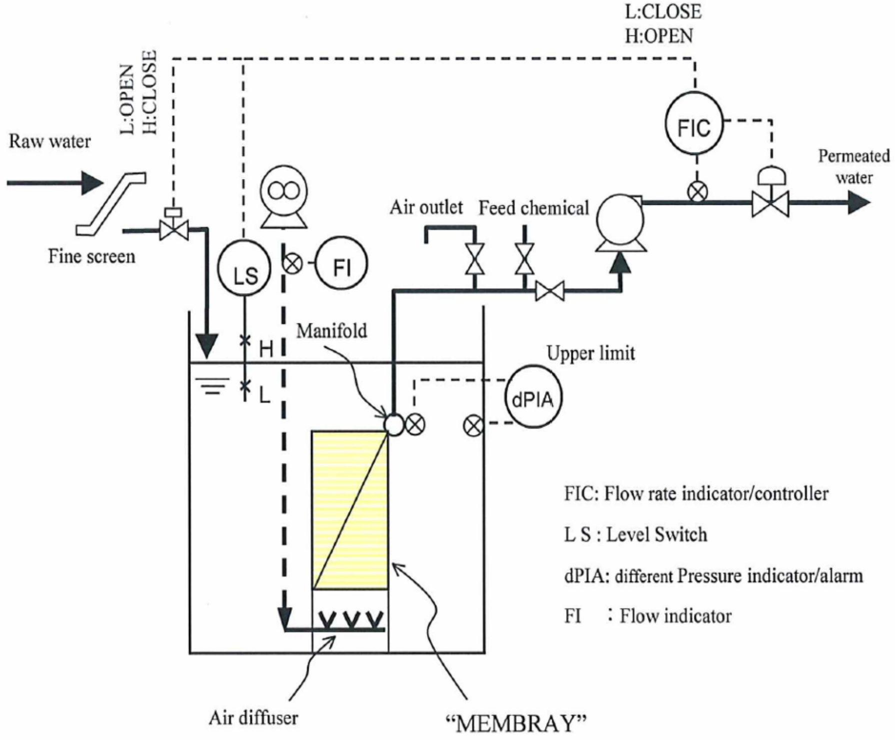


OPERATION MODE OPTIONS

Natural Water Head / Gravity Operation



Pump Suction Operation



Precreening Requirement: 3 mm finescreen.

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Typical MBR Applications

- Municipal wastewater
- Industrial wastewater
- Commercial development wastewater
- Ship-board wastewater
- Retrofit of existing plants
- Water reuse

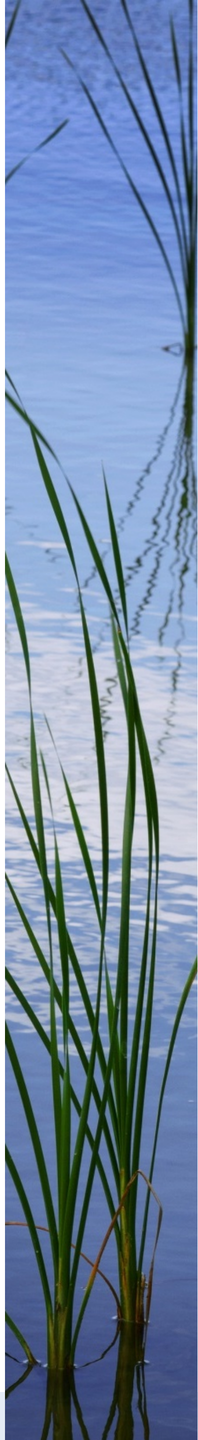
Typical MBR Effluent Quality

- Based on Municipal Sewage
  - BOD < 5 mg/L (typically non-detectable)
  - TSS < 5 mg/L (typically non-detectable)
  - NH3-N < 1 mg/L (typically <0.5 mg/L)
  - TN < 10 mg/L (<3 mg/L achievable in warm climate)
  - TP< 0.5 mg/L (<0.1 mg/L achievable)
  - Turbidity < 1 NTU (<0.2 NTU 95% of the time achievable)

Activated Sludge

Effluent

Best approach to meet future effluent quality requirements and water reuse



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TYPICAL PERFORMANCE DATA

PARAMETER		UNIT	TMR140-050S	TMR140-100S	TMR140-200W	TMR140-200D
Permeate Quality	TSS	mg/L	Not higher than 3.0			
	Turbidity	NTU	Not higher than 1.0			

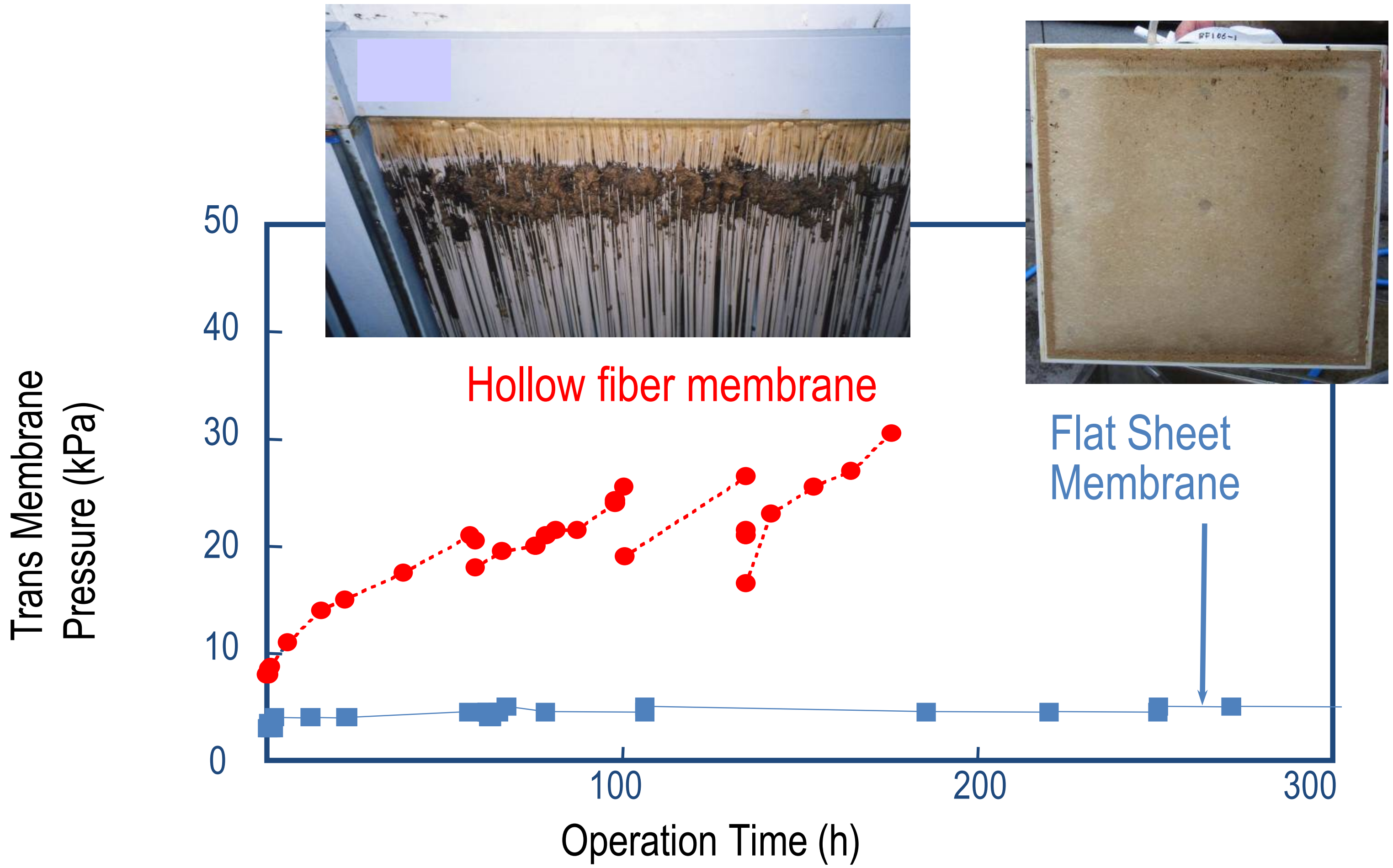
1: Sewage Results of the CDPH Pilot Test (Sewage)

Parameter	Specifications
Turbidity	< 0.2 NTU 95% of the time < 0.5 NTU 100% of the time
MS2 Virus Reduction	1.8 log

Flat Sheet or Hollow Fiber Membrane

Type	Advantages	Disadvantages
Flat Sheet	▪ Less Chemical Cleaning (effective cleaning with scouring air) ▪ Operate with Gravity (less pressure loss) ▪ High Flux ▪ Easy Maintenance	▪ Slightly Larger Membrane Area per Footprint for Systems > 5 MGD
Hollow Fiber	▪ Slightly Smaller Membrane Area per Footprint (Systems > 5 MGD) ▪ Backwash Cleaning	▪ Finer screen required for Pre-treatment (Inter-fiber fouling causing flux decline) ▪ More Frequent Chemical Cleaning (fouling with SS)

Flat Sheet or Hollow Fiber Membrane



Industrial Wastewater Treatment Test (Flux:10 gfd / 0.4m/d)

