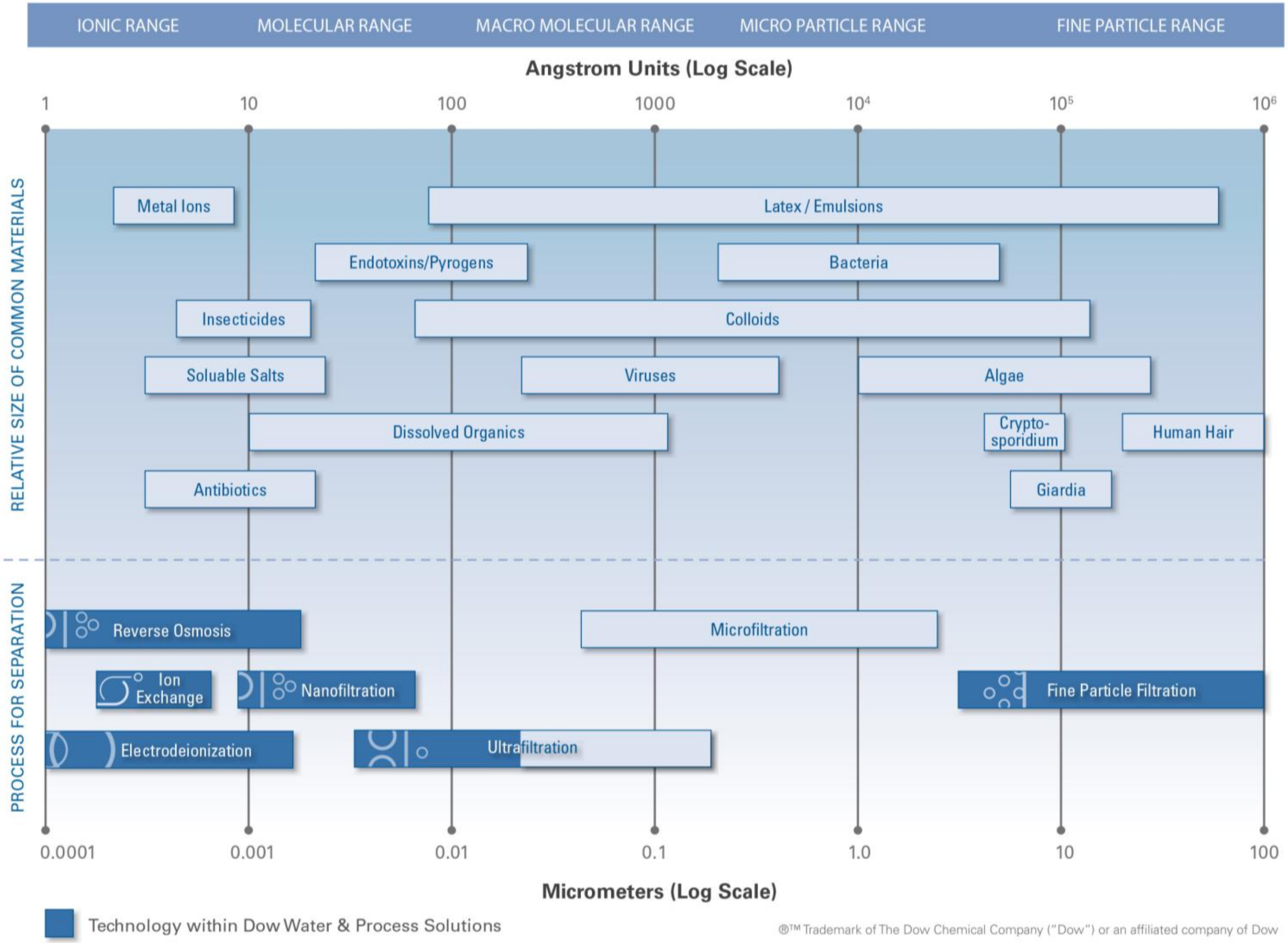
WATER & PROCESS SOLUTIONS

Reverse Osmosis 101

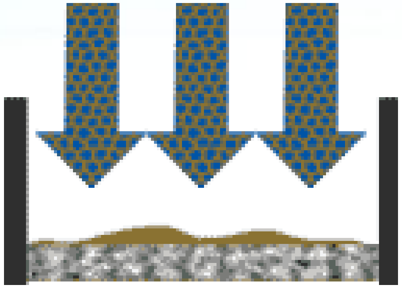
Content

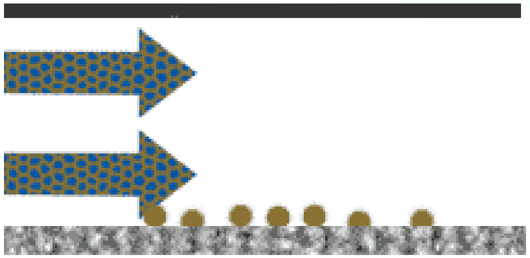
- Filtration spectrum of membranes
- Basics of Reverse Osmosis and equations
- Factors which affect membrane performance
- Thin Film Composites and Spiral Wound Membranes
- Applications and Markets

Filtration spectrum



Membrane operation modes





Dead-end filtration

Not feasible for RO/NF:

- Sparingly soluble salts precipitate and foul the membrane.
- Filter cake build-up

Cross-flow filtration

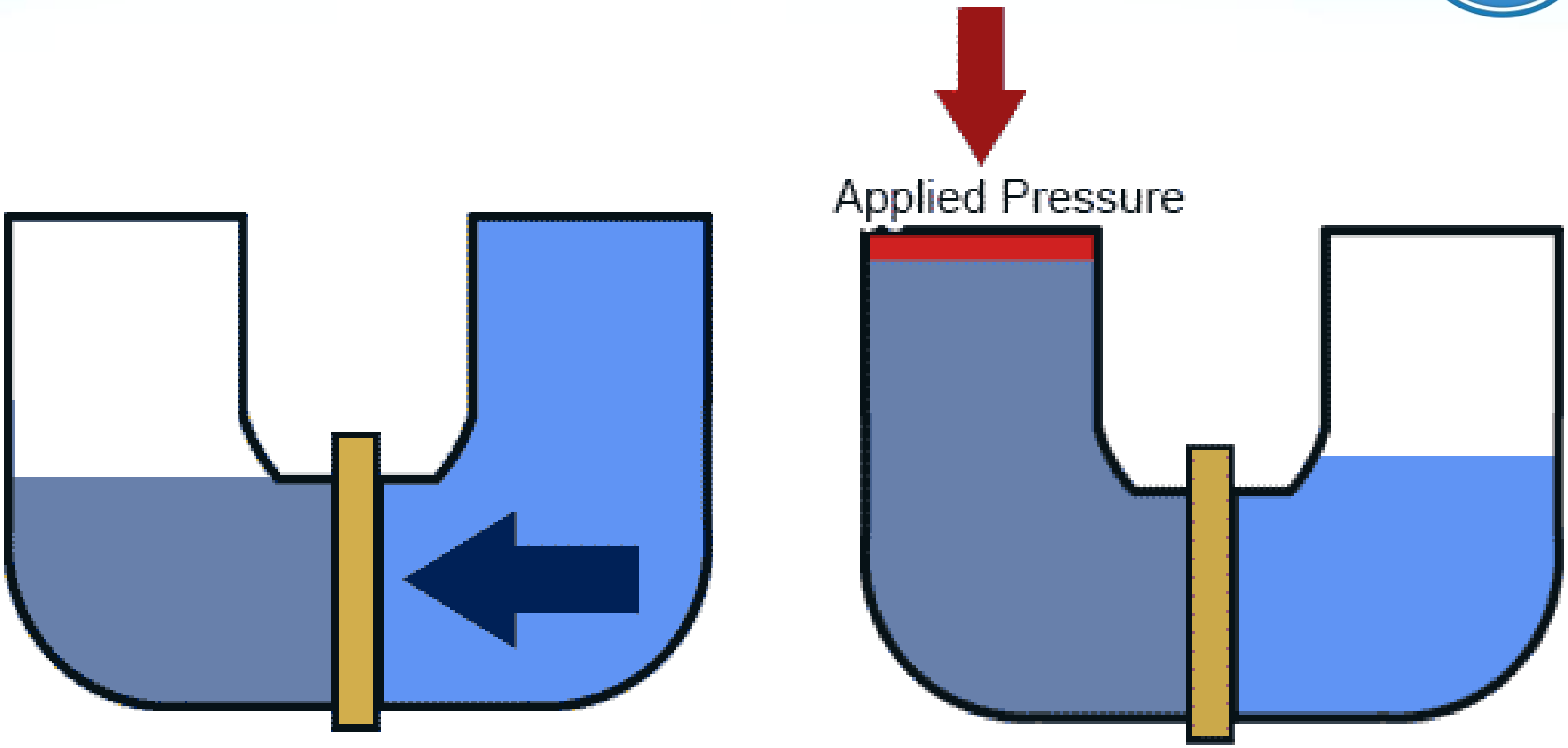
Required for RO/NF:

- Sweeps away membrane foulants
- Minimizes concentration polarization
- Generates a concentrate stream and a permeate stream

Typical operating pressures of different pressure driven processes

Membrane Process	Typical Operating Pressure Range (bar)	Typical Operating pressure (psi)
Reverse Osmosis Seawater Brackish water	 55 – 76 10 - 40	 800 - 1100 145 - 580
Nanofiltration	3.5 - 15	50 - 220
Ultrafiltration	2 – 7	30 - 100
Microfiltration	0.1-3	1.5 - 45

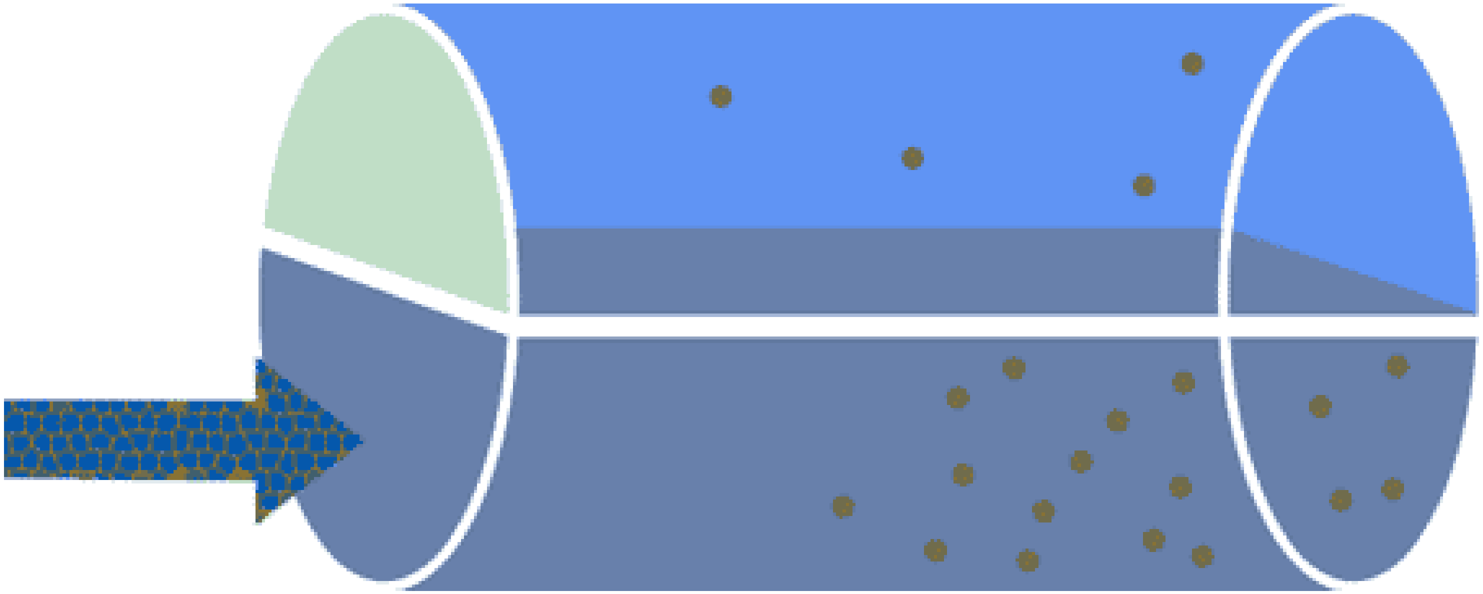
Basics of reverse osmosis



Osmosis

Reverse Osmosis

Reverse osmosis separation process



What RO can do?

- ✓ Remove purified water from a feed stream (permeate)
- ✓ Concentrate chemicals in a feed stream (reject)
- ✓ Selectively separate small ions and molecules

What RO cannot do?

- Cannot concentrate to 100%
- Cannot separate to 100%

Osmotic pressure – rule of thumb

- Convert TDS to osmotic pressure:
  - TDS in ppm divided by 100: osmotic pressure in psi
  - TDS in ppm divided by 1400: osmotic pressure in bar
- Examples:
  - 100 ppm TDS » 1 psi osmotic pressure (» 0.07 bar)
  - 1,000 ppm TDS » 10 psi osmotic pressure (» 0.7 bar)
  - 35,000 ppm TDS » 350 psi osmotic pressure (» 25 bar)

Osmotic pressure

For dilute solutions, osmotic pressure is approximated using the Van’t Hoff equation:

$$\pi = \phi \, C_i \, RT$$

π - osmotic pressure, atm

ϕ - osmotic pressure coefficient

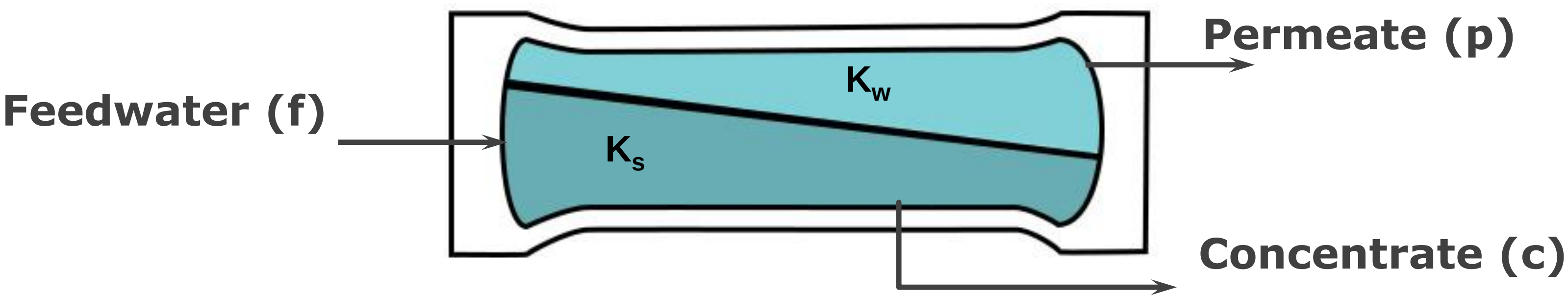
C_i - molar concentrate of the solute, mol/l

R - gas constant

T - absolute temperature (° K)

Homogenous solution diffusion model

Describes water flux, salt flux and mass-transfer in pressure-driven membrane systems



