CornellEngineering
Civil and Environmental Engineering

CEE 4540

Sustainable municipal drinking water treatment

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Class #10 10/01/2018 2:55 – 4:10pm

Membrane Basics

YuJung Chang

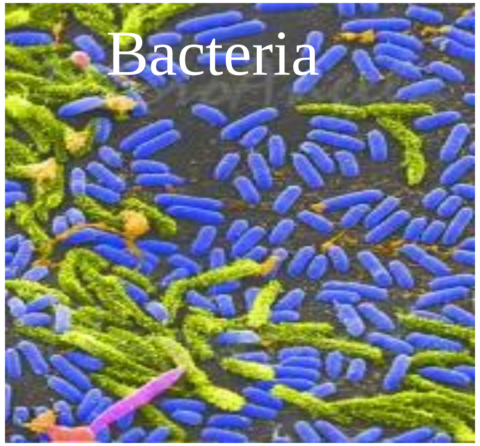
Membrane Filtration

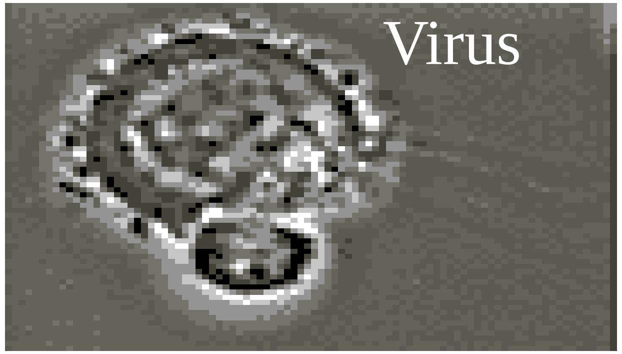
- Membrane Classification
- Membrane Operation
- Membrane Fouling
- Membrane Cleaning
- Membrane Procurement
- Pilot Study
- Cost
- Membrane Applications

Membrane Basics

Membrane Classification

Solutions to New Challenges: Low Pressure Membranes





What Can Membranes Do for You?

- Absolute barrier for particulate
- LT2 ESWTR Compliance (Guaranteed)
- Viruses projection (UF Membranes)
- Turbidity (< 0.1 NTU)
- Very reliable water quality

What Else Do You Need to do?

- Need to achieve additional 0.5 log inactivation of Giardia by disinfectant (Double Barrier)
- Pretreatment (depend on raw water quality)
- 3-7 % wastewater (backwash) treatment/disposal

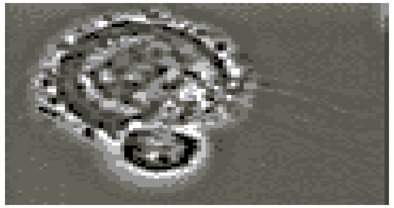
Membranes Classification:
Pore Size

- Microfiltration (MF)
  - 0.1 ~ 0.2 μm (most common)
  - Good for all pathogens but viruses
  - Evoqua, Pall, Metawater
- Ultrafiltration
  - 0.025 ~ 0.035 μm (most common)
  - Good virus rejection (depend on pore size)
  - SUEZ,Koch, Hydronautics, Evoqua

Cryptosporidium

5-10 μm

Virus



0.025 μm

Membranes Classification:
Membrane Material

- Cellular Acetate (CA) Derivatives
  - Aquasource; prefer lower pH (< 8.5)
- Polypropylene (PP)
  - USFilters (old), not oxidant tolerant
- Polyvinyl Difluoride (PVDF)
  - Pall, SUEZ (Zenon), Evoqua (Memcor); Toray; Hydranautics
- Polysulfone (PS)
  - Koch, Hydranautics, Ionics/Norit (polyethersulfone); Polycera
- Ceramic
  - Metawater; Nanostone

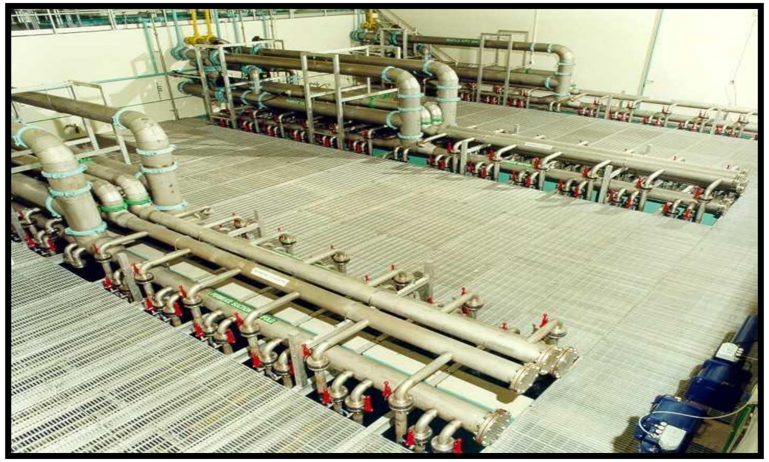
Membranes Classification:
Driving Force

- Pressure (Canister Membranes)
  - More compact design
  - Cannot handle high solid concentration (> 100 NTU) for a substantial period of time

Membranes Classification:
Driving Force

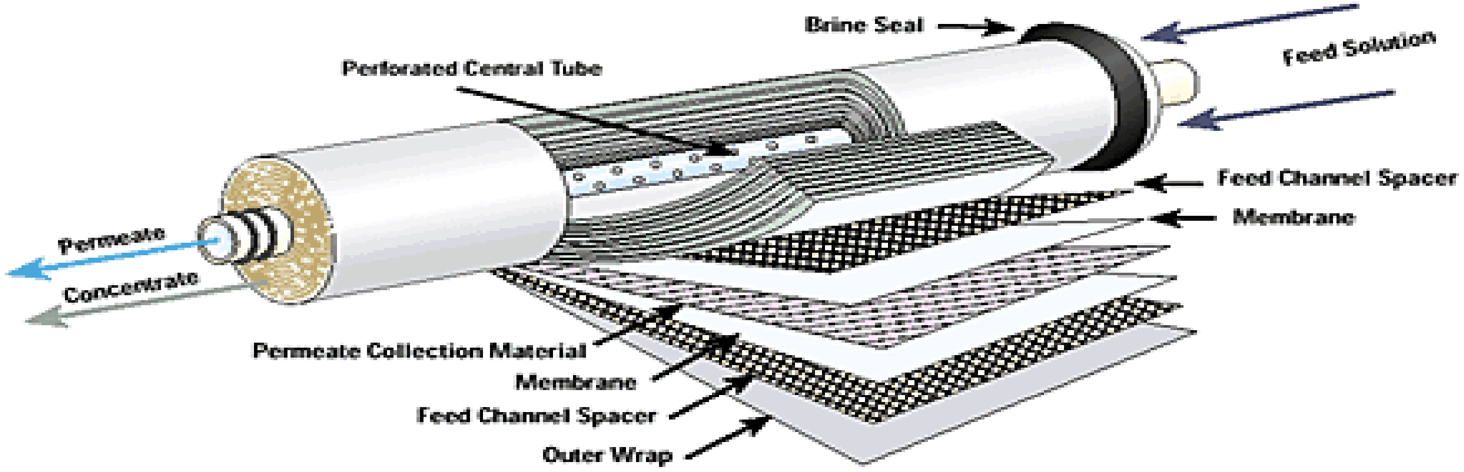
- Vacuum (Submerged Membranes)
  - Compatible with higher solid concentration
  - Can be used for retrofit
  - High energy demand with air scouring
  - Noise & evaporation concerns



Membranes Classification:
Membrane Configuration

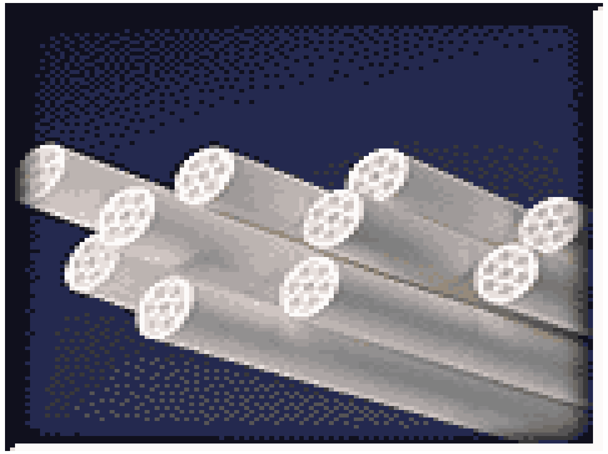
- Flat Sheet (Spiral-wound)



Mostly used in Reverse Osmosis

Membranes Classification:
Membrane Configuration (cont.)

– Tubular Membranes (OD > 3 mm)



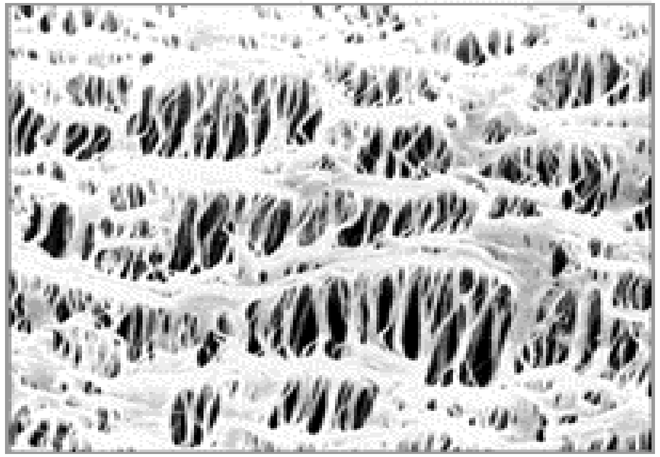
BASF Multi-bore membrane

Mostly used in Industrial MF

Membranes Classification:
Membrane Configuration (cont.)

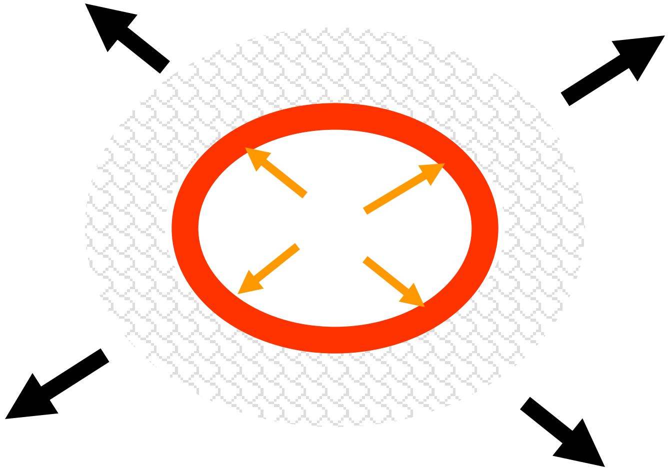
– Hollow Fiber Membranes (ID < 1.5 mm)


Cross Section 200 µm


Inner Surface 1 µm

Membranes Classification:
Location of Membrane Surface

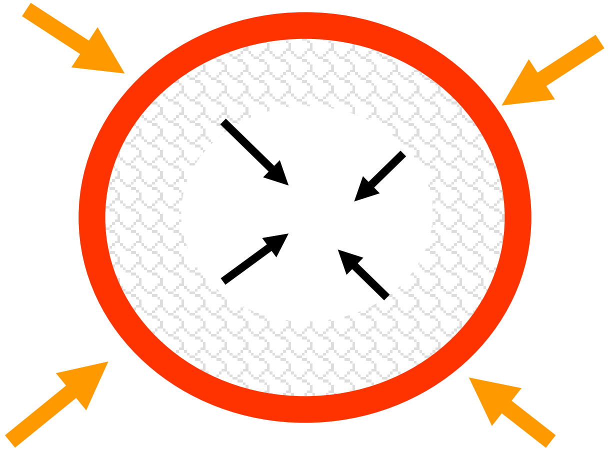
Inside-out Membranes



Raw Water

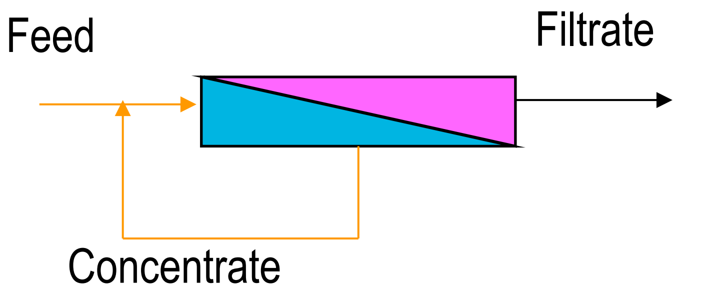
Filtered Water

Outside-In Membranes



Membranes Classification:
Reject Circulation

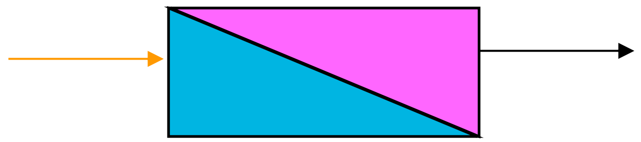
– Cross Flow (with circulation)
- Provide tangential scouring
- Reduce fouling potential (e.g., high solids)
- Requires more energy



Dead End (without circulation)

Energy efficient

More sensitive to change of water quality

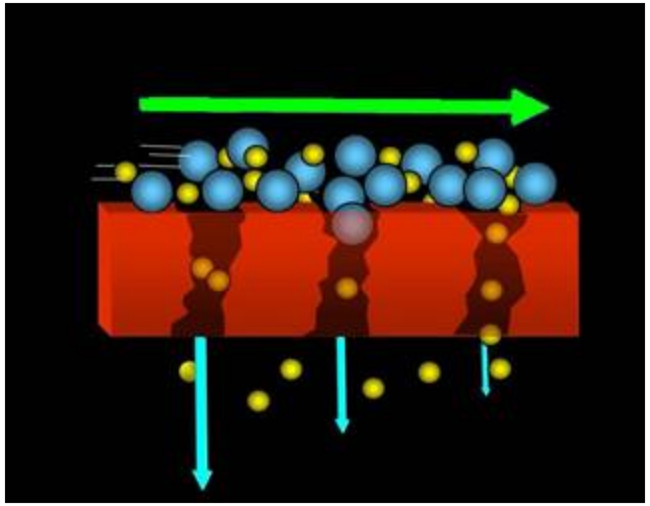


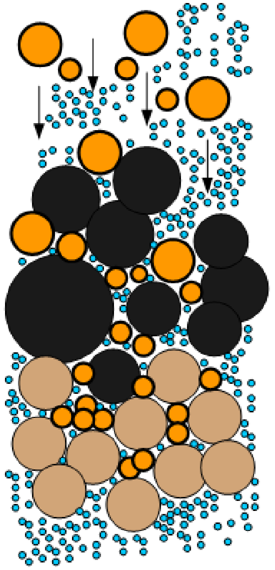
Membrane Basics

Membrane Operation

Membranes v.s. Sand

- Membrane filtration mechanism
  - Sieving/Straining
- Sand filtration mechanism
  - Interception, collision, electrostatic attraction
  - Straining only happens in cake filtration





Finished Water Comparison

	Conventional	Ultrafiltration
Turbidity	0.05 ~ 0.3	< 0.1
Virus removal	2 log	> 4 log
Influent quality change	Affected	Not affected
Water chemistry change	Affected	Not affected
Operating conditions change	Affected	Not affected

Performance Comparison

	Conventional	Ultrafiltration
High feed turbidity	Shorter run time	Higher pressure (if turbidity is excessive for a long duration)
High feed TOC	Not affected	Higher pressure, need freq. chemical cleaning
High $FeCl_3$ dose	Shorter run time	$FeCl_3$ not required
Low feed temp.	Not affected	Higher pressure or lower output
Capacity increase	Shorter run time	Higher pressure, need freq. chemical cleaning

Typical Membrane Filtration Cycle

- Filtration (15 ~ 50 minutes)
- Backwash (20 sec ~ 2 min)

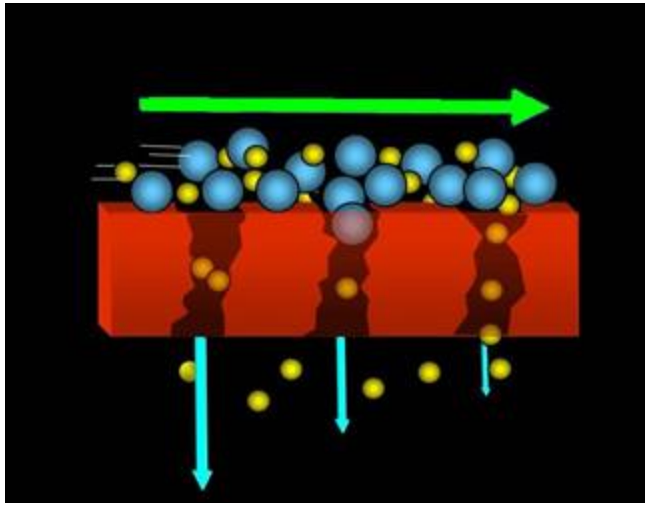
(No rinsing, surface wash, or filter-to-waste)

Special Operation/Maintenance

- Chemical Cleaning
- Membrane Repair

Critical Operating Parameters

- **Flux:** Filtration rate per unit surface area (gallons per ft^2 per day, gfd)
- **Transmembrane pressure (TMP):** Pressure difference across the membrane, driving force for filtration
- **Permeability:** Quantity of water that 1 psi can push through the membranes (per hour, per m^2, temperature corrected).
- **Recovery:** percentage of product water goes into the distribution system versus the total water production from membranes



Terminology Comparison

Conventional Filters Terms	Equivalent Membrane Terms
Filters	Membrane Skids
Media	Membranes (Module)
Filter Area	Membrane Surface Area
Feed Water	Feed Water, Influent
Finished Water	Finished Water, Permeate, Filtrate
Backwash Water	Backwash Waste

Terminology Comparison (cont.)