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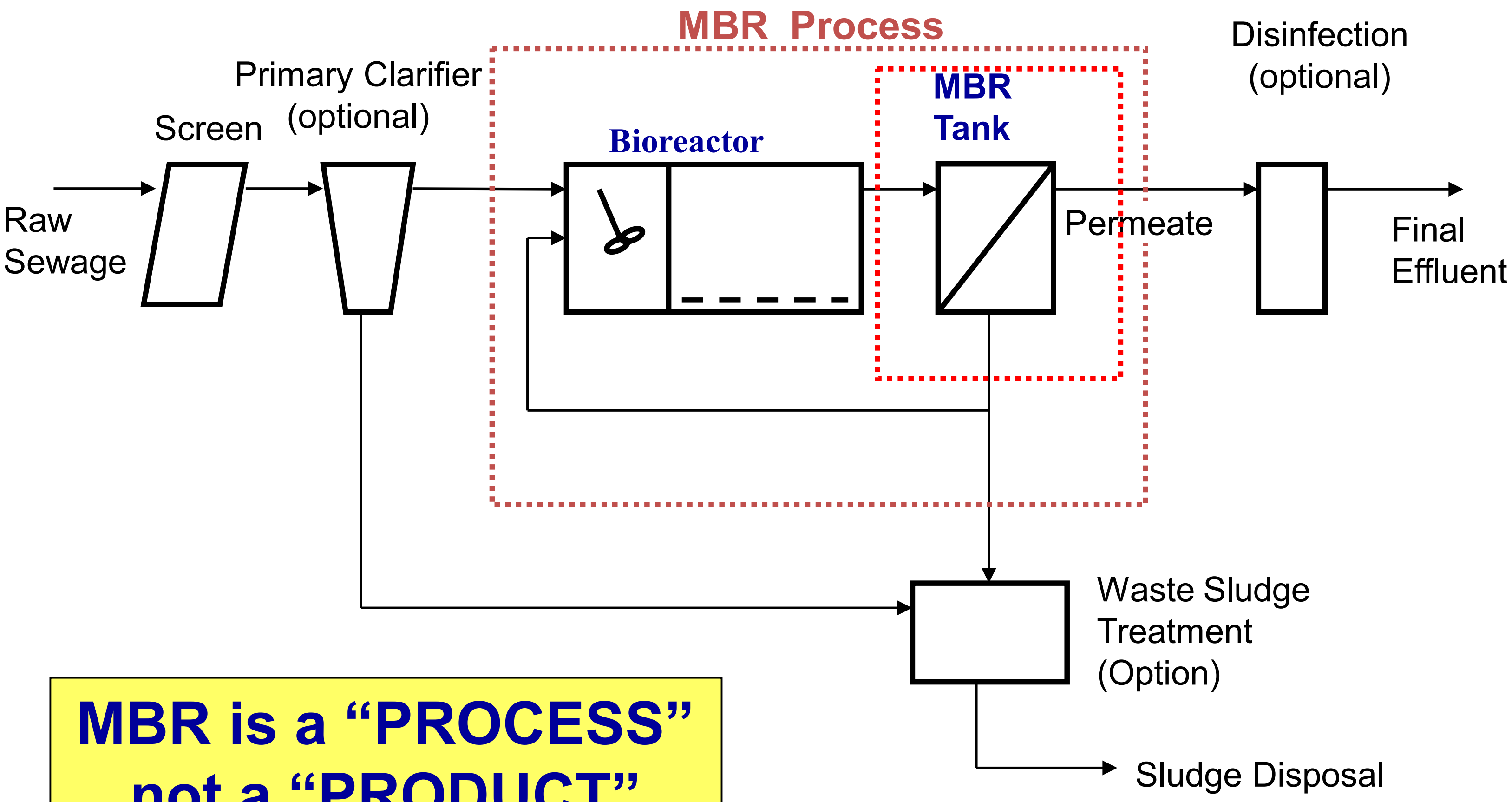
KAESER


VALLEYWIDE

GENERAL PROCESS DESIGN

PROCESS DESIGN
-Treatment Steps MBR Process-



MBR is a "PROCESS" not a "PRODUCT"

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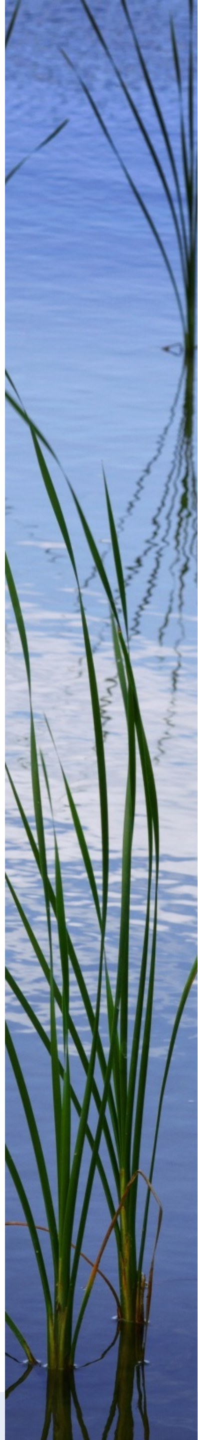
PROCESS DESIGN
-Responsibility-

TREATMENT STEP	Membrane Manufacturer	OEM /Consultant
Pre-treatment processes		
·Screening	Recommendation	X
·Grit removal		X
·Grease removal	Recommendation	X
·Primary clarification		X
Biological Processes		
·Min. required conditions for MBR process	X	
·BOD/Nitrogen/P-Removal		X
·Tank designs		X
Membrane Process		
·Needed Membrane area, operation conditions	X	
·Specification membrane related equipment	X	
·Tank designs, piping etc.		X
Sludge Handling & Treatment		
·Usage of polymers	Aligned with Membrane Manufacturer	X
·Digestion/Dewatering/Disposal		X

FLOW EQUALIZATION

- **Use of Flow Equalization (EQ)**
  - Reduces the number of membranes required to handle large short-term peak flows
  - Suitable for small to medium sized plants with large peak hourly flows (>2Q)
    - ***MBR plants can handle peak hourly flow rates up to 1.5-2x Q*.**
  - Not suitable for extended peak flow conditions (more than a day) nor practical for plants > 5 mgd
- **Alternative to Flow Equalization**
  - Add standby membranes to use during peaking conditions
    - CAPEX & OPEX of membranes vs. EQ volume must be evaluated on a case by case basis
- **Type of Flow Equalization**
  - In-tank equalization (< 4 hr peak)
    - level of aeration and membrane tank varies to handle short-term peaks
  - Detention tank after primary settling and before the bioreactor
    - in-line with the process or off-line
  - Detention tank upstream of the plant or in the headworks
    - *need mixing to prevent solids settling*
    - *need aeration to prevent odor problems*



PROCESS DESIGN

PROCESS DESIGN CONSIDERATIONS

- Information Required for Design
  - Site Conditions
  - Hydraulic loading conditions
  - Wastewater characteristics
  - Effluent quality objectives
- Process Design Alternatives
  - Components required for the MBR process
  - MBR process configurations
  - Selection of treatment process

INFORMATION REQUIRED FOR DESIGN

Hydraulic Loading Conditions

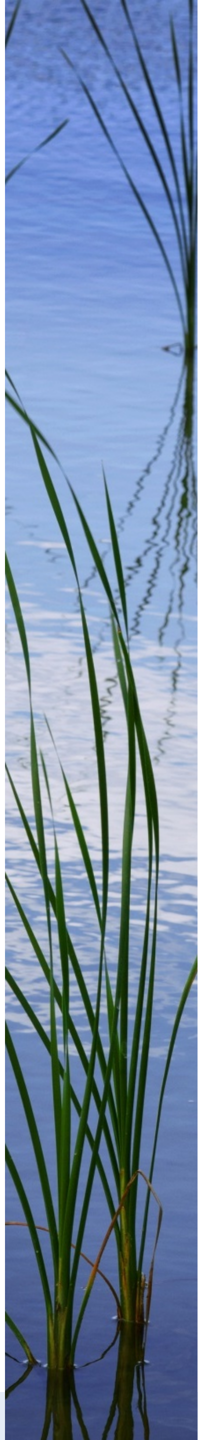
- Average Daily Flow
  - Based on total annual flow rate
  - Used to design bioreactors, sludge handling systems, and define plant capacity
- Peak Conditions
  - Flow rate and duration of peak flow is required
  - Important conditions are hourly peak and peak daily flow rates
  - Used to design pretreatment process and membrane filtration system
- Seasonal Variations
  - Flow and load variations due to seasonal or industrial activities
  - Use peak season average daily flow and organic loading to design biological process

INFORMATION REQUIRED FOR DESIGN

Wastewater Characteristics

- Minimum Parameters for MBR Process Design

➢ BOD, COD	- to estimate organic loading rates
➢ TSS, VSS	- to design pretreatment systems
	- to estimate inert suspended solids (ISS) for MLSS and SRT calculations
➢ N and P	- to design nutrient removal process
	- to verify if nutrient is sufficient (especially for industrial WW)
➢ Alkalinity	- to design for nitrification / denitrification, and chemical P removal
➢ Temperature	- minimum value used for both biological and membrane process design



INFORMATION REQUIRED FOR DESIGN

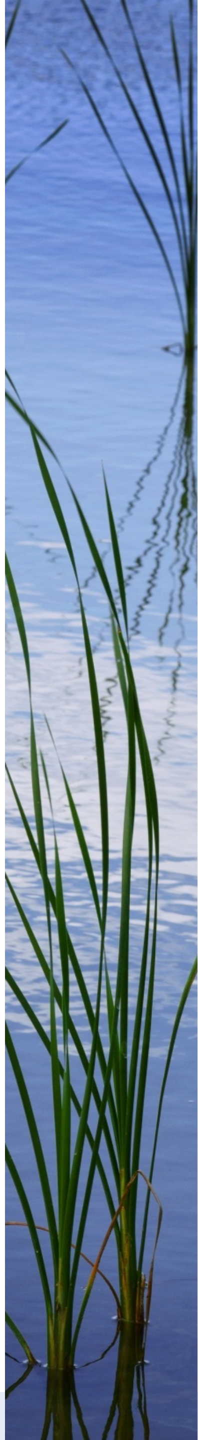
Other Parameters

- Needed to assess pretreatment options and special precautions
  - fat, oil and grease (FOG)
  - heavy metals
  - toxics / foam suppressants / antibiotics etc.
  - pH

INFORMATION REQUIRED FOR DESIGN

Effluent Quality Objectives

- Specify target parameters
- Current and future effluent limits required
- Effluent limits based on concentration, mass loading, or percent removal of target parameters?
- Regulatory criteria vs. Plant objectives (e.g., for water reuse)
  - Plant objectives usually more stringent than legal limit
  - Reuse water quality



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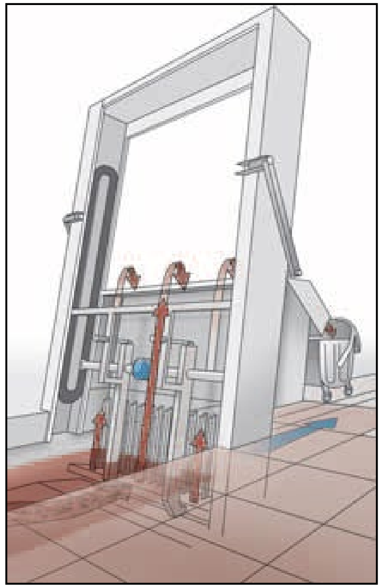
SCREENING
–Types of Screens-

- Bar Screens (coarse and medium) down to 6 mm as pre-screening
- Step Screens (coarse and medium) down to 6 mm as pre-screening
- Rotary drum screens (1-3 mm) Fine screening for MBR process
- Travelling band screens (1-3 mm) Fine screening for MBR process
- Rotating brush Screens(1-3 mm) Fine screening for MBR process

SCREENING
Screens for Pre-Screening

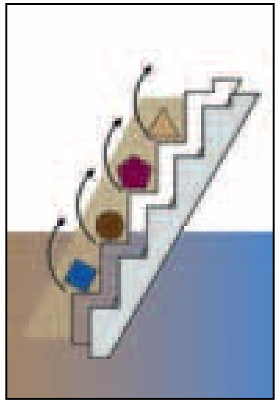
Bar Screens (coarse and medium) down to 6 mm