Homogenous solution diffusion model

Water and Solute Flux

$$F_w = K_w\,(\Delta P - \Delta\pi)$$

F_w - solvent flux [gallons per square foot per day=gfd]
K_w - solvent mass transfer coefficient [gfd/psi] (A value)
ΔP - transmembrane pressure differential [psi]
$\Delta\pi$ - osmotic pressure differential [psi]

$$Fs = Ks\,(\Delta C)$$

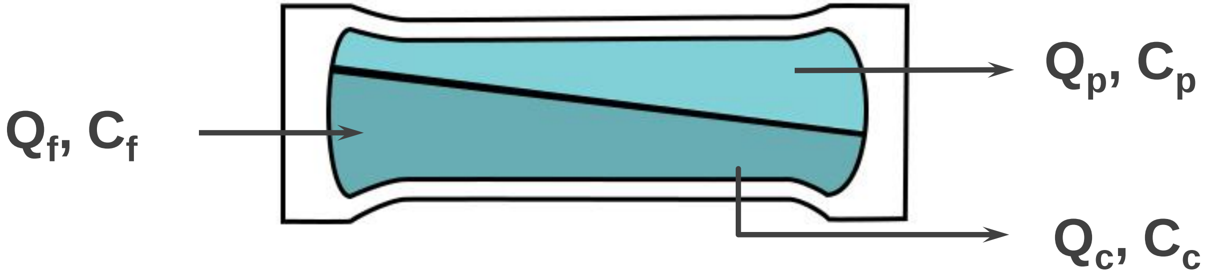
F_s - solute flux [pounds per square foot per day, lbfd]
K_s - solute mass transfer coefficient [gfd] (B value)
ΔC - transmembrane concentration differential [lb/gal]

Mass balance equations

$$Q_f = Q_p + Q_c$$

$$Q_f C_f = Q_p C_p + Q_c C_c$$

Q_f - feed flow [gal/min]
Q_p - permeate flow [gal/min]
Q_c - concentrate flow [gal/min]
C_f - feed solute concentration [lb/gal]
C_p - permeate solute concentration [lb/gal]
C_c - concentrate solute concentration [lb/gal]



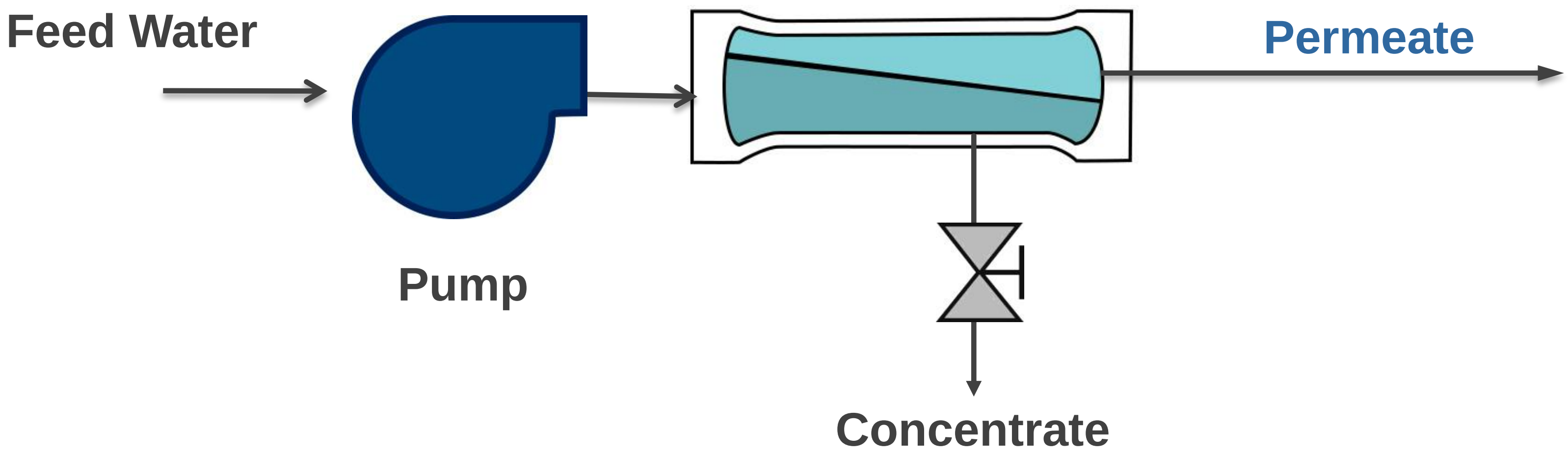
Basic definitions

$$\text{Recovery (\%)} = \frac{\text{Permeate flow}}{\text{Feed flow}} \times 100$$

$$\text{Salt Passage (\%)} = \frac{\text{Permeate Salt Concentration}}{\text{Feed Salt Concentration}} \times 100$$

Salt Rejection (%) = 100 – Salt Passage

Simplified RO system



100 to 600 psi (brackish water)
800 to 1,200 psi (seawater)

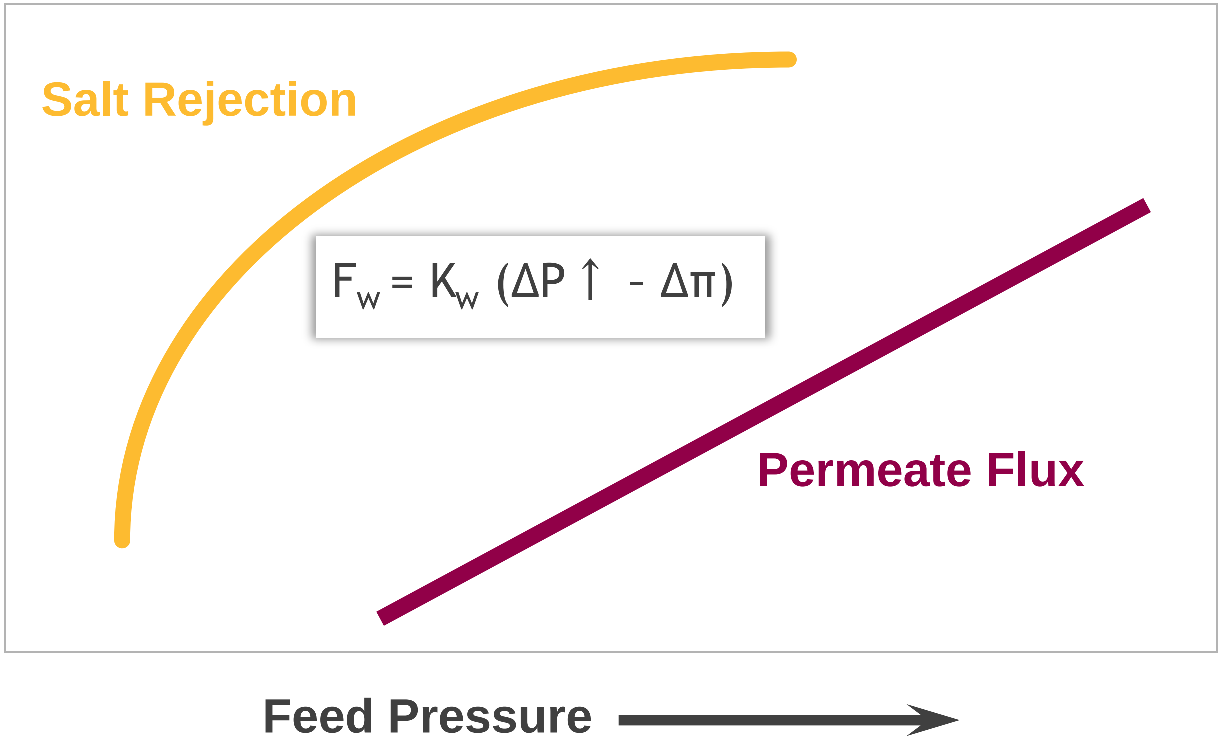
Factors which effect membrane performance