Conventional Filters Terms	Equivalent Membrane Terms
Filter Run Time	Filtration Cycle
Backwash	Backwash
Recovery	Recovery
Loading Rate (gpm/ft^2)	Flux (gpd)
Headloss	TMP
Gas Binding Problem	Re-wetting Problem
Turbidity Breakthrough	Fiber Breakage

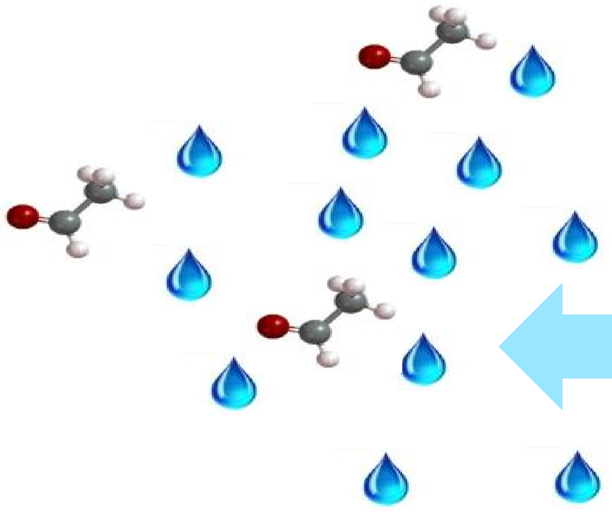
Membrane Basics

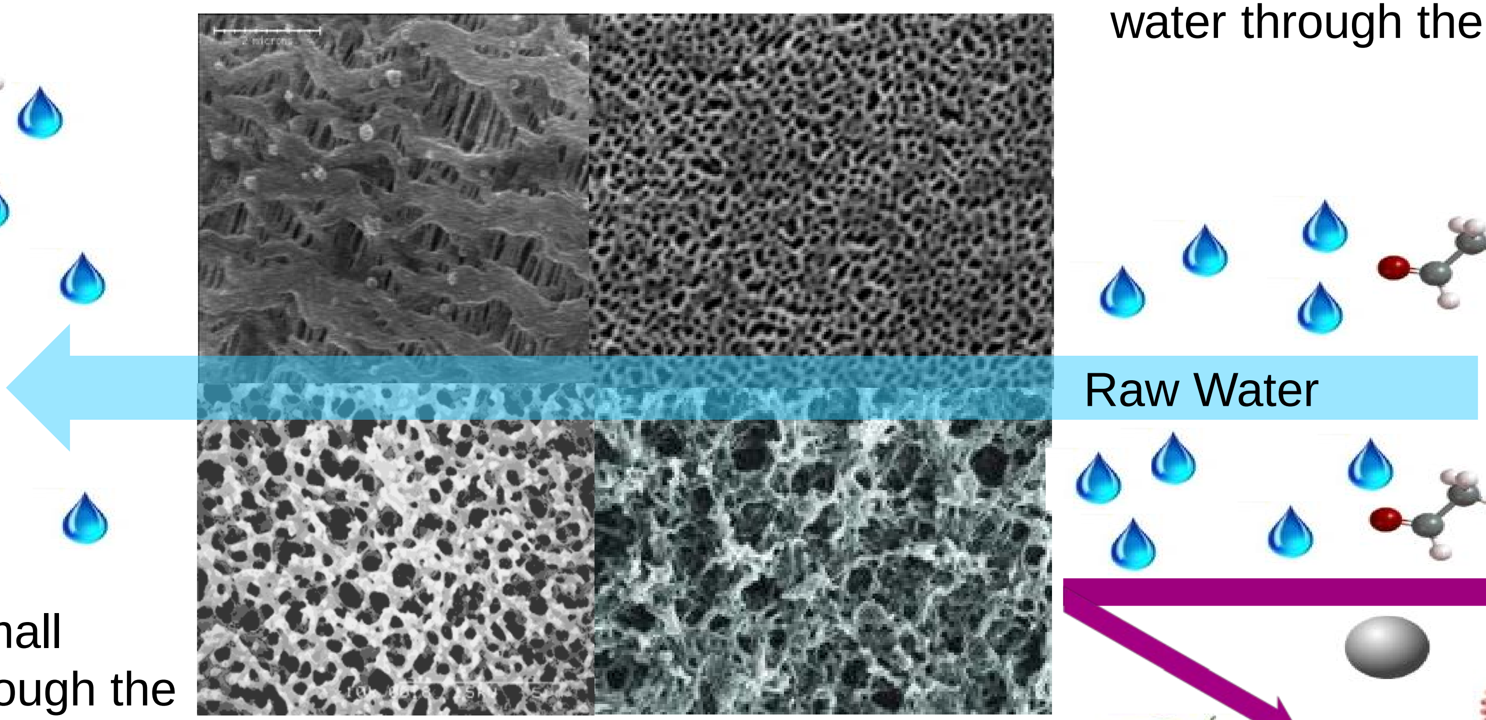
Membrane Fouling

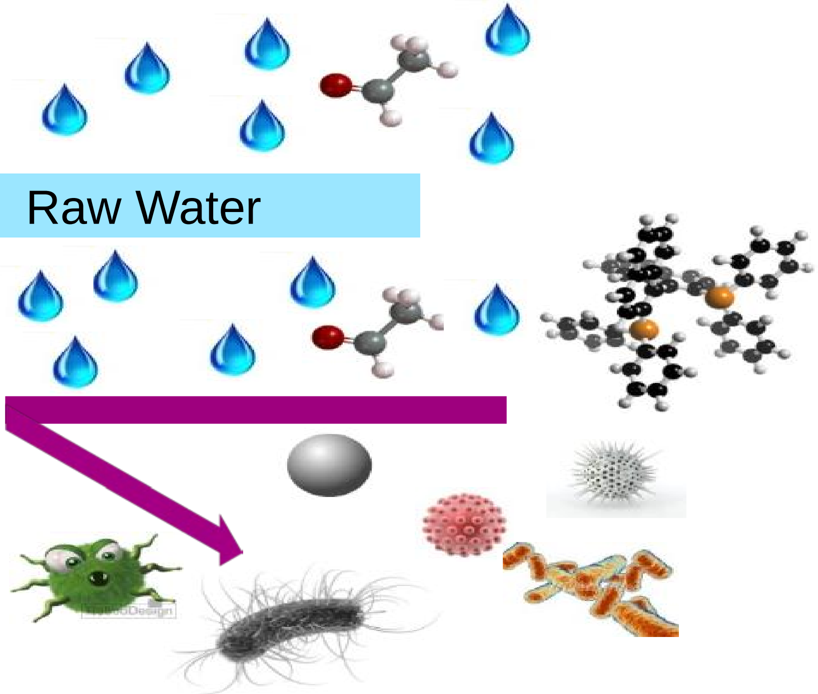
What is a membrane and how does it work?

1. Membranes is semi-permeable surface with microscopic pores

2. Pressure or vacuum drives water through the membranes



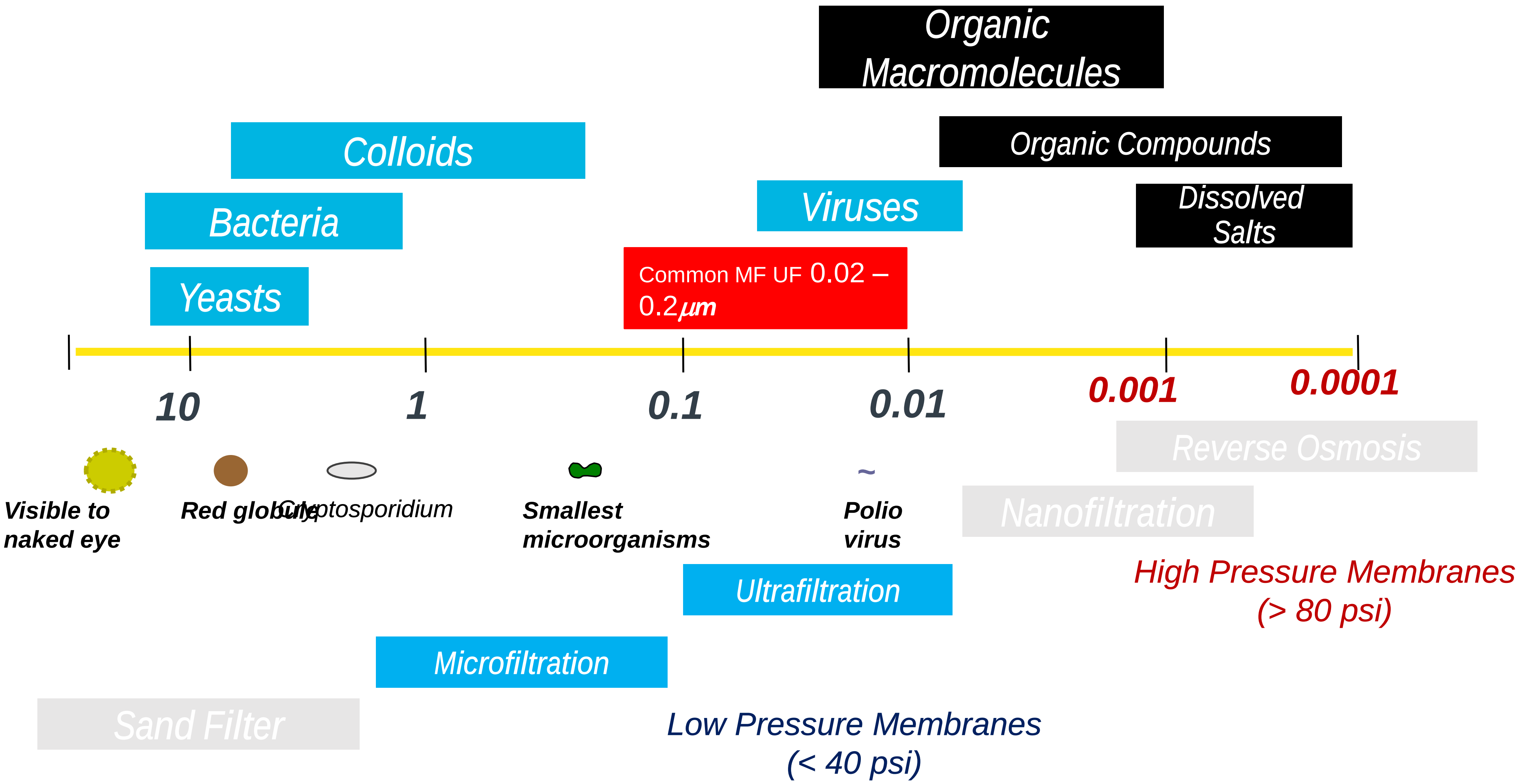




4. Clean water, salts, and small molecules/particles pass through the membrane

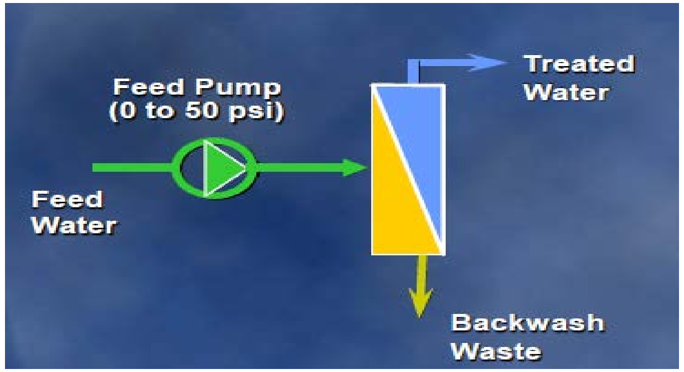
3. Particles and pathogens larger than membrane pores are rejected

Types of Membranes



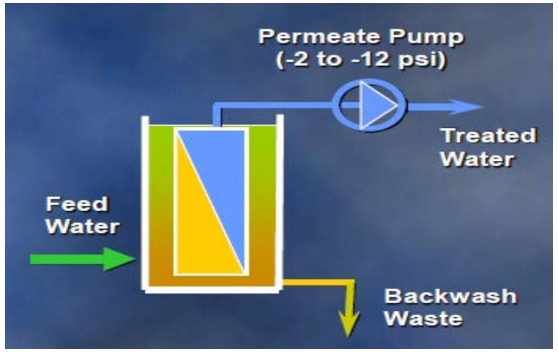
Pressurized Membrane System

A system where membranes are encased in a housing and pressure us used to force water through the membranes to produce a permeate (product water)



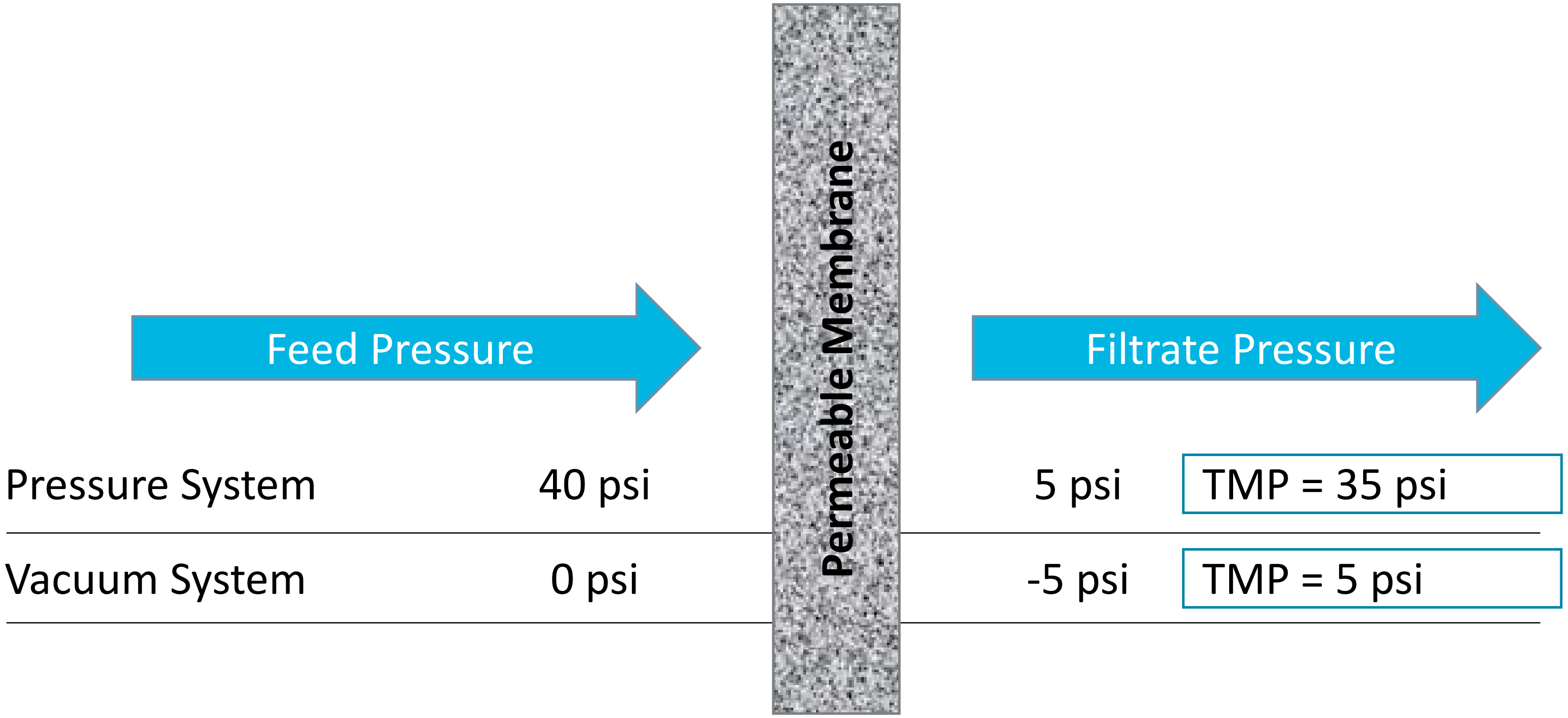
Submerged Membrane System

A system where membranes are immersed in a basin. Usually a vacuum is applied to produce filtrate (product water)



Transmembrane Pressure (TMP)

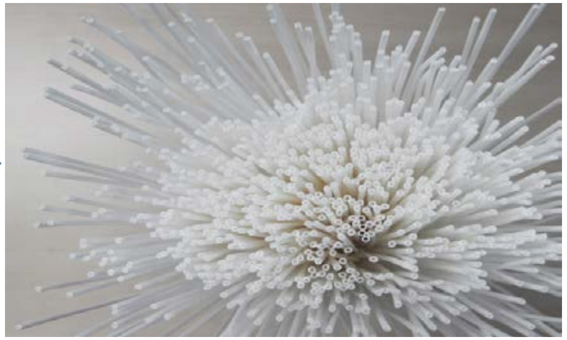
– The difference in pressure from the feed to the filtrate across a membrane, pounds per square foot (psi)

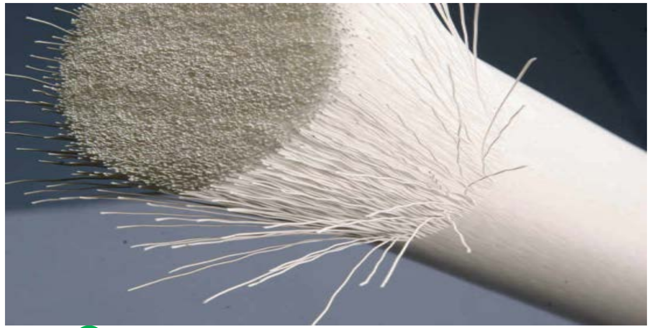


Membrane Filtration Flux

- The throughput of a membrane filtration system, expressed as flow per unit of membrane area, gallons per square foot per day (gfd)
- Typical flux for drinking water application ranges from 30 gfd to 70 gfd
- Ceramic membranes can produce > 200 gfd