Source: Huber GmbH

SCREENING
Screens for Pre-Screening

Step Screens (coarse and medium) down to 6 mm



Source: Huber GmbH

GRIT REMOVAL

Longitudinal Grit Trap

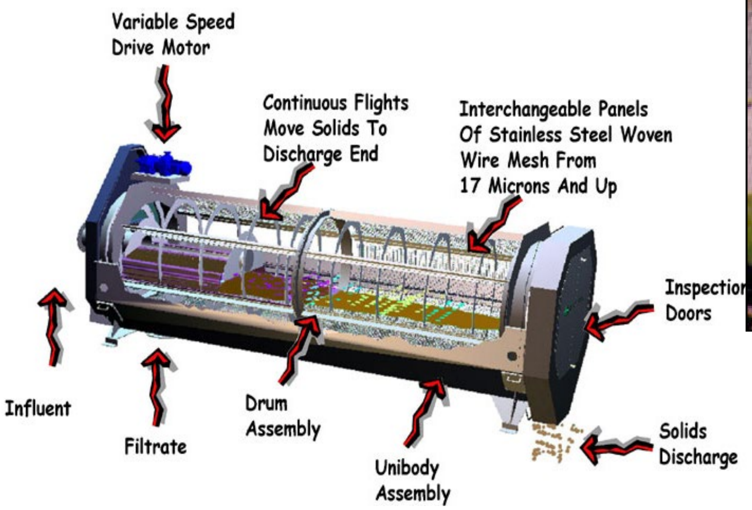
Circular Grit Trap

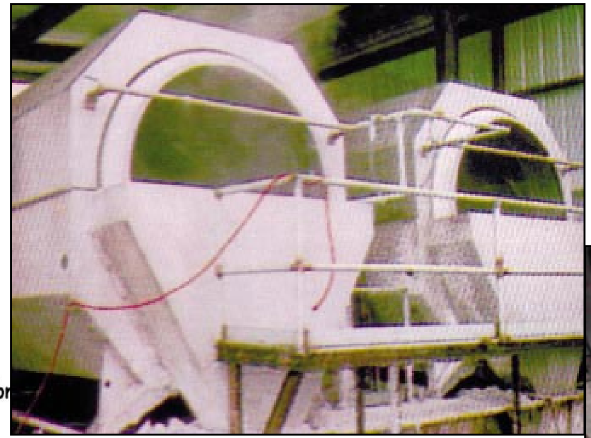
Grit Removal Requirement

- **No Specific Requirement**
  - Grit removal options same as for conventional activated sludge process
- **Design Engineer's Option**
- **Grit chamber is preferably located after pre-screening**

SCREENING –
Screens for Fine Screening

Internally Fed rotary drum screens (1 – 3 mm)
Fine screening for MBR process (pumped raw water)



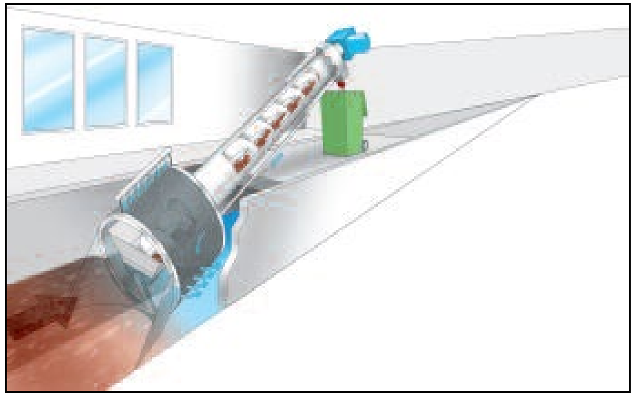


Source: Baycor Inc.

SCREENING –
Screens for Fine Screening

In Channel rotary drum screens (1 – 3 mm)

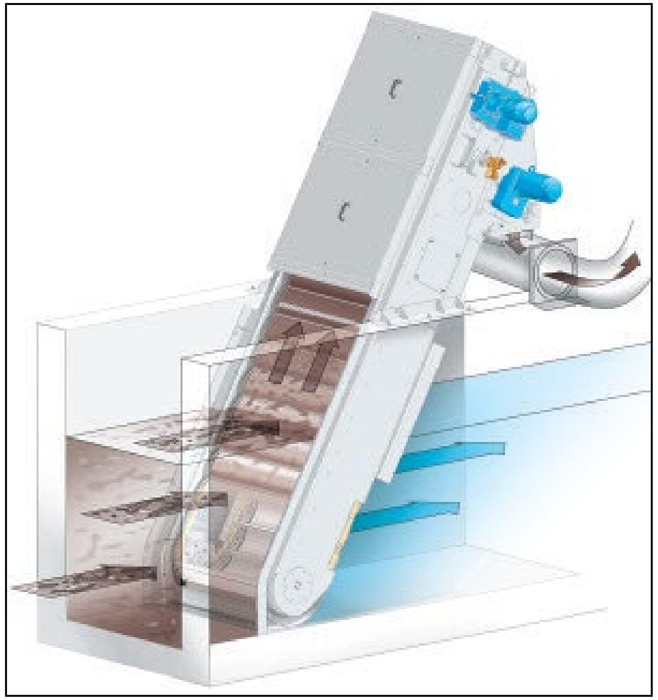
Fine screening for MBR process



Source: Huber GmbH

SCREENING
Screens for Fine Screening

Travelling band Screens (1 – 3 mm) Fine screening for MBR process



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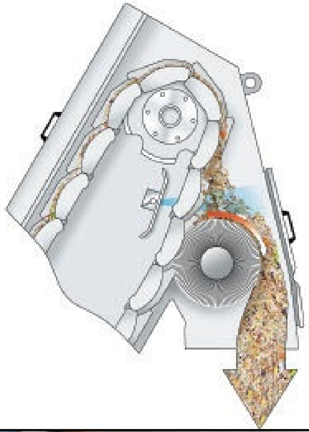
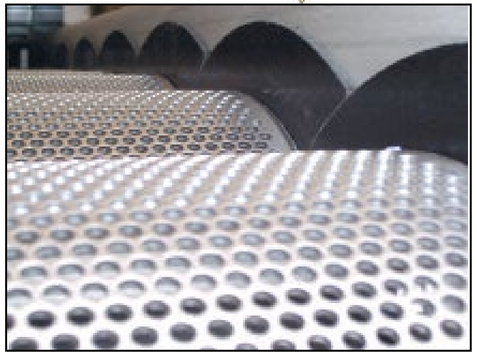
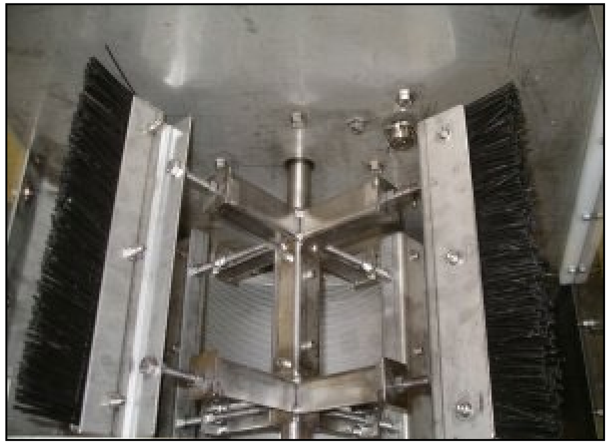




SCREENING
Screens for Fine Screening

Rotating brush Screens (1 – 3 mm) Fine screening for MBR process



Source: Or-Tec Inc.

SCREENING - CRITERIA

Raw sewage screening must satisfy all these criteria

Criterion	Comments
Absolute screen size opening	</= 3 mm mesh or punch-hole screen – not wedge-wire or bar
Low headloss	In-channel screen with no additional pumping to the screen
Maximum efficiency	Ability to operate with complete matting & incremental movement
No trash by-pass or carry-over	Effective removal as screenings always remain on the dirty side of the screen
Adequate capacity	Screen must be designed for peak flow conditions, with redundancy where possible
Water velocity	Water flow to screen must be > 1 m/s to eliminate potential for solids settling

FOG – FAT, OIL AND GREASE

Fat, Oil and Grease (FOG) Requirements

- FOG levels typically found in domestic wastewater will not affect membrane performance
- Maximum allowable biodegradable FOG in municipal wastewater is 50 mg/L
- FOG will form scum layer in aeration tank (principally anoxic zone)
  - No impact on membrane performance
  - Aesthetic issue in some cases
- FOG Removal Method
  - Design Engineer's Option
  - Fine screening with matting will remove significant FOG in MBR systems
  - Low levels of emulsified FOG will be degraded in plant with long SRT

PRIMARY CLARIFICATION

Use of Primary Clarification

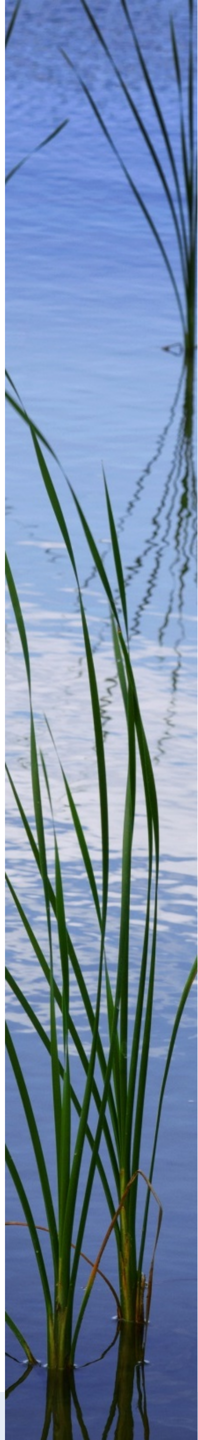
- Not a requirement - **Design Engineer's Option**
- Larger MBR plants can be designed without primary clarification as compared to conventional activated sludge plants, because
  - MBR plants can be operated at higher MLSS and organic loading rate as compared to conventional plants
- **Factors Supporting the Use of Primary Clarification**
  - Large plants (>10,000 m^3/d)
  - Retrofit plants that already have primary clarifiers
  - Space available
  - Anaerobic sludge digestion
  - Metal salt addition for phosphorus removal and to improve sludge filterability
  - High inert solids concentration in the feed

PRIMARY SEDIMENTATION - REASONS

- **Benefits of Primary Clarification**
  - Reduce solids and organic loading to the bioreactor
    - up to 50 - 60 % suspended solids removal
    - up to 30 - 40 % BOD_5 removal
    - reduce oxygen requirement (energy) and bioreactor volume
  - Reduce trash and fibrous materials entering the bioreactor and provide extra protection to the membrane
  - Metal salt (Al or Fe) addition upstream of primary clarifiers for
    - chemical phosphorus removal
    - improving sludge filterability
  - Removal of free oil and grease and other floatable materials – Maximum 50 mg/l of Biodegradable FOG to the MBR
  - Provide primary treatment to overflows during storm conditions

