Introduction to cross flow filtration with focus on reverse osmosis

March 2007

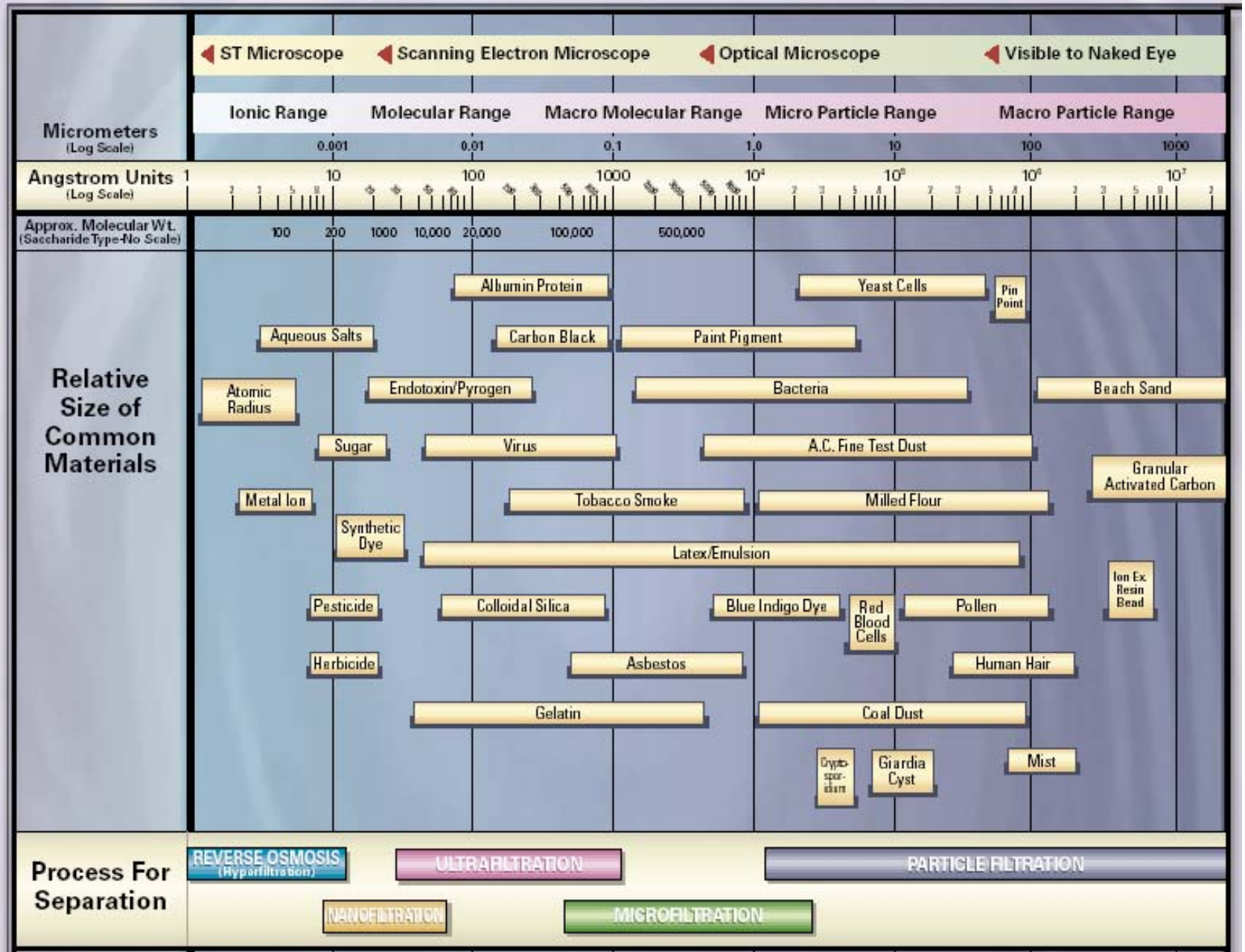
imagination at work

Outline

- Membranes and modules
- Osmosis/reverse osmosis
- Membrane chemistry
- Element construction
- System design

Membranes & Modules

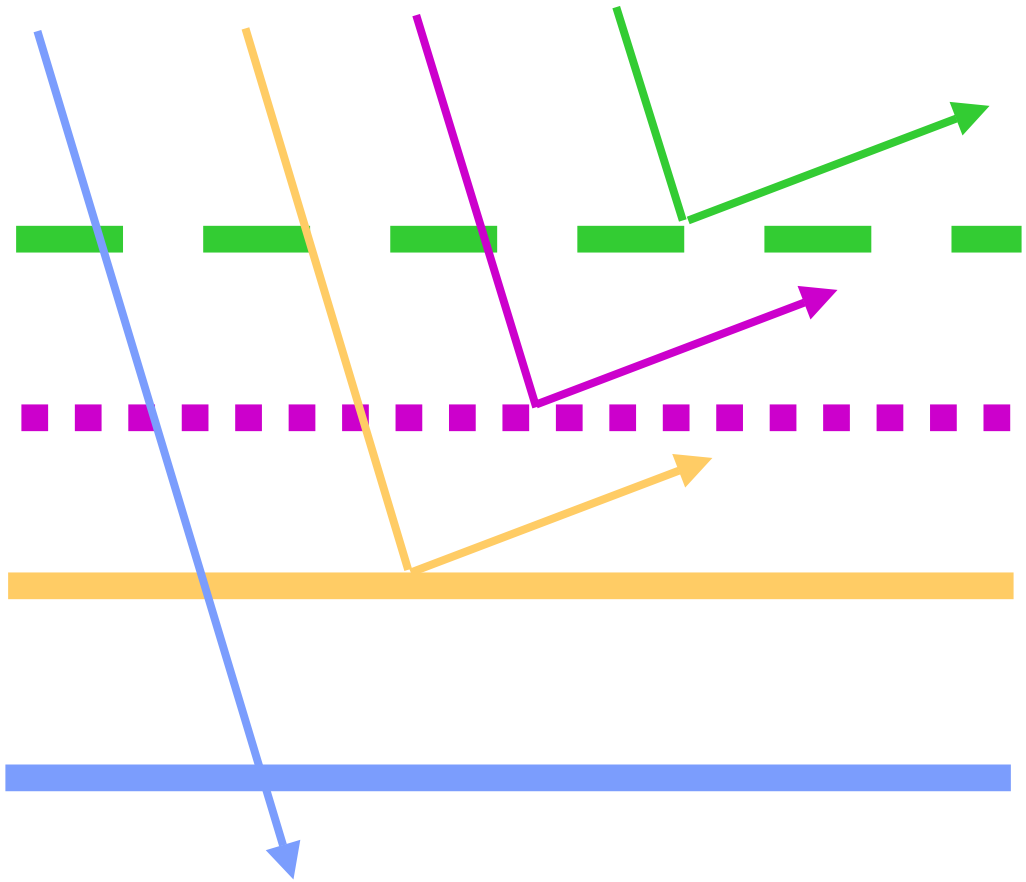
Filtration and Separation Spectrum



Membrane Size Classification By Molecular Weight Cut-Off

Microfiltration	0.1 to 1 micron
Ultrafiltration	6K to 100K MWCO
Thin-Film Ultrafiltration	500 to 1,000 MWCO & 1K to 6K MWCO
Nanofiltration	150 to 500 MWCO
Reverse Osmosis	50 to 200 MWCO

Filtration Classifications



MF

Bacteria & fine solids

UF

Colloids pigments solids

NF

Divalent ions sugar dyes

RO

Metal ions; salts

Membranes & Modules

Membranes	Membrane Modules
Reverse Osmosis	Spiral wound
Nanofiltration	Tubular
Ultrafiltration	Hollow Fiber
Microfiltration	
Prevaporation	Plate & Frame
Gas/gas	

GEWater products

Membrane Applications And Elements

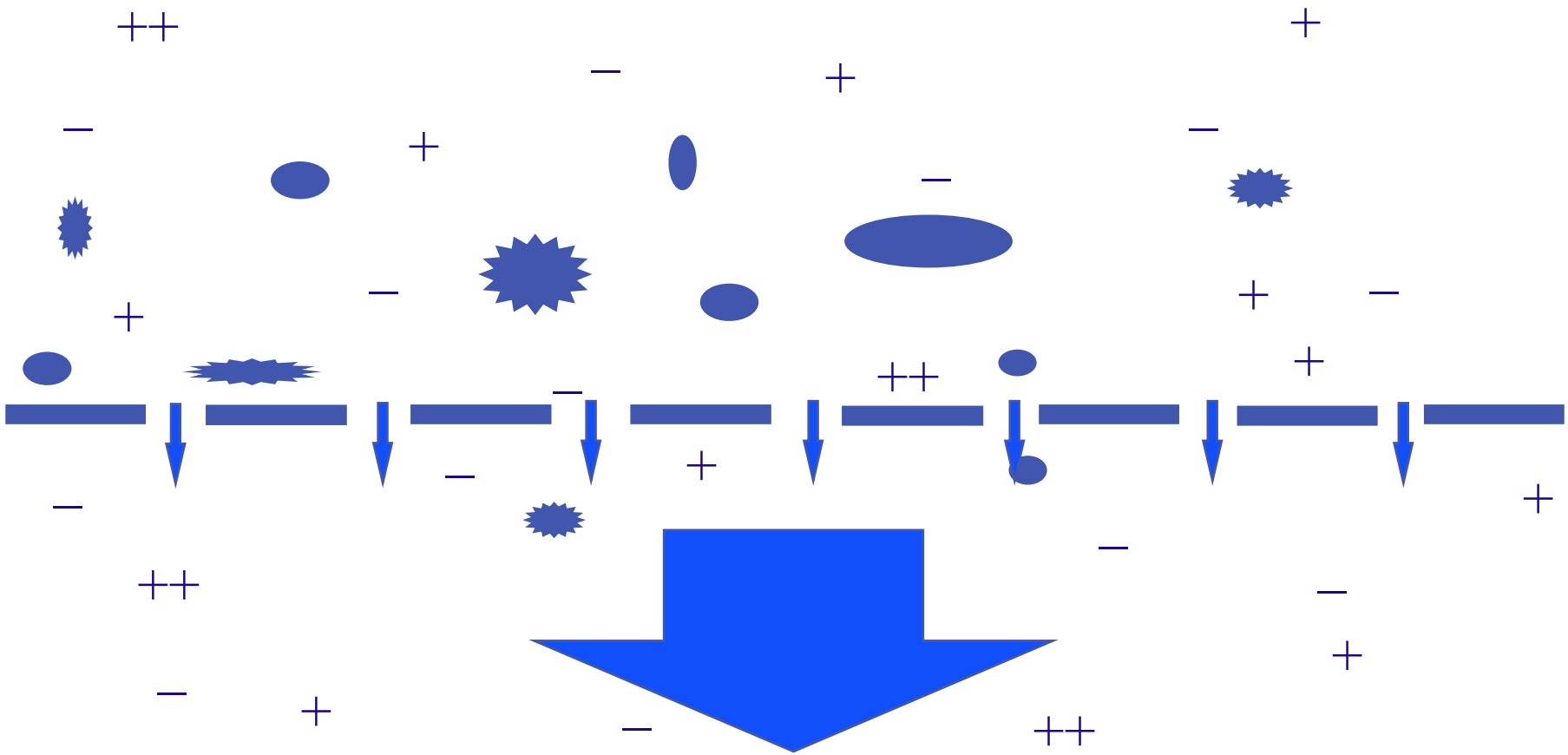
Separation process involves either:

- Normal, pass-through filtration

Or

- Cross-flow filtration

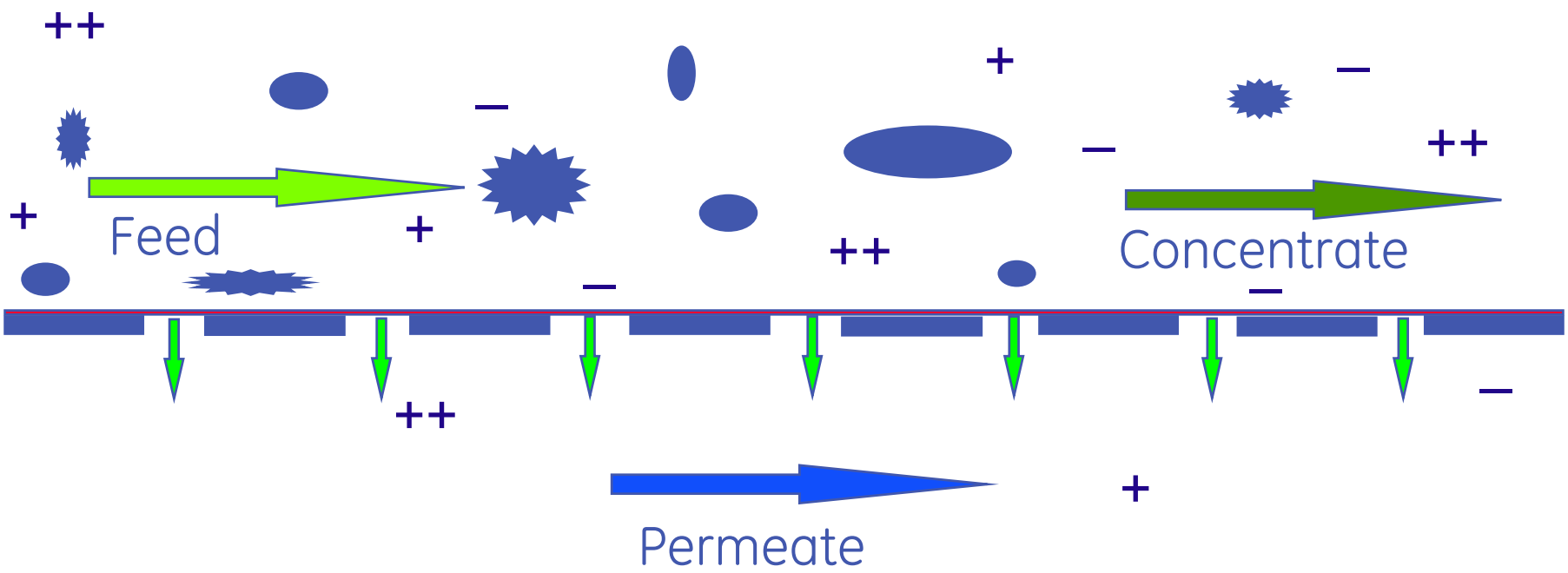
Normal Filtration



All material passes through the filter

Used in: cartridge filters, dual media filters, etc.