Feed





Filtrate

Filtrate Flow =	1,000,000 gpd
Membrane Area =	28,600 sf
Flux =	35 gfd

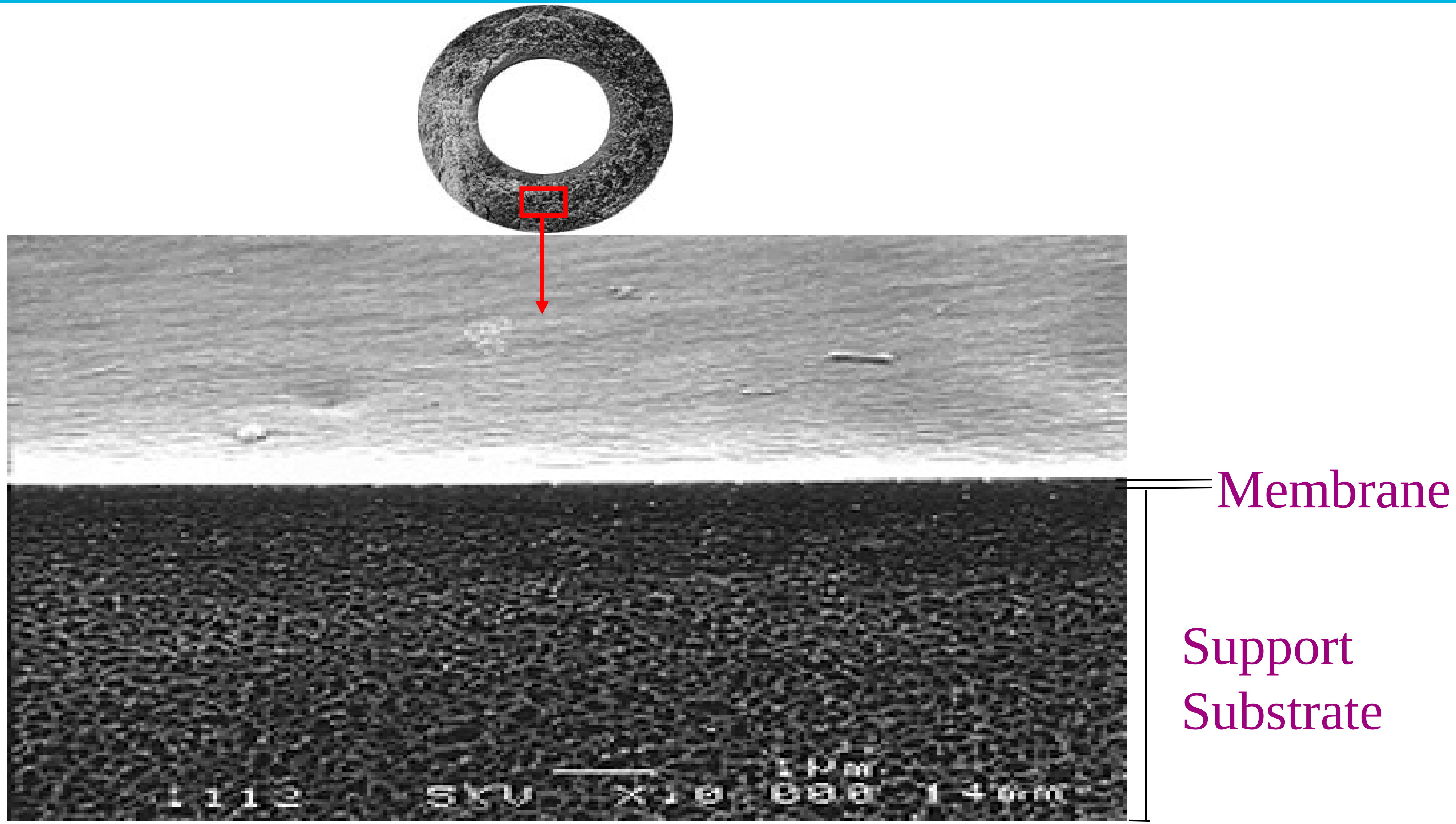
$$\frac{1{,}000{,}000 \text{ gal/day}}{28{,}600 \text{ sf}} = 35 \text{ gal/day/sf} = 35 \text{ gfd}$$

Challenges to Membrane Operations

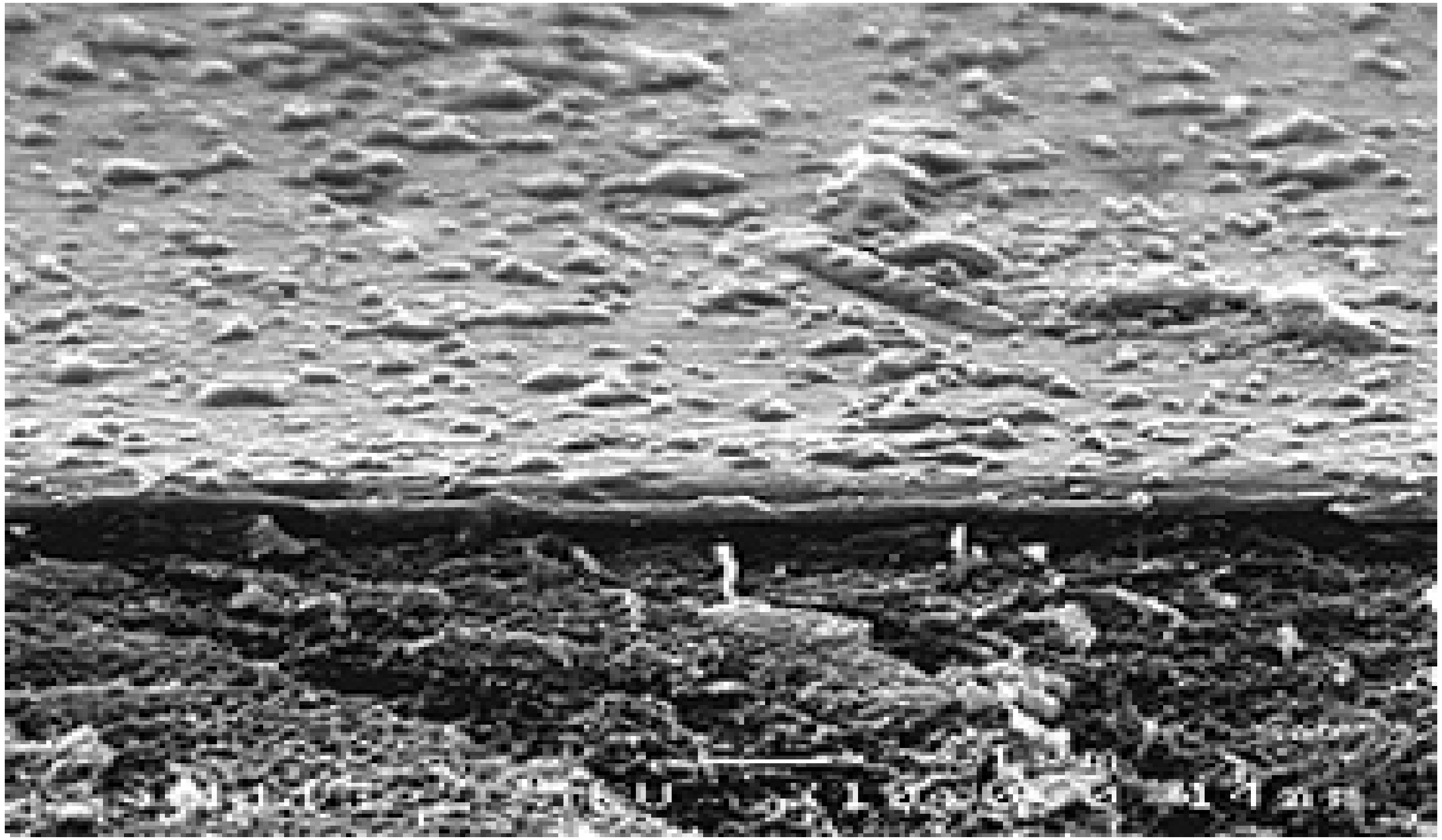
– Membrane Fouling: Loss of Membrane Permeability
  - Rapid Permeability Decline
  - Low Permeability Recovery

– Membrane Integrity: fibre Breakage/Module Deterioration

Clean Membrane Surface



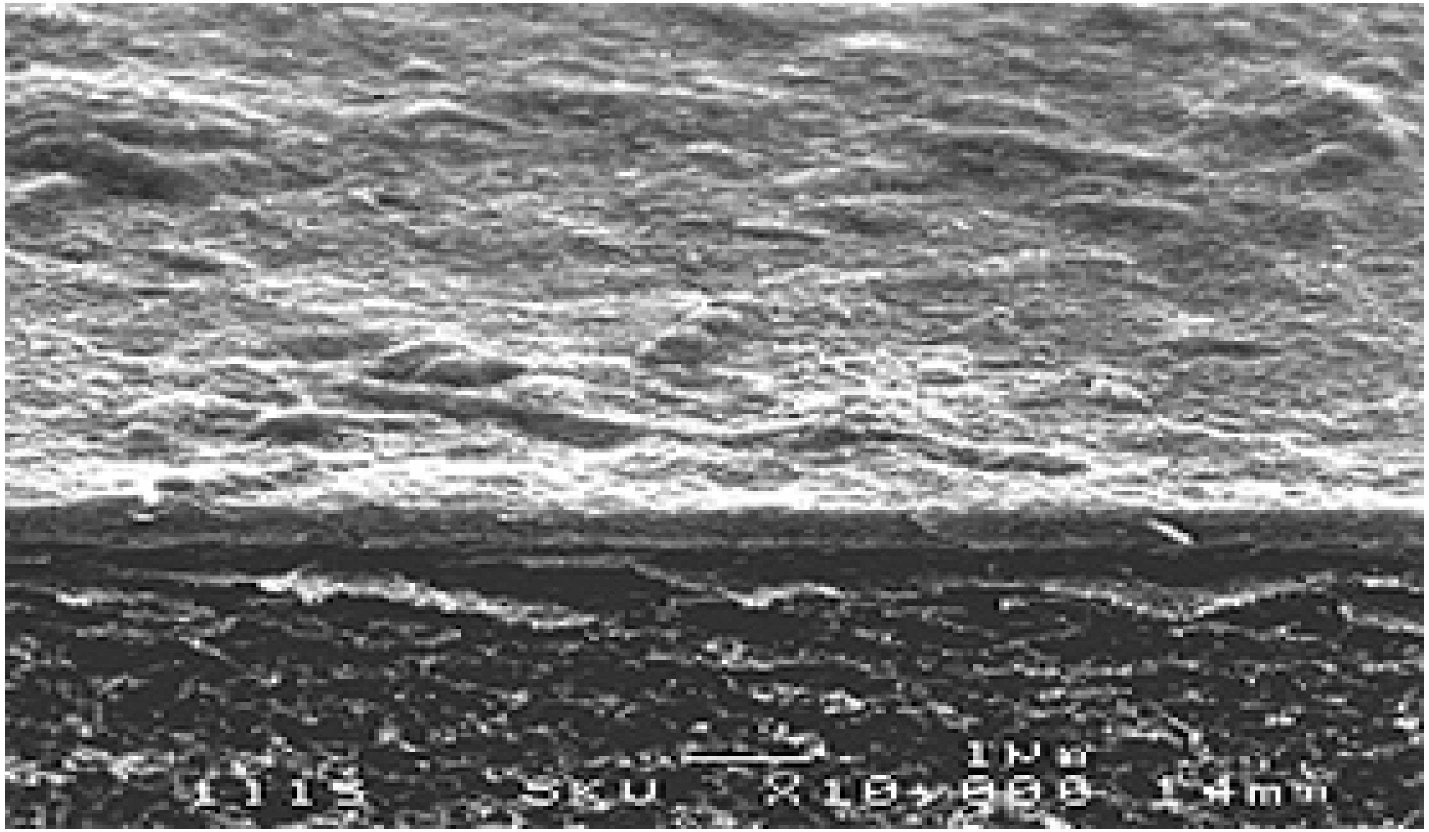
Dead End Filtration for 30 min



Film Thickness: NA

Permeability Decline: 10%

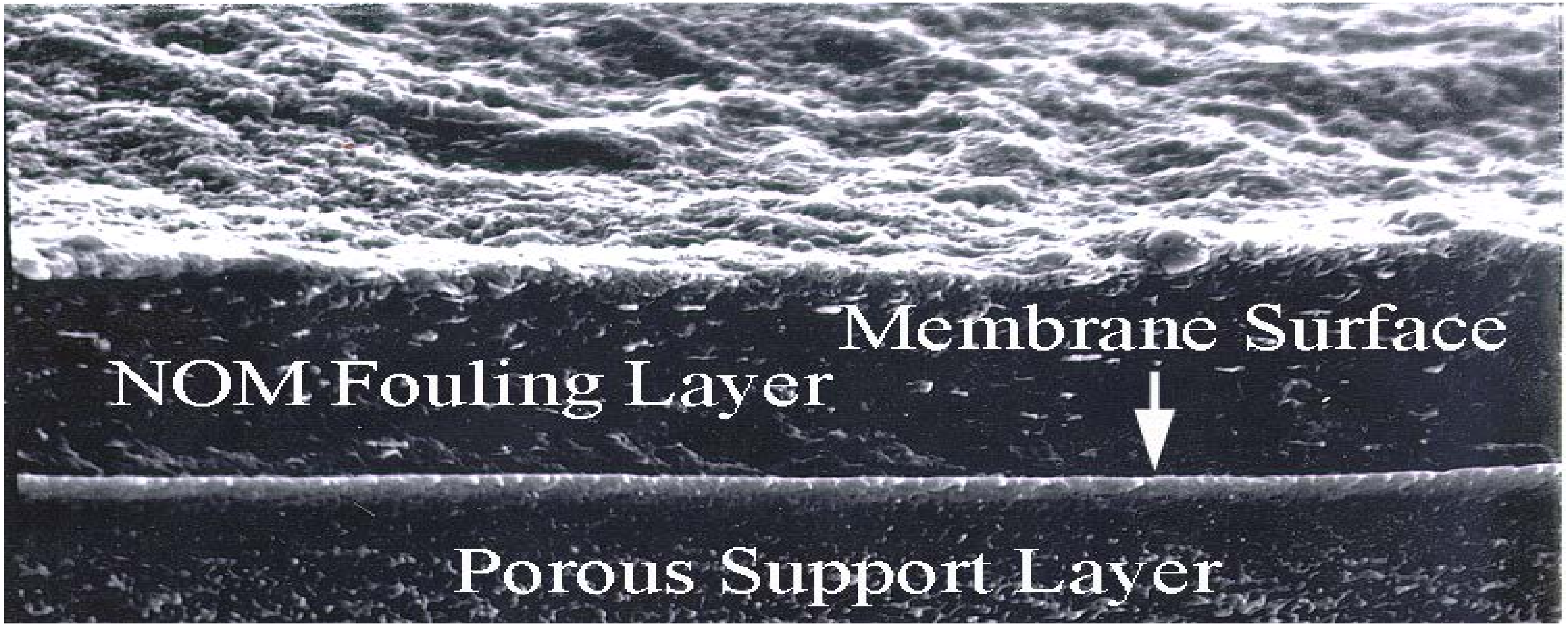
Dead-End Filtration – 1.5 hour



Film Thickness: < 0.1 μm

Permeability Decline: 30%

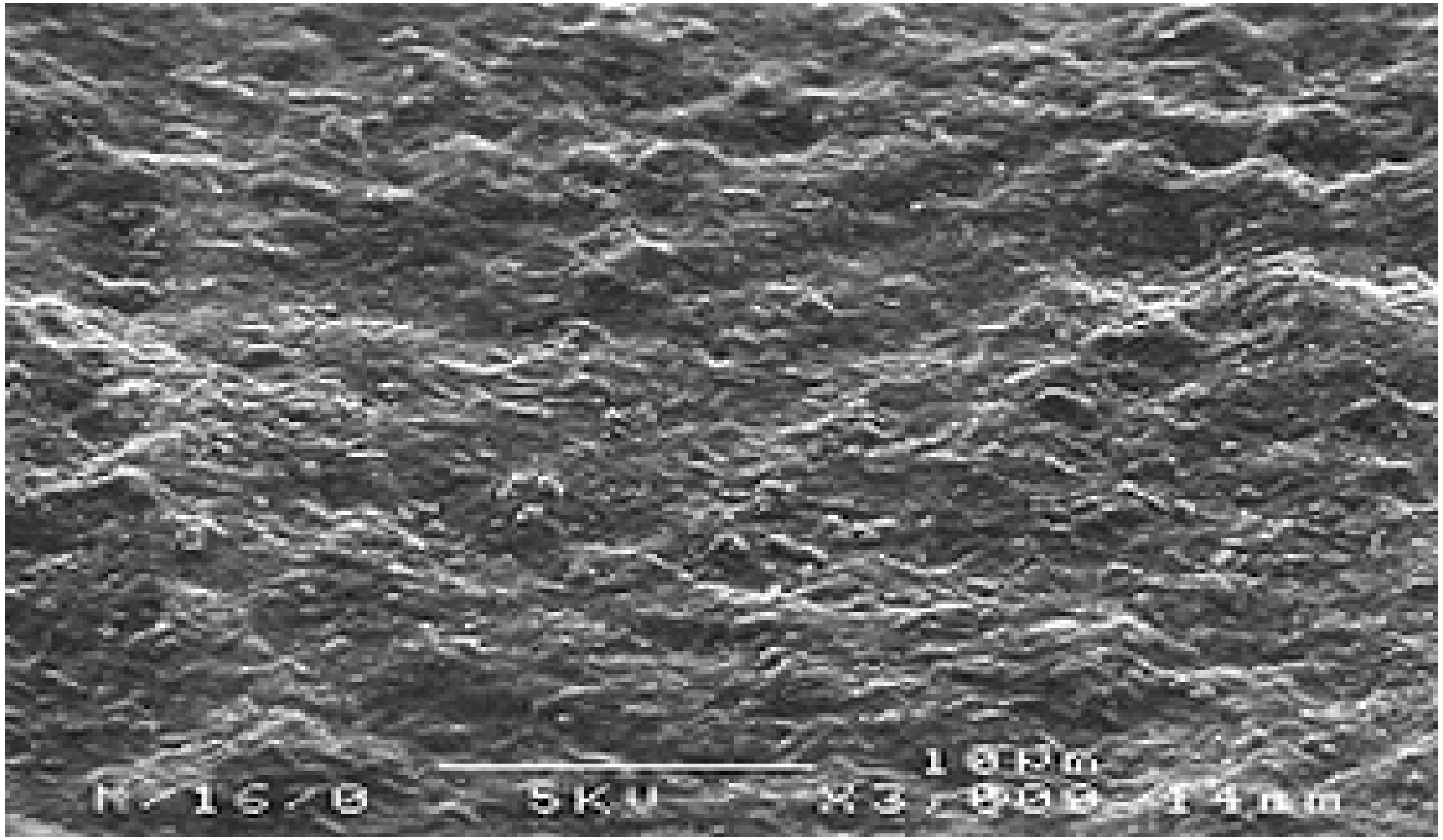
Dead End Filtration -- 20 hours



Film Thickness: 1.5 μm

Permeability Decline: 79%

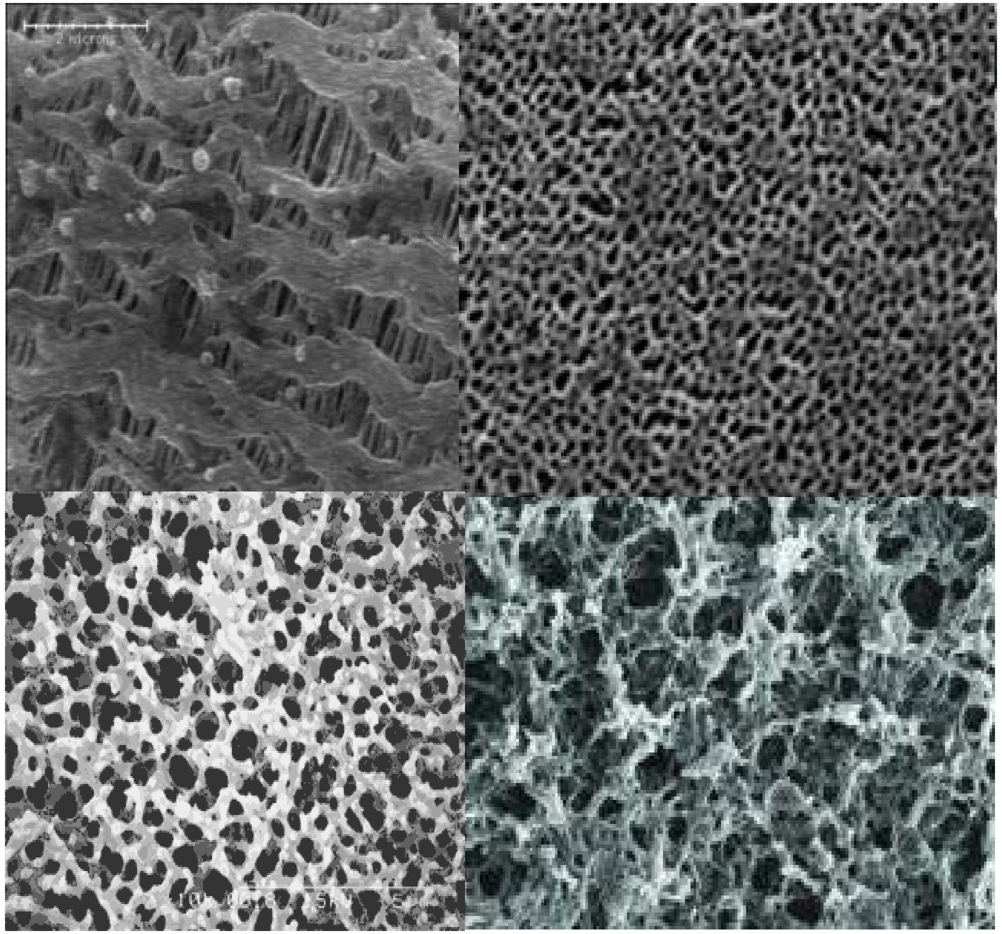
NOM Layer Before Backwash



NOM Layer After Backwash

Membrane Fouling Mechanisms

- Organic & Inorganic
- Particulate & Soluble
- Various Mechanisms
  - Surface & Pore
  - Deposition & accumulation
  - Adsorption, precipitation, coagulation