WATEREUSE

BIOLOGICAL PROCESS DESIGN

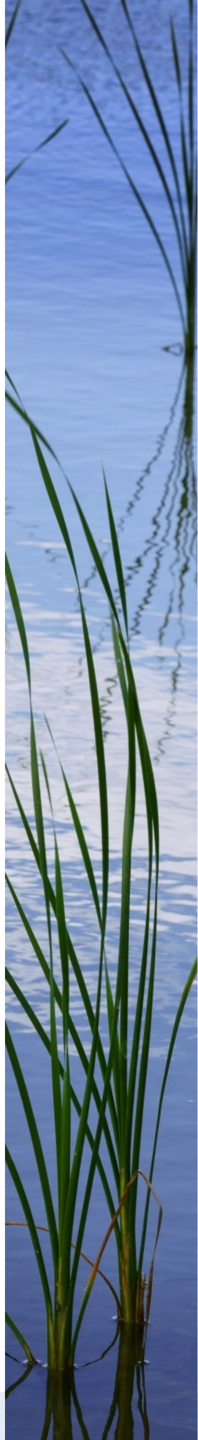


WateReuse

Biological Treatment

Wastewater contains high concentrations of organic matter, nutrients and colloidal solids

- **Objective:**
  - **Remove suspended colloidal solids**
  - **Reduce the organic content**
  - **Reduce concentrations of nutrients such as N and P**
  - **Conform to legislation and regulations**
- **Microorganisms (e.g. bacteria) are used to accomplish these objectives.**
- **The microorganisms convert colloidal and dissolved carbonaceous organic matter and nutrients into by-products (CO_2, CH_4), including cell tissue.**
- **The cell tissue created by the microorganisms is removed from the effluent in a solids separation process step.**
- **Microporous Membranes only provide a solid retention but no retention related to dissolved N/P/C or other substances**



BIOLOGICAL PROCESS – TREATMENT
Objectives & Oxygen Conditions

Unit Process	Characteristic
Carbon degradation	Aerobic
Nitrification (transformation of ammonia into nitrate)	
Denitrification (transformation of nitrate into nitrogen)	Anoxic
Phosphorous elimination (biological or chemical)	Anaerobic



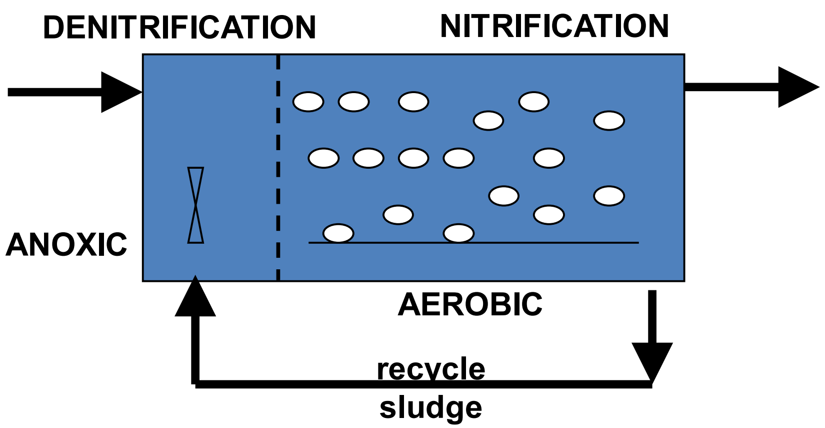

BIOLOGICAL PROCESS – ADVANCED
Nitrification / Denitrification

NITRIFICATION…

- Transformation of Ammonium (NH_4-N) to Nitrate (NO_3-N)
- Intermediate steps: NH_4 → NO_2- (Nitrite) →NO_3- (Nitrate)
- Bacteria: Nitrosomonas, Nitrospira, Nitrosococus, Nitrobacter, Nitrosystis
- Oxygen condition: Aerobic

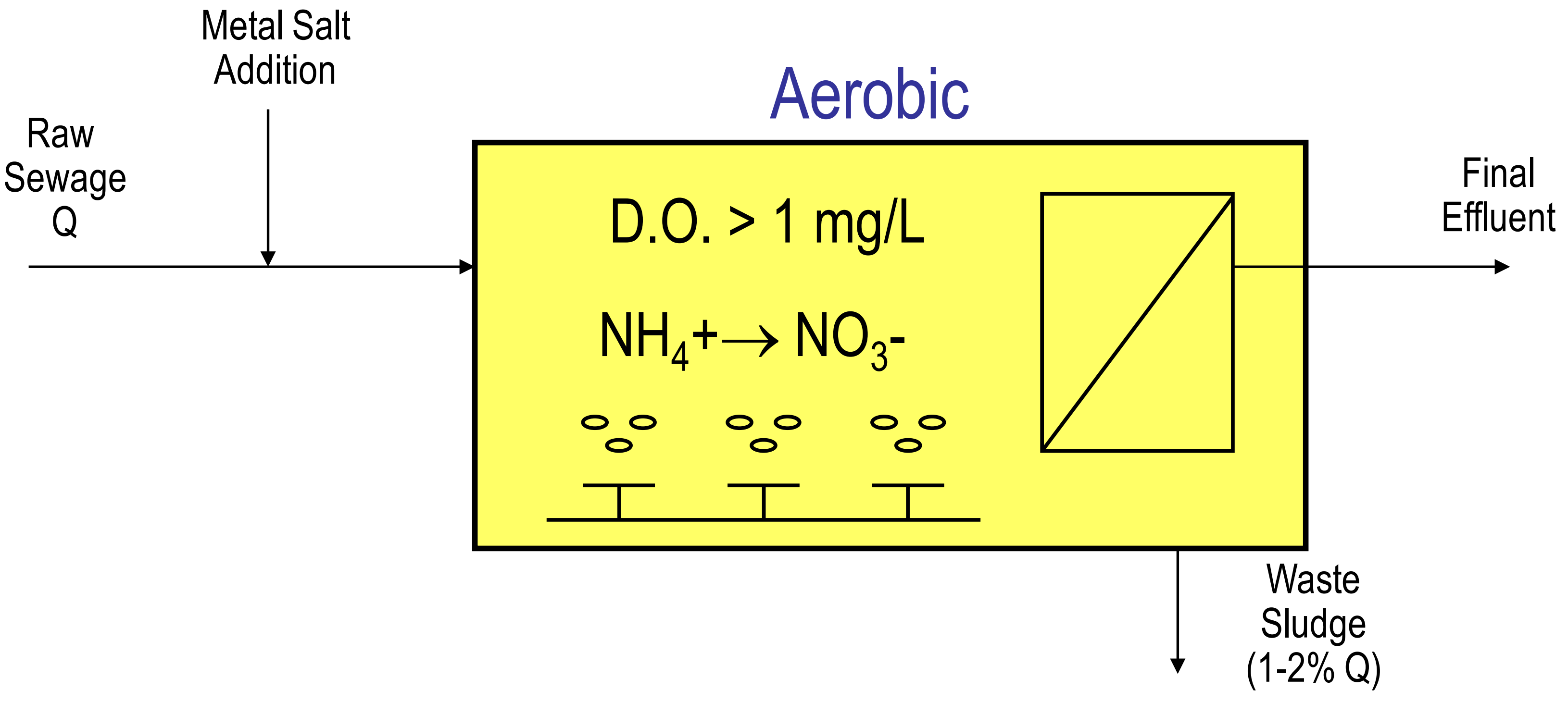
DENITRIFICATION…

- Transformation of Nitrate (NO_3-N) to Nitrogen (N_2)
- Intermediate steps: NO_3- →NO_2- →NO (Nitrogenmonoxyde) →N_2 (Nitrogen)
- Bacteria: Pseudomonas
- Oxygen condition: Anoxic