- Feedwater
  - Concentration
  - Temperature
  - Osmotic pressure
  - pH

- Operation parameters
  - Pressure
  - System recovery

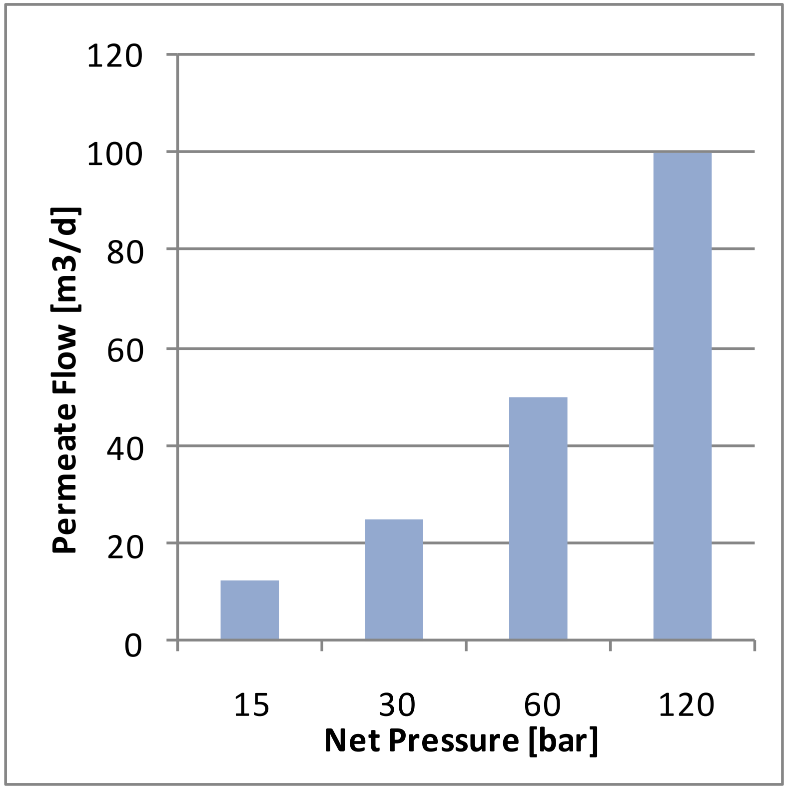
- Concentration Polarization

Affect of feedwater pressure on flux and salt rejection



Assuming temperature, recovery and feed concentration are constant

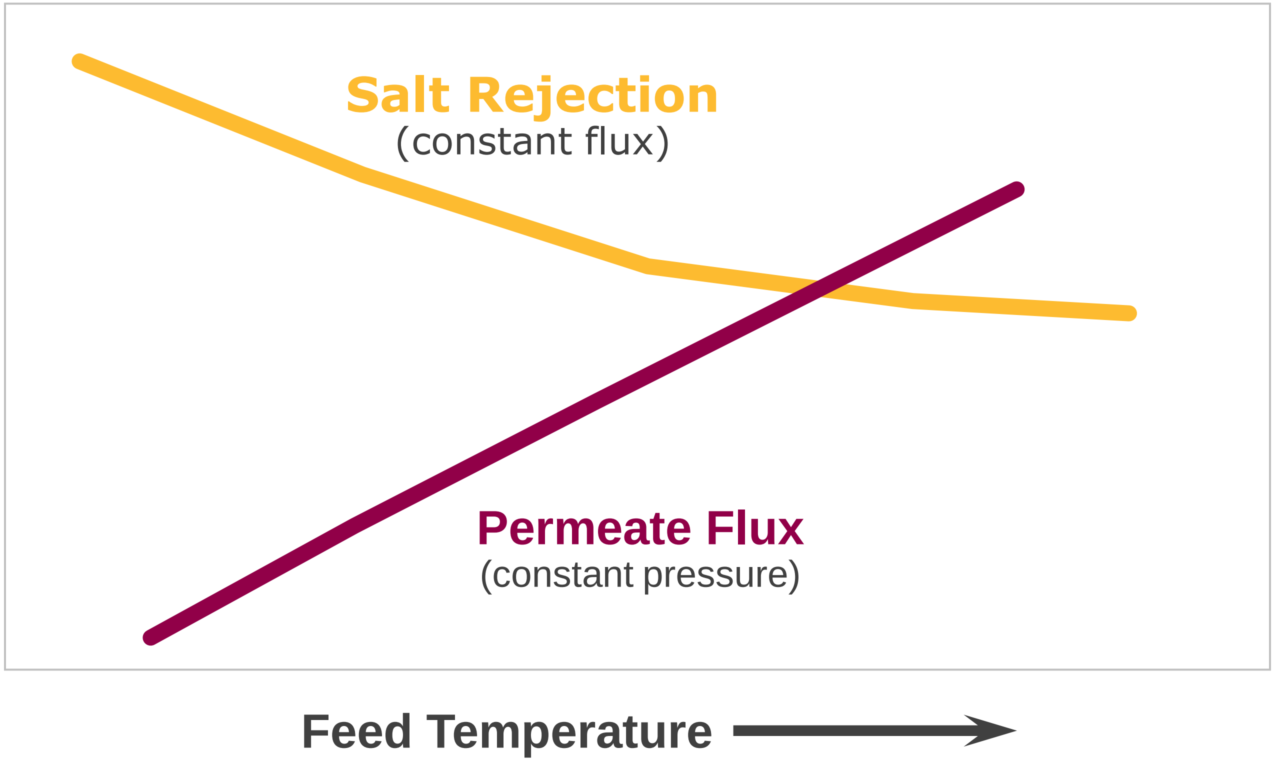
Pressure Affect



- If you double net driving pressure (NDP) to an RO unit you will double your permeate flow.
- NDP is the sum of all forces acting on the membrane