Membrane Cleaning

- Hydraulic Cleaning (10~30 minutes)
  - Water/Air Backwash
  - Air Scouring
  - Water Flushing
- Chemical Cleaning (1~8 weeks)
  - Free Chlorine (Sodium Hypochlorite)
  - Acid/Base
  - Other strong oxidants, such as H_2O_2
  - Reducing agent, such as SBS
  - Chelating chemicals, such as EDTA
  - Proprietary Chemicals (surfactants)

Fouling Material & Cleaning Chemicals

For Fouling Material	Cleaning Chemical
Biological; NOM; Synthetic polymers	NaOCl
Inorganic deposits	Acids (HCl, H_2SO_4, Citric Acid)
NOM	NaOH
Reducible metals (Fe, Mn)	Sodium bi-sulfite (SBS)
NOM	H_2O_2
Metals	EDTA

Monitor Your Membrane Performance: Key Operating Parameters

– **Flux:** Filtration rate per unit surface area (gfd, lmh)

– **Transmembrane pressure (TMP):** Pressure difference across the membrane, driving force for filtration

– MIT: Membrane Integrity Testing (psi/min; kpa/min)

– Permeability: Temperature corrected specific flux (gfd/psi, lmh/kpa)

- Permeability is a normalized parameter that takes into the consideration of operating flux, pressure, and temperature
- Permeability can serve as an unbiased indicator of membrane health

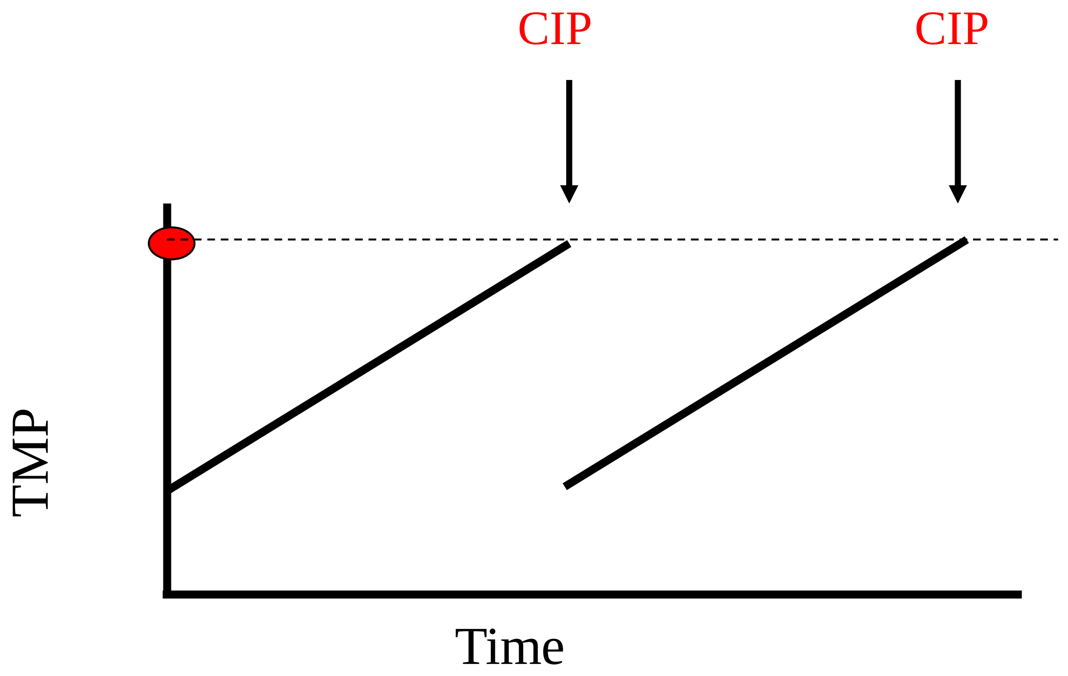
$$Permeability = \frac{Flow\ Rate\ \left(\frac{gal}{day}\right) \times Water\ Viscossity\ (cP)}{Membrane\ Surface\ Area\ (ft^2) \times TMP(psi)}$$

- *A normalized parameter that takes into the consideration of Flux, TMP, Temp*
- *An unbiased indicator of membrane heath*

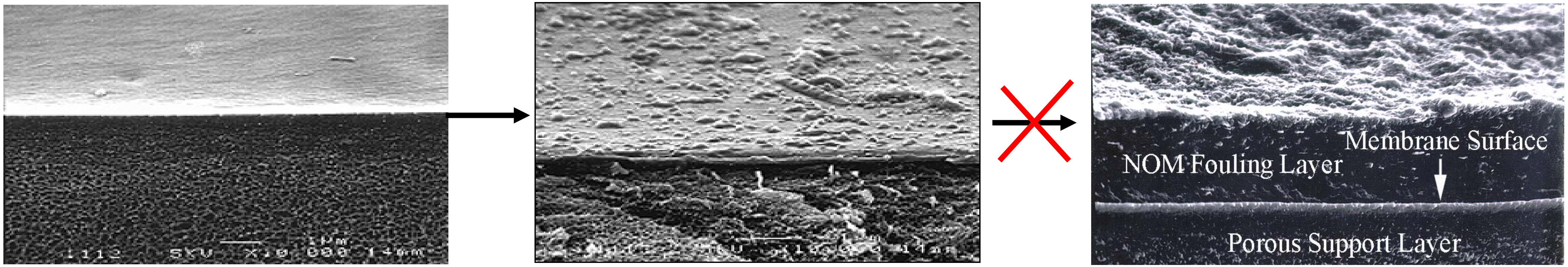
Chemical Cleaning

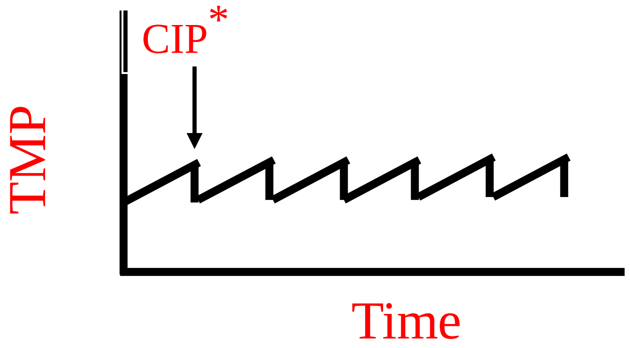
– Chemical addition in backwash water

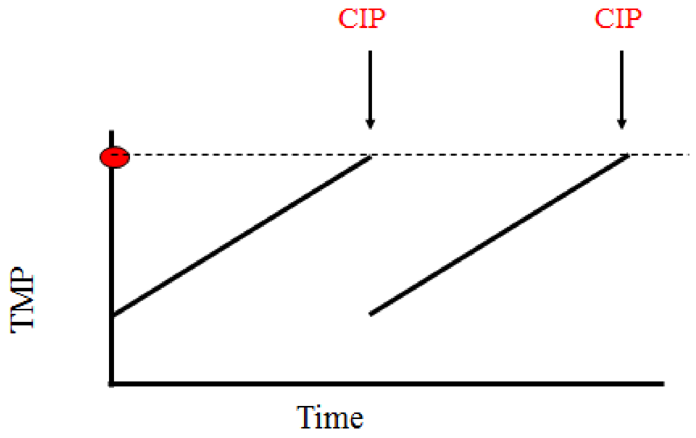
– Clean-in-place (CIP)
  - Multiple chemicals
  - High chemical doses
  - Long soaking time (> 1 hour)



A Different Cleaning Concept: Frequent & Low-Dose Cleaning







Frequent Chemical Cleaning (FCC)

- Frequent Cleaning
  - Few hours to few days
- Low dosages
  - Higher than backwash chemicals
  - Lower than CIP dosages
- Short soaking time
  - 10-30 minutes (< 1hr)
- Automatic
  - Use existing backwash system

Variations of FCC

- Different frequencies
- Different chemicals
- Different concentrations
- Different names
  - Chemical Enhanced Backwash (CEB-Ionics/Norit)
  - Enhanced Flux Maintenance (EFM-Pall)

Illustration of Conventional CIP Koch System

5% Citric Acid
@ 110 ^{o}F

Rinse

0.25% NaOH
200 ppm Cl_2

pH 6-9.5

Circulation for 1 hour

Koch System Performance

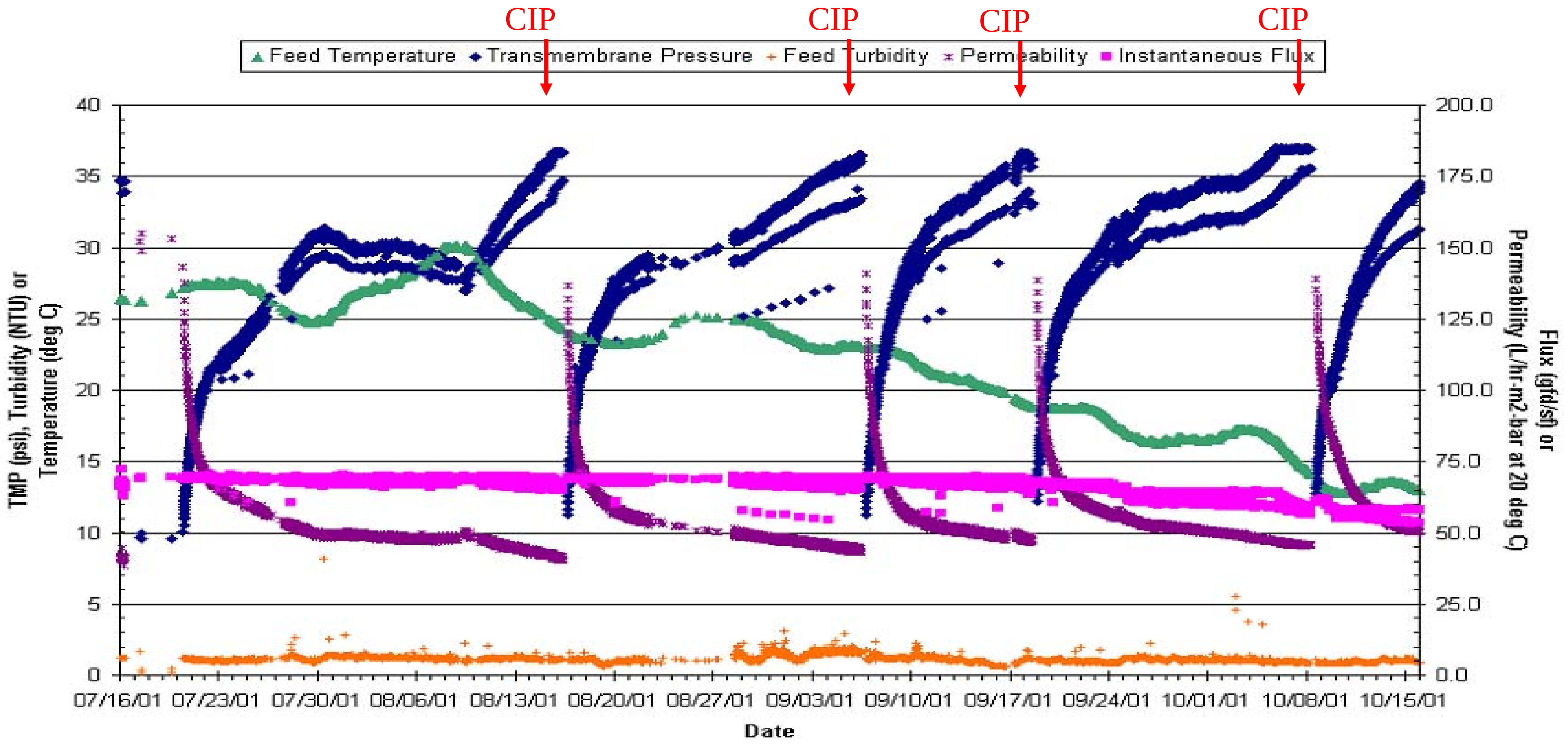


Illustration of Ionics CEB

Backwash

30 sec.

Backwash/Chemical

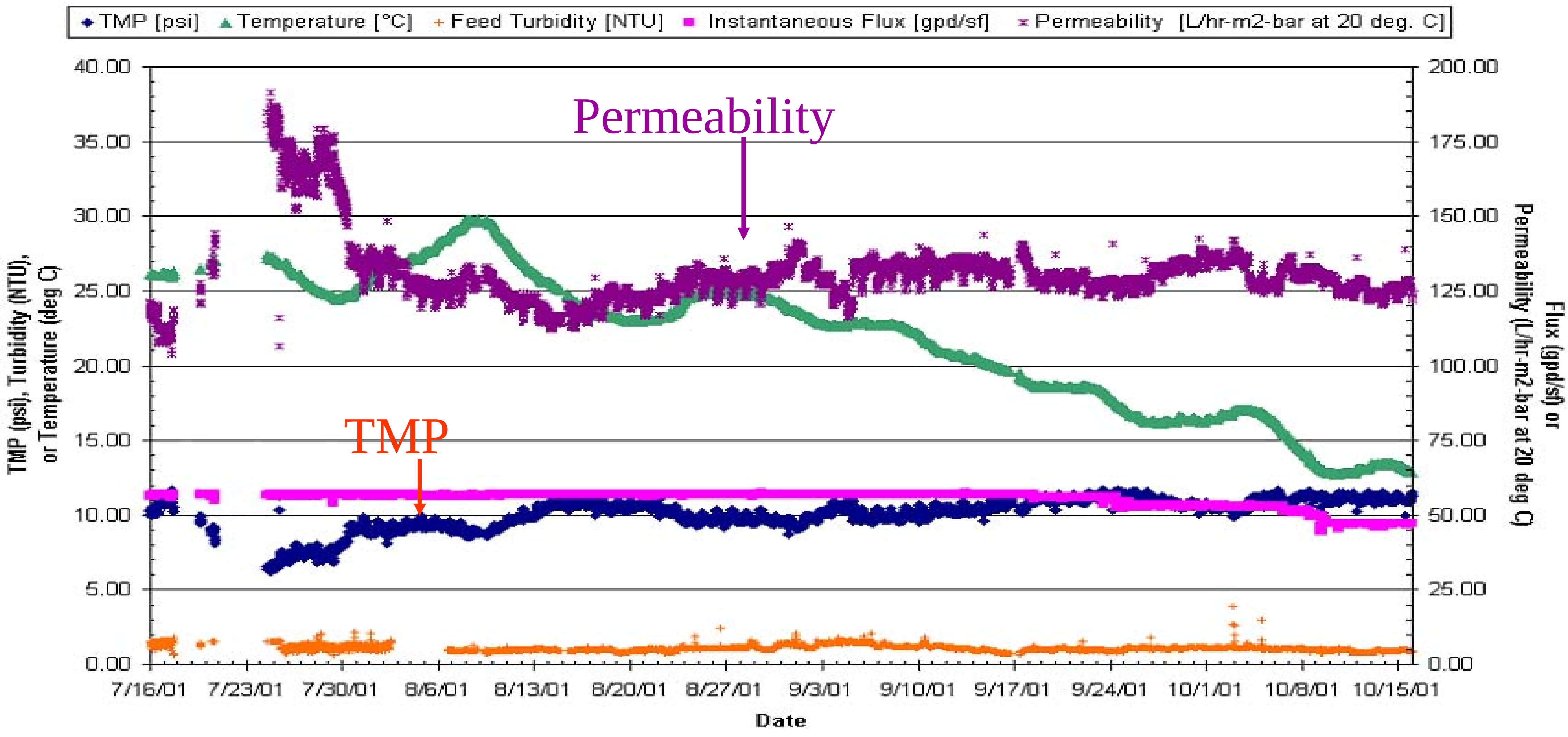
30 sec.

Backwash/Rinse

60 sec.

Soaking 10 min.