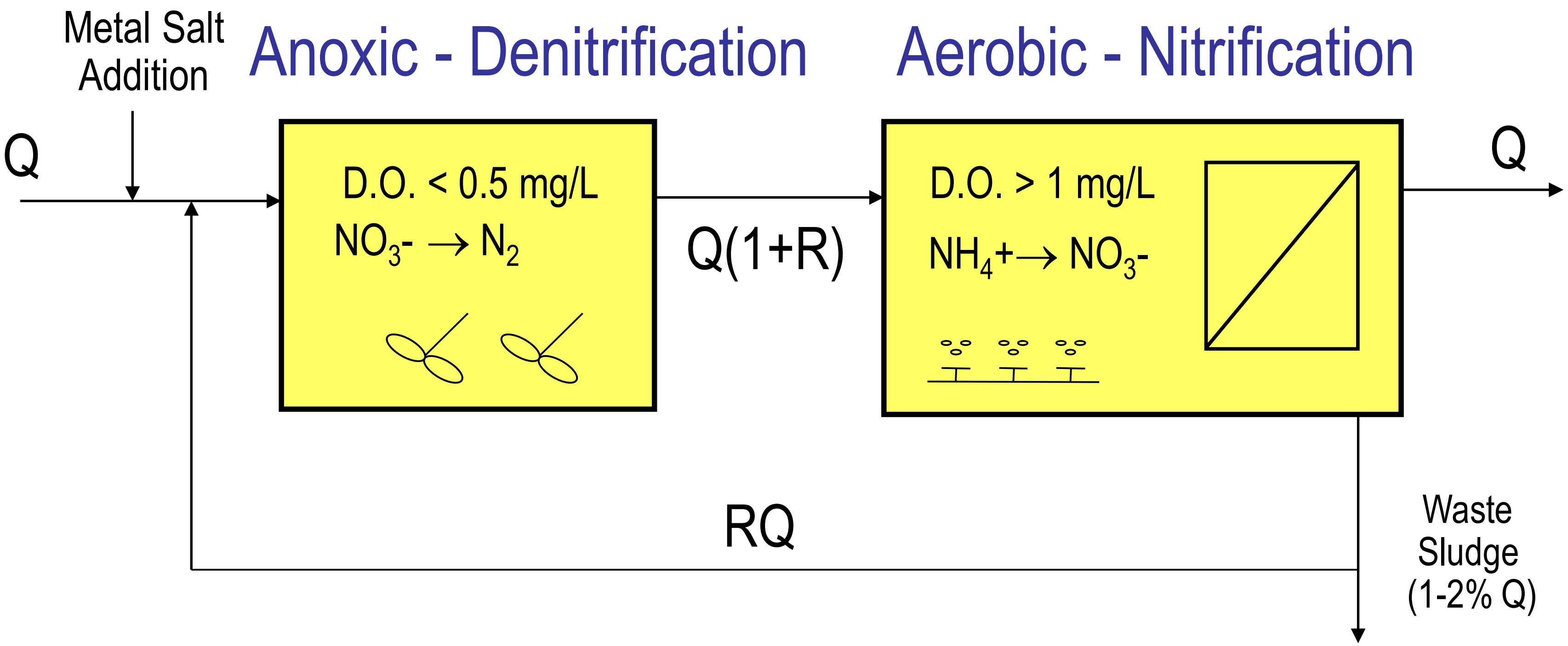
MBR Process Configurations

Nitrification and BOD Removal
Chemical TP Removal

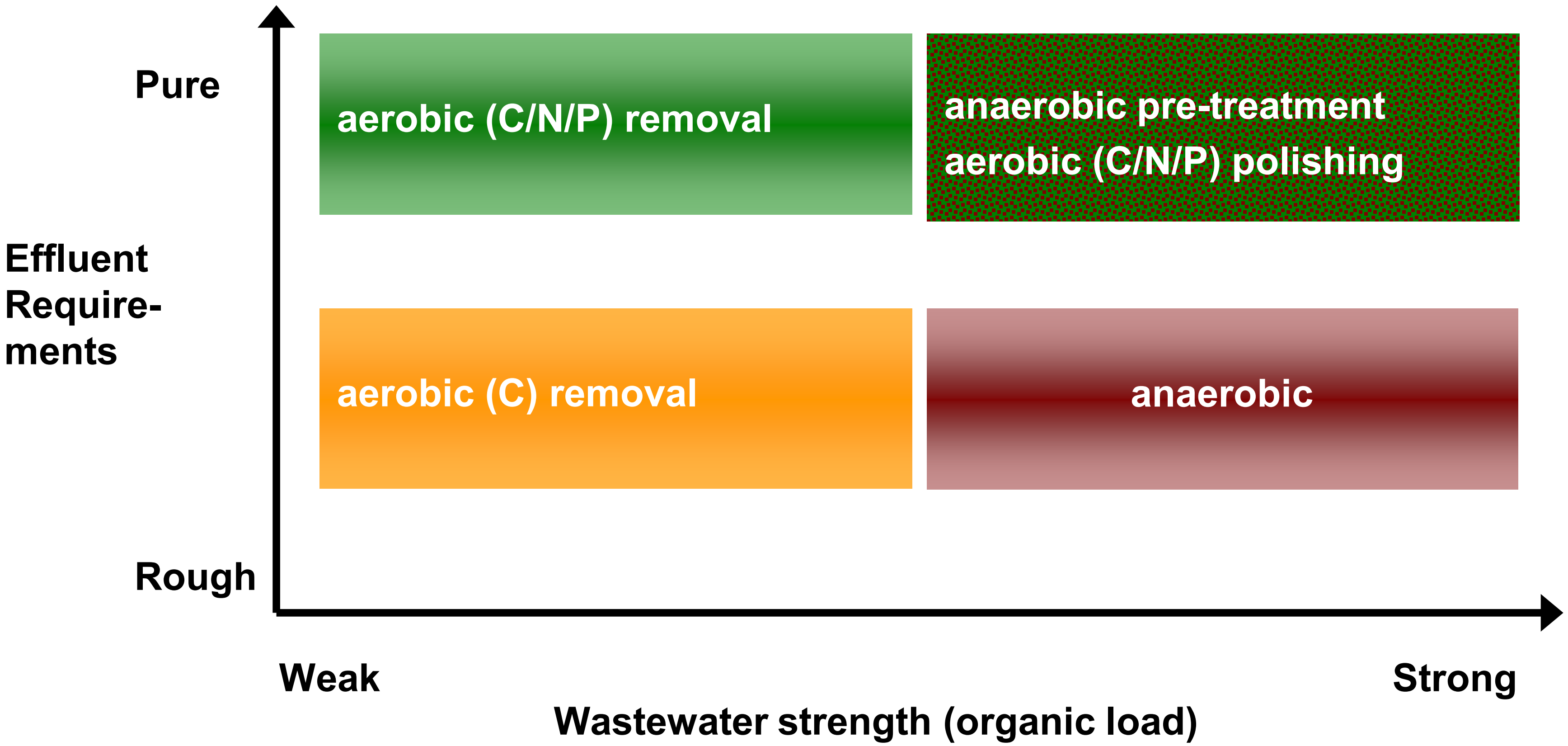


MBR Process Configurations

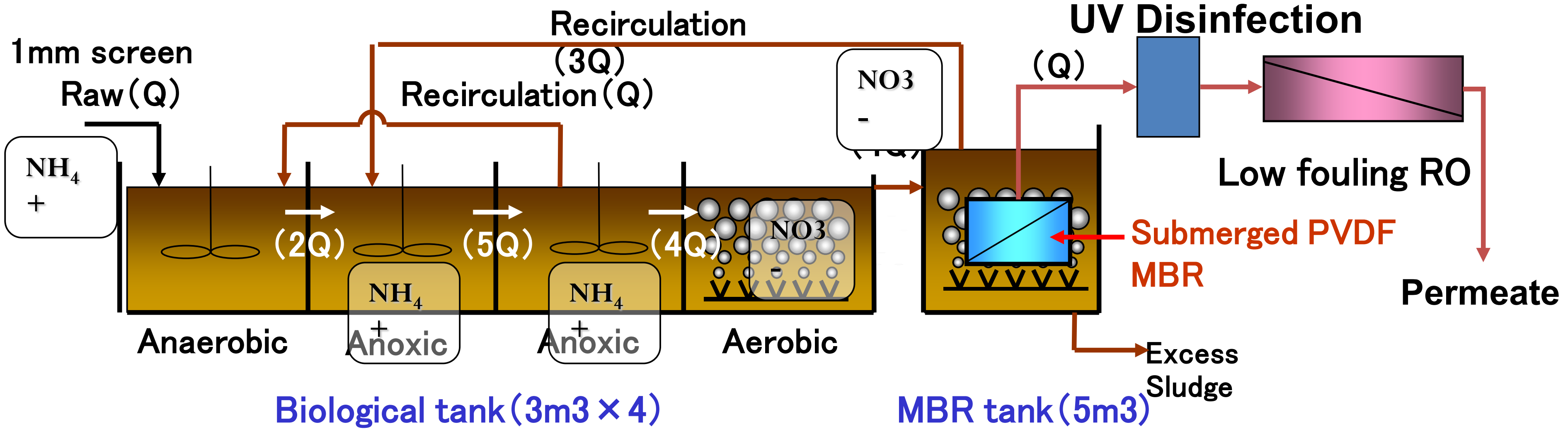
BOD and Total-N Removal
Chemical TP Removal



Wastewater strength
(effluent requirements and related processes)



Process Configuration (MBR+RO)



Terminology

Biochemical Oxygen Demand – BOD_5

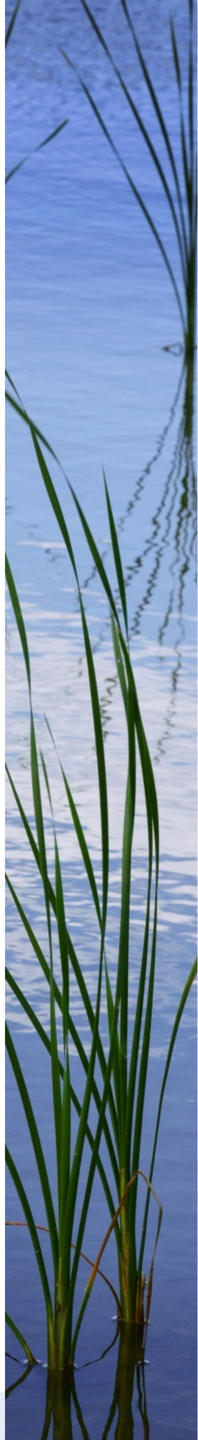
- **Typical to measure organic pollutants in wastewater: amount of oxygen consumed by organisms over a specified time to oxidize the organic matter in a sample**
- **Test results in 5-days**
- **BOD measurement (mg/L or ppm)**
  - Carbonaceous BOD (oxidation of organic carbon)
  - Nitrogenous BOD (oxidation of ammonia to nitrate)
  - Total BOD (sum of the CBOD and NBOD)

Chemical Oxygen Demand - COD

- **Measures oxygen required to oxidize the organic matter using a strong chemical oxidizing agent**
- **Correlation BOD/COD:**
  - typical WW ratio 0.4-0.8
  - if ratio <<0.3: need anaerobic preTreatment
- **Test results in less than 3-hours**

Mixed Liquor Suspended Solids – MLSS

- **The concentration of suspended solids in a bioreactor, measured in g/L, mg/L, or %**
- **MLSS includes an organic fraction and an inorganic fraction**



WATEREUSE

Terminology (2)

Hydraulic Retention Time - HRT

- Average length of time that a molecule of water remains in the reactor system.

  $$\text{HRT (hr)} = \frac{\text{Total operating volume of reactor } (m^3)}{\text{Wastewater flowrate } (m^3/d)}$$

- Conventional: HRT and SRT related
- Industrial MBR: different design for different HRT/SRT

Solids Retention Time - SRT

- A measure of the time that the biological solids remain in the reactor system.
- The longer the solids remain in the reactor, the greater the possibility that they will be broken down and consumed.
- SRT varies depending on plant conditions (temperature, feed water characteristic etc.) Typically range from 10 - 30 days.
- $$\text{SRT } (d) = \frac{\text{Total operating volume of reactor } (L \text{ or } gal)}{\text{Volume of sludge wasted per day } (L/d \text{ or } gal/d)}$$

WATEREUSE

BIOLOGICAL PROCESS DESIGN

Determination of the required or optimum Sludge Age (SRT) depends on the effluent requirements & water temperature

Carbon removal	**5d**
Nitrification	**8-10d**
Denitrification	**10-20d**
Aerobic stabilization of sludge	**25-30d**

Recommendation:

Minimum SRT of 15 days

Maximum biological design temperature of 25oC

BIOLOGICAL PROCESS DESIGN
Typical Parameter

Parameter	Unit	Design Range	Typical Design
BOD Loading Rate	kg BOD/m3.day	0.5 – 2	1
Food to Microorganism (F:M) Ratio	kg BOD/kg SS.d	< 0.08	0.06
SRT	Days	8 – 30	15
HRT	h	6 – 10	>6
MLSS	g/L	8 – 15	12
Sludge Recycle Rate	%	200 – 600%	200%
Oxygen Transfer Efficiency	%	50 – 60 %	60%
Sludge Production	kg SS/kg BOD.d	0.6 – 1.2	1.0
Anoxic Volume	% of biological volume	15 – 50	40

BIOLOGICAL DESIGN
Output

- ✓Biological process (engineers opinion)
- ✓Required biological volume including Anoxic and Aerobic volume (engineers opinion)
- ✓Needed Oxygen input (engineers opinion)
- ✓Waste sludge output
- ✓Sludge recycling rate
- ✓MLSS concentration in biological and membrane system