$$NDP = \Delta P - \Delta \pi$$

Feedwater temperature vs. flux and salt rejection



Assuming feed pressure, recovery and feed concentration are constant

Temperature Affect

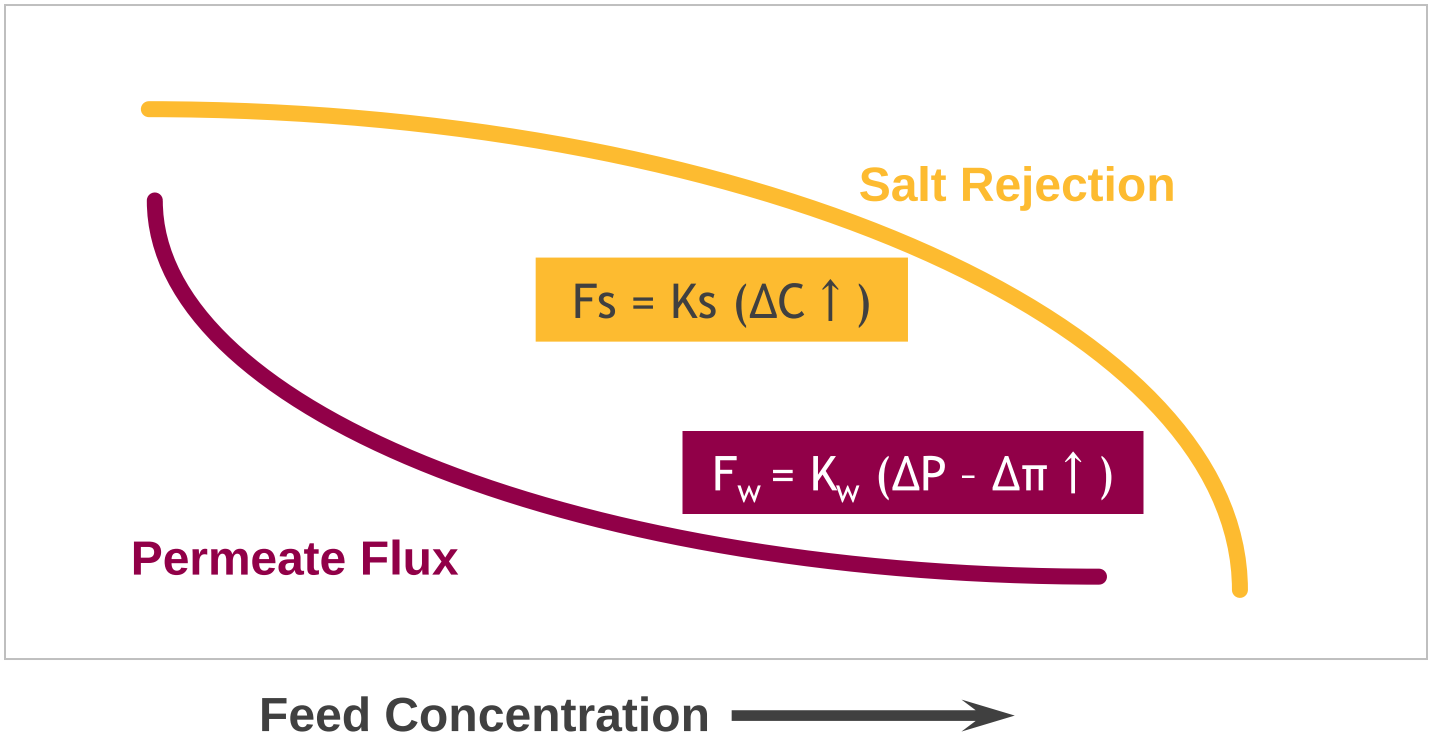
Permeate flow

- The higher the temperature the higher the permeate flow
- Why? Lower viscosity makes it easier for the water to permeate through the membrane barrier
- RULE OF THUMB – for every 1ºC the permeate flow will increase ~ 3%

Salt passage

- Rule of Thumb: salt passage increases 6% for 1ºC increase.
- Increasing temperature increases salt passage more than water passage.
- Generally you will get better rejections at lower temperatures.

Salt concentration vs. flux and salt rejection

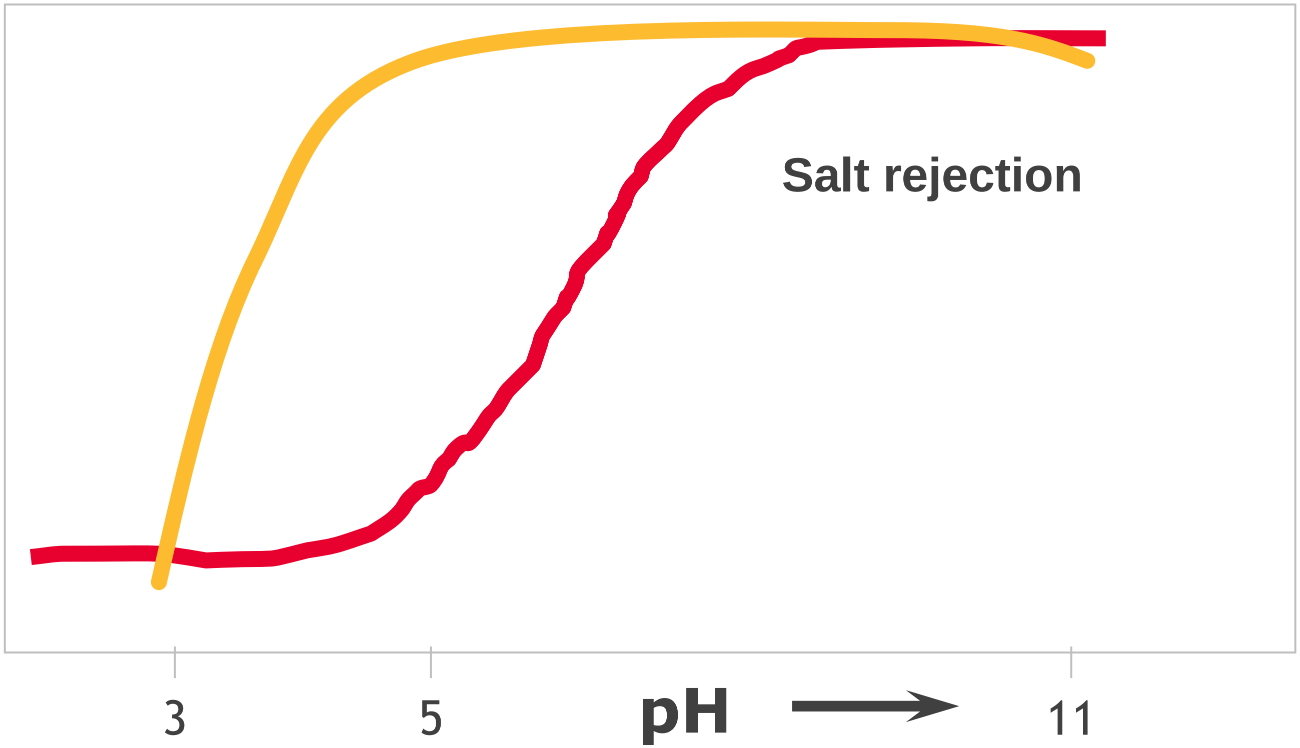


Assuming temperature, feed pressure and recovery are constant

Salt concentration affect

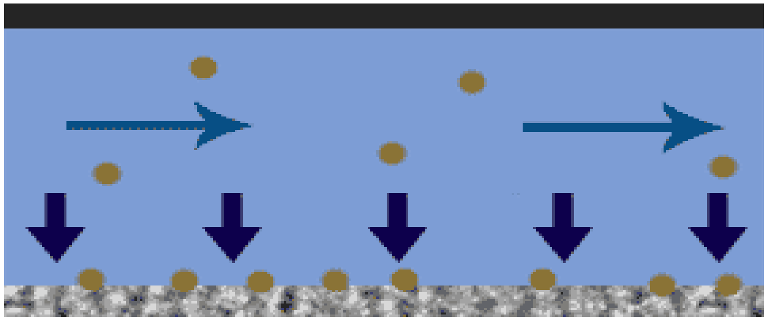
- Salt concentration affect on permeate flow
  - Higher salt concentration will decrease the permeate flow.
  - Why? Because higher osmotic pressure will reduce the NDP.
- Salt concentration affect on salt passage
  - Higher salt concentration will increase the salt concentration gradient and increase the rate of salt passage.
- Salt concentration affect on permeate quality
  - Overall water quality is lower for two reasons, higher rate of salt passage combined with less permeate water.

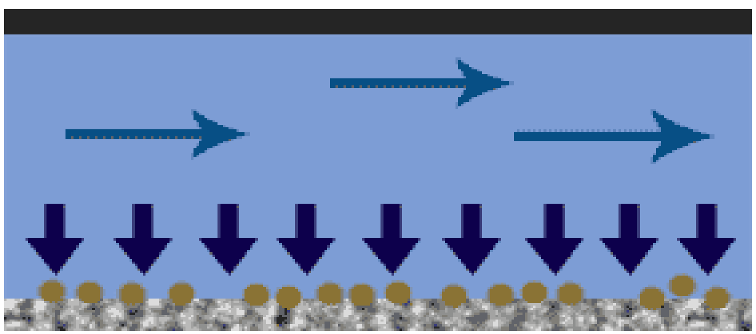
pH influence on salt rejection



Assuming temperature, feed pressure and concentration are constant

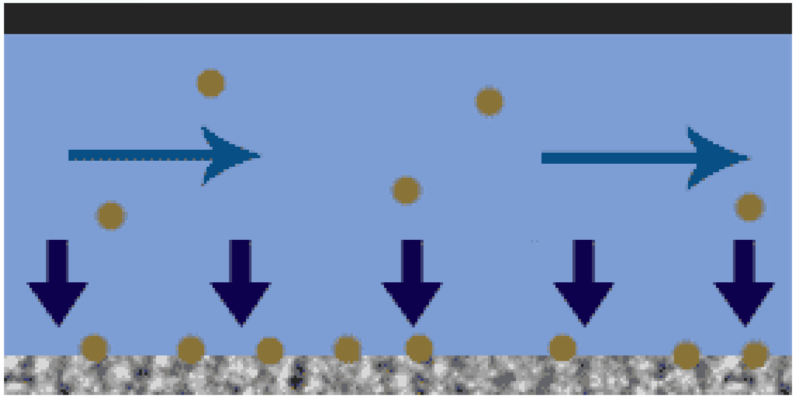
Boundary layer

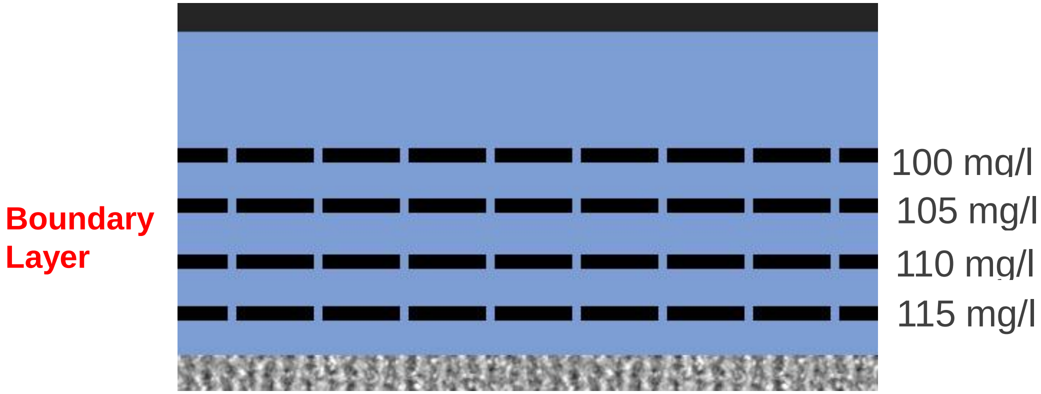




- Water near the membrane surface has little to no cross flow
- Creates an area for particulates & colloids to collect and foul the membrane.
- Water flux through the membrane helps hold foulants in place.

Concentration polarization

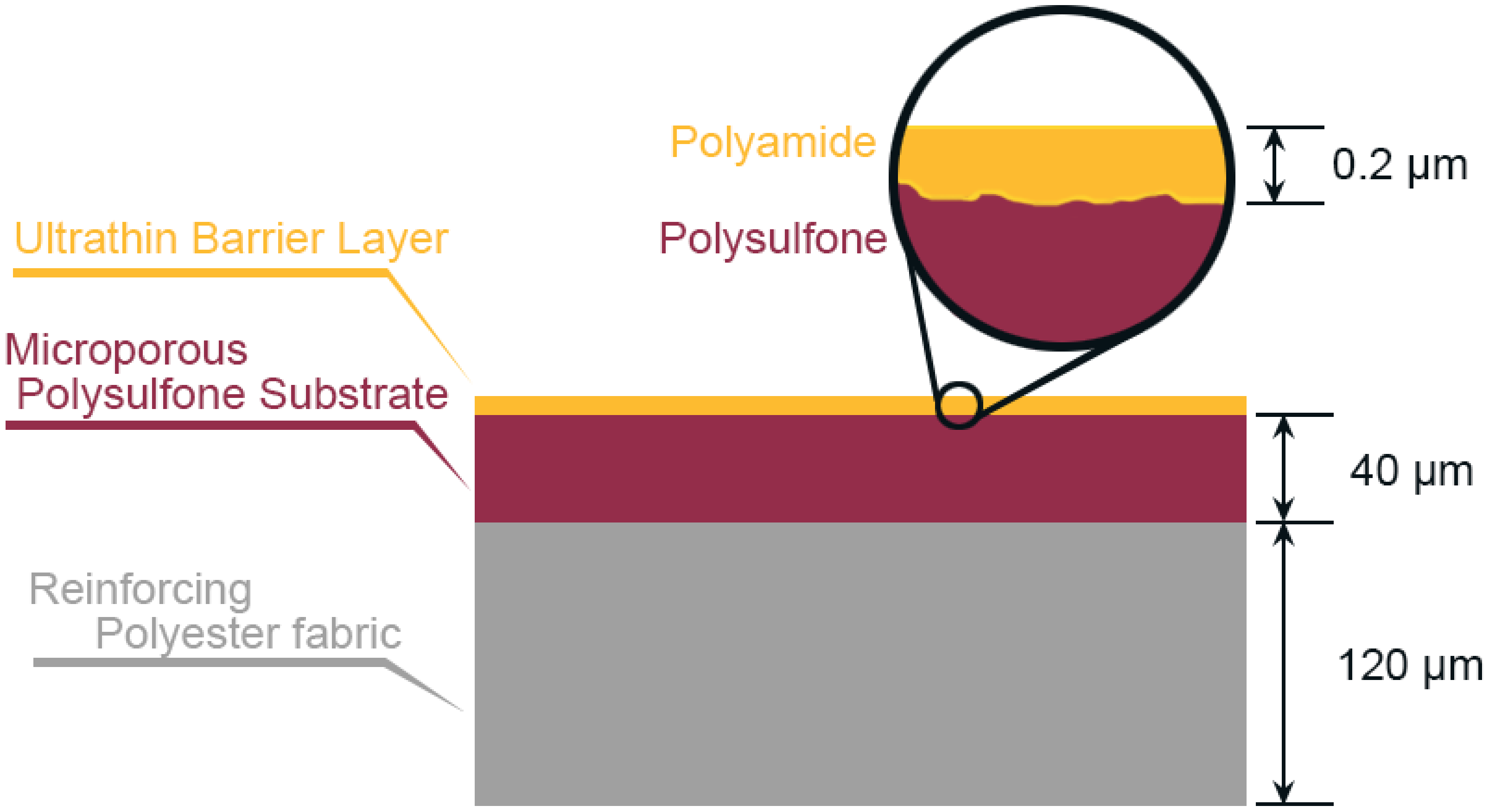




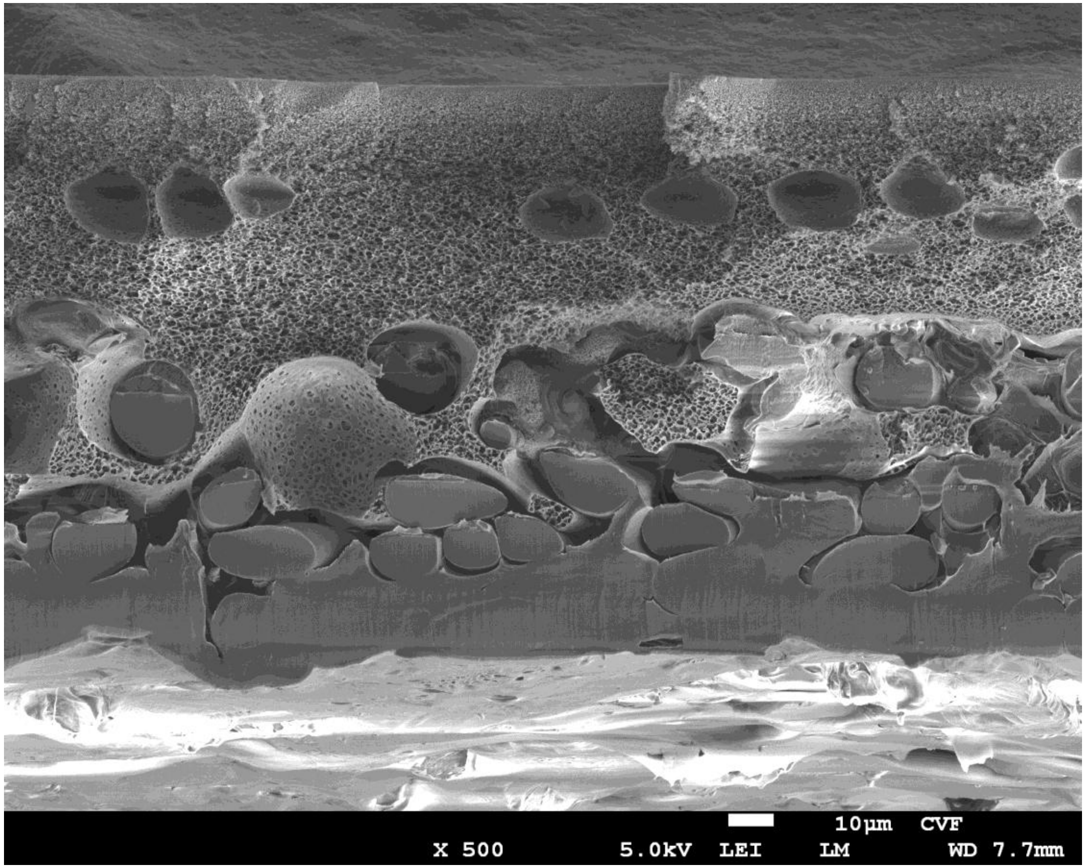
- Concentration polarization is a function of the boundary layer.
- It results in an increased salt concentration at the membrane surface.
- The higher the flux rate through the membrane the higher the salt concentration at the membrane surface.
- Typically the TDS is 13–20% higher than the concentration in the bulk stream.

Thin Film Composite Membranes
Spiral Wound Elements

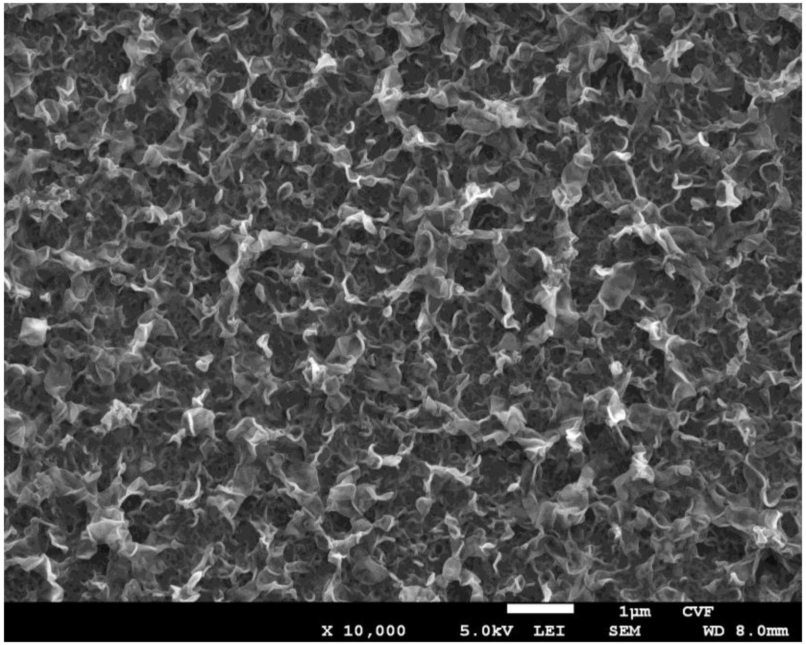
Cross-section of thin film composite membrane



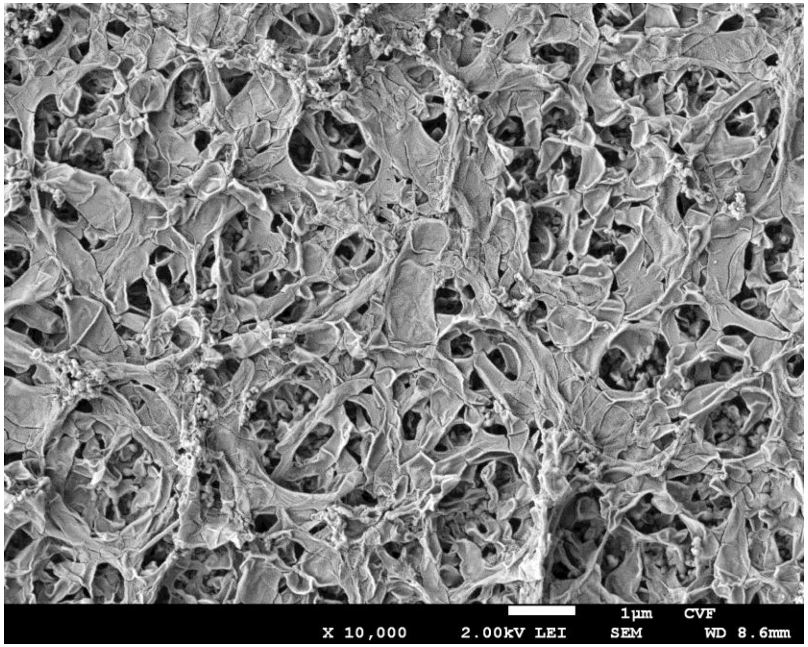
FILMTEC™ membrane cross-section (SEM image)



Surface of barrier layer of FT30 (SEM image)