Ionics System With Stable TMP and Permeability



Design Procedure for a Membrane Filtration Plant

- Start with communicating with State Department of Health (DOH)
  - Membrane products approved by the State
  - Log removal credit needed by the new plant
  - Pilot testing requirements
    - Duration
    - Log Removal Credit need to achieve
- Select the right membrane for your application
  - Pilot testing
  - Procurement process: monetary & non-monetary criteria
    - Membrane integrity (fiber breakage) history
    - Lost of membrane permeability

Membrane Permeability (Specific Flux)

- **Flux:** Filtration rate per unit surface area (gfd)
- **Transmembrane pressure (TMP):** Pressure difference across the membrane, driving force for filtration
- **Permeability:** Temperature corrected specific flux (gfd/psi)

$$Permeability = \frac{Flow\ Rate\ \left(\frac{gal}{day}\right) \times Water\ Viscossity\ (cP)}{Membrane\ Surface\ Area\ (ft^2) \times TMP(psi)}$$

- *A normalized parameter that takes into the consideration of Flux, TMP, Temp*
- *An unbiased indicator of membrane heath*

Minimum Permeability (Specific Flux)

$$Perm_{min} = \frac{Design\ Flux\ @\ 20\ ^{o}C}{Max\ TMP}$$

Example:
Design Flux @ 20 ^{o}C = 50 gfd
Maxim allowable TMP = 30 psi
Minimum Permeability = 50/30 = 1.67gfd/psi

Min. permeability needs to be maintain in order to produce design flow when needed

Factors Affecting Permeability

- Membrane feed water quality
  - Turbidity, NOM, Fe/Mn, algae, Cu, FOG, etc.
  - Feed conditioning (coagulation, Cl_2, etc.)
- Operating flux
- Cleaning Approach
  - Frequency, type of chemicals, concentrations

Water Production

- Total water treated: MGD
- Water consumption for cleaning
- Beneficial Use

  = Total Water Treated – Water Consumption

- Water Recovery

  - $$R = \frac{Beneficial\ Use\ (mgd)}{Total\ Daily\ Producion\ (mgd)} \sim 90 - 95\%$$

Is your Membrane Working too Hard?

- Actual operating flux depends on…
  - Design concept (const. flow or const. flux)
  - Standby and/or redundant units?
  - Actual production down time
    - # of units in backwash
    - Backwash + maintenance clean
    - Backwash + CIP
- Is system operated at flux higher than the instantaneous flux?

Example of Actual Flux Calculations

- Design Capacity: 15 mgd
- # of Units: 7
- Design Flux: 58.5 gfd
- Total Downtime: 216 min
- Single surge (1 unit down): 1,258 min @ 68 gfd
- Double surge (2 unit down): 36 min @ 82 gfd

Membrane operated at flux rates > design flux most of the time!

Comparing CEB vs. CIP

- Advantage of CEB
  - More stable operation
  - Fully automated
- Disadvantage of CEB
  - More chemical consumption
  - More chemical waste

Potential Fouling Material
Particulate/Colloids

- Inorganic particles alone would not cause much fouling
- Inorganic particle cake layer could be easily removed by backwash
- Excessive turbidity could clog membrane fiber lumens
- Inorganic particles mixed with NOM could cause substantial fouling
- Organic colloids could cause significant fouling and could be difficult to clean

Potential Fouling Material
Natural Organic Matter

- NOM with high SUVA
- TOC > 4 mg/L would be a concern
- Organic fouling is "sticky" and difficult to clean
- Organic may serve as "cement" to bind other particulates and form a strong cake layer
- Caustic cleaning (e.g. NaOH) and strong oxidant (e.g. H_2O_2) are effective for NOM fouling cleaning

Potential Fouling Material
Inorganic Material

- Precipitation of Ca, Mn, Mg, Fe, and Al could cause significant fouling
- Prefer a negative Langelier Index

$$\textit{Langelier Index} = \textit{Actual pH} - \textit{Saturation pH}$$

$$\textit{Saturation pH} = 2.18 - \log[Ca^{+2}] - \log[HCO_3^-]$$

L.I. > 0 : Oversaturated (tend to precipitate)

L.I. < 0 : Undersaturated (tend to dissolve more)

Potential Fouling Material
Inorganic Material (cont.)

- Presence of soluble Fe, Al, and Mn could possibly foul membranes
- Fine inorganic colloids (< 0.05 μm) could clog membrane pores and cause fouling
- Acid, EDTA, SBS cleaning could be effective for inorganic fouling

Potential Fouling Material
Synthetic Polymers

- Polymers used for coagulant/filter aids & backwash water treatment
- Presence of polymers in feed water could cause dramatic fouling, and sometimes irreversible
- Free residual polymer is worse than particle-associated polymer
- Cationic polymers are worst
- Some polymers can be easily cleaned with chlorine and therefore are consider compatible with membranes

Flux-Pressure-Fouling Potential

– Higher flux would cause higher fouling potential by…
  - Bringing more fouling material toward the membrane surface during the same operation cycle length
  - Requiring higher pressure to push more water through. Higher TMP will cause more compaction on the material deposited on membrane surfaces

– High TMP (due to higher flux or fouling) could aggravate fouling and cause durable fouling

Fouling Mitigation
Pretreatment

- Reduce TOC level (< 4 mg/L)
- Reduce Turbidity (< 5 NTU)
- Reduce Hardness (< 150 mg/L)
- Avoid substantial change in water chemistry, such as pH and other pretreatment chemicals
- Prevent Oil and Polymers from entering the feed water

Fouling Mitigation
Operation

- Use crossflow if turbidity is high (with higher energy consumption)
- Bleed a portion of the concentrate to avoid solid buildup (not common)
- Operate at a lower flux with lower TMP (more membrane equipment)
- Enhance pretreatment

Fouling Mitigation
Cleaning Strategy

1. Frequent BW (shorter filtration cycle)
2. Longer BW duration
3. Higher BW pressure
4. Add cleaning chemicals in BW water
5. Frequent chemical cleaning

Options 1-3 will increase water consumption and thereby reducing overall recovery.

Membrane Basics

Membrane Cleaning

Membrane Fouling Mechanisms

- Organic & Inorganic
- Particulate & Soluble
- Various Mechanisms
  - Surface & Pore
  - Deposition & accumulation
  - Adsorption, precipitation, coagulation

Membrane Cleaning

- Hydraulic Cleaning (10~30 minutes)
  - Water/Air Backwash
  - Air Scouring
  - Water Flushing
- Chemical Cleaning (1~8 weeks)
  - Free Chlorine (Sodium Hypochlorite)
  - Acid/Base
  - Other strong oxidants, such as H_2O_2
  - Reducing agent, such as SBS
  - Chelating chemicals, such as EDTA
  - Proprietary Chemicals (surfactants)

Homework

- Reading Assignment: Chapter 12
- A membrane plant is designed for 10 mgd at 20C
  - Maximum operation pressure is 30 psi
  - Initial clean membrane operating pressure is 10 psi

- What's the clean membrane permeability?
- What's the plant's production at 5C in the winter time?
- What's the minimum permeability that the plant needs to maintain at any given time to ensure the plant will be able to produce 10 mgd at the end of the membrane's projected life

CornellEngineering
Civil and Environmental Engineering

CEE 4540

Sustainable municipal drinking water treatment

Topic: MF/UF Membranes Design

Instructor: YuJung Chang
YuJung.Chang@aecom.com

Class #15 10/22/2018 2:55 – 4:10pm

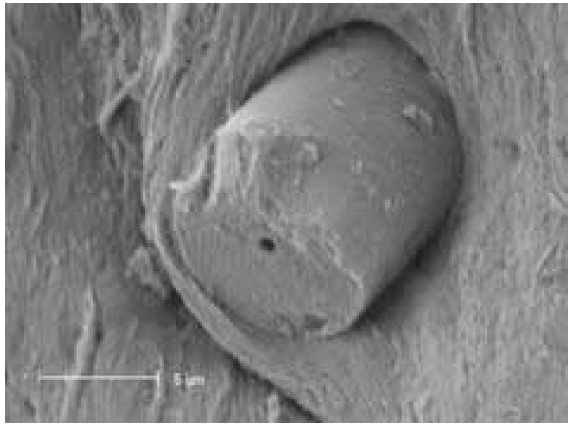
Homework for Class #15

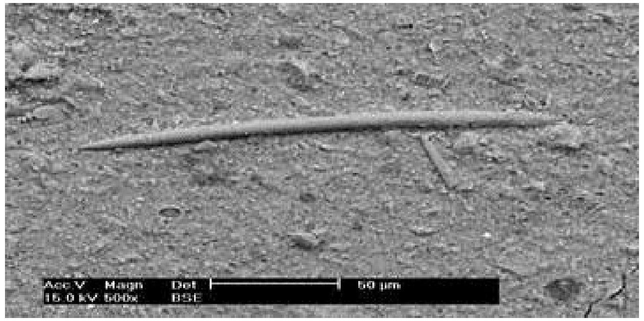
- Provide a Process Design for a 10 mgd membrane WTP
  - Pressurized membrane from Pall
  - Designed for water temperature from 5C – 25C
  - Assuming 40 membrane module per skid
- Provide following design parameters with explanations/justifications
  - Number of membrane skids
  - Number of membrane trains
  - Design Flux (gpm/ft2)
  - List functions and equipment should be included in your design
- Provide at least 2 considerations for Mechanical Design
- Homework Due 10/29

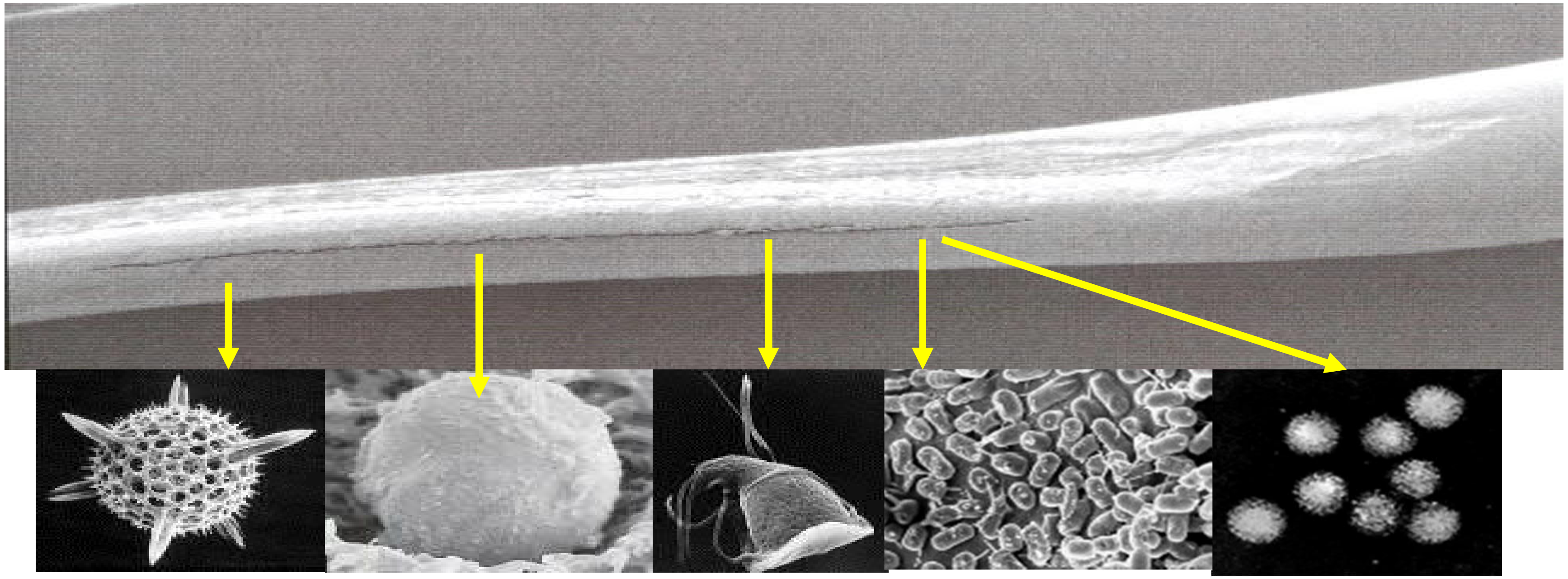
Membrane Basics

Membrane Integrity

Membrane failure is rarely catastrophic – less serious than microbial penetration of rapid sand filter beds.





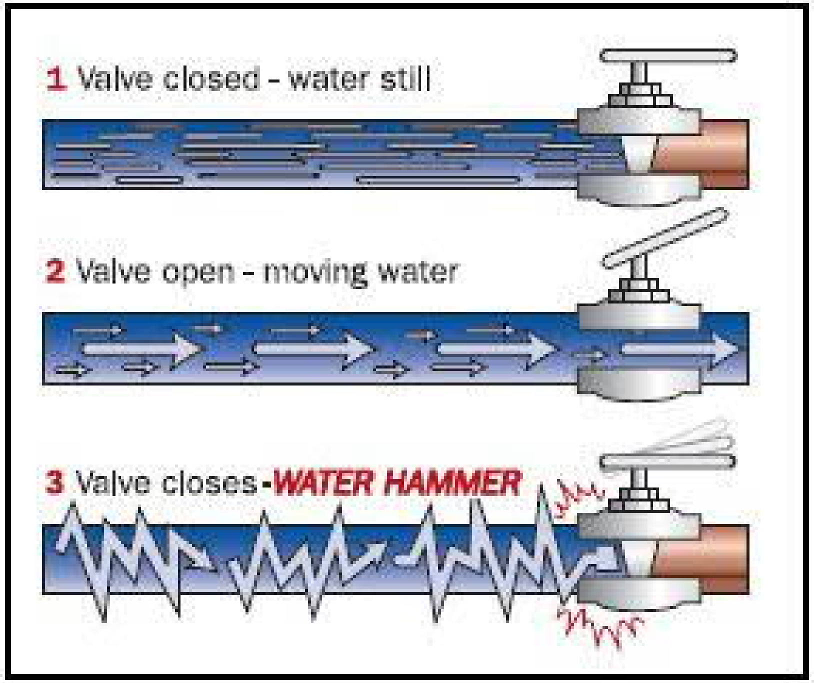


- **Membranes fail incrementally – one fiber at a time, unless for a catastrophic event.**
- **Statistically, individual fiber breaks are insignificant to the overall microbial water quality.**

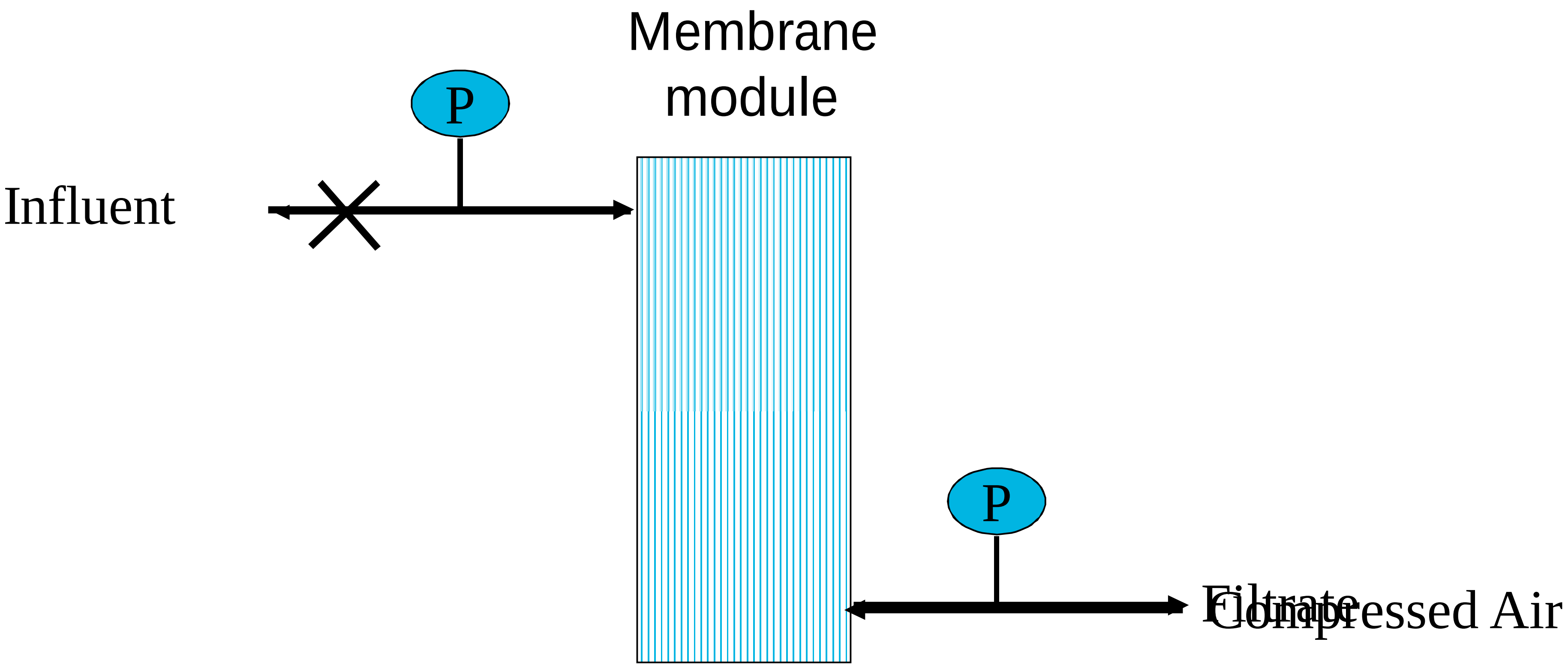
But….. Catastrophic Does HAPPEN!!!!