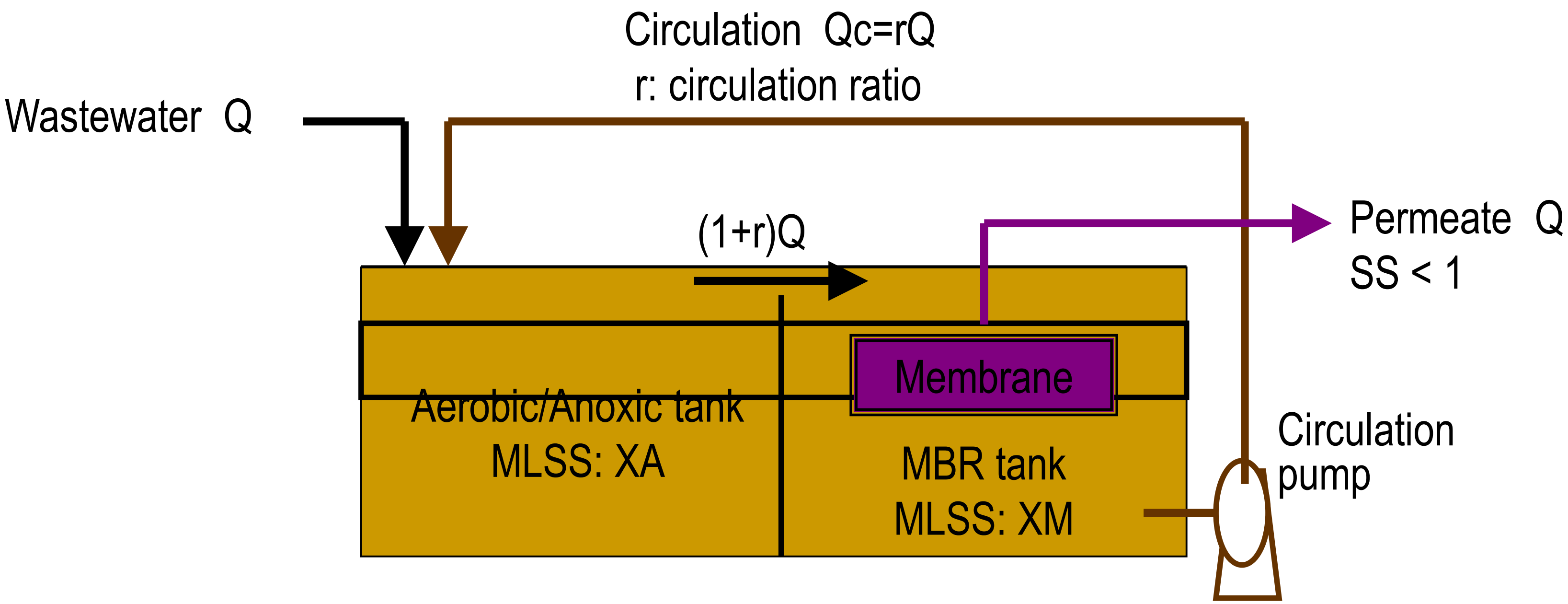
MEMBRANE FILTRATION PROCESS

WATEREUSE

KEY DESIGN OUTPUT PARAMETERS

- **Design Flux**
  - Depends on minimum temperature, MLSS and peak conditions
- **Membrane Modules**
  - Depends on flux, modules offline for cleaning, and future expansion
- **Aeration**
  - Depends on number of modules and mode of aeration
- **Filtration Cycle**
  - Depends on mode of operation
- **Sludge Recycle**
  - Minimum value depends on aeration tank to MBR tank MLSS and peaking factor

MLSS Calculation



Mass balance around MBR tank

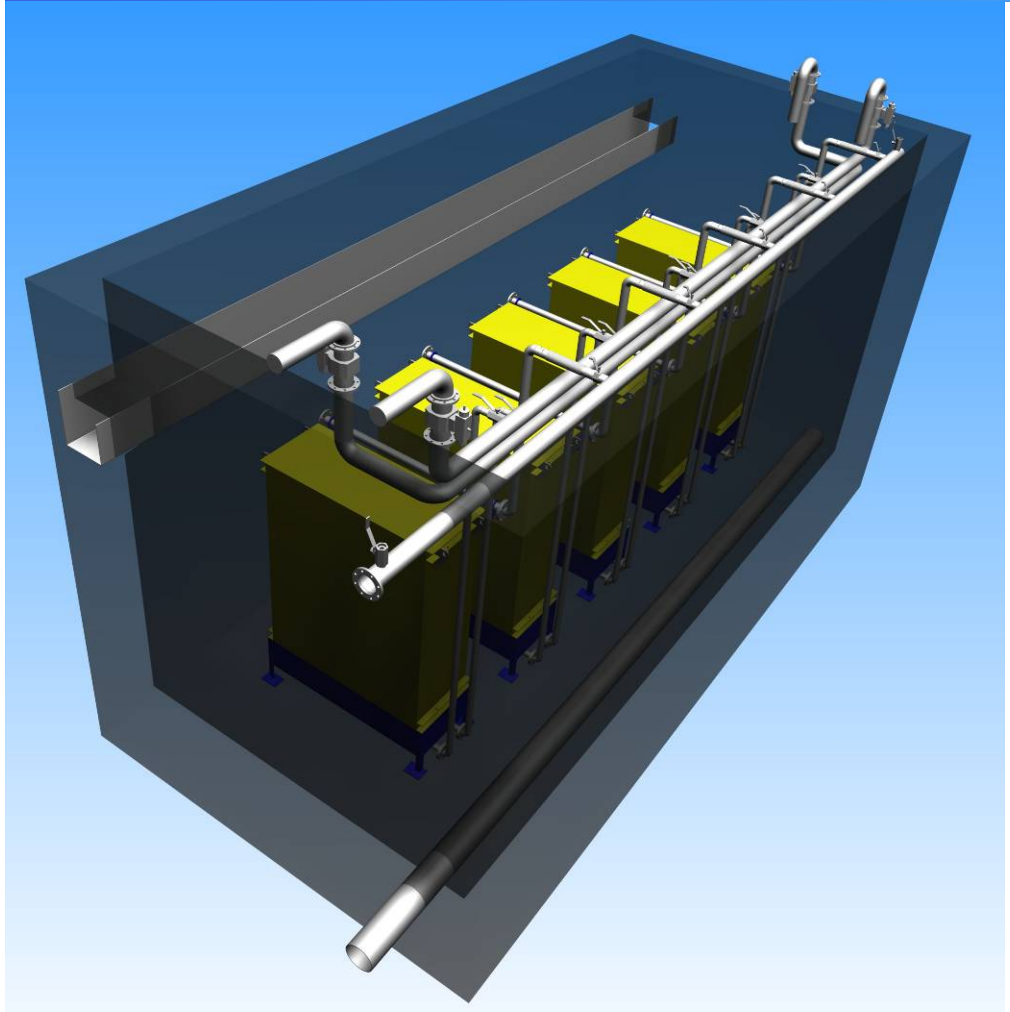
$$(1+r) Q * XA = r Q * XM$$

$$XA = r / (1 + r) * XM$$

r	XA	XM
2	12,000	18,000
3	13,500	18,000
4	14,400	18,000

MBR can keep higher MLSS, i.e. more microbes to treat.
--- less hydraulic retention time (HRT), less tank volume

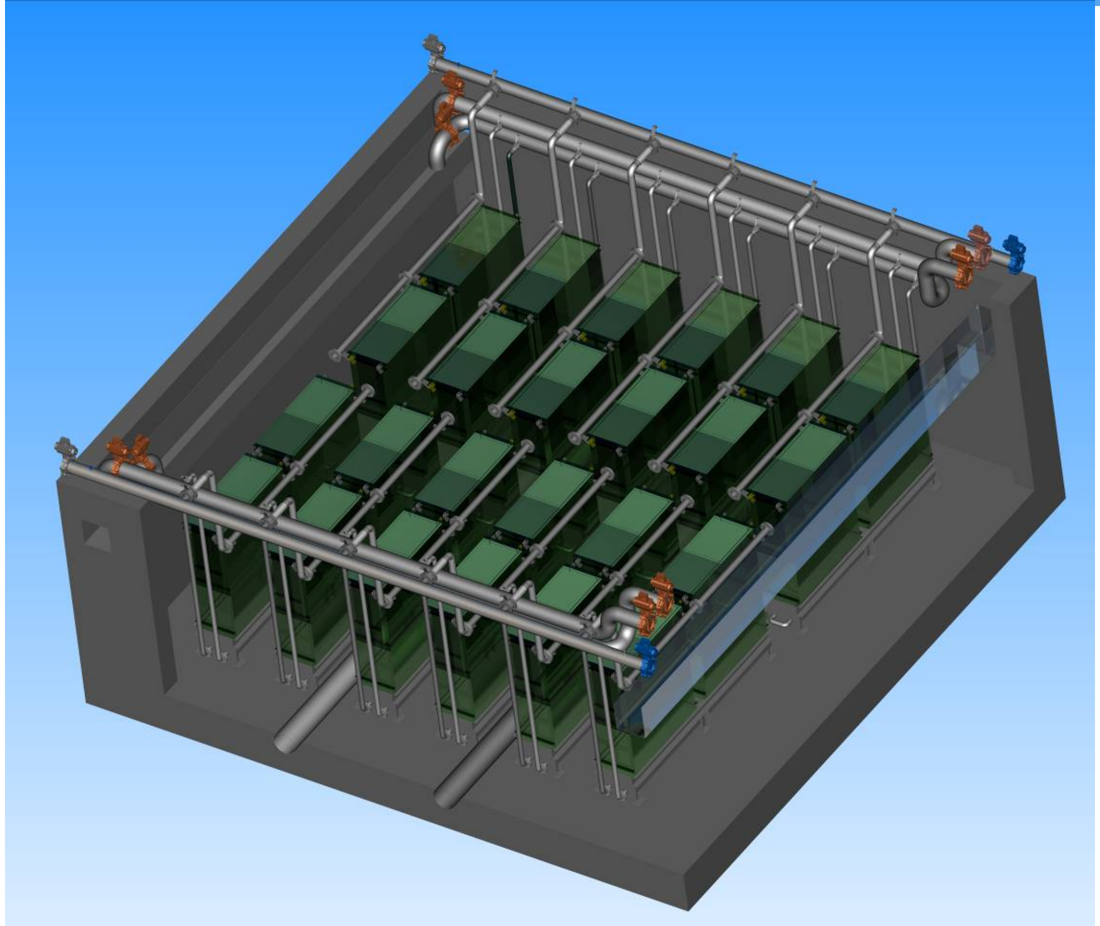
TANK DESIGN – SINGLE TRAIN SYSTEMS



- Typical small size application
- Up to 6 modules (typically TMR140-100S)
- Automatic diffuser flush
- MBR feed by pump or gravity
- Equal sludge distribution to modules (constant MLSS)