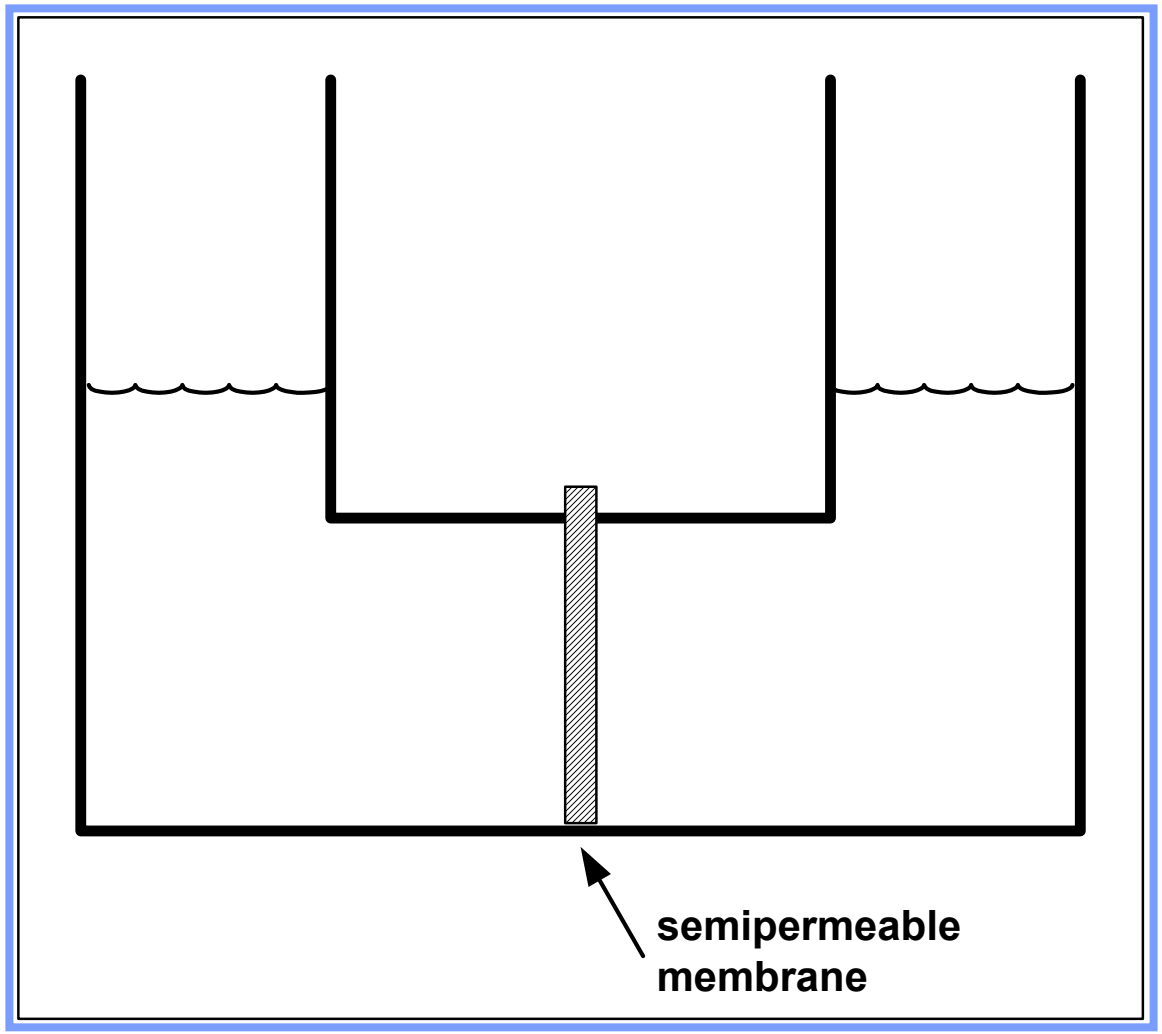
Cross Flow Filtration



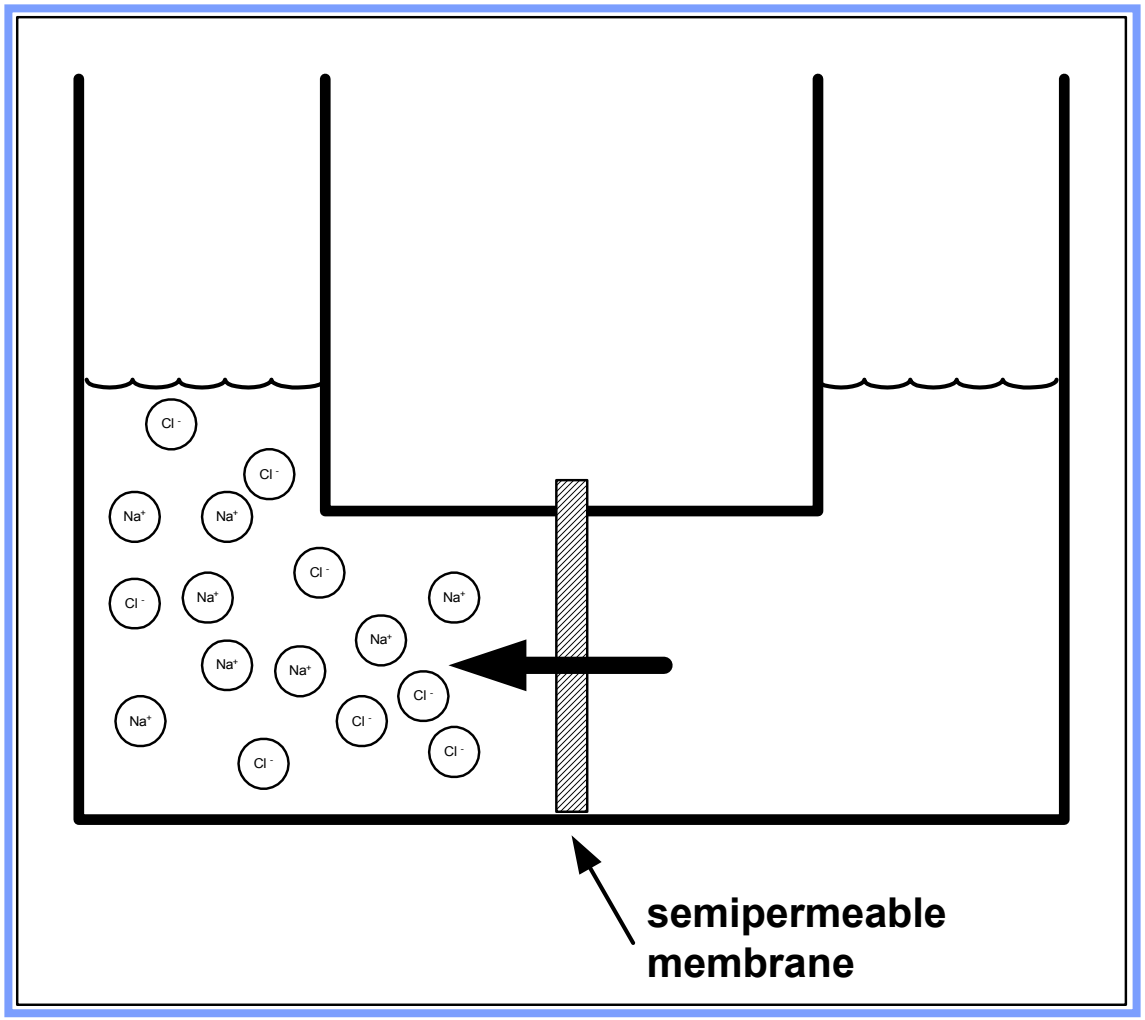
The majority passes through and the impurities concentrate up
Rejection: Depends on membrane type.

Osmosis/reverse Osmosis

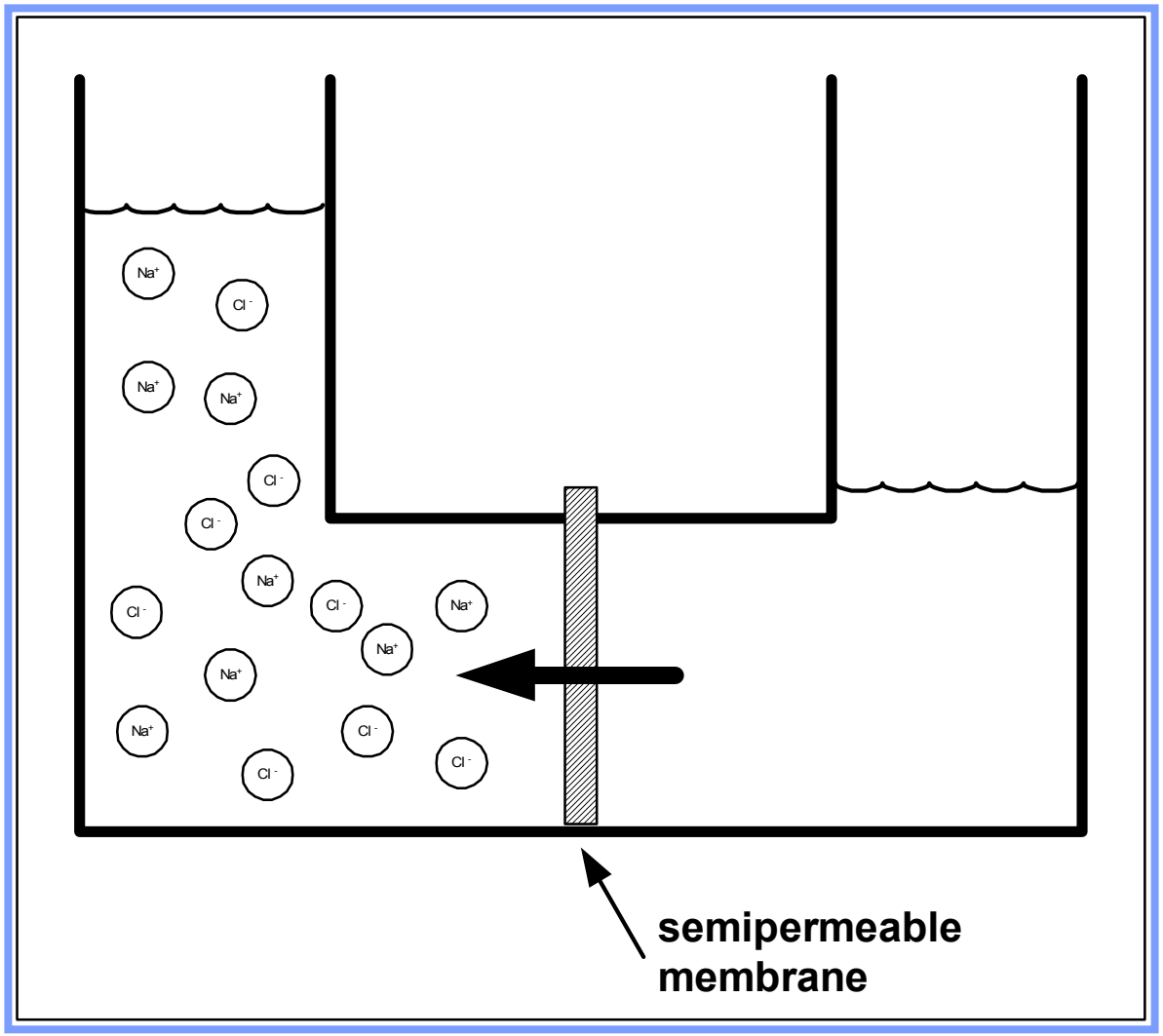
Semipermeable Membrane



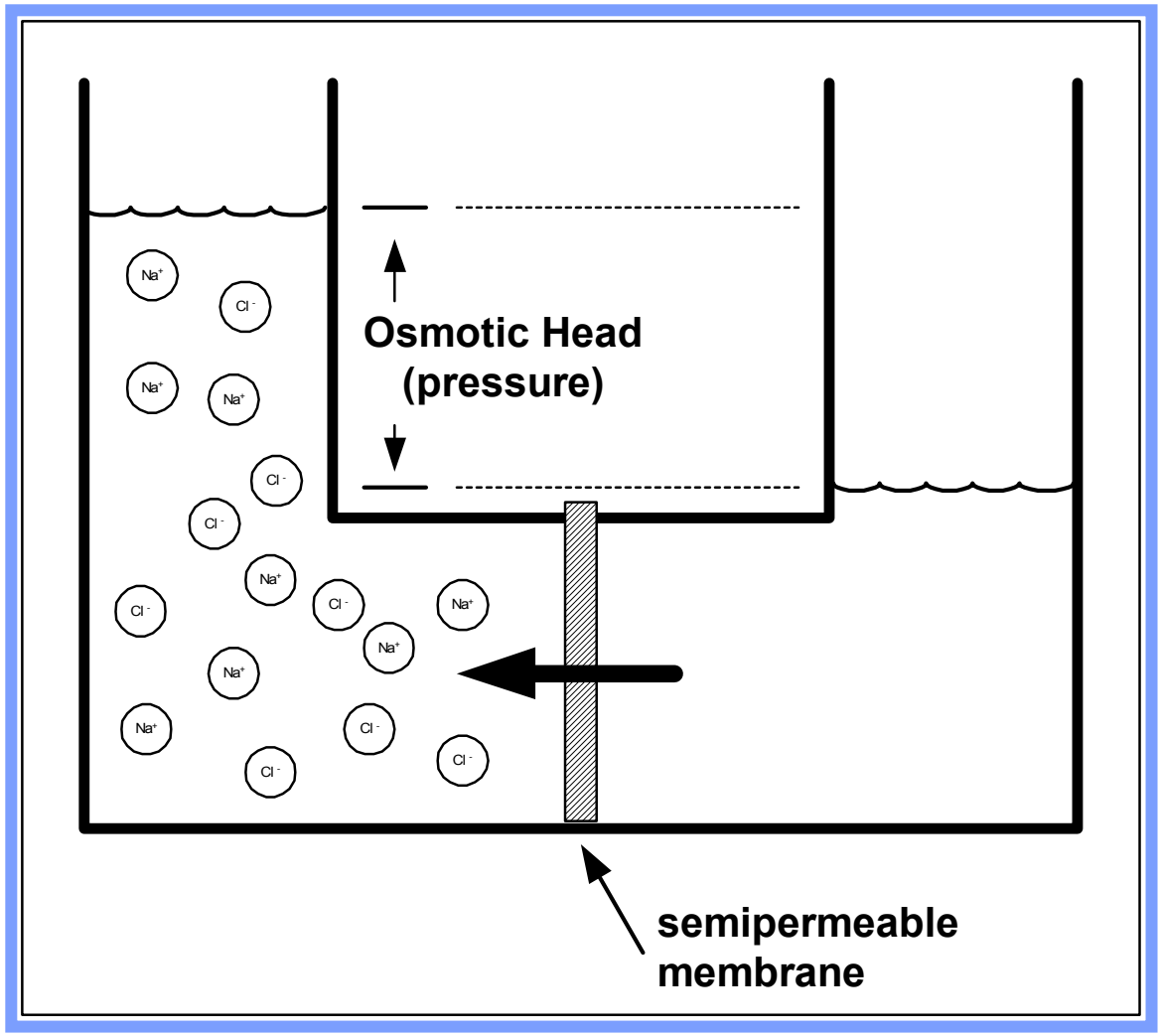
Osmosis



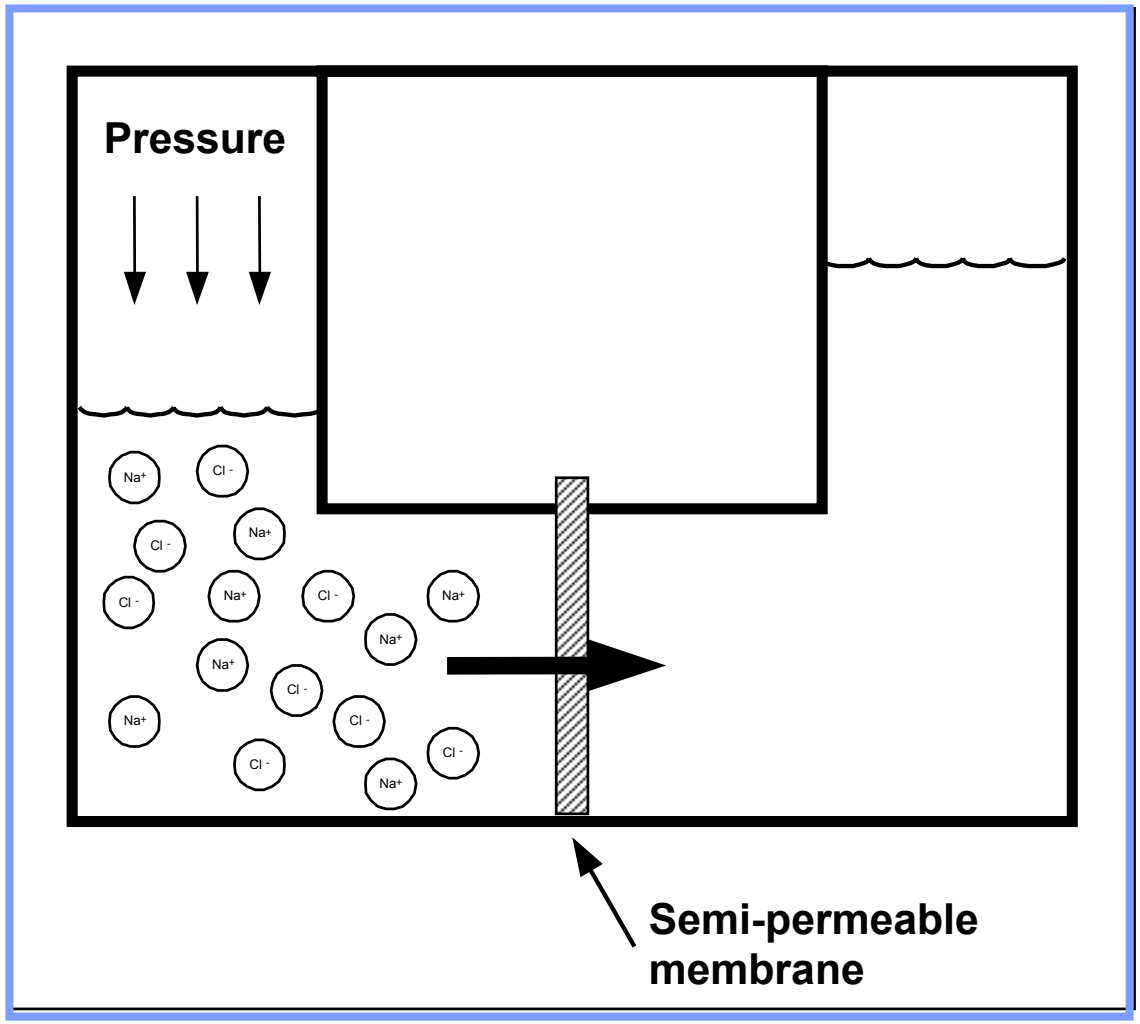
Osmosis



Osmotic Pressure



Reverse Osmosis



Terms & Formulas

- Semi-permeable membrane:
  - a membrane that allows water to pass through but rejects most ions and molecules.
- Osmotic Pressure:
  - the pressure needed to stop the flow of water through a semipermeable membrane

Terms & Formulas

- Osmosis:
  - The tendency of water to flow through a semi-permeable membrane into a more concentrated solution.
- Reverse osmosis:
  - The passage of water out of a solution when a pressure greater than the osmotic pressure is applied on the solution side of a semi-permeable membrane.

Terms & Formulas

- Reverse Osmosis (RO)
  - RO membrane acts as a barrier to all dissolved salts and inorganic molecules, as well as organic molecules with a molecular weight greater than approximately 100Da.
  - Rejection of dissolved salts is typically 95-99 percent.
  - operating pressures for RO typically range from 7 for low energy elements to 55 bar for seawater.

Terms & Formulas

Cross Flow filtration

Separation of solution components flowing under pressure across and through a “semi-permeable” membrane, resulting in two streams:

- Permeate
- Concentrate

Terms & Formulas

Permeate

Fraction of the feed solution that passes through the membrane

Concentrate

Fraction of the feed solution retained by the membrane

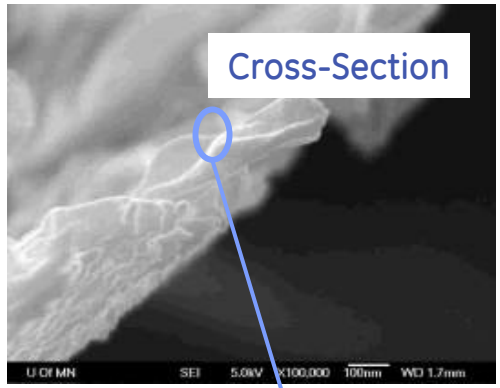
Membrane Chemistry

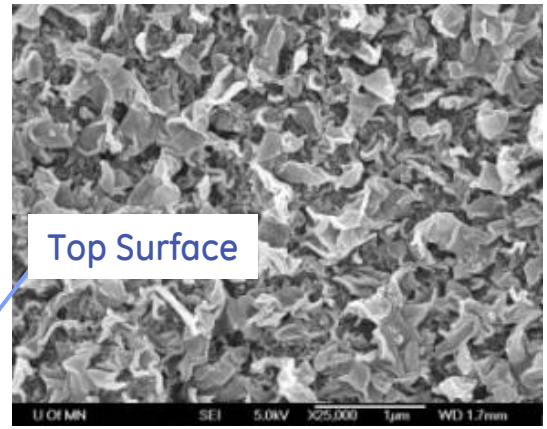
What is a Membrane?

Two classes of membranes:

- Porous (UF, MF)
- Non-porous (RO, NF)

Non-porous membranes typically comprise a thin film on a support



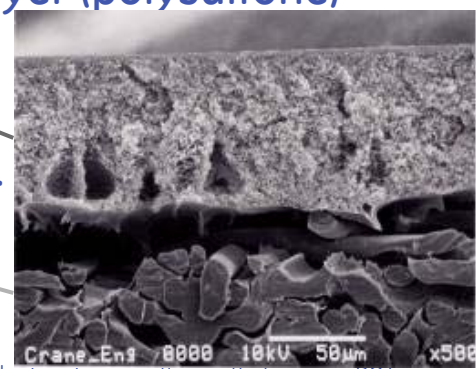


Composite Membrane Cross-section:

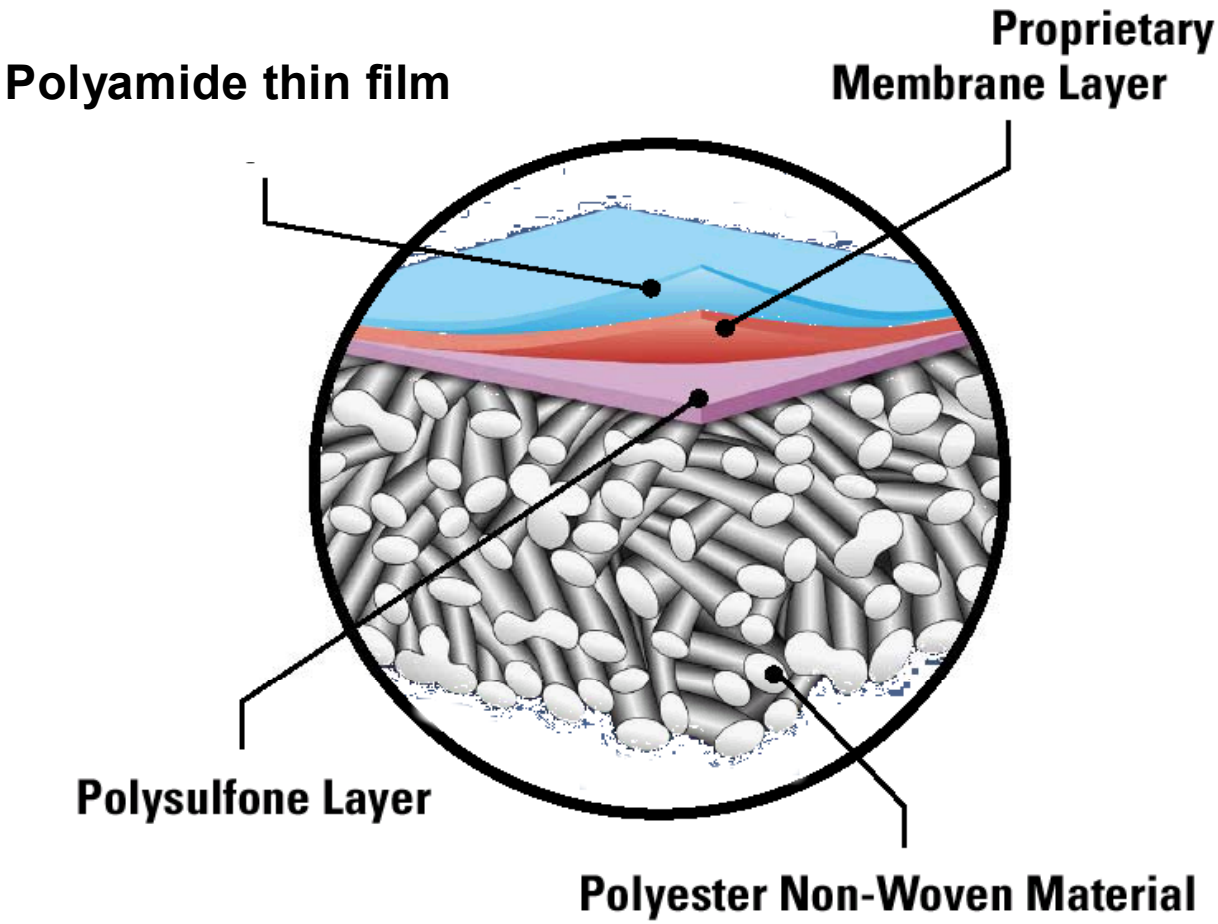
Non-porous film ~ 0.2µm

Porous layer (polysulfone) ~ 40µm

Fabric (Polyester support web) ~ 120µm

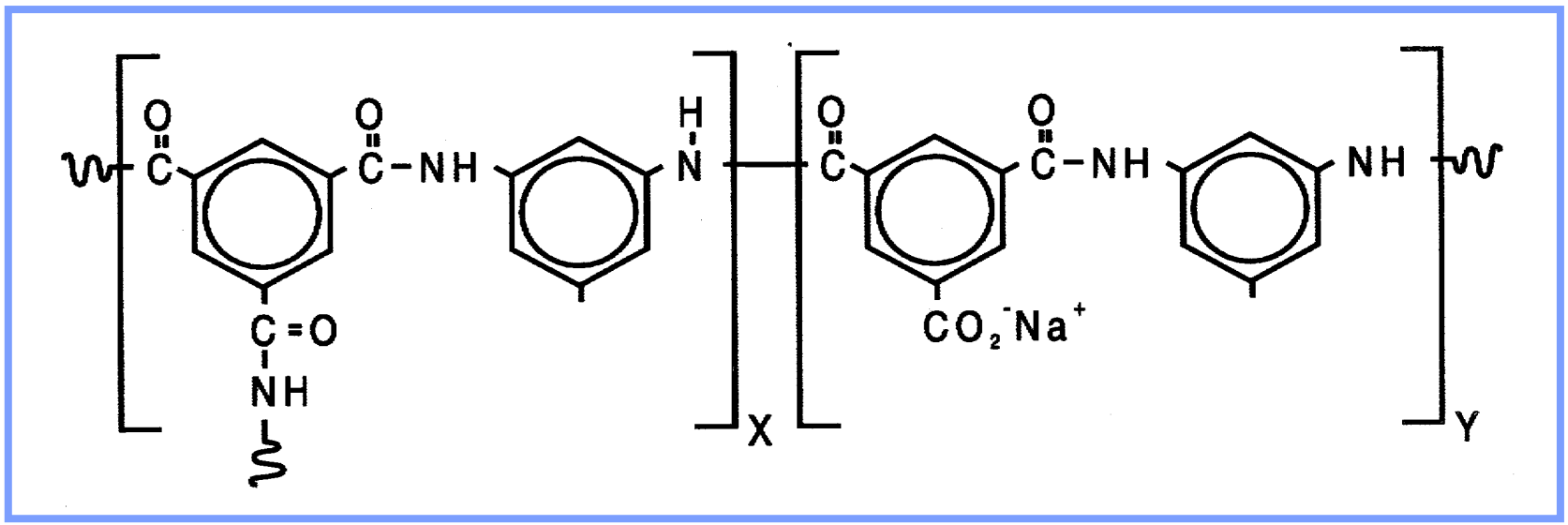


Membrane Morphology



Structure of Polyamide Membrane

Polyamide is a widely used material for RO, NF & UF thin film.



Characteristics of TFC membrane

- Can’t tolerate oxidants: dechlorination mandatory
- RO rejection on NaCl typically >98%
- Typical operating pressures 10 to 15 bar
- pH operating range of 4 to 11
- Maximum feed water temperature: 50°C

MEMBRANE MANUFACTURING

ELEMENT CONSTRUCTION

Element construction

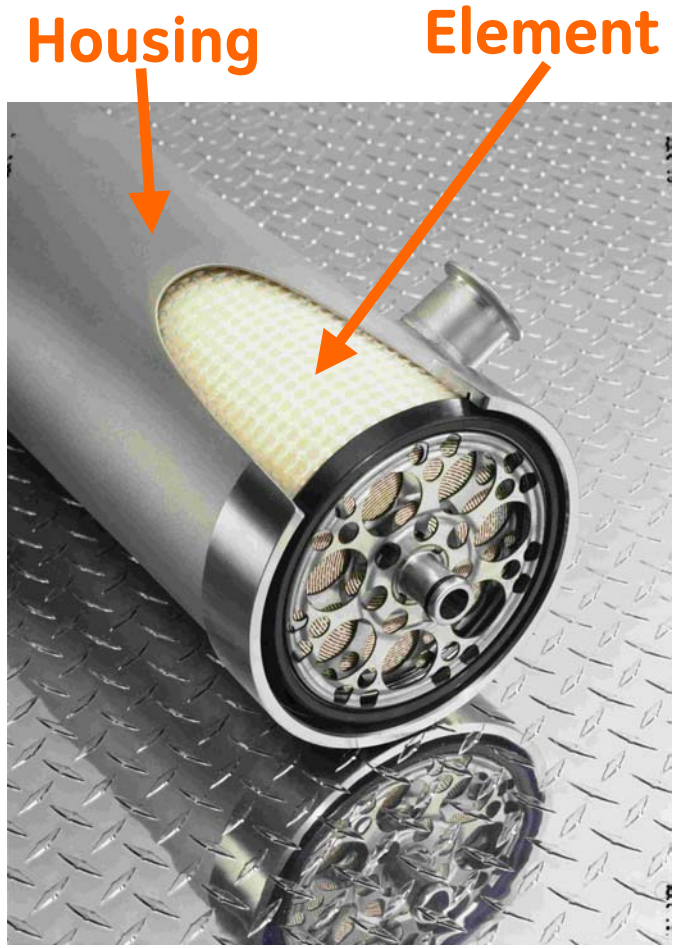
Spiral Wound Membrane Element

End View of Element

Critical Terms

Element- The piece of equipment that performs the separation process. A membrane element can have a variety of configurations (e.g. spiral wound and hollow fiber).

Housing- The device designed to contain a membrane element. It must be capable of handling the required high pressures. Also known as a "pressure vessel"

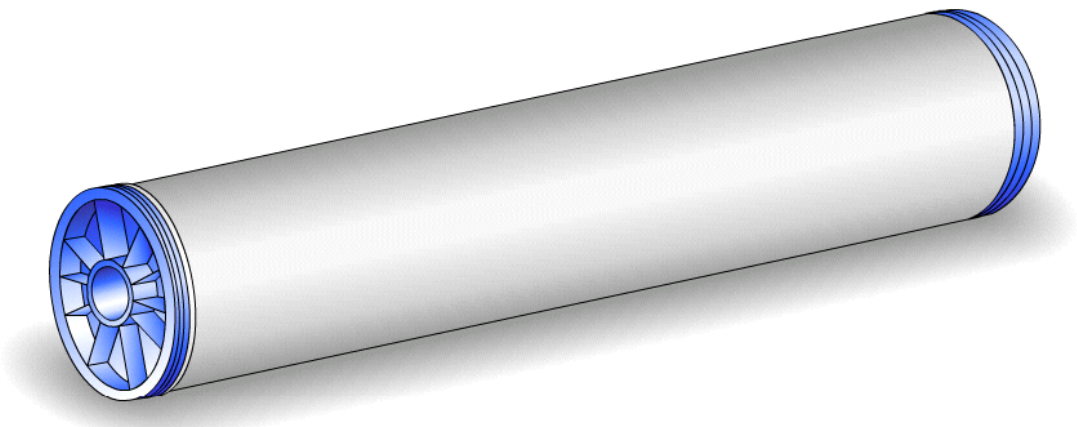


Spiral Wound Element

Overview | Separation | Construction | Fluid Dynamics

Spiral Wound Membrane Element

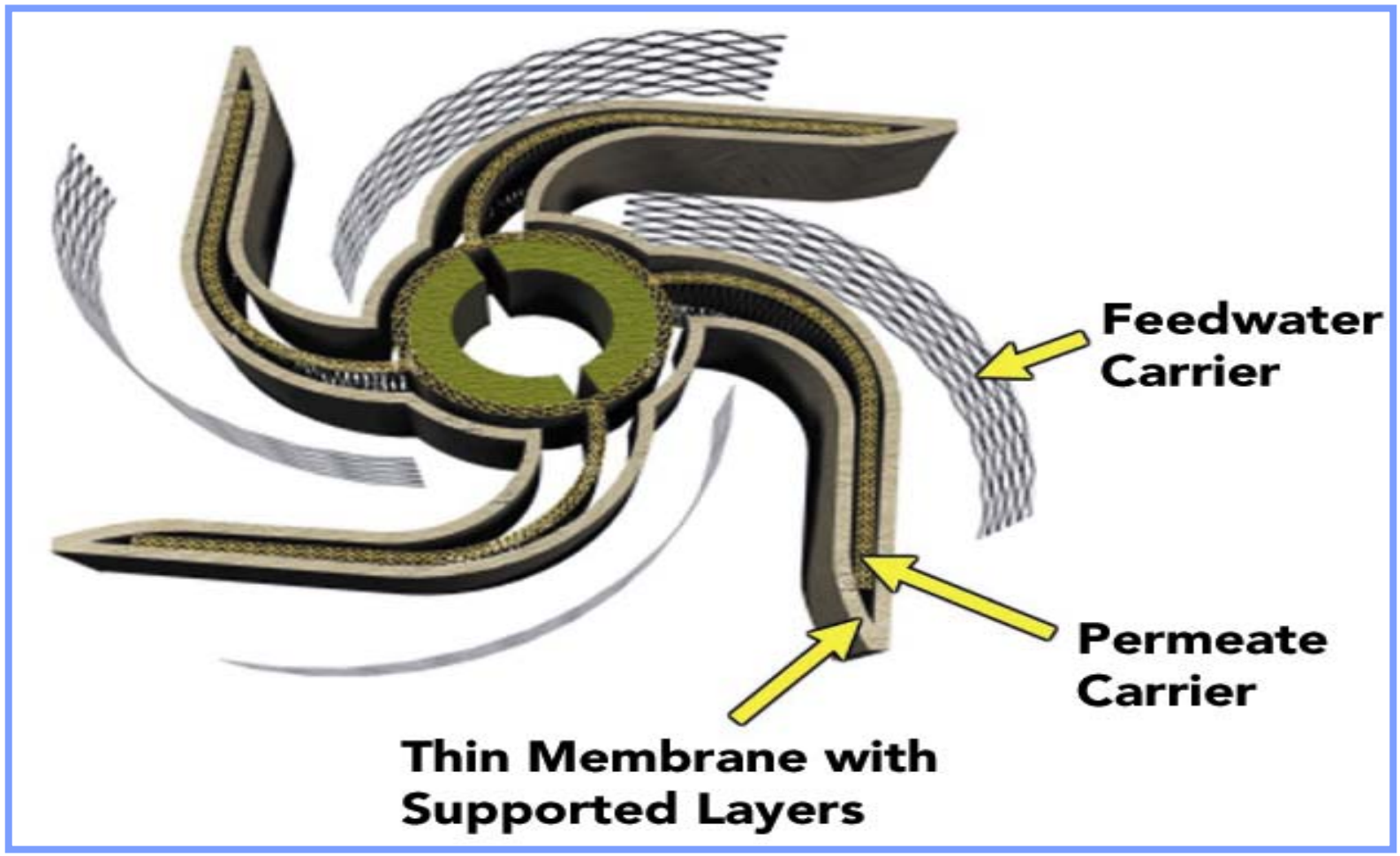
What it Does: **Overview**



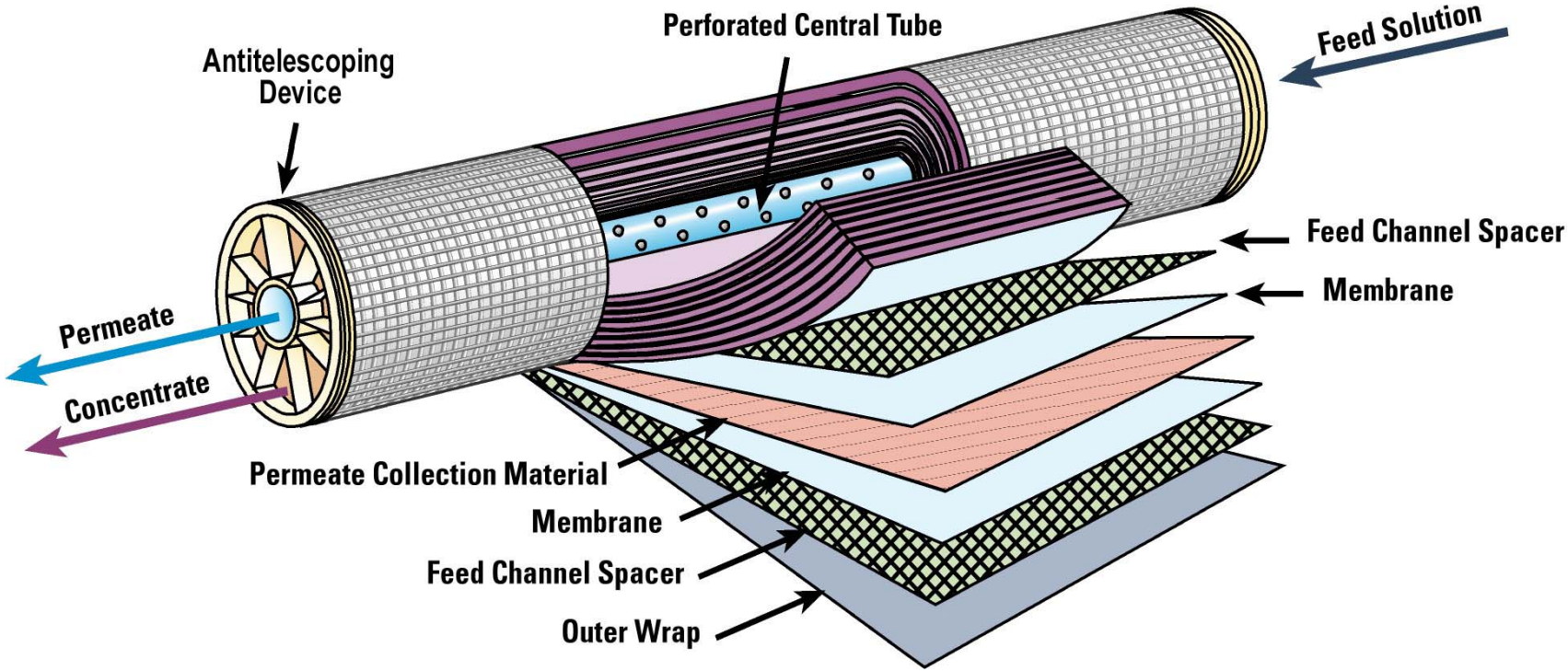
Flash presentation found on TSC:
http://supportcentral.ge.com/products/sup_products.asp?prod_id=**23870**

Under the URL address:
http://data.supportcentral.ge.com/upload/23870/doc_418602.exe

Spiral Wound Element Construction

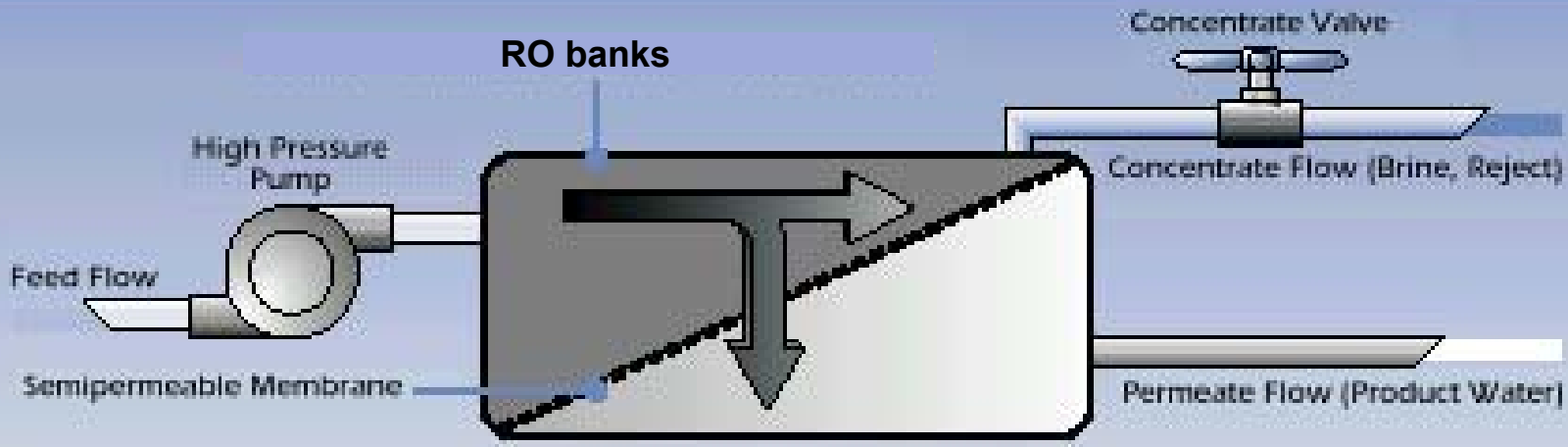


Spiral Wound Module



Membrane Leaves

RO System design



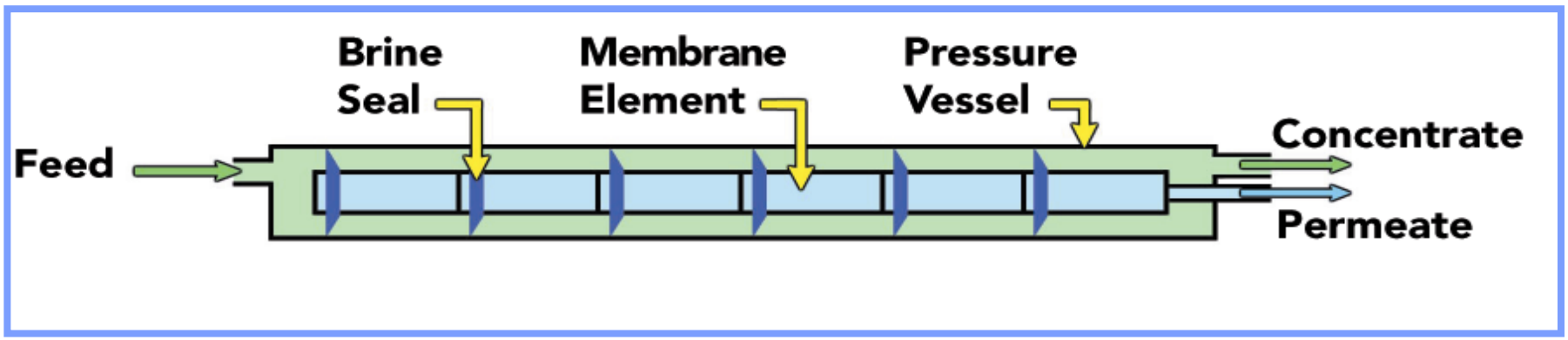
$$\text{Recovery (\%)} = \frac{\text{Permeate Flow} \cdot 100}{\text{Feed Flow}}$$

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

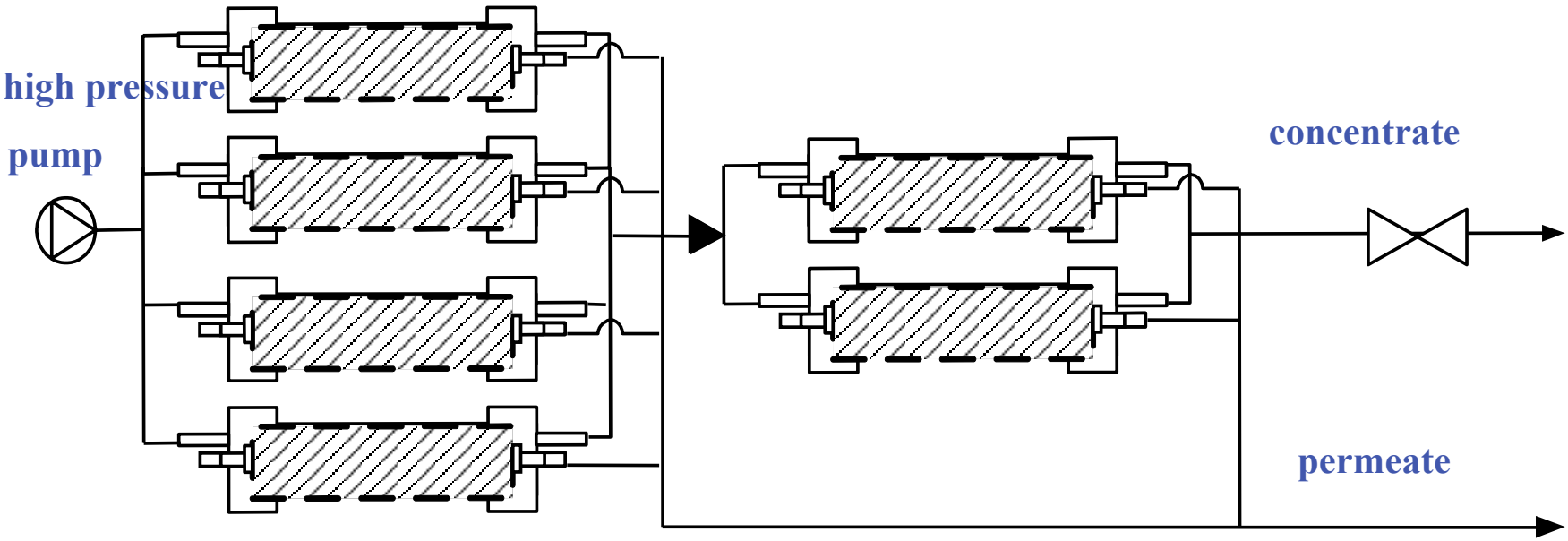
$$\text{Salt Rejection (\%)} = 100 - \text{Salt Passage}$$

REVERSE OSMOSIS PROCESS

RO Pressure Vessel

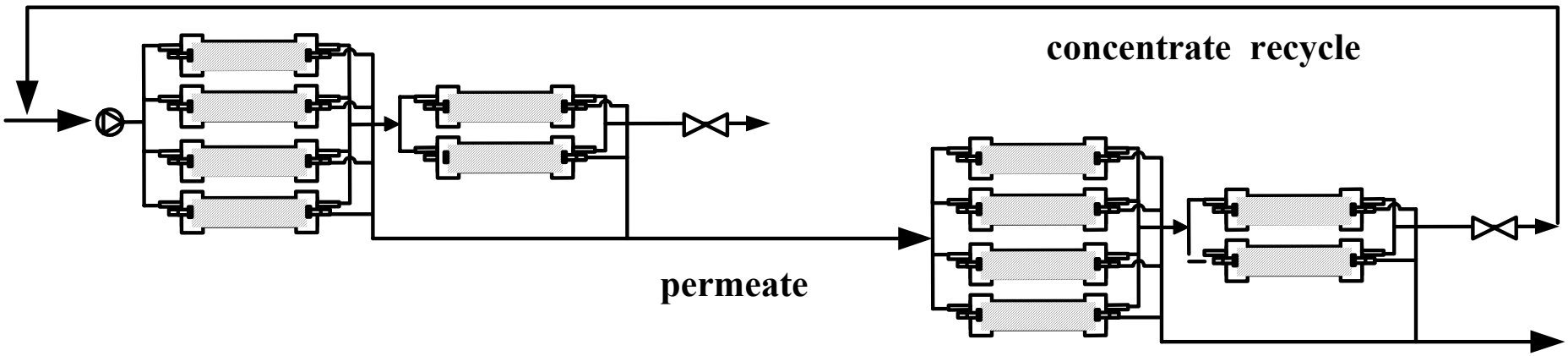


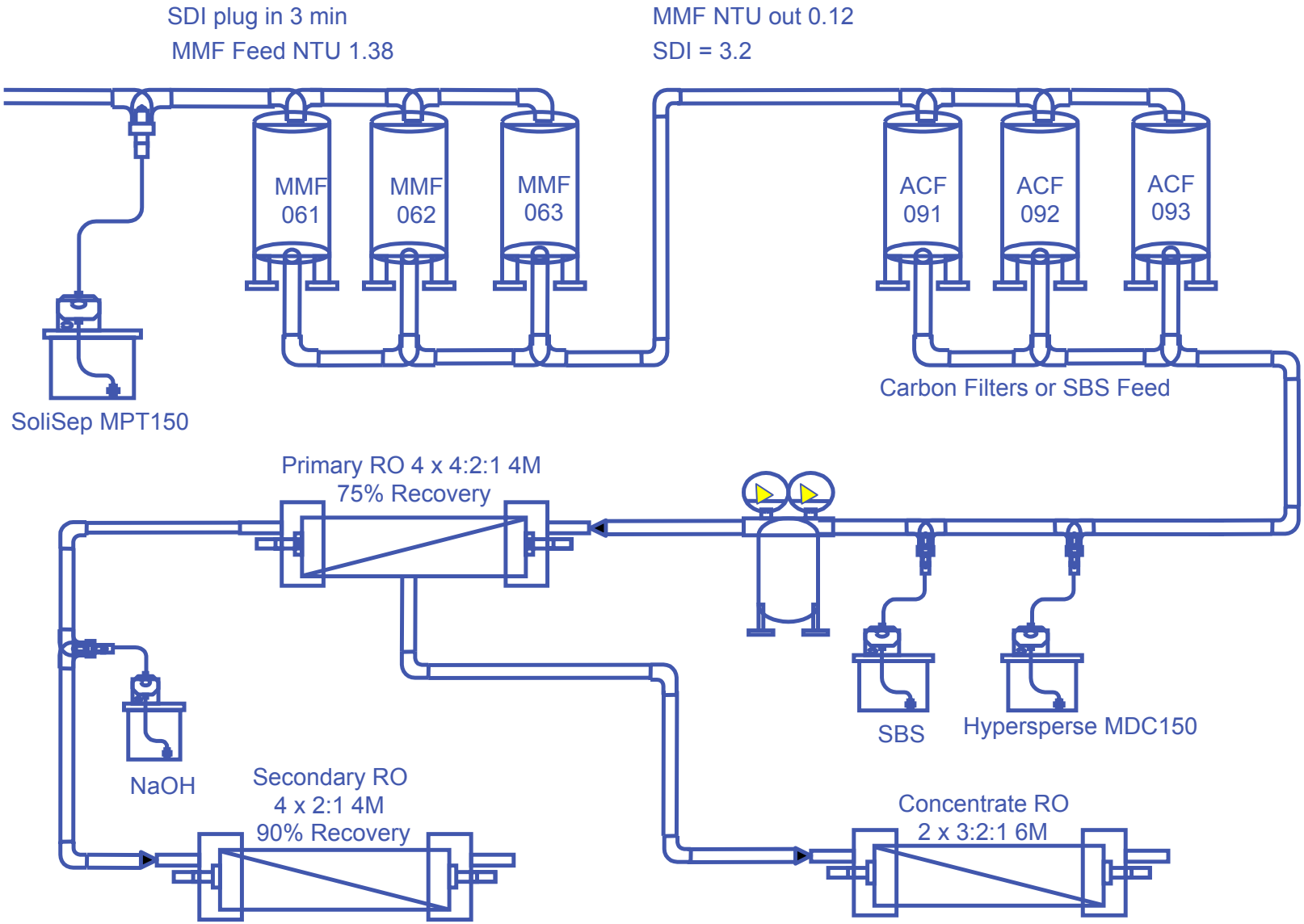
Two Array System



Permeate Header

Permeate Staged System




SDI plug in 3 min
MMF Feed NTU 1.38
MMF NTU out 0.12
SDI = 3.2
MMF 061
MMF 062
MMF 063
ACF 091
ACF 092
ACF 093
SoliSep MPT150
Carbon Filters or SBS Feed
Primary RO 4 x 4:2:1 4M
75% Recovery
NaOH
SBS
Hypersperse MDC150
Secondary RO
4 x 2:1 4M
90% Recovery
Concentrate RO
2 x 3:2:1 6M

Terms & Formulas

- Recovery
  - The percent of permeate water that is recovered from the feed water
  - Calculation:
    - Recovery = Qp/Qf x 100
    - %Recovery = (Permeate flow/Feed flow) (100)
  - Example
    - (75 m3/h/100 m3/h) (100) = 75% Recovery

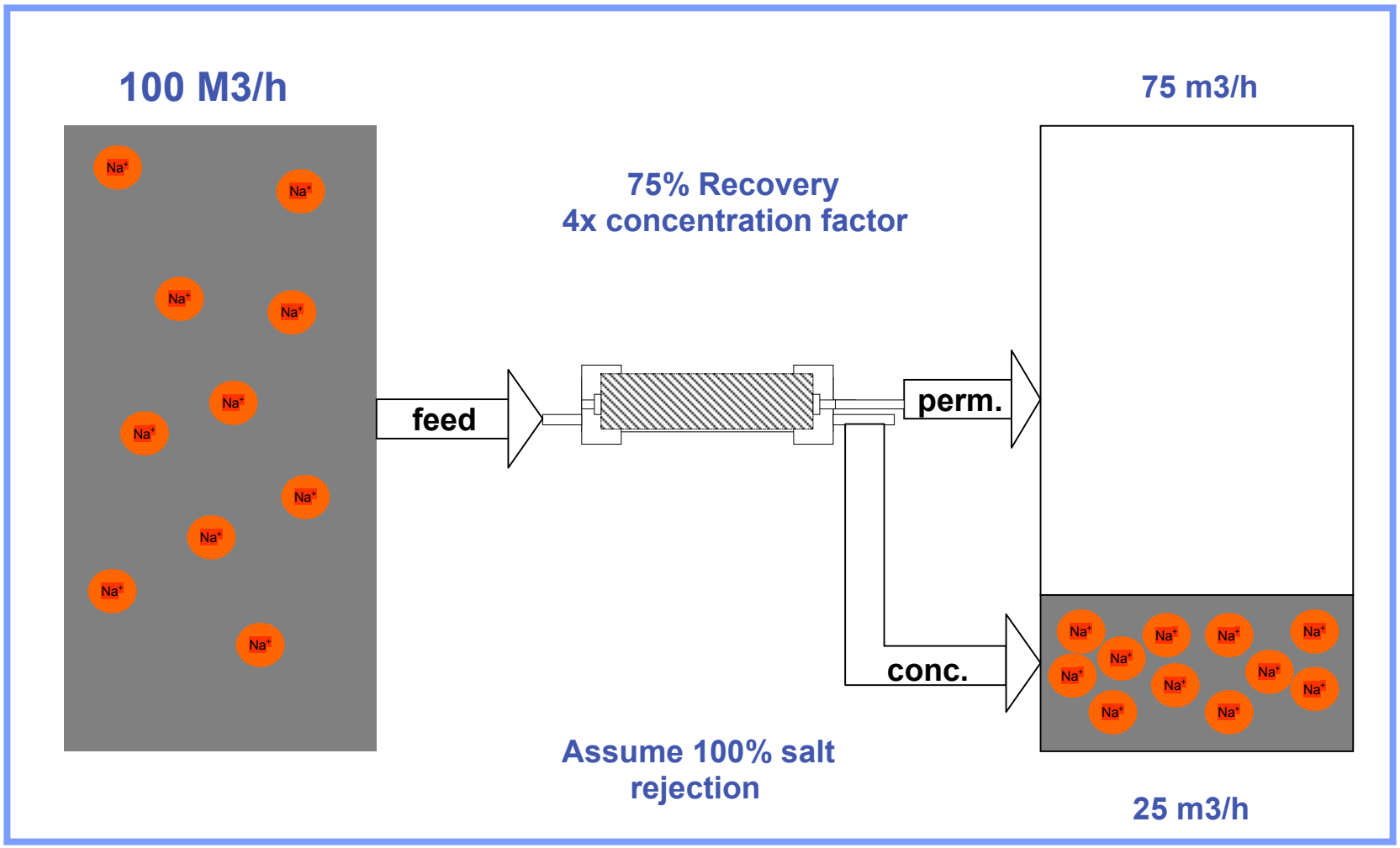
Terms & Formulas

- Salt Rejection:
  - The percent of dissolved material which is rejected by the membrane
  - Calculation:
    - % rejection = {1 - (permeate TDS/feed TDS)}100
  - Example
    - {1- (20/1000)} 100 = 98%

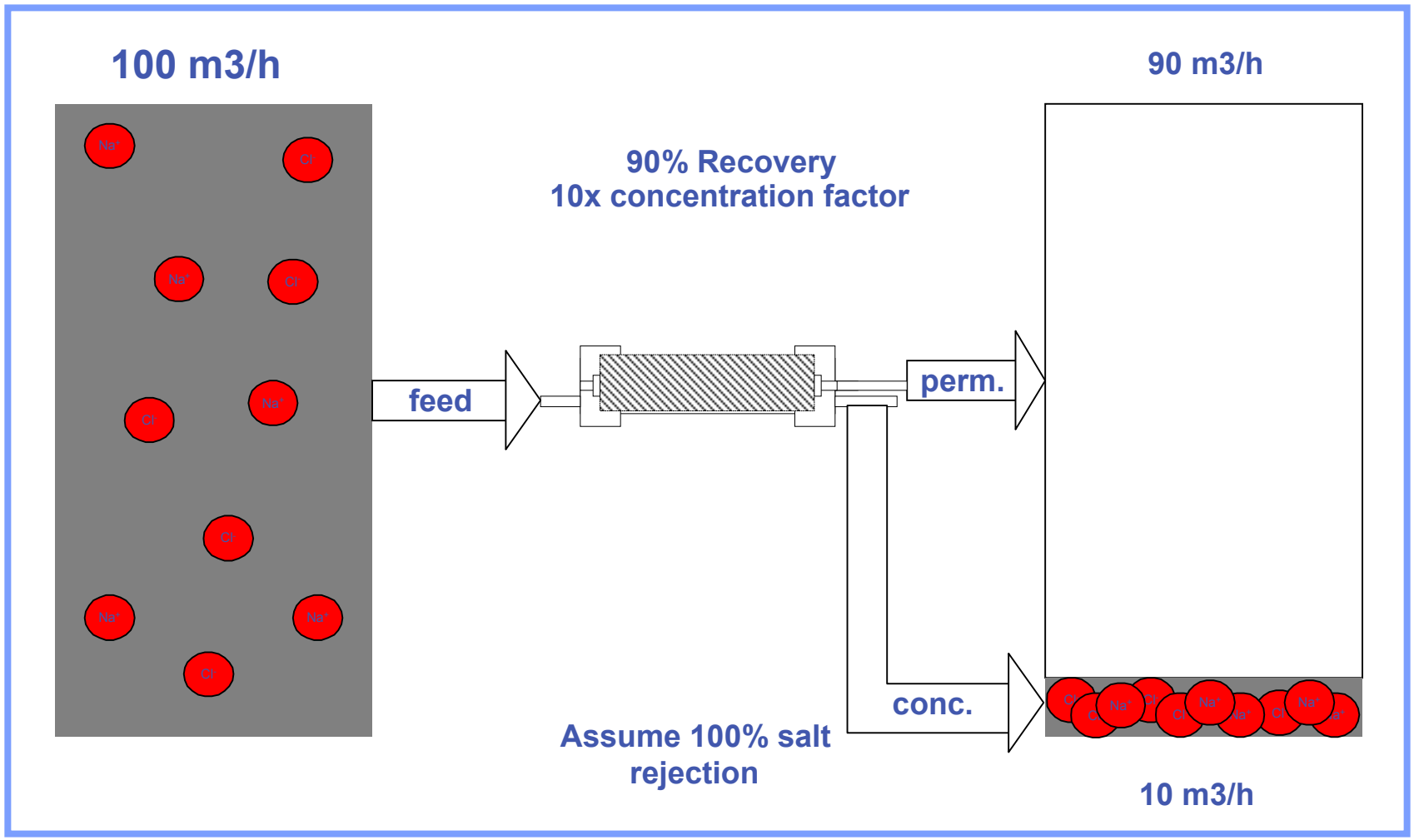
Terms & Formulas

- Concentration Factor
  - The factor by which the feed salts will concentrate up in the RO, based on recovery
  - Calculation:
    - 1/(1-recovery) or
    - feed Flow/concentrate flow
  - Example:
    - 1/(1-0.75) = 4 or
    - 100 m3/h/ 25 m3/h = 4

Concentration Factor at 75% Recovery



Concentration Factor at 90% Recovery