Deign Consideration: Water Hammer

- There is “momentum” of moving water in addition to static pressure
- Water Hammer happens when Valve closed suddenly
- Valving sequence (open & close valve) was wrong



Pressure Holding Test



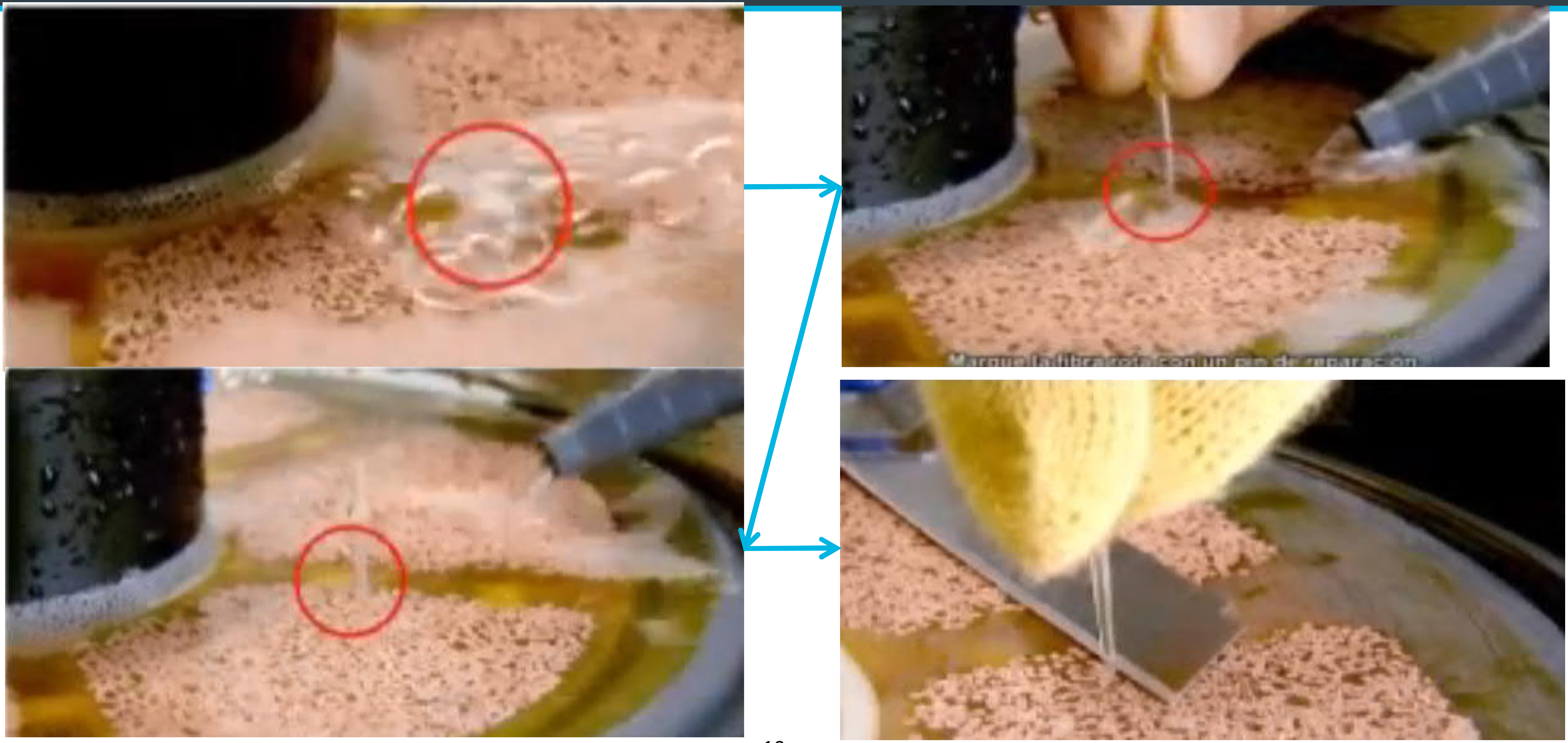
Membrane Integrity Monitoring

- On-Line Turbidity Monitoring
  - 0.08 NTU 95% of the time, 0.1 NTU max.
- On-Line Particle Count (not common anymore)
  - Baseline establishment (< 50 particles/mL)
  - Could be affected by air bubbles
  - Sensitivity: Not sensitive enough (yet) for the detection of a 3 μm breach
  - Too easy for false alarms
- Pressure Holding Test (Air integrity testing)
  - Direct Integrity Testing is required by EPA
- Virus Seeding Test (UF)
  - Only for initial product verification, cannot be used for continuous monitoring

Membrane Fiber Cut Test

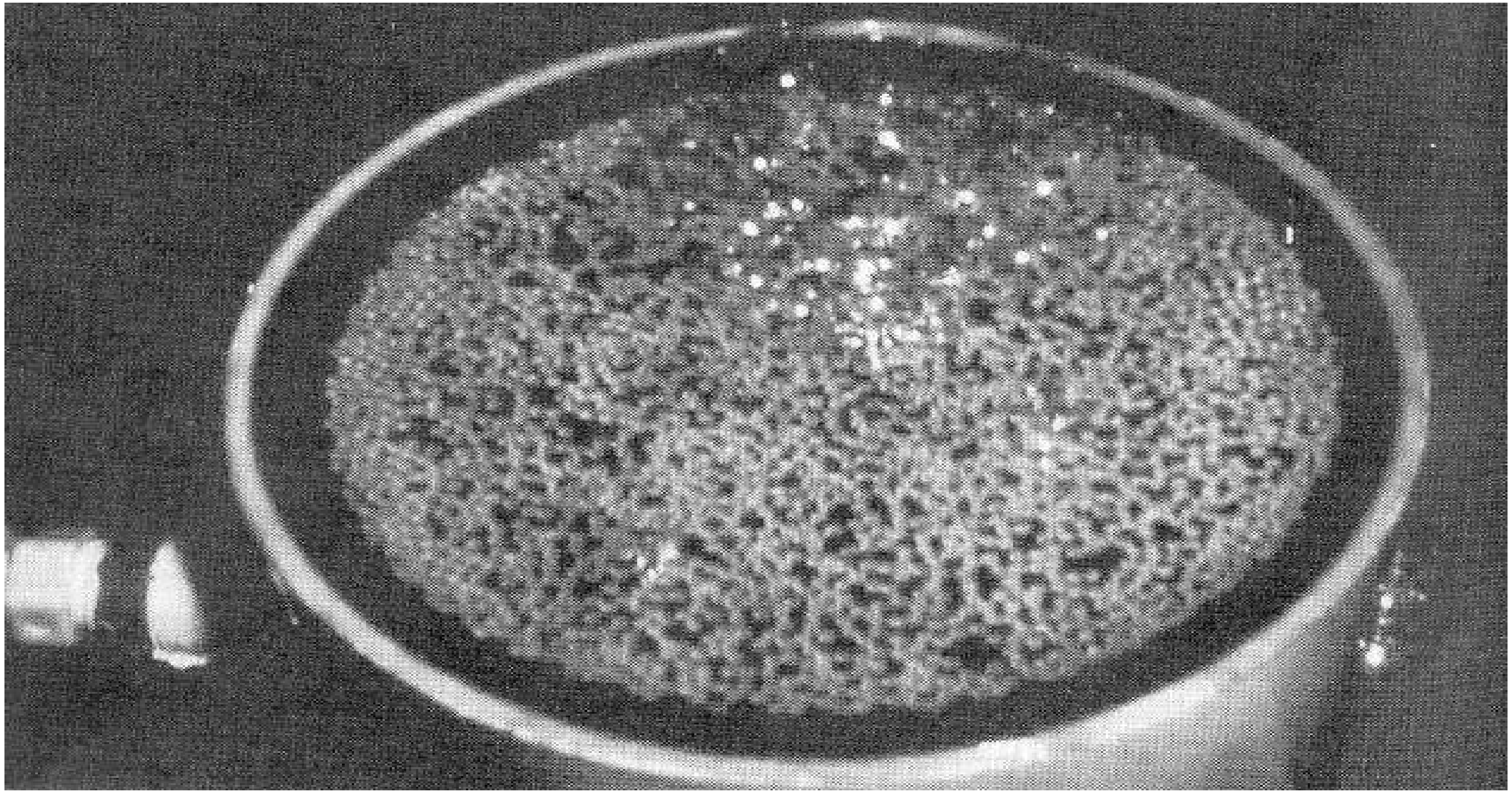
Pre-Cut Membrane Module

Membrane Repair with Pins



Remove Repair Pins

Broken Fiber Identification



Mark the Broken Fiber

Compromised Module

Water Quality with Broken Fiber

	No Broken Fiber			1 Broken Fiber			
Op. Time (min)	5	15	20	5	13	17	23
Feed Turbidity	1.52	1.58	1.58	1.42	1.49	1.47	1.45
Filtrate Turbidity	0.068	0.067	0.067	0.076	0.068	0.068	0.067
Filtrate PC > 2 μm	0.46	0.04	0	9.80	5.08	4.74	5.92

– Although particle count (PC) seems to be sensitive, false alarm from air bubbles render its reliability as a membrane Past/Fail indicator

Module Integrity Inspection

Virus (Pathogen) Seeding Test

All 3 tests at the beginning, the middle, and the end of Performance Testing showed > 5 log virus rejection.

Membrane Autopsy

Technics to Identify What Went Wrong with Membranes

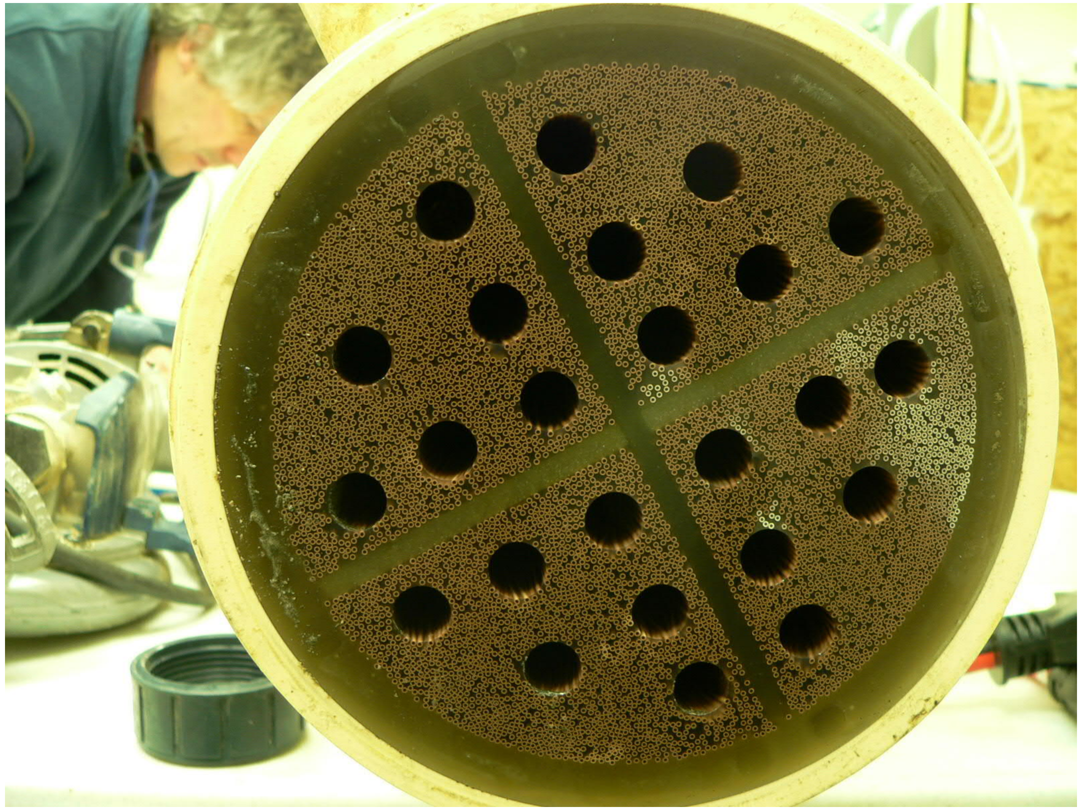
Objectives of Membrane Autopsy

- It is an effective tool to reveal the natural of membrane fouling & physical damage
- It provides hints to improve influent pretreatment and cleaning regime
- Autopsy could identify how membranes are compromised

General Autopsy Procedure

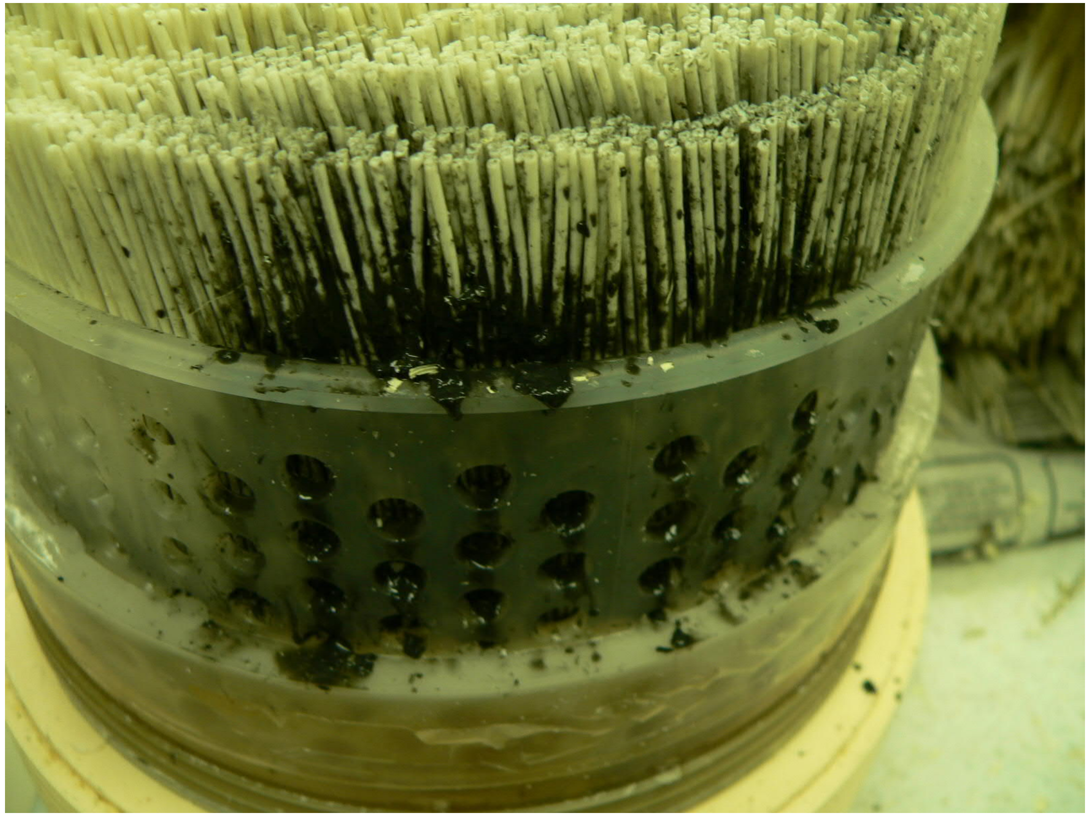
- Membrane module selection (pick the ones that are leaking and representative)
- Physical inspection
- Module dissection
- Microscopy analysis
- Fouling material analysis
- Membrane fiber physical strength test
- Cleaning efficacy study
- Data interpretation and recommendation

Membrane Inspection & Opening the Module

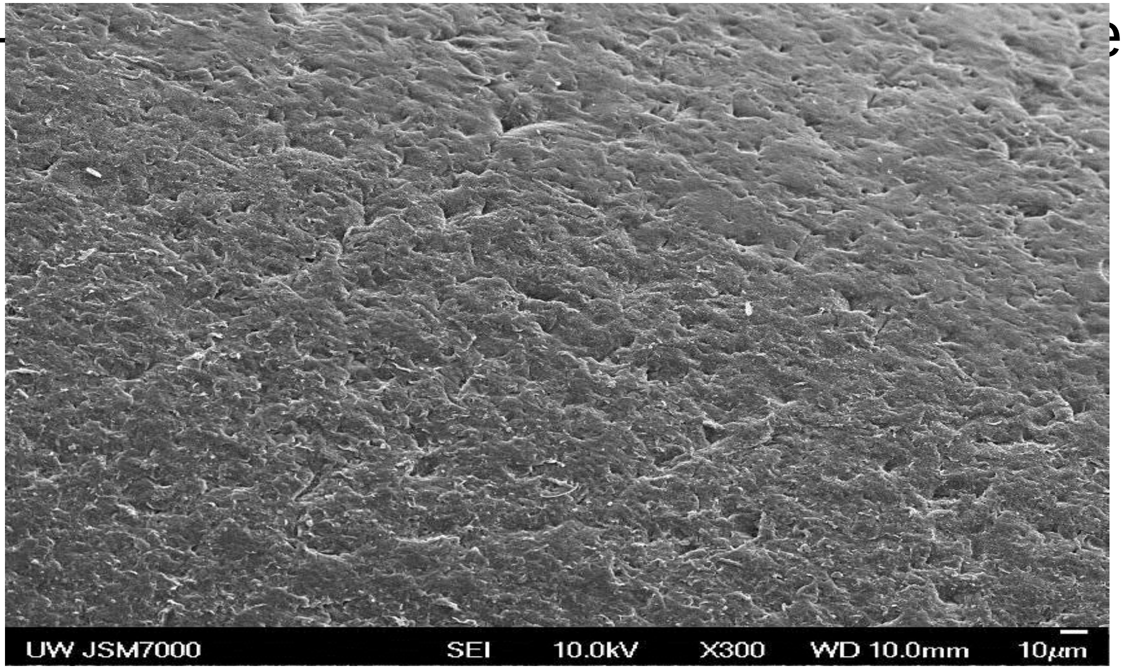


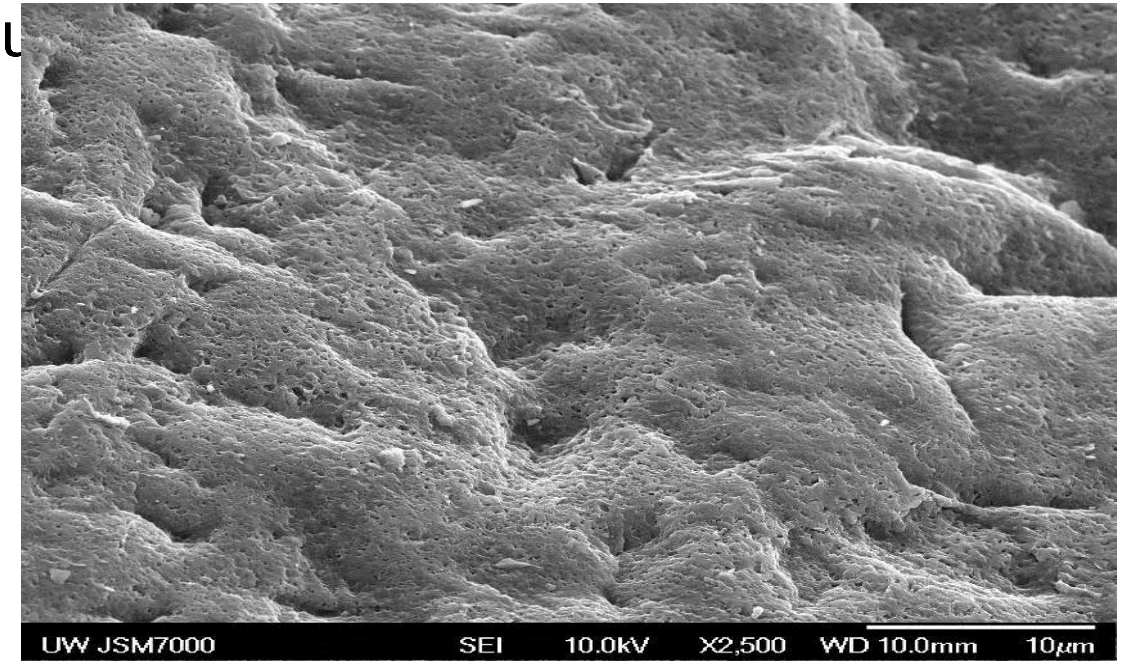
Membrane Inspection

– Sludge accumulate around the perimeter, indicating unbalanced and insufficient hydraulic backwash design



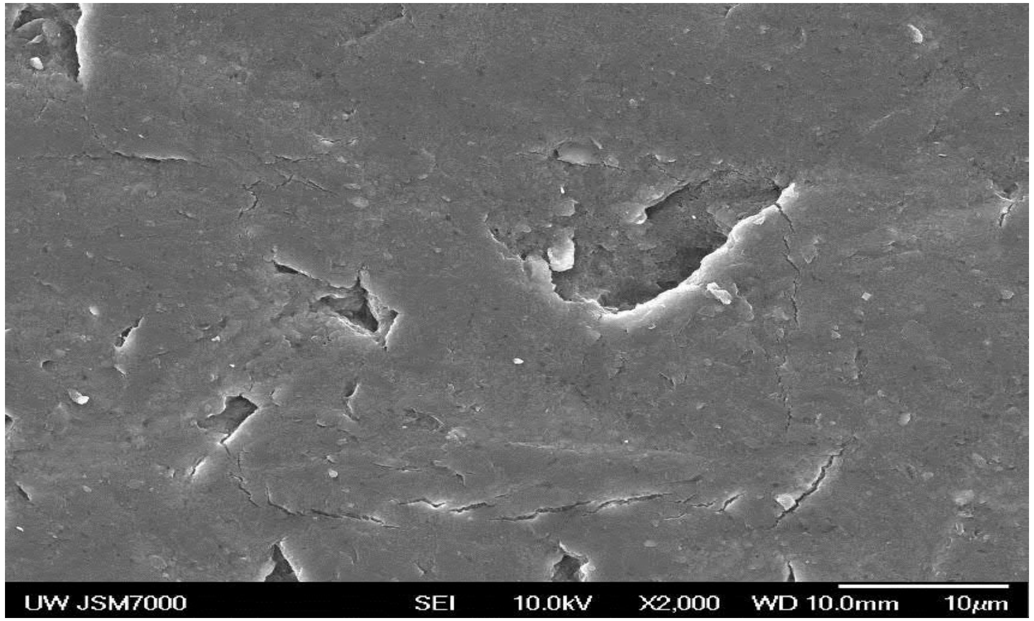
Physical Damage on Membrane Surface

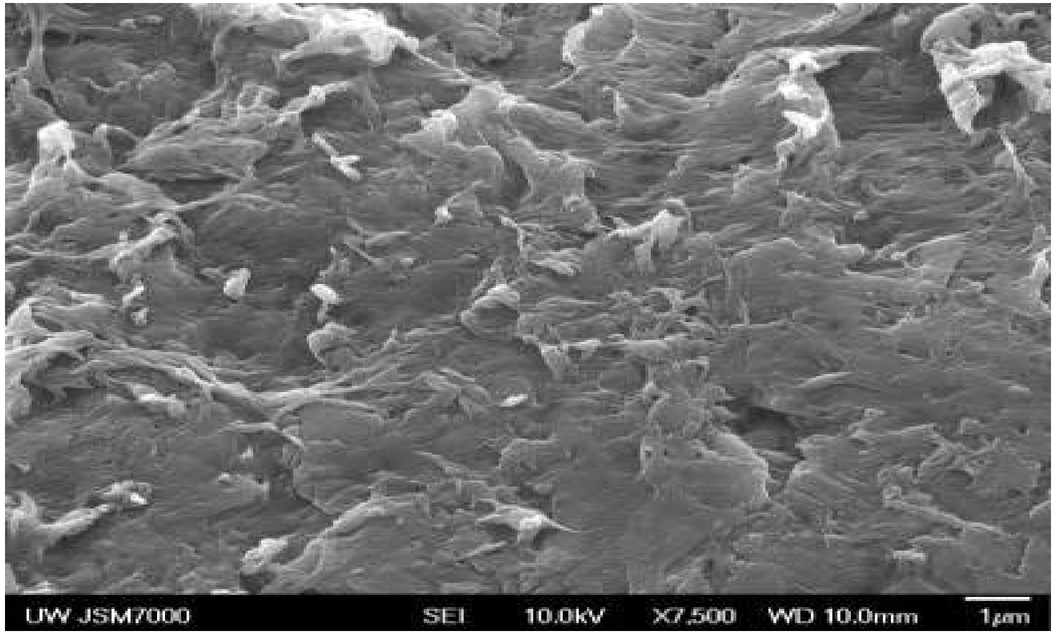




Chemical Damage to Membrane Surface

- Serious membrane surface damage due to aggressive chemical cleaning
  - Strength of cleaning chemical could be too high
  - Too many and frequent extensive CIP
- Chemical damage to membranes could lead to reduced permeability and weaken mechanical strength of membrane fiber





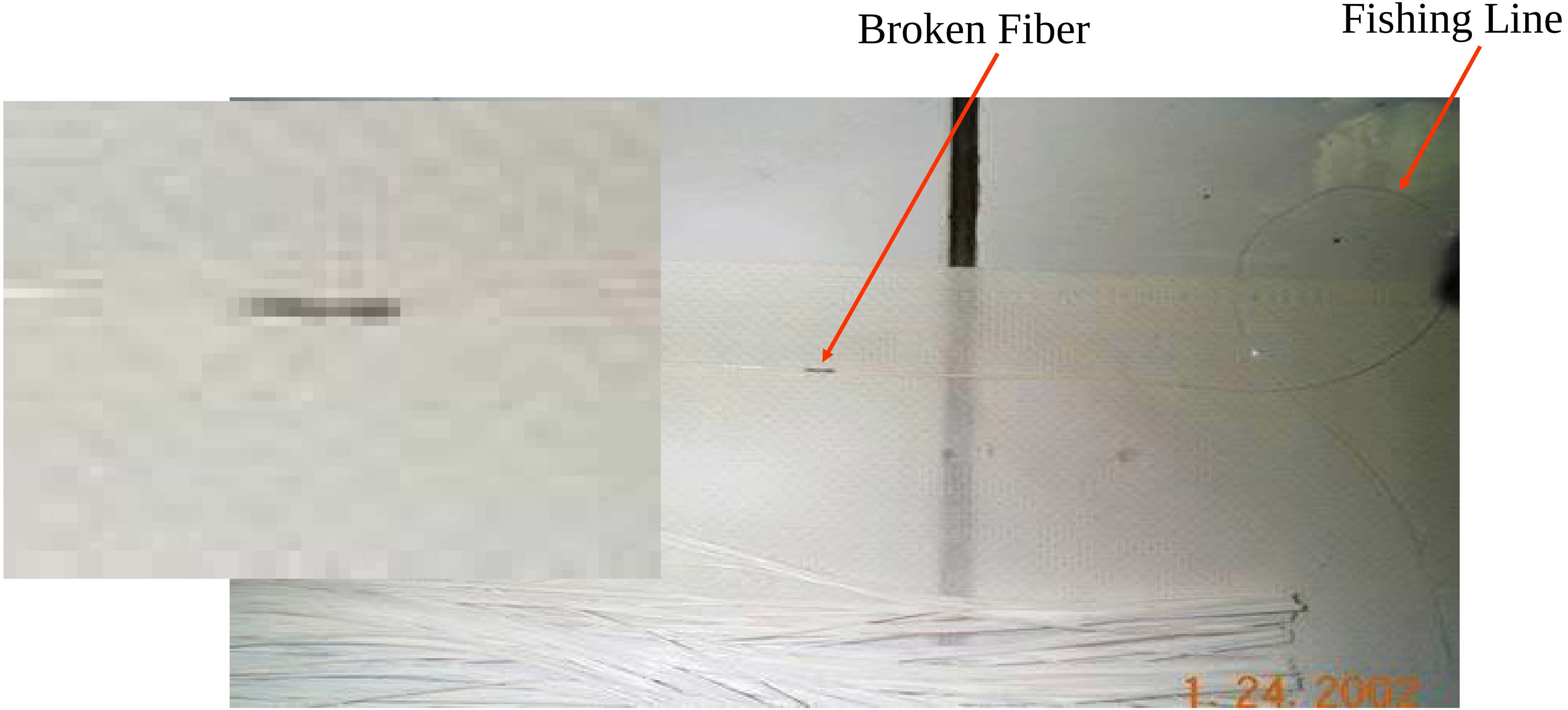
Module Integrity Inspection

– A fishing line was used to mark the broken fiber

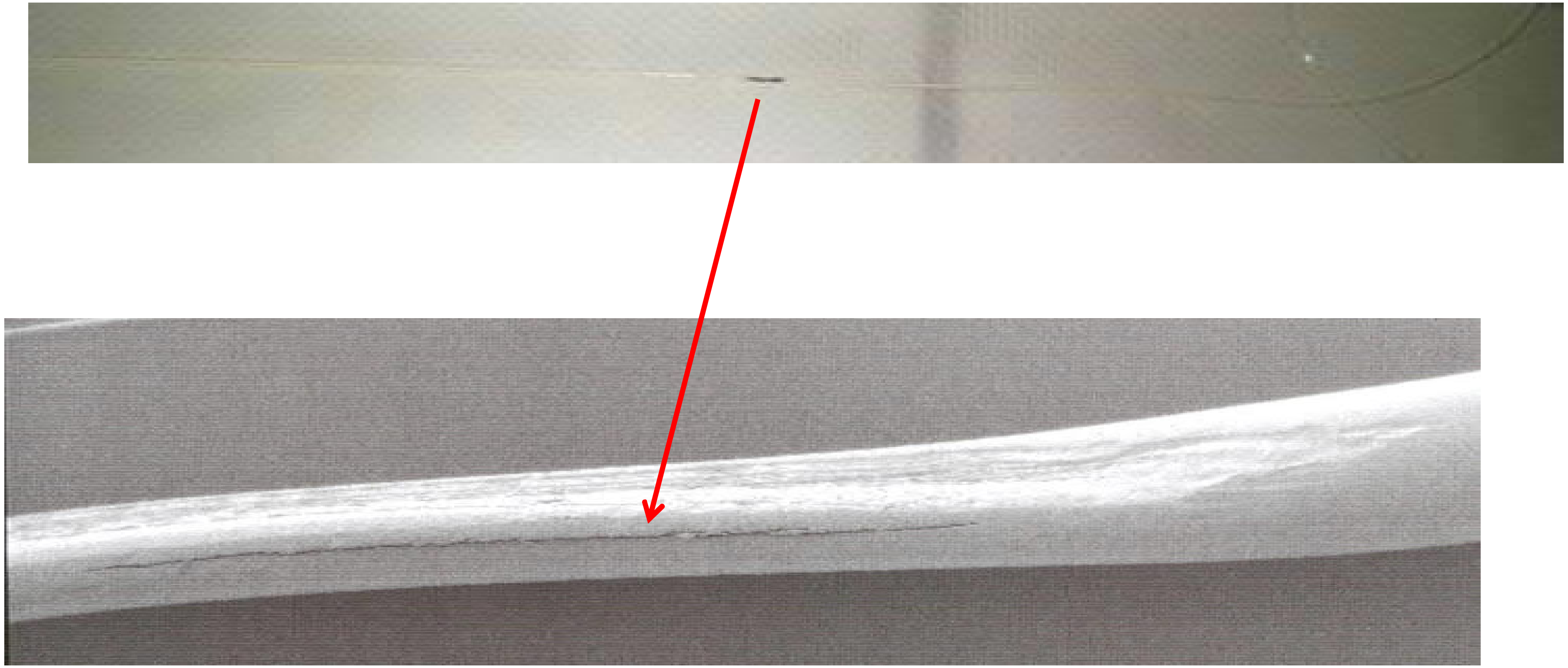
Membrane Module Dissection

Locate Broken Fiber

Identify Broken Fiber



Broken Membrane Fiber



Membrane Autopsy with Microscopic Analysis

- Light scattering microscope
- Scanning electron microscope (SEM)
- Environmental SEM (ESEM)
- Field emission SEM (FESEM)

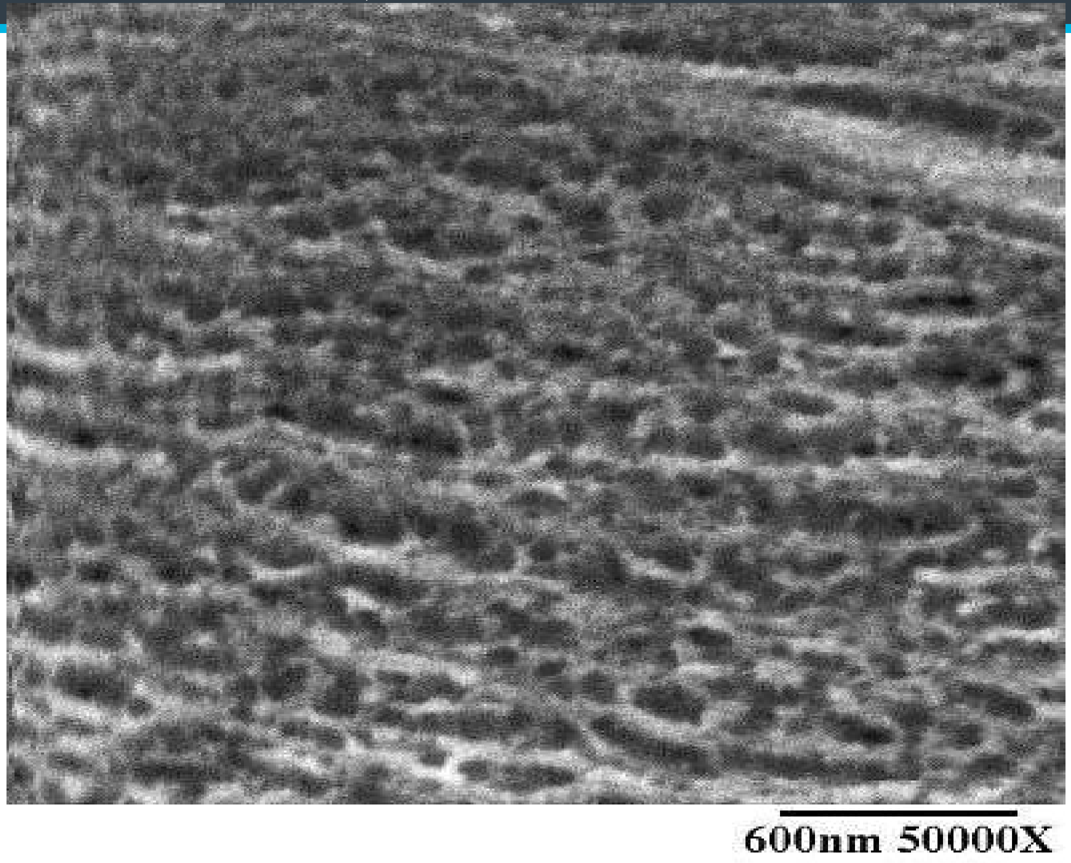
Light Reflective Microscope

New Membranes

- No sample preparation; no distortion
- Color image (3 - 100 X)

Field Emission SEM (FESEM)

New Membrane Surface

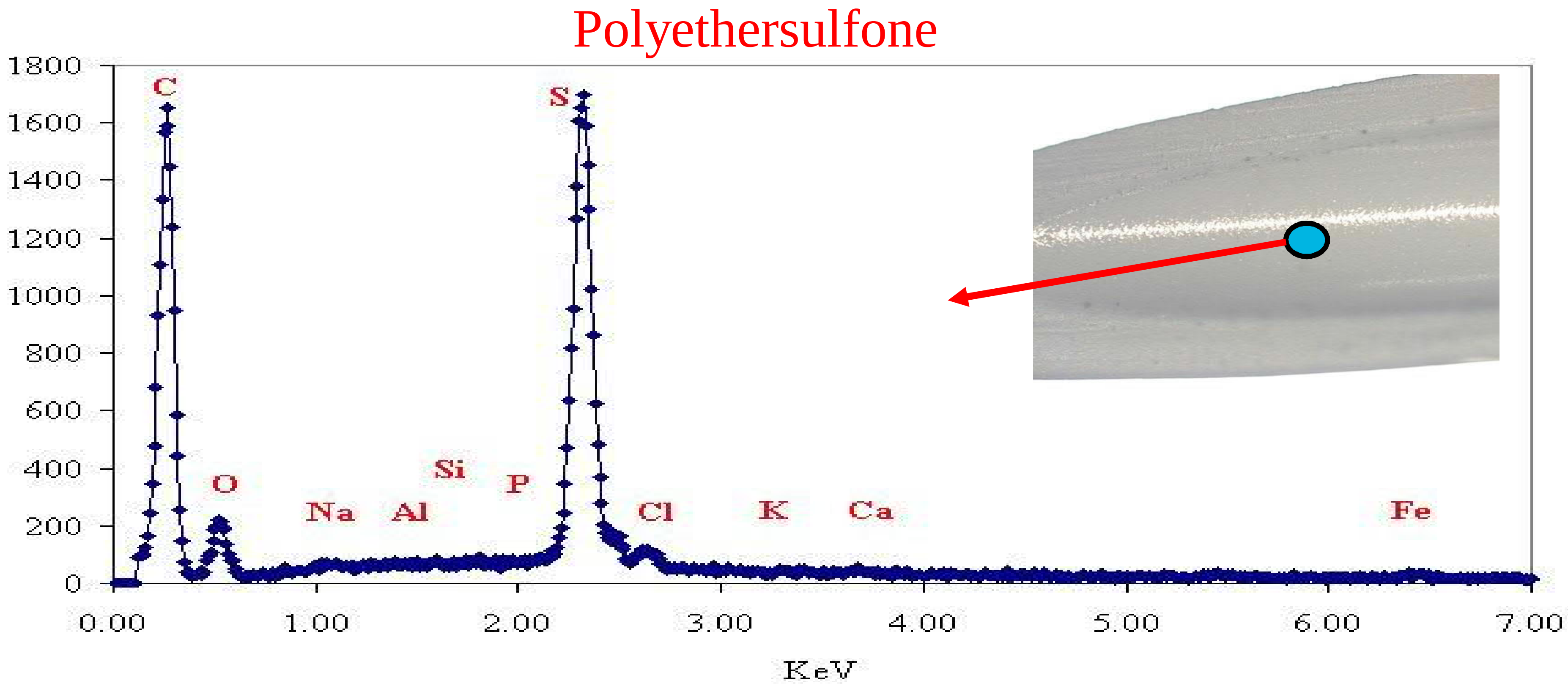


Pore Structure

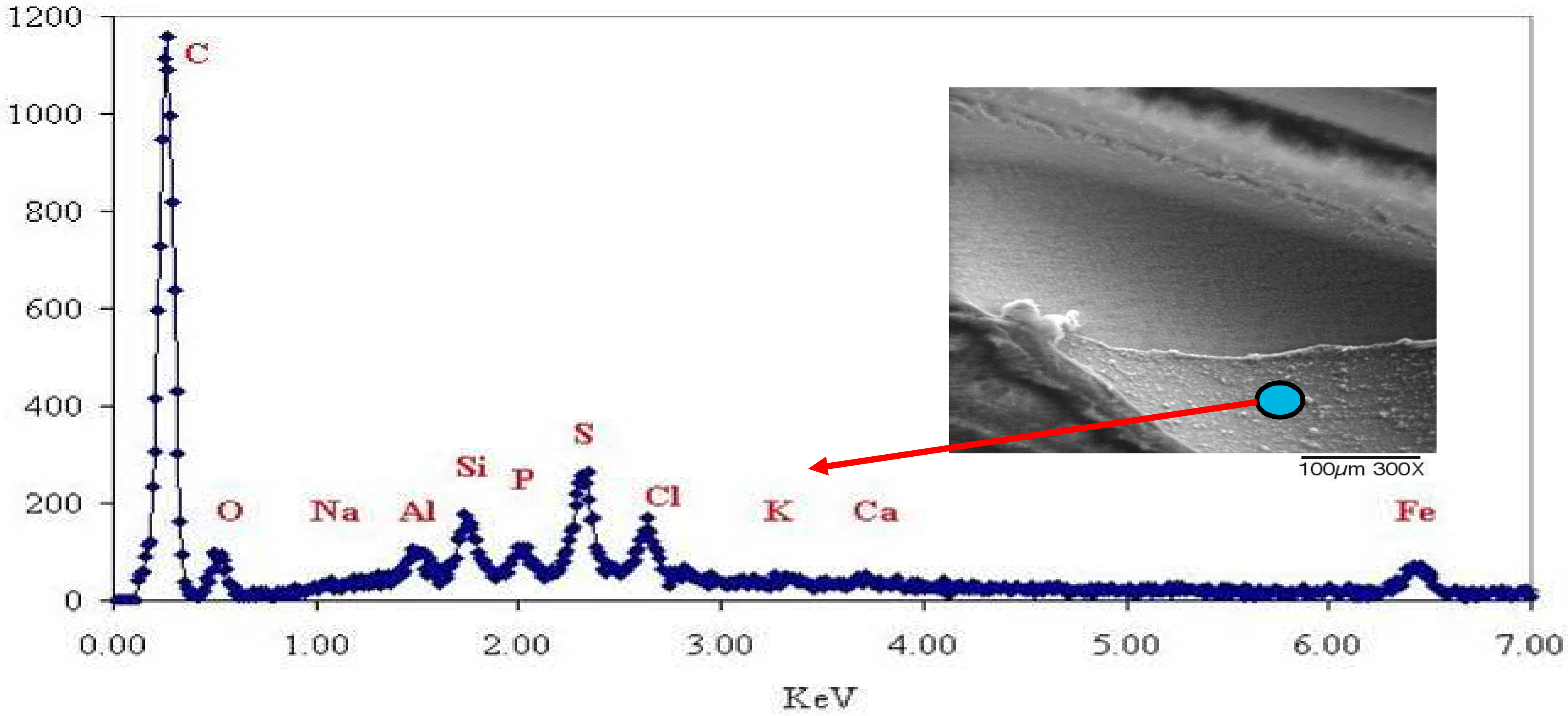
Very high magnification for detail structure

Electron Dispersion Spectrum (EDS)

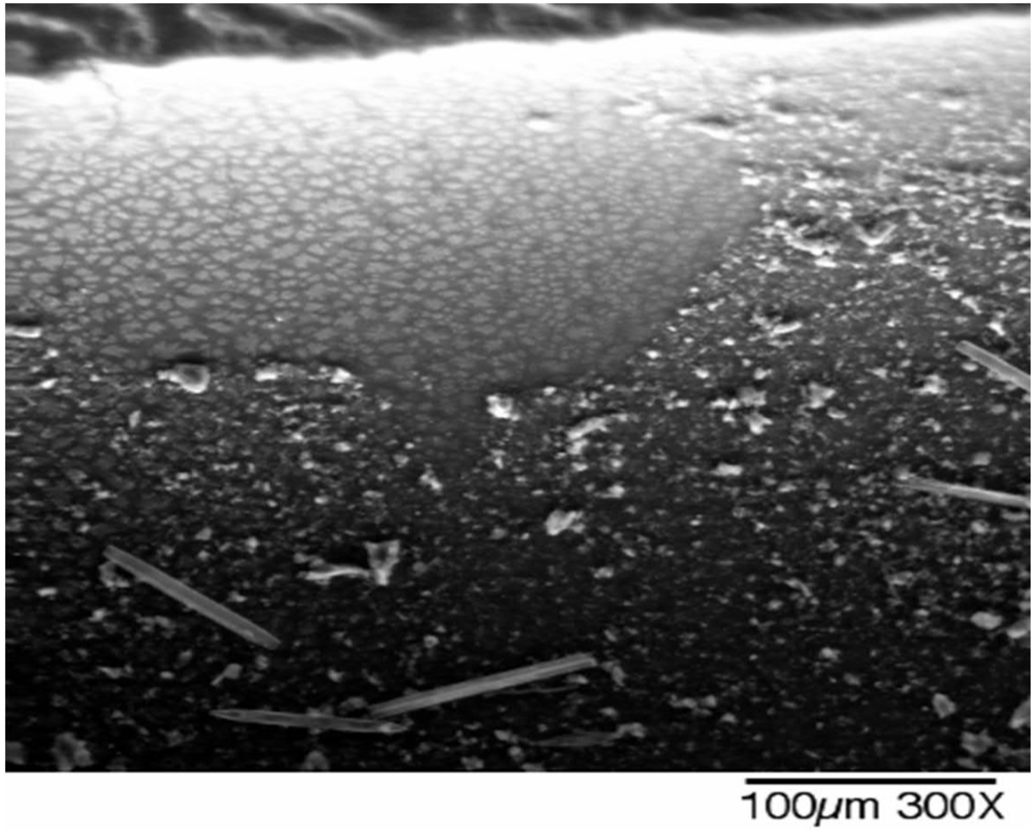
Perform elemental analysis, excellent for inorganic compound

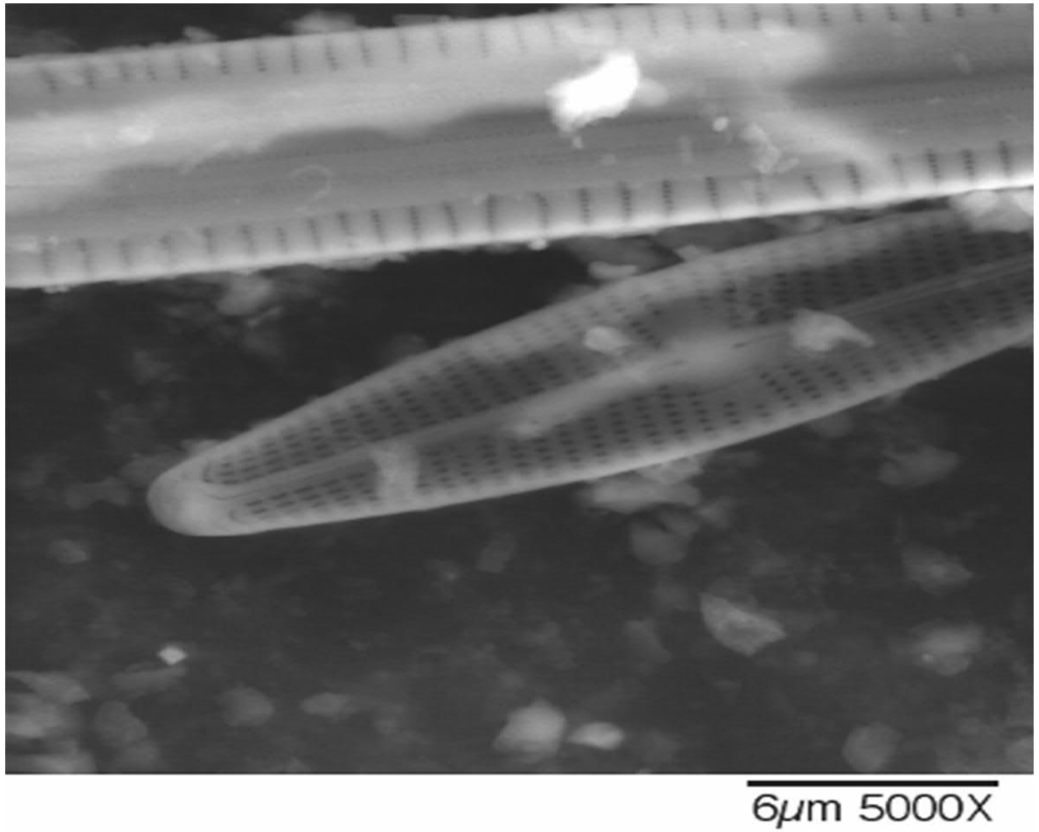


EDS on Delaminated Film



Environmental Scanning Electron Microscope (ESEM)

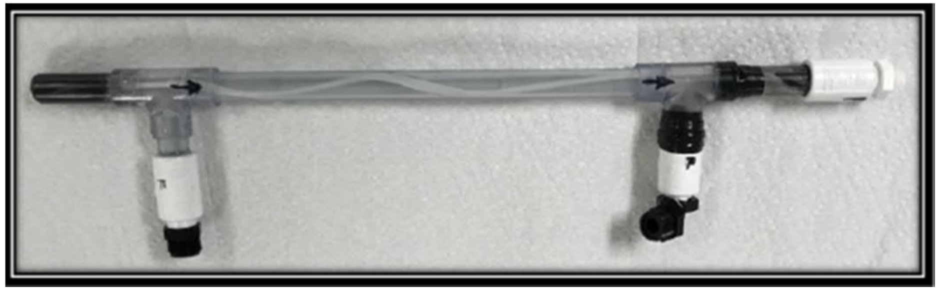




- No sample preparation; no distortion
- High magnification

Advanced Membrane Testing & Research

- Mini Module Testing
- Chromatic Elemental Imaging (CEI)



Mini-module Testing Equipment

Features

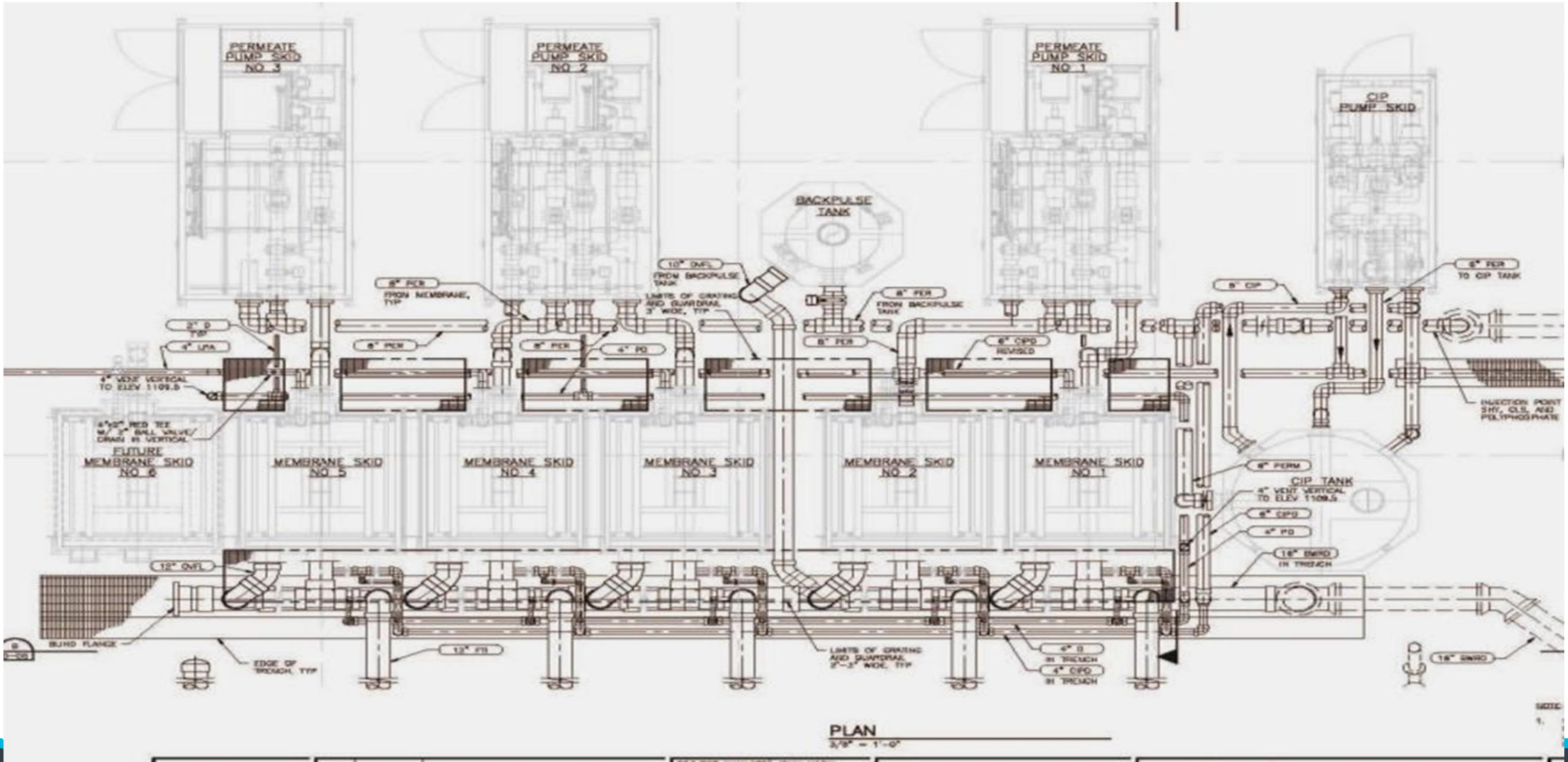
- Computer integrated
- Backwash
- CEBs
- ECEB

- Complete simulation
- Re-pot used fibers into mini-module
- Optimize chemical cleaning approach

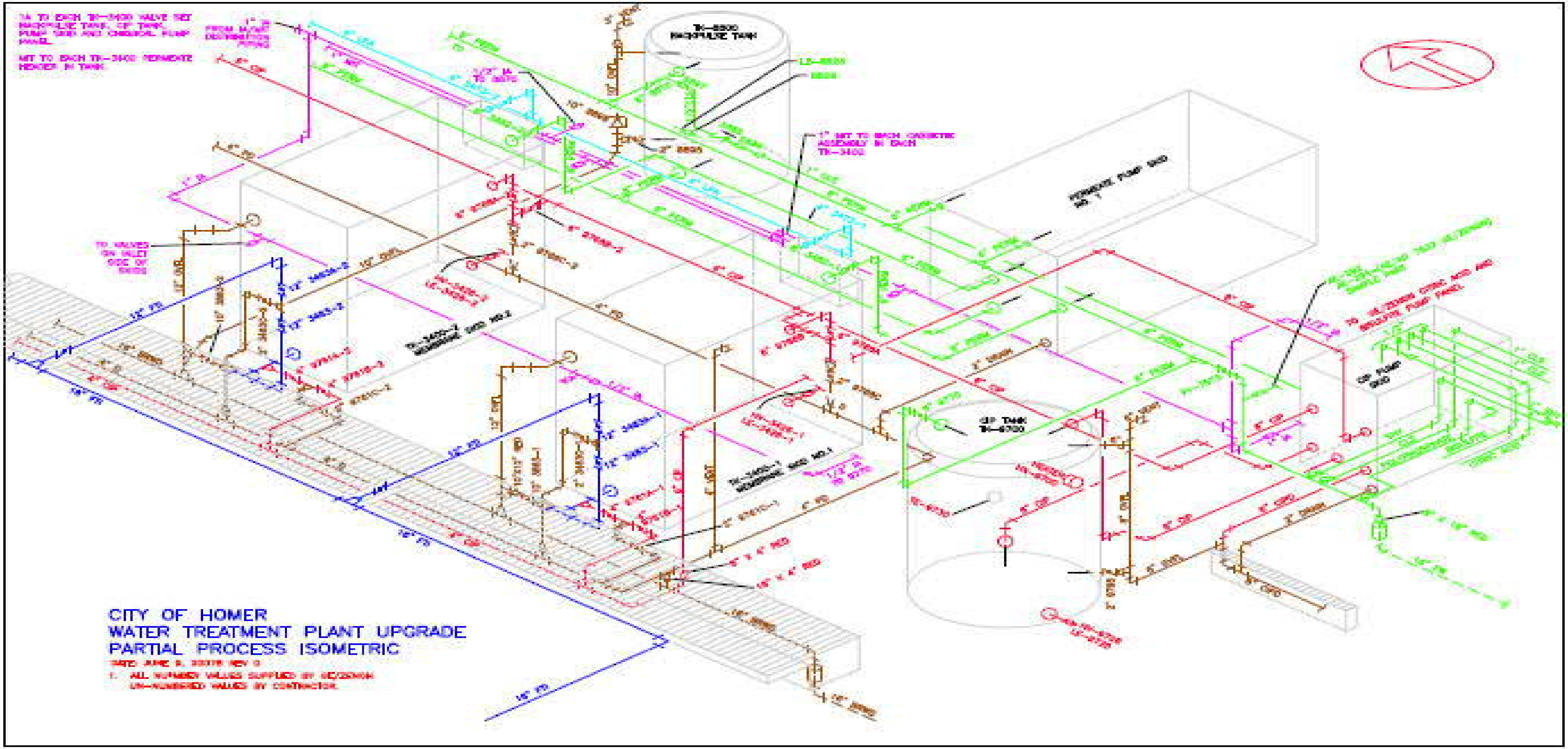
Membrane Process Design Considerations

- Make sure adequate membrane surface area is acquired to provide firm capacity regardless of water temperature
- Adequate safety factors should be included to account for membrane aging issues
- Monitor membrane permeability rather than TMP
- Adequate pretreatment should be included to accommodate potential raw water quality changes
- Overall plant hydraulics and flow balance should be evaluated: constant flow or constant flux

Piping Looks Relatively Simple - Sure



Piping Isometric Constructed From P&ID’s and Vendor‘s Various Shop Drawings



Approved Shop Drawing Could be Changed

Permeate – Backwash – CIP Supply Piping to Pump Skids

Seismic Design Should be Included

Ventilation should be considered for Chemical Cleaning

Planning For Startup Begins In Design

Easy Puzzle to Put Together?
Installation Manuals Up to Date and Clear?

Inlet – Backwash Waste – Overflow – CIP Return – CIP Drain Piping
From Opposite Ends of Inlet Side of Tanks