ENGINEERING

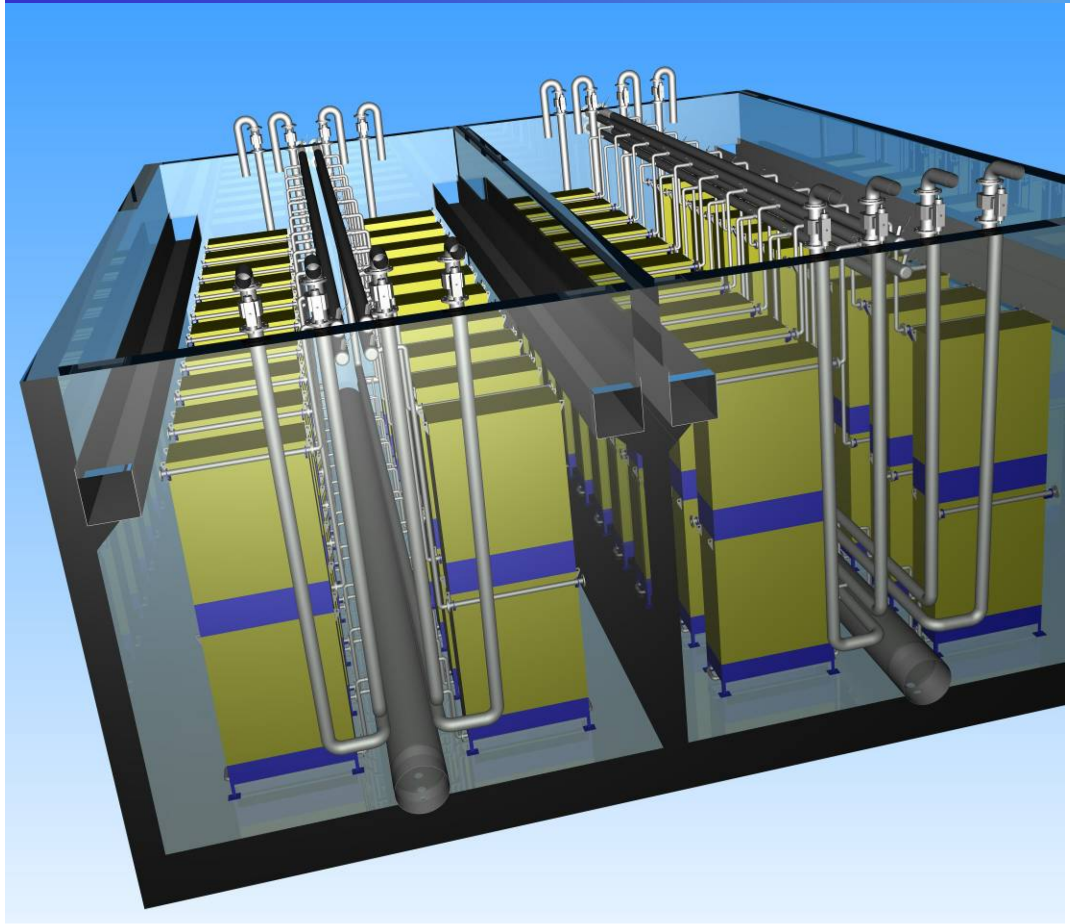
TANK DESIGN
- MULTI TRAIN SYSTEMS (SINGLE DECK) -



- Typical large size application
- Water level < 4,70 m
- Automatic diffuser flush
- MBR feed by pump or gravity
- Equal sludge distribution to modules

ENGINEERING

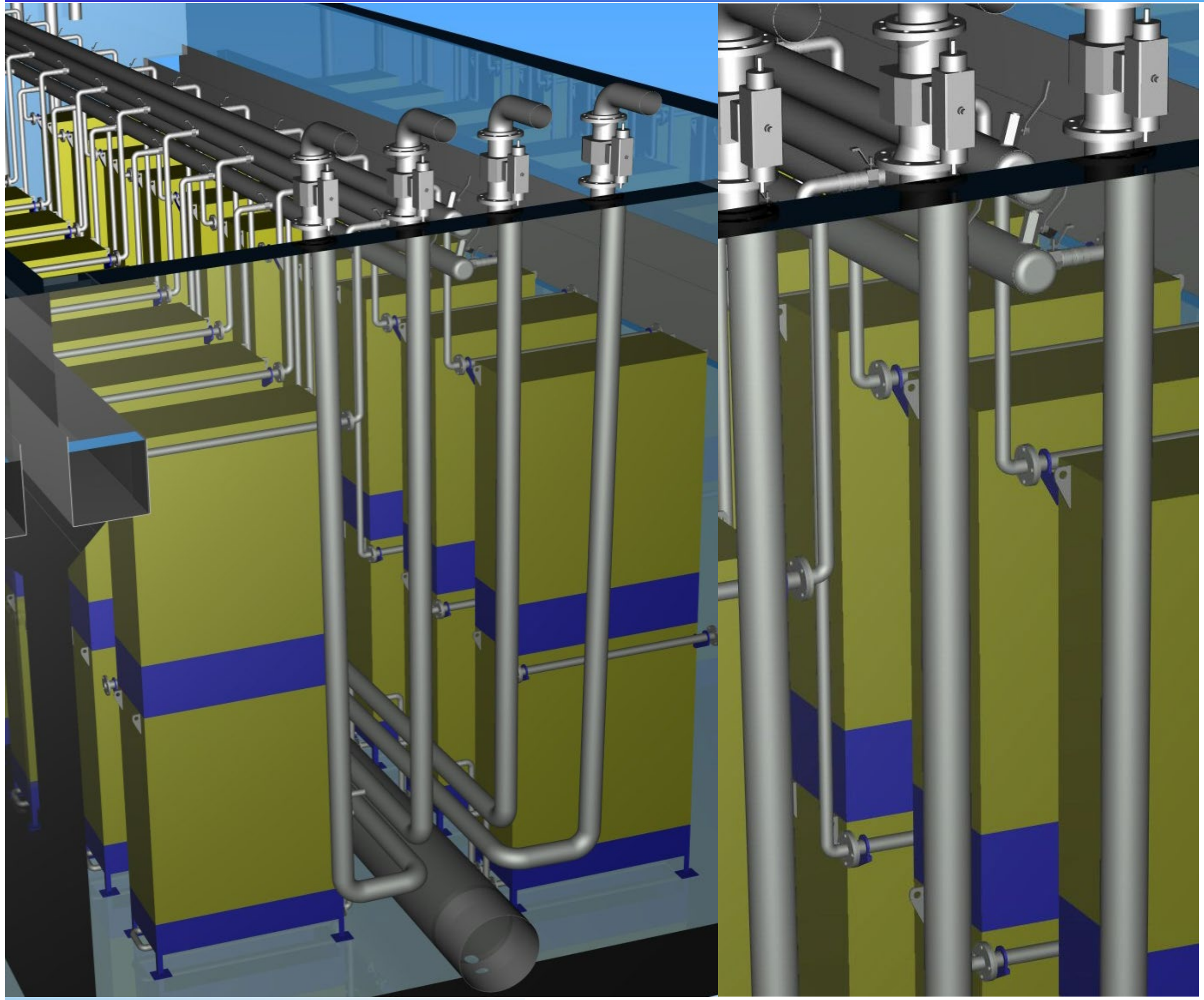
TANK DESIGN
- MULTI TRAIN SYSTEMS (DOUBLE DECK) -



- Typical large size application
- Lowest footprint & scouring air demand
- Water level > 4,70 m
- Automatic diffuser flush
- MBR feed by pump or gravity
- Equal sludge distribution to modules

ENGINEERING

DOUBLE DECK = TWO PERMEATE HEADERS

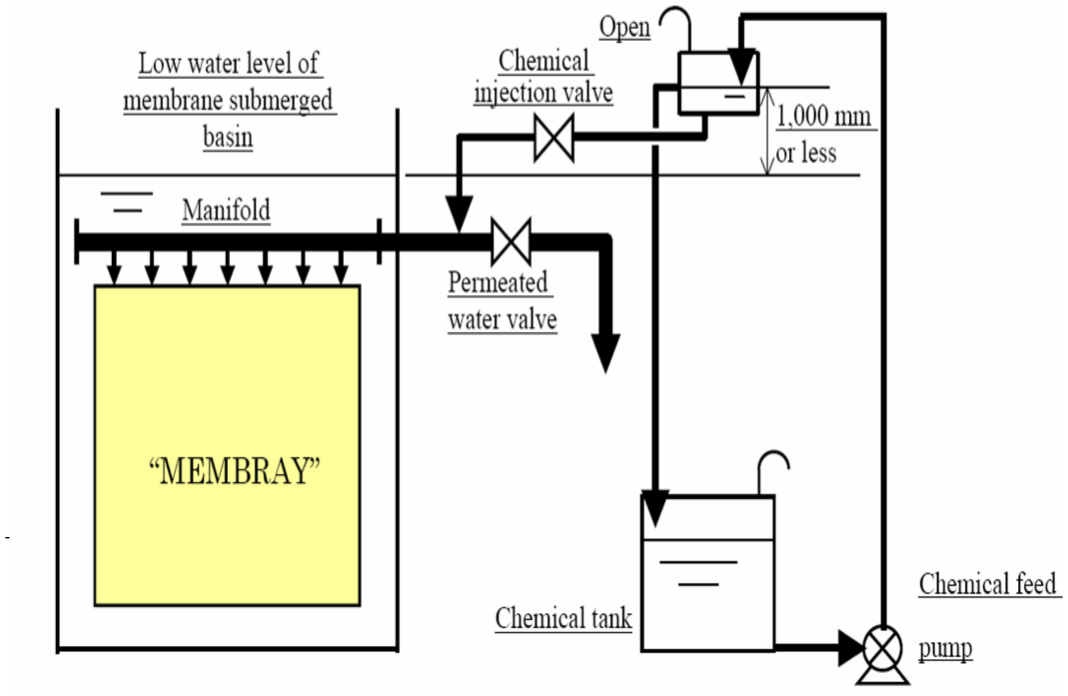


- Different TMP
- Lower deck + 200 mbar
- 10 % different flux possible
- Separate header allows separate permeate flow control

ENGINEERING

CHEMICAL CLEANING IN PLACE

Chemical Cleaning Interval: 6 months or if TMP increases by 0.7 psig

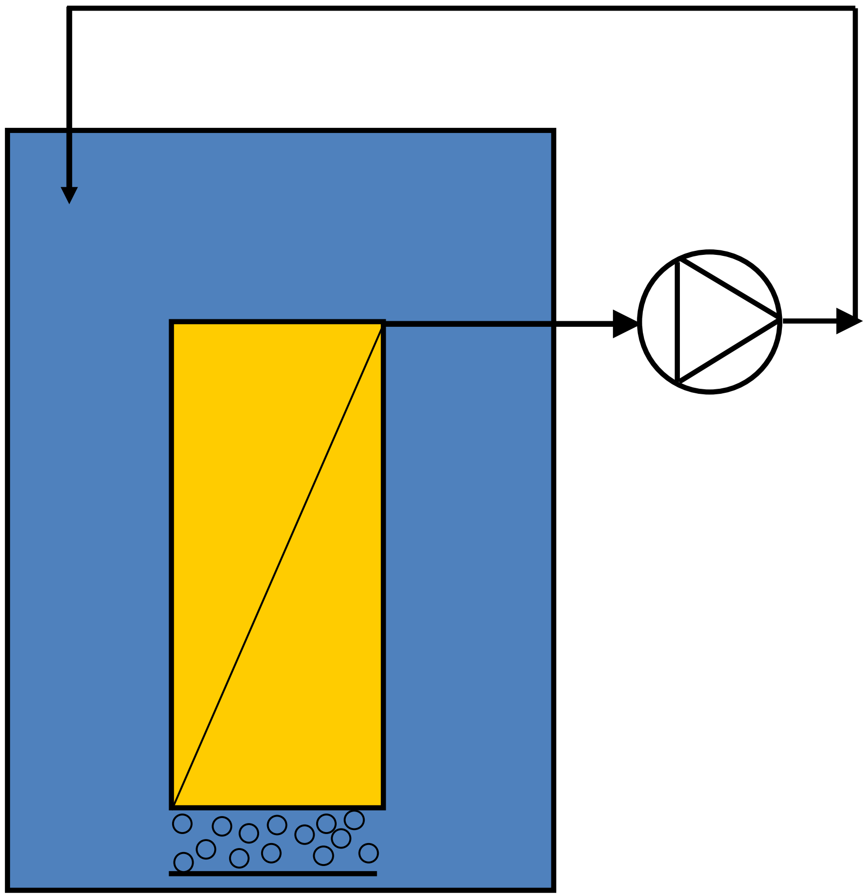


Fouling	Organic matter	Inorganic matter
Chemical	Sodium hypochlorite	Citric acid
Cleaning concentration	1 – 4 g/l	1 – 3 wt%
Amount	5 liters per element	
Hold time	1 – 3 h	