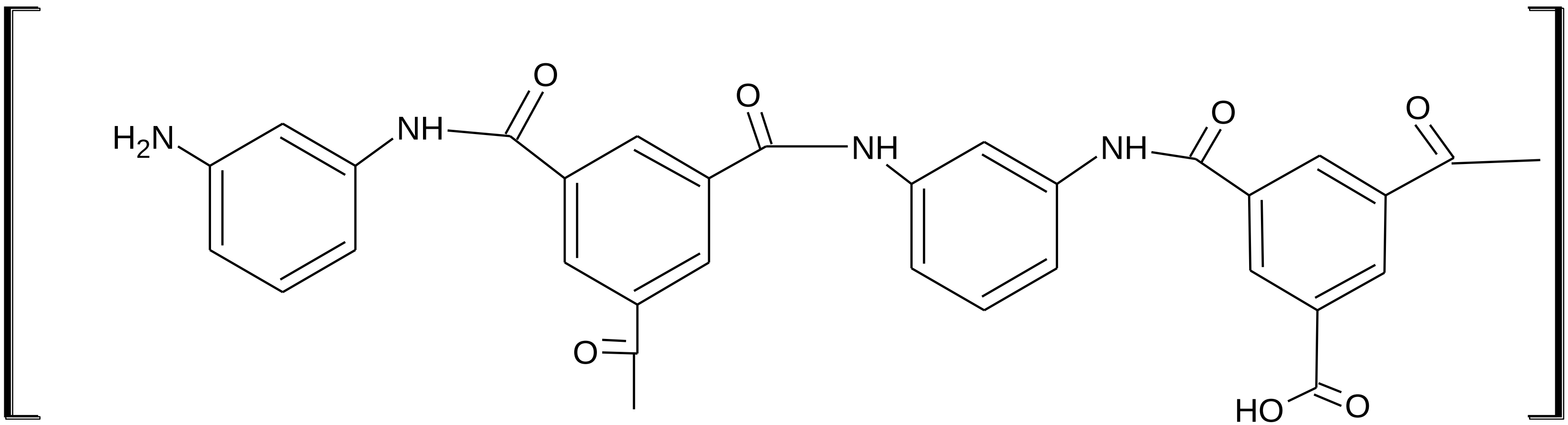


BW30 Membrane



XLE Membrane

Flat sheet membrane FT30 chemistry



Free amine **Carboxylate**

Aromatic Polyamide Barrier Layer

Factors affecting membranes solute rejection

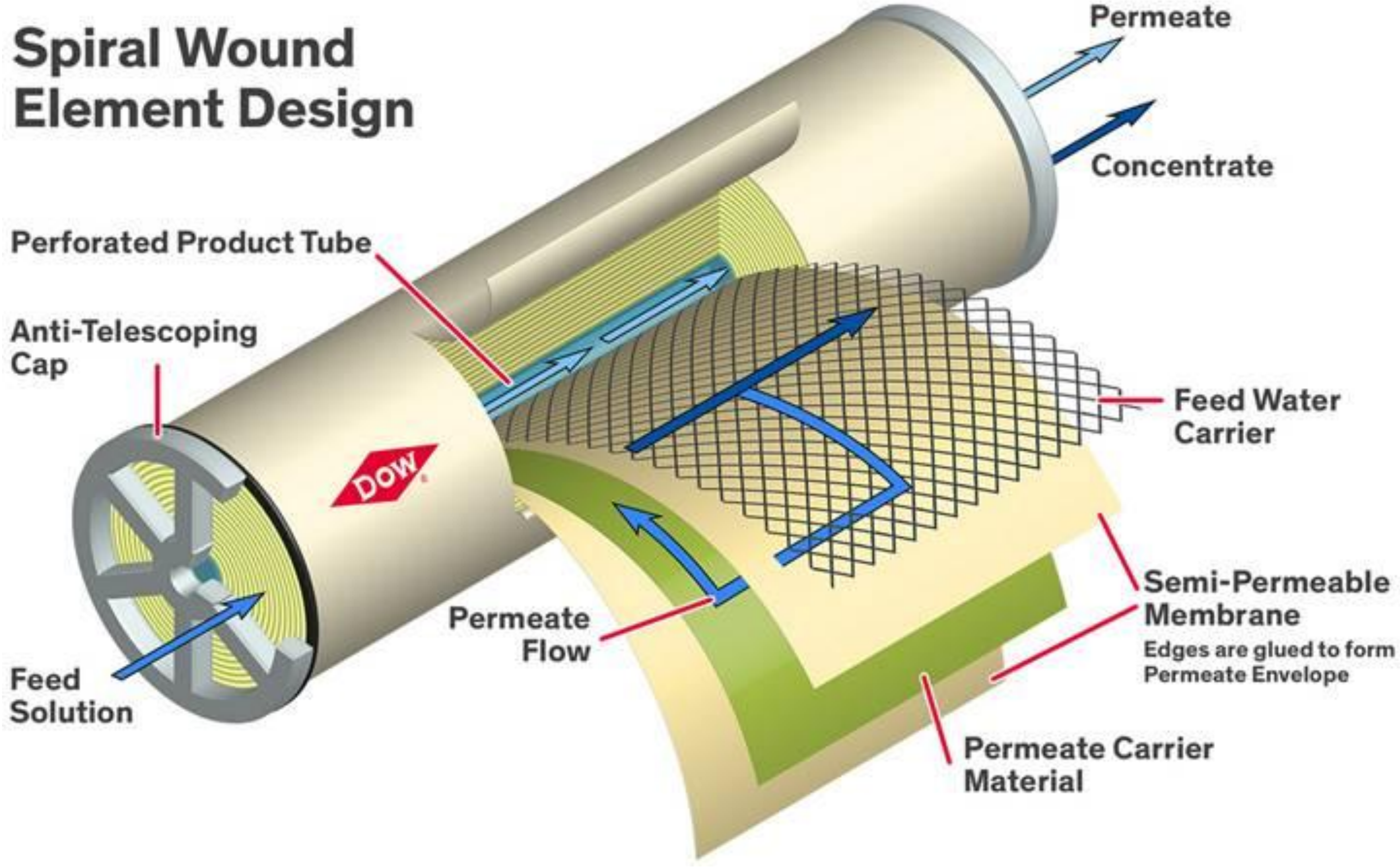
Membrane type/condition:

- SW30XHR NaCl 99.75%,
- XFRLE NaCl 99.4%
- NF90: NaCl 85-95%

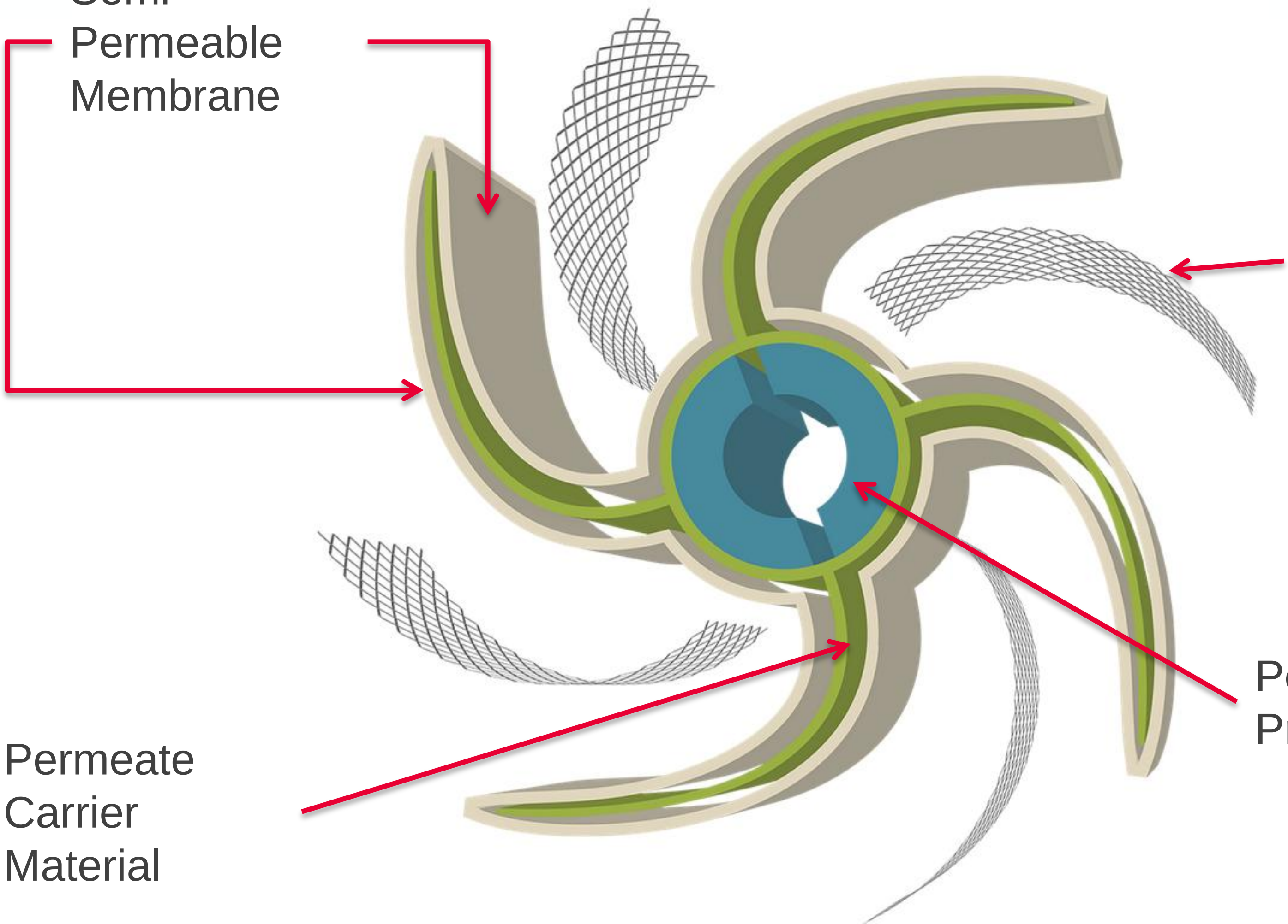
Solute characteristics

- Charge
- Polarity and/or Degree of Dissociation
- Degree of Hydration
- Molecular weight and Degree of Branching

Spiral wound RO membrane element



Spiral wound RO membrane element



FILMTEC™ product range

Brackish Water

- High rejection
- Low energy
- Fouling resistant

Seawater Desalination

- Low energy
- High rejection

Nanofiltration

Special products

- Ultrapure Water
- Sanitary style
- Food and Dairy

Flexible sizing

- 8” X 40”
- 4” X 40”
- 2.5” x 40”
- 1.8” x 12”

Delivery

- Dry
- Wet

Applications and markets





Municipal

- Sea Water desalination & brackish water purification for potable use
- Agricultural irrigation

Industrial

- UPW, process water, boiler feed water and utility water
- Water purification or concentration of substances

Water reuse

Commercial

- Car Wash, Laboratory, Restaurant

Food and Nutrition

- Dairy, Juice, Beverages

Military

Households

Thank You!

For more information please visit our web site or contact your local Dow representative.
http://www.dowwaterandprocess.com/

Questions?