CornellEngineering
Civil and Environmental Engineering

CEE 4540

Sustainable municipal drinking water treatment

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Membrane Basics

YuJung Chang

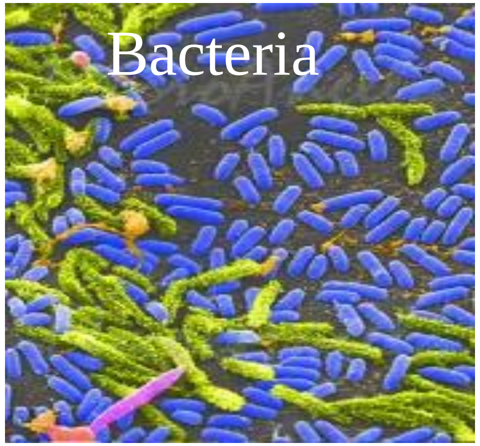
Membrane Filtration

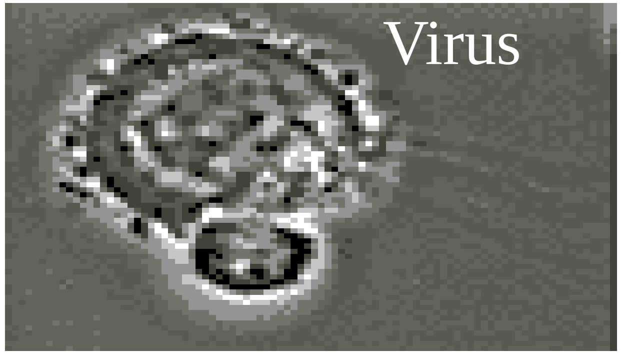
- Membrane Classification
- Membrane Operation
- Membrane Fouling
- Membrane Cleaning
- Membrane Procurement
- Pilot Study
- Cost
- Membrane Applications

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

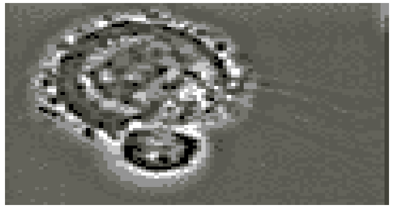
Membranes Classification:
Pore Size

- 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

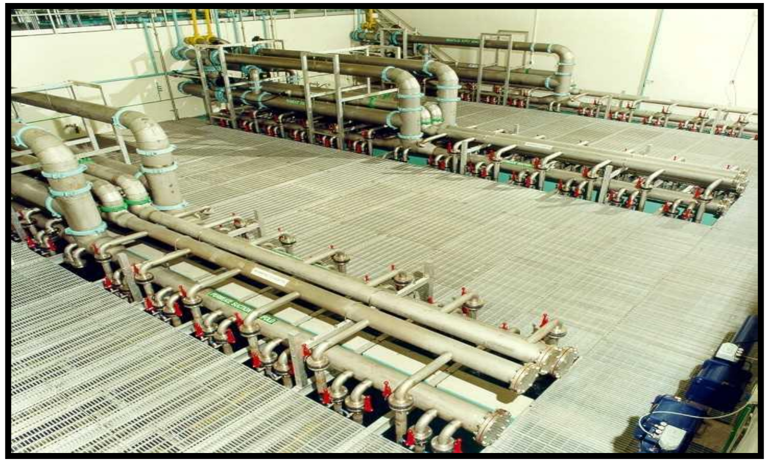
Membranes Classification:
Driving Force

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

Membranes Classification:
Driving Force

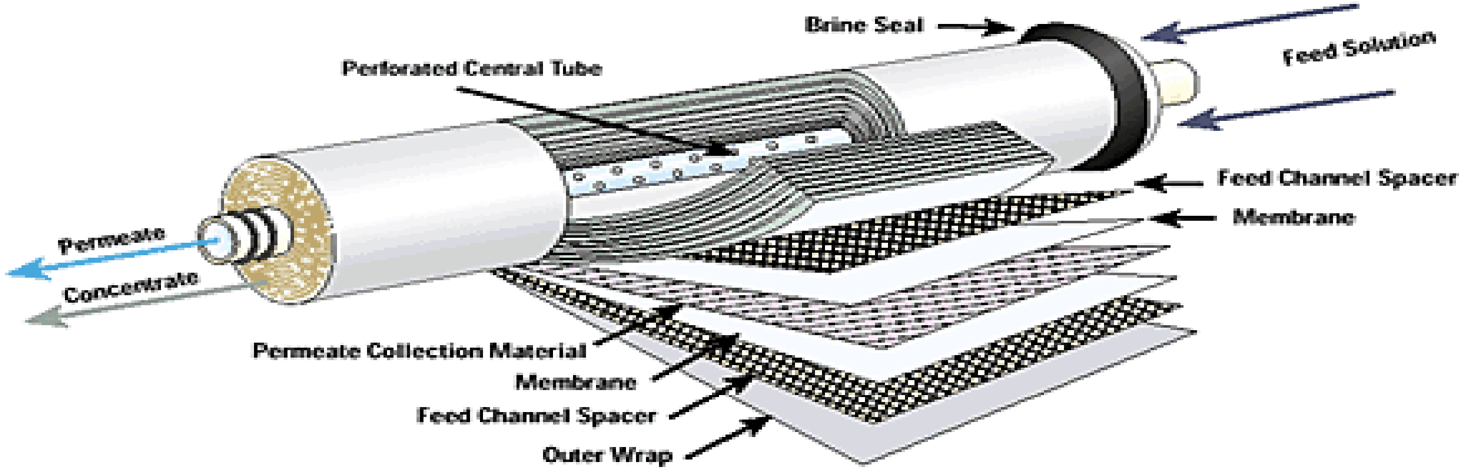
- Vacuum (Submerged Membranes)
  - Compatible with higher solid concentration
  - Can be used for retrofit
  - High energy demand with air scouring
  - Noise & evaporation concerns



Membranes Classification:
Membrane Configuration

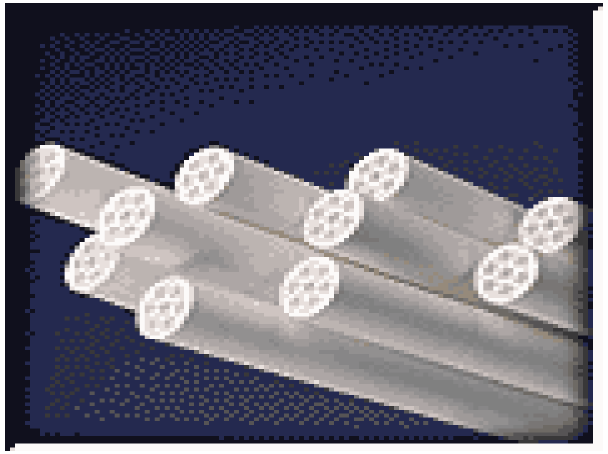
- Flat Sheet (Spiral-wound)



Mostly used in Reverse Osmosis

Membranes Classification:
Membrane Configuration (cont.)

– Tubular Membranes (OD > 3 mm)

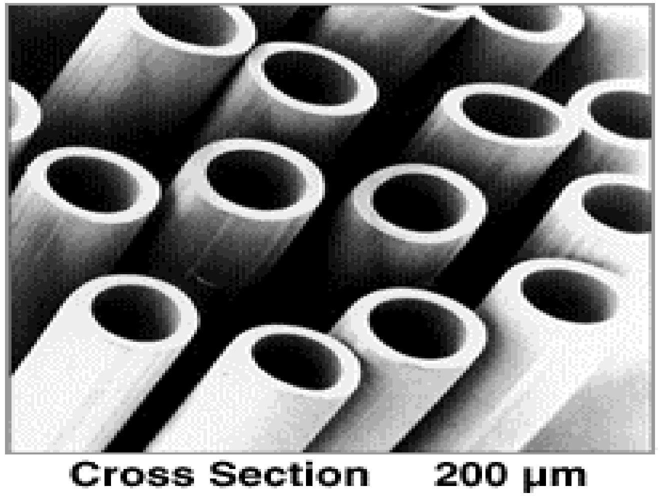


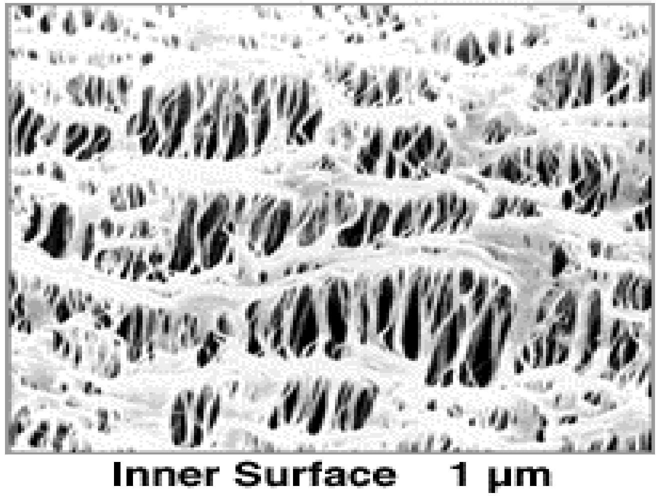
BASF Multi-bore membrane

Mostly used in Industrial MF

Membranes Classification:
Membrane Configuration (cont.)

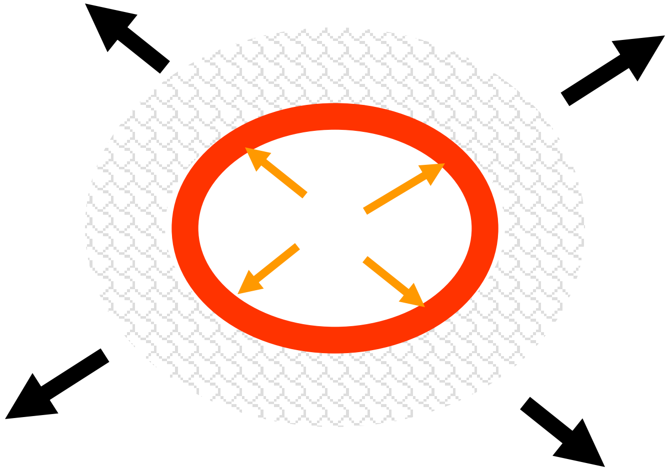
– Hollow Fiber Membranes (ID < 1.5 mm)





Membranes Classification:
Location of Membrane Surface

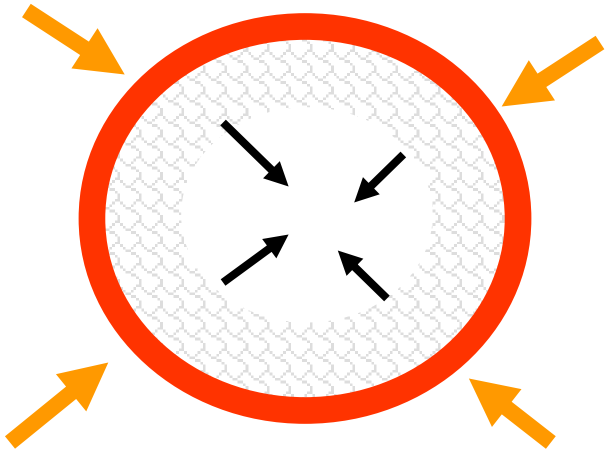
Inside-out Membranes



Raw Water

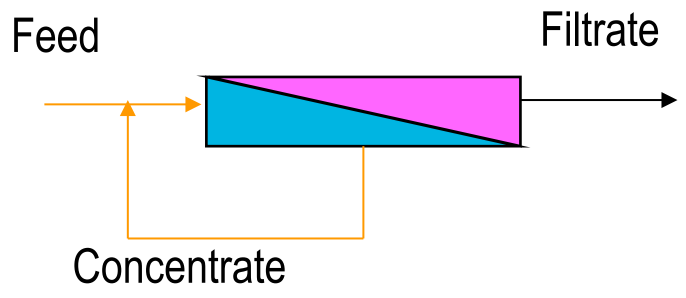
Filtered Water

Outside-In Membranes



Membranes Classification:
Reject Circulation

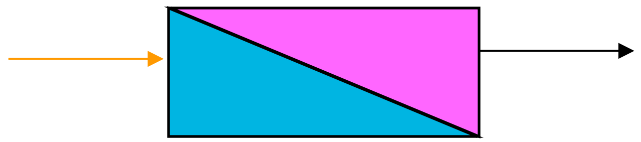
– Cross Flow (with circulation)
- Provide tangential scouring
- Reduce fouling potential (e.g., high solids)
- Requires more energy



Dead End (without circulation)

Energy efficient

More sensitive to change of water quality



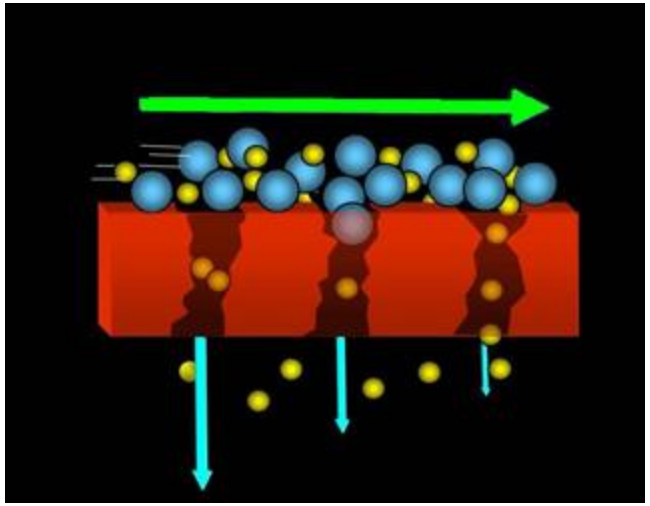
Membrane Basics

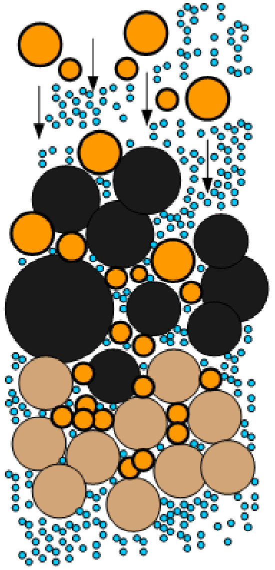
Membrane Operation

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)

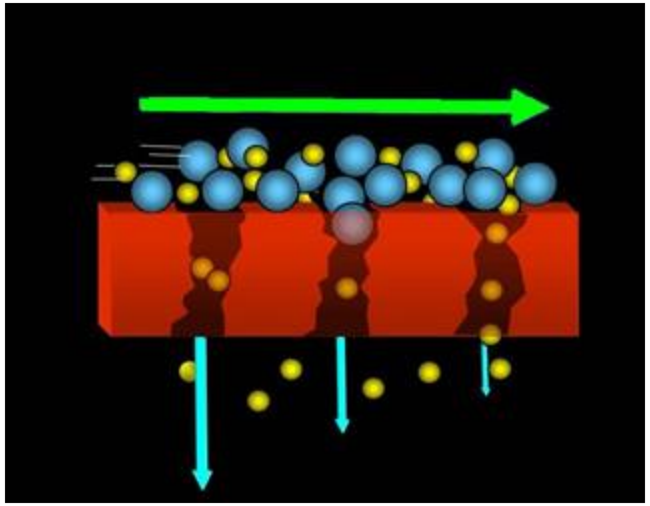
(No rinsing, surface wash, or filter-to-waste)

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

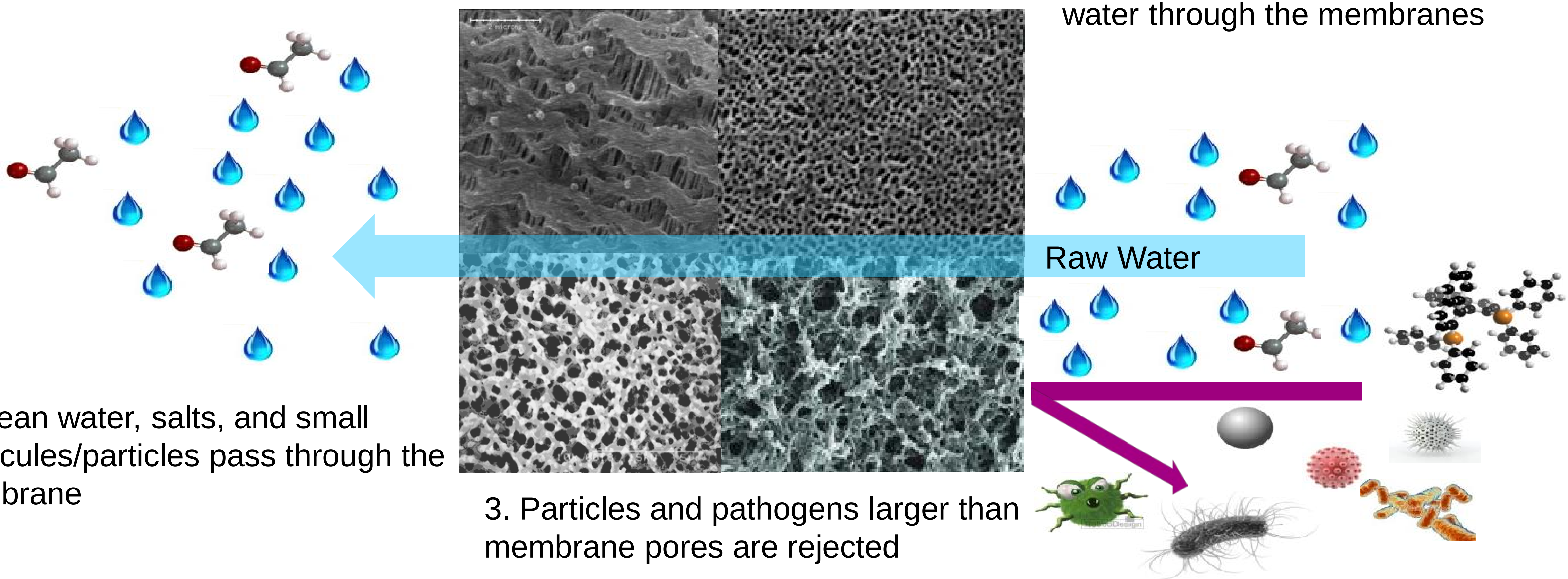
Membrane Basics

Membrane Fouling

What is a membrane and how does it work?

1. Membranes is semi-permeable surface with microscopic pores

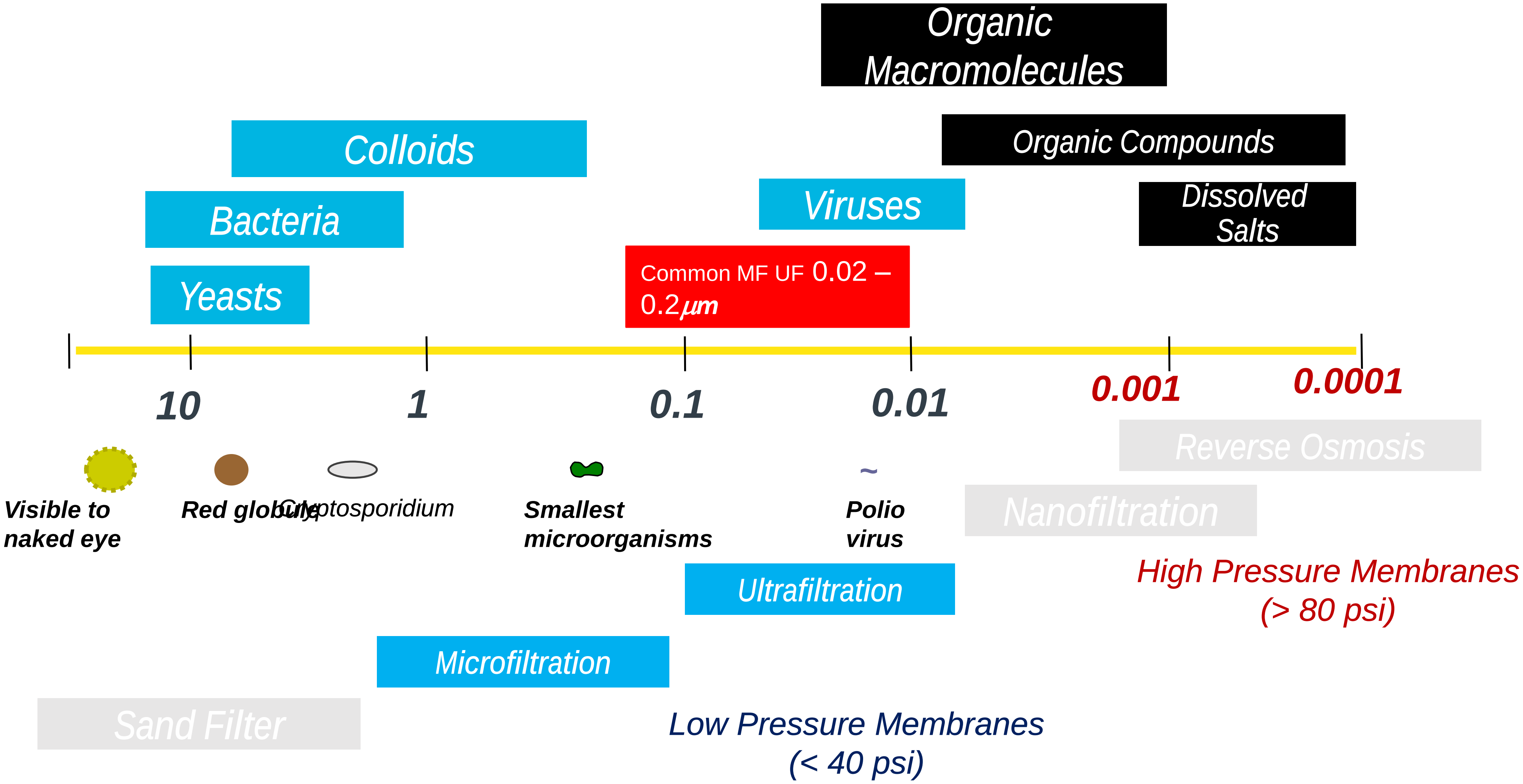
2. Pressure or vacuum drives water through the membranes



3. Particles and pathogens larger than membrane pores are rejected

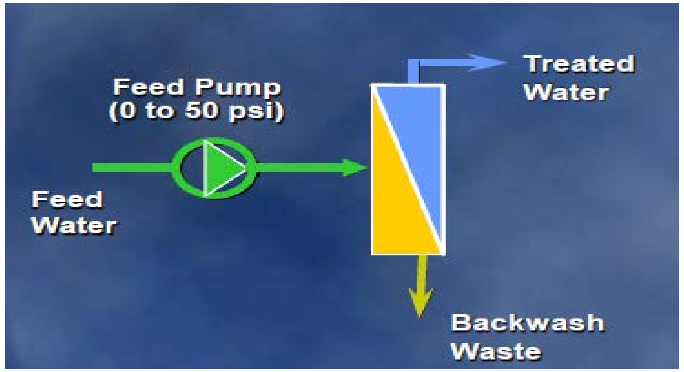
4. Clean water, salts, and small molecules/particles pass through the membrane

Types of Membranes



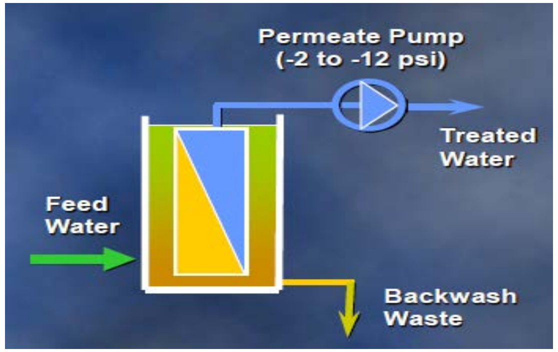
Pressurized Membrane System

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)



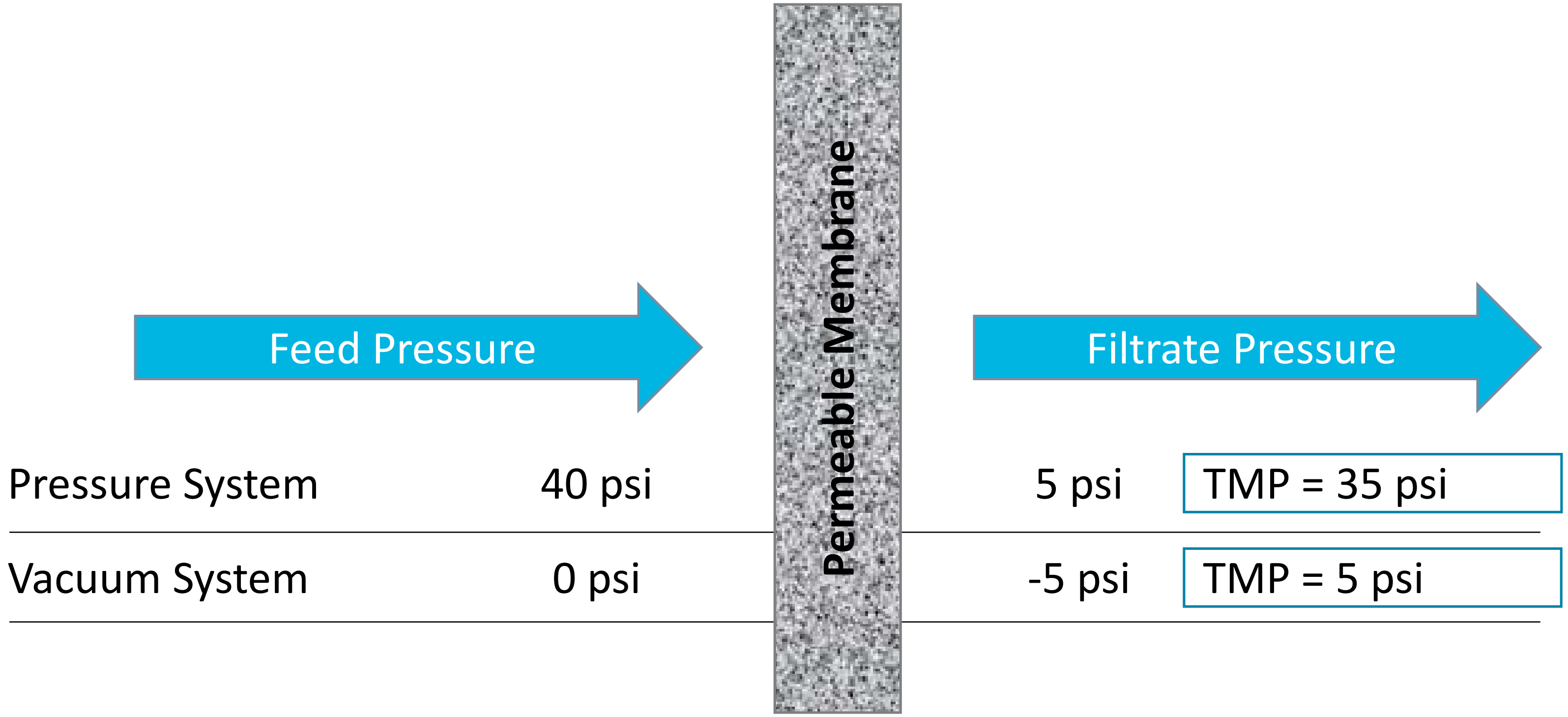
Submerged Membrane System

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)



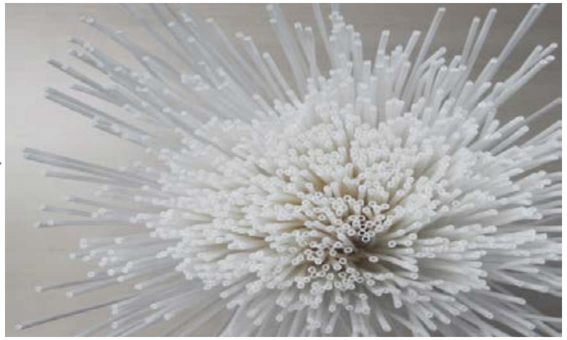
Membrane Filtration Flux

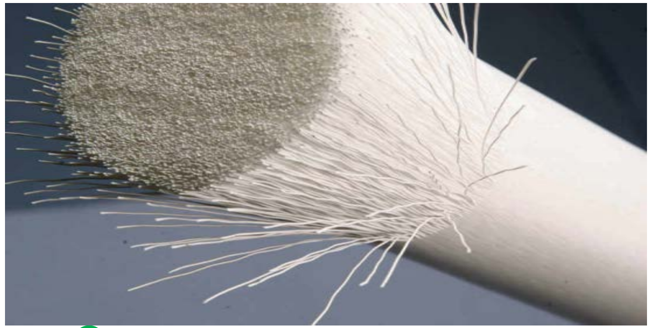
– The throughput of a membrane filtration system, expressed as flow per unit of membrane area, gallons per square foot per day (gfd)

– Typical flux for drinking water application ranges from 30 gfd to 70 gfd

– Ceramic membranes can produce > 200 gfd

Feed





Filtrate

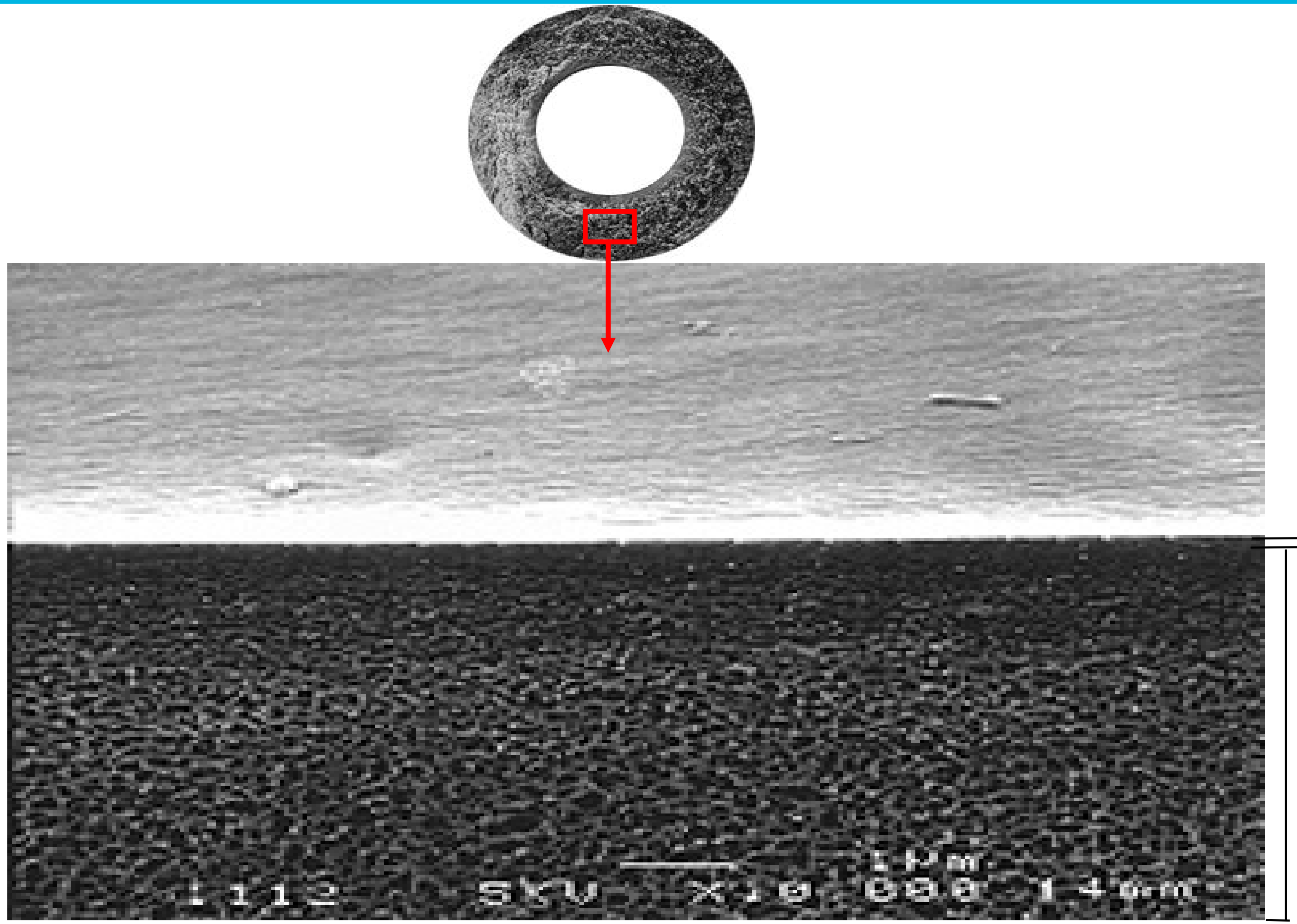
Filtrate Flow = 1,000,000 gpd
Membrane Area = 28,600 sf
Flux = 35 gfd

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

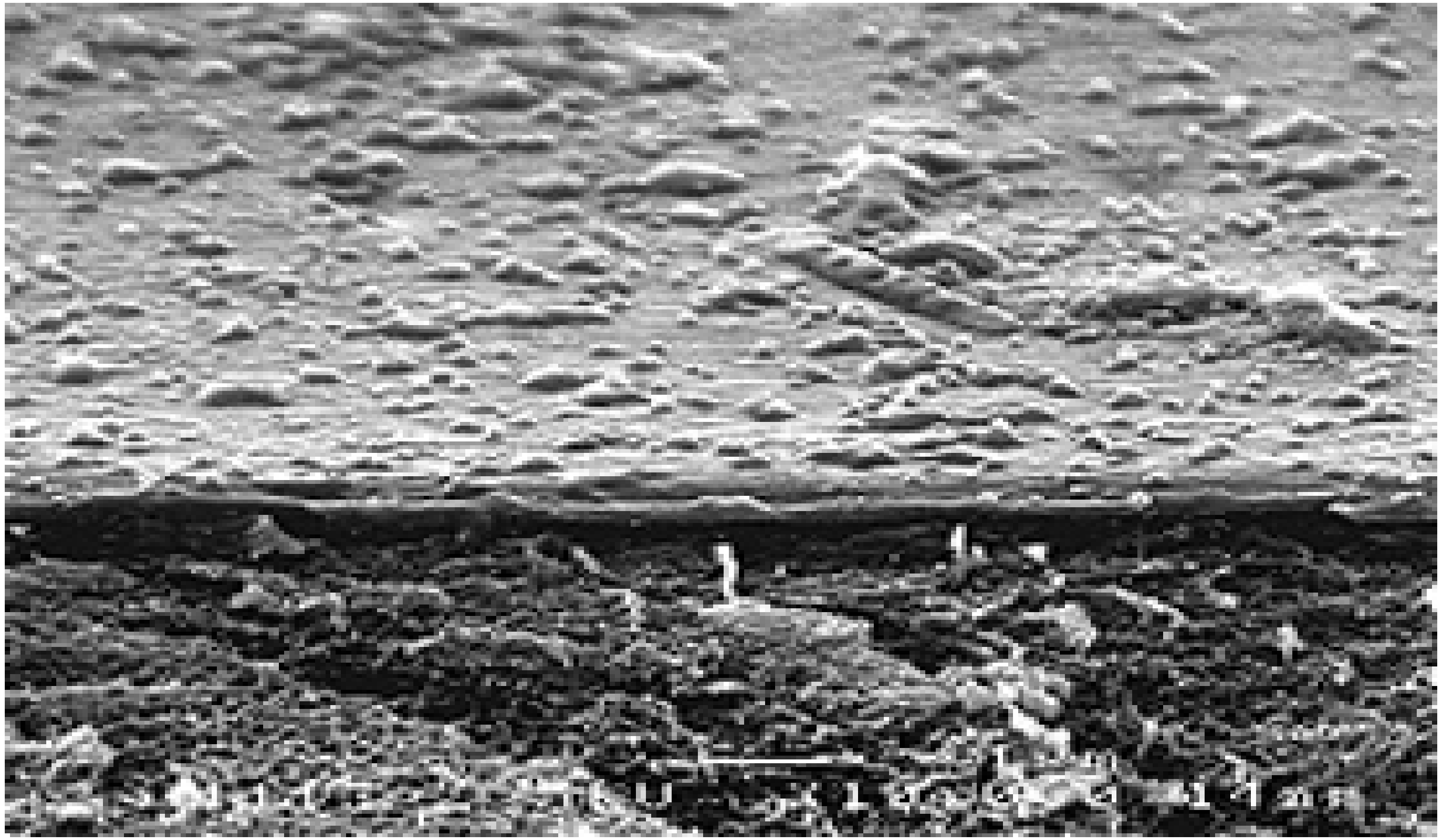
Challenges to Membrane Operations

- Membrane Fouling: Loss of Membrane Permeability
  - Rapid Permeability Decline
  - Low Permeability Recovery
- Membrane Integrity: fibre Breakage/Module Deterioration

Clean Membrane Surface



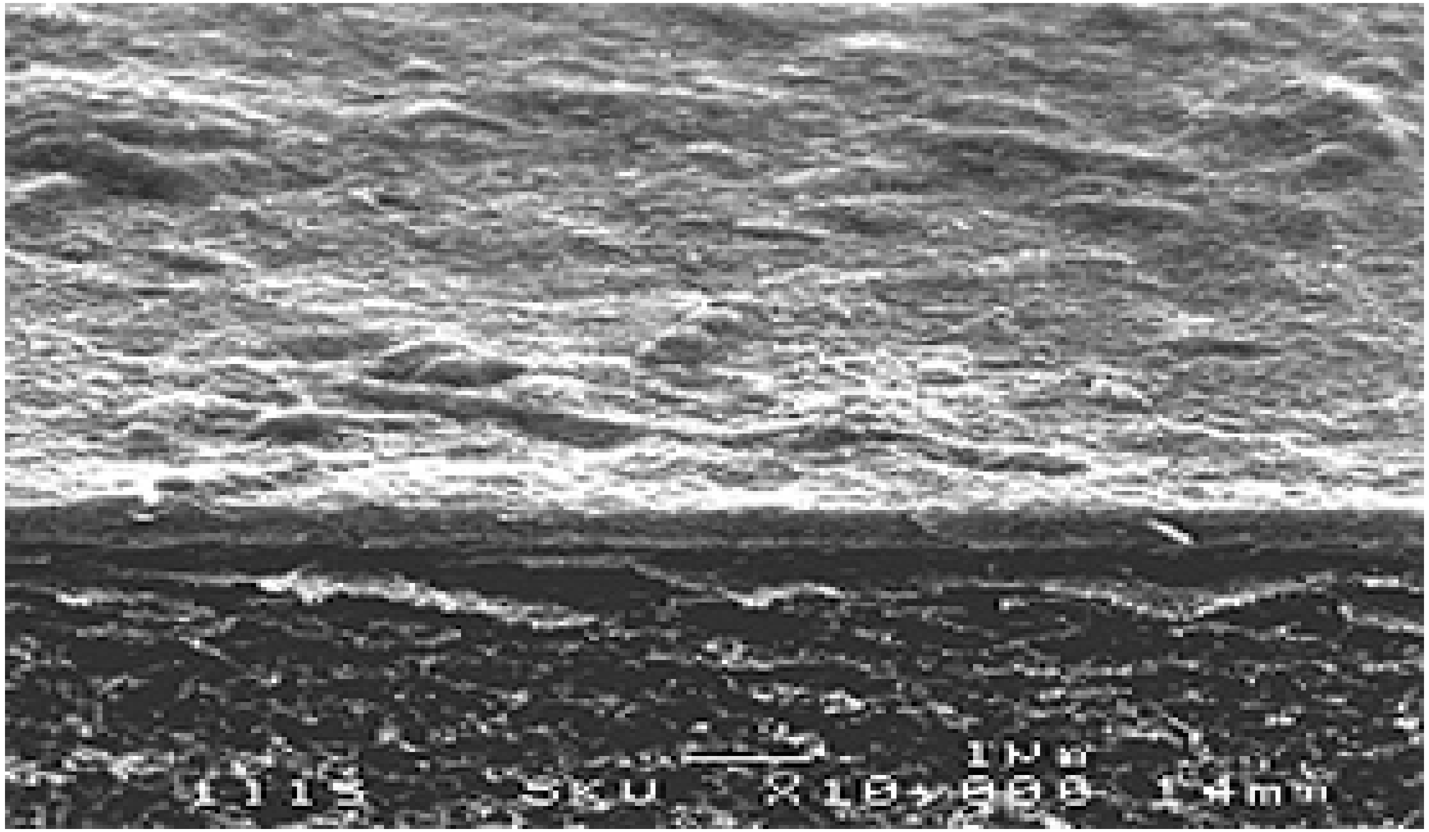
Dead End Filtration for 30 min



Film Thickness: NA

Permeability Decline: 10%

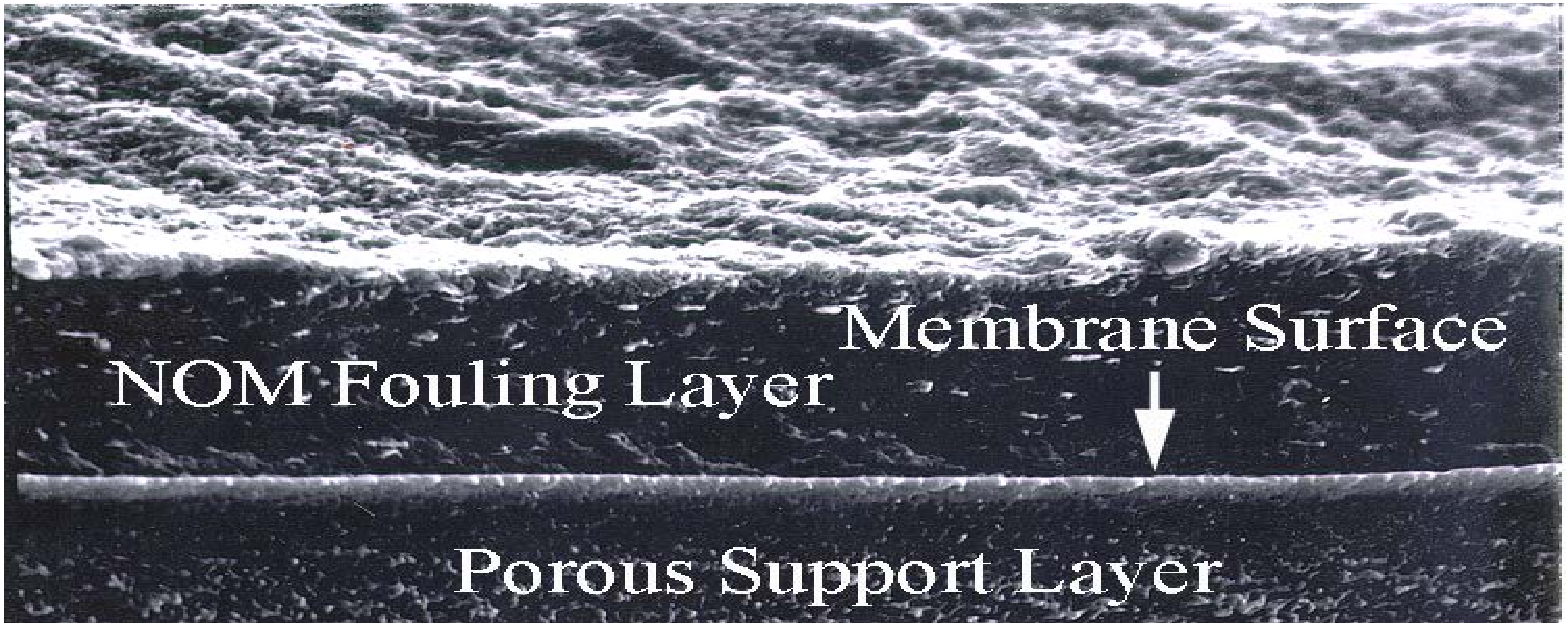
Dead-End Filtration – 1.5 hour



Film Thickness: < 0.1 µm

Permeability Decline: 30%

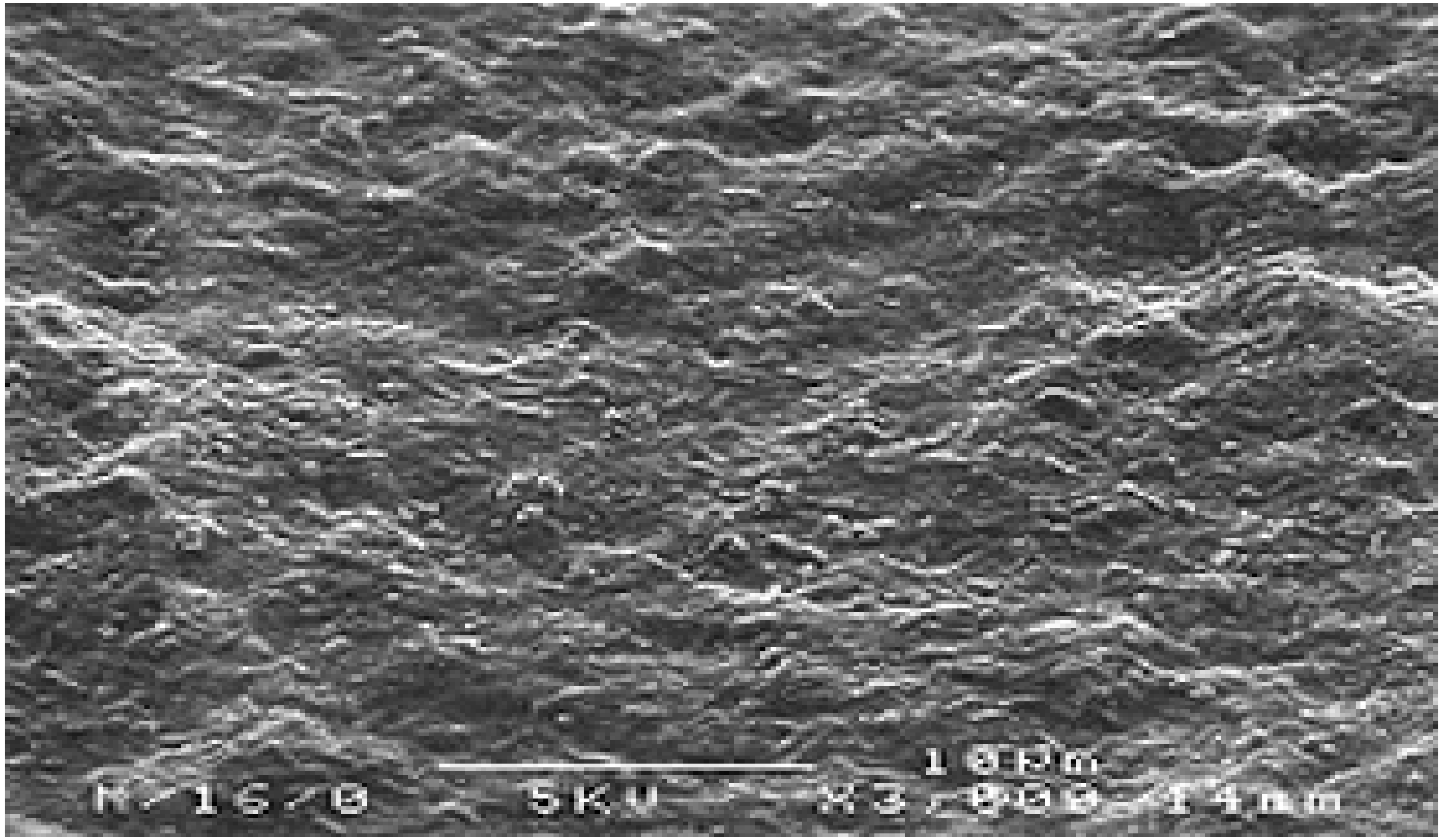
Dead End Filtration -- 20 hours



Film Thickness: 1.5 μm

Permeability Decline: 79%

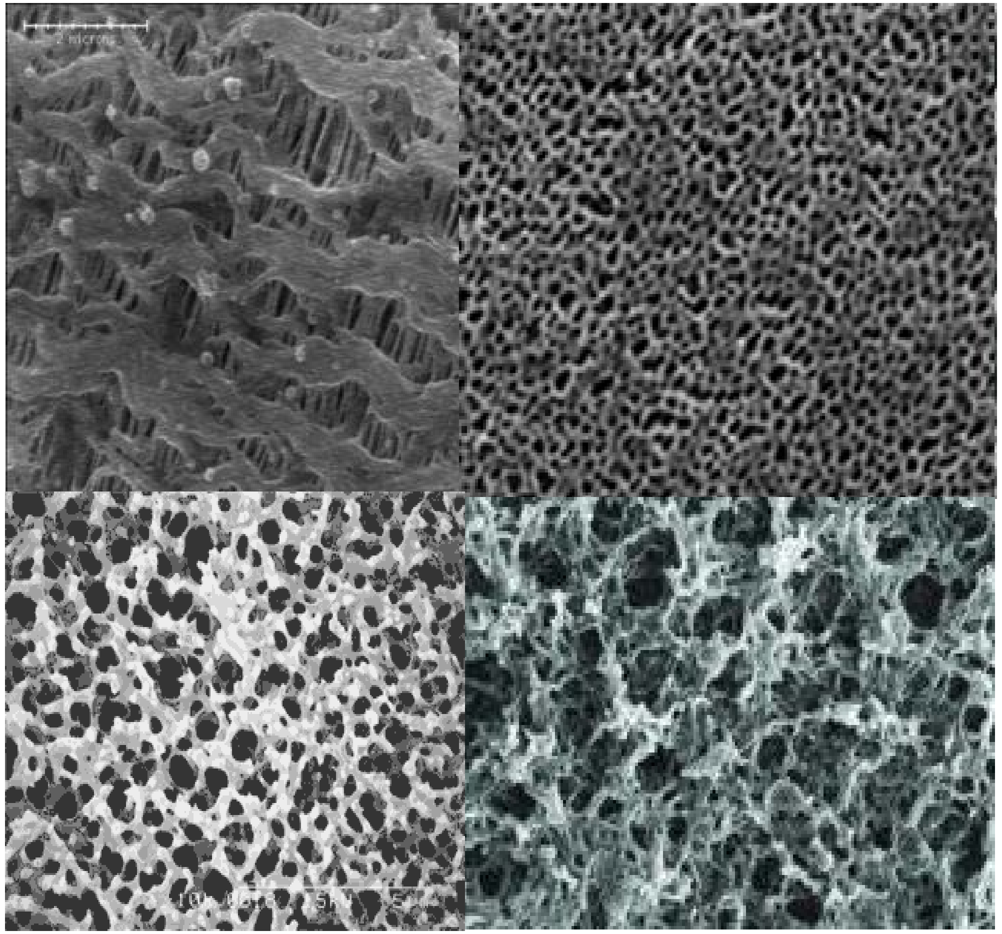
NOM Layer Before Backwash



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

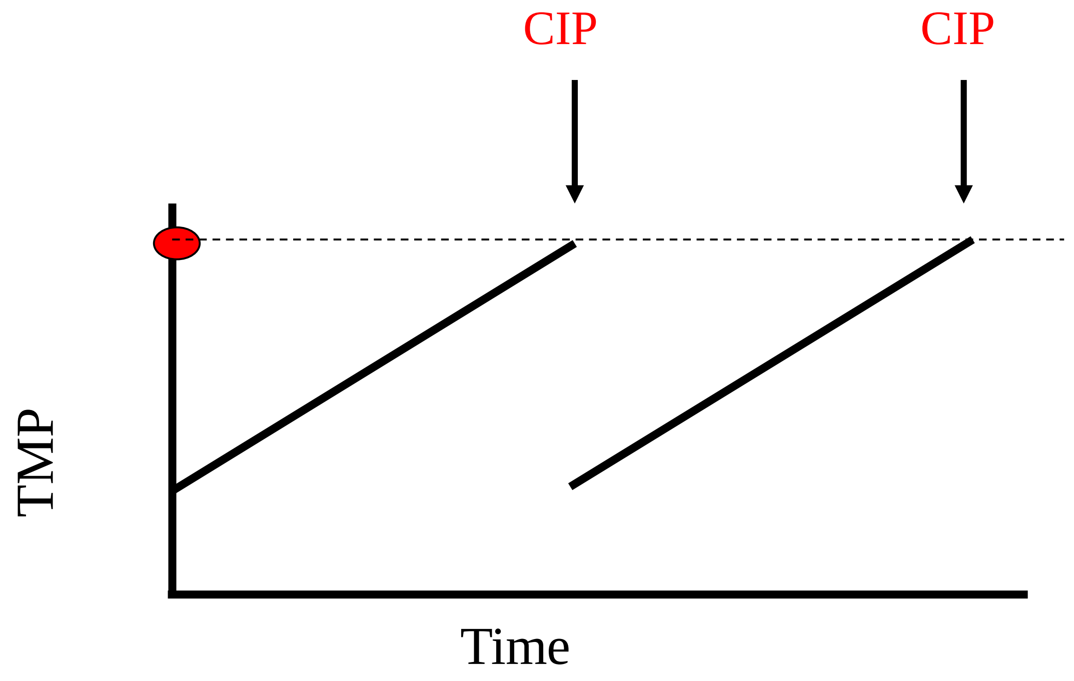
$$Permeability = \frac{Flow\ Rate\ \left(\frac{gal}{day}\right) \times Water\ Viscossity\ (cP)}{Membrane\ Surface\ Area\ (ft^2) \times TMP(psi)}$$

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

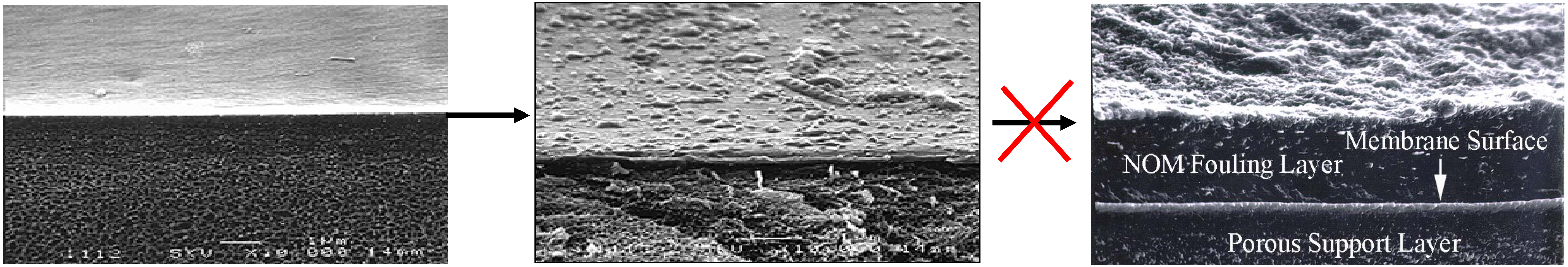
Chemical Cleaning

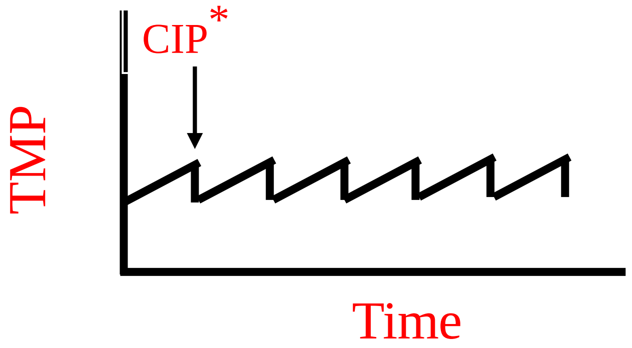
– Chemical addition in backwash water

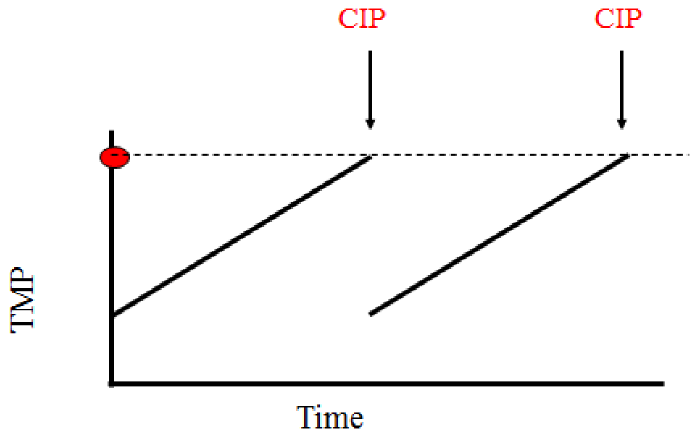
– Clean-in-place (CIP)
  - Multiple chemicals
  - High chemical doses
  - Long soaking time (> 1 hour)



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 ^oF

Rinse

0.25% NaOH

200 ppm Cl_2

pH 6-9.5

Circulation for 1 hour

Koch System Performance

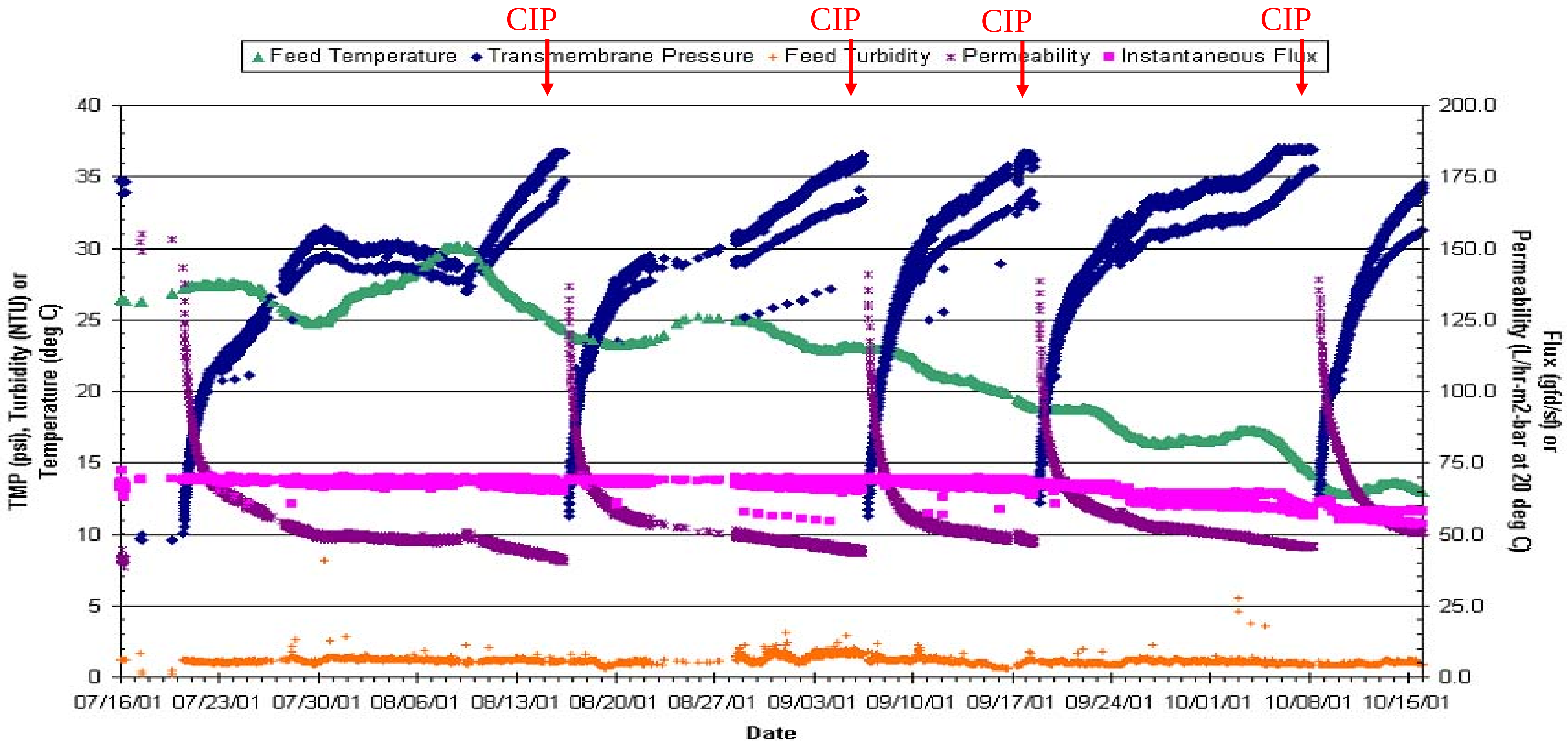


Illustration of Ionics CEB

Backwash

30 sec.

Backwash/Chemical

30 sec.

Backwash/Rinse

60 sec.

Soaking 10 min.

Ionics System With Stable TMP and Permeability