EXTERNAL TANK CLEANING – CARRING OUT

- **Sludge clogging cleaning**:
  - NaOH for pH adjustment to pH 10
  - 6 – 12 h
  - Scouring aeration
- **Cleaning biological fouling**:
  - NaOCl (1000 mg/l)
  - 6 – 12 h close loop filtration (15 – 20 l/m2.h)
  - continuous aeration
- **Cleaning inorganic fouling:**
  - Citric acid (2500 mg/l)
  - 6 – 12 h close loop filtration (15 – 20 l/m2.h)
  - continuous aeration

The cleaning will be more intensive at higher water temperatures (30° C).



PROCESS

AUTOMATIC AIR DIFFUSER CLEANING

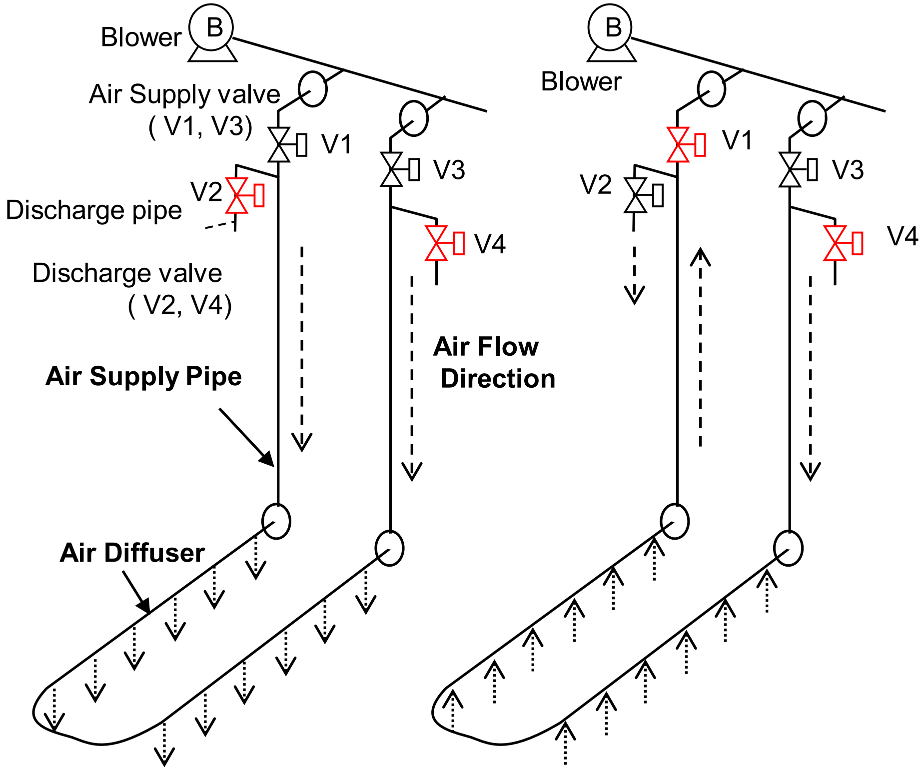
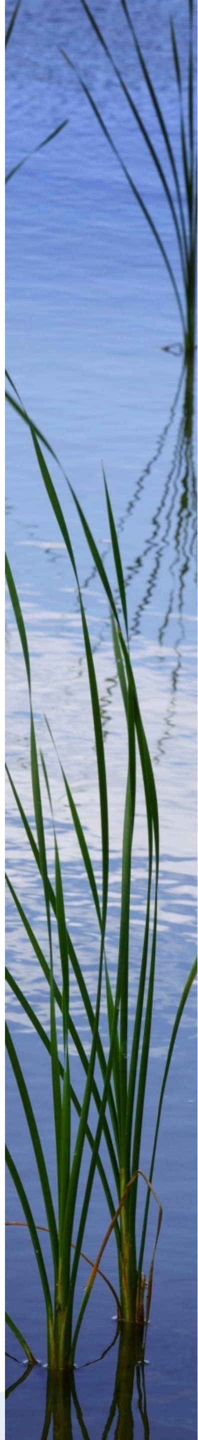


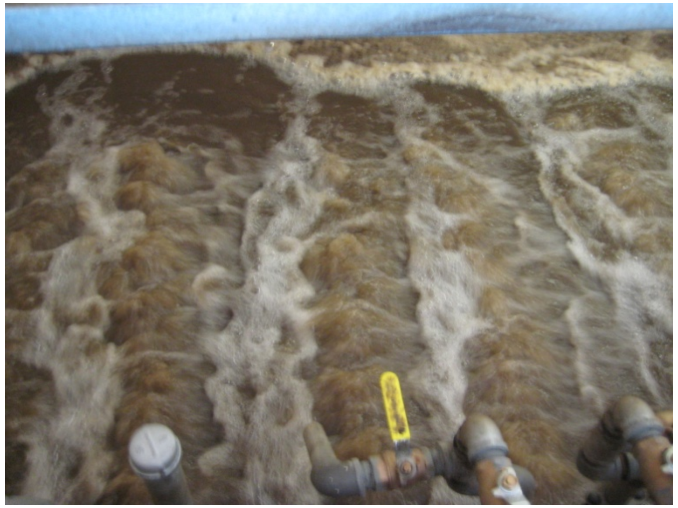
Fig.1 Normal Operation **Fig.2 Cleaning Air Diffuser**

WATEREUSE

Routine records and maintenance

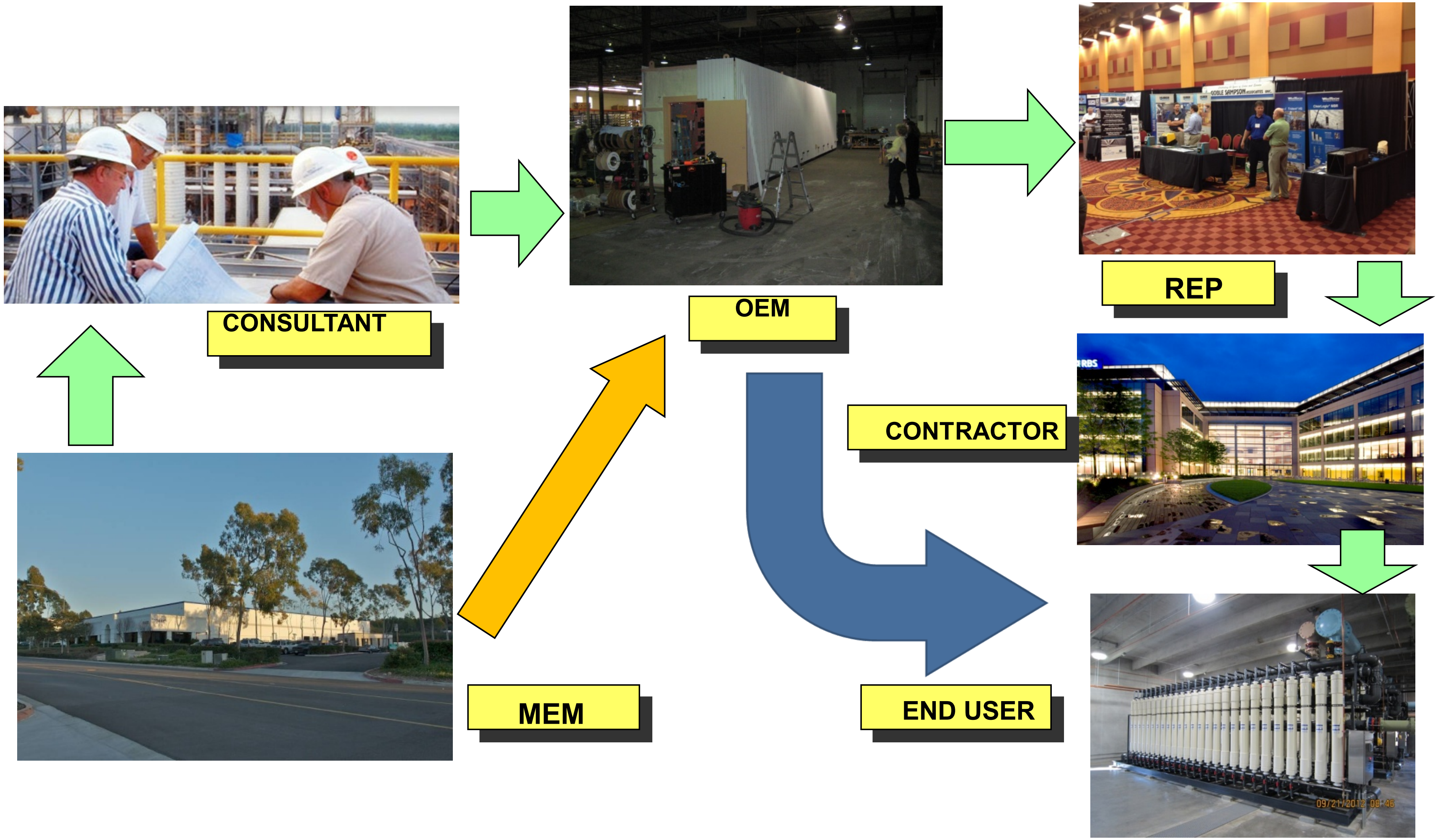
- As a minimum, the following parameters shall be monitored and recorded daily
  - Air flow rate
  - Trans-Membrane Pressure (TMP)
  - Temperature
  - Dissolved Oxygen
  - Sludge concentration
  - Permeate quality (Turbidity or TSS)
- The Membrane Air Diffusers shall be cleaned daily
- The Membrane shall be cleaned with chemicals once every 6 months or when the TMP increases 5 kPa above the initial TMP





WATEREUSE

Execution Path to the Order



Contact the Players in the Channels to the Market

Questions?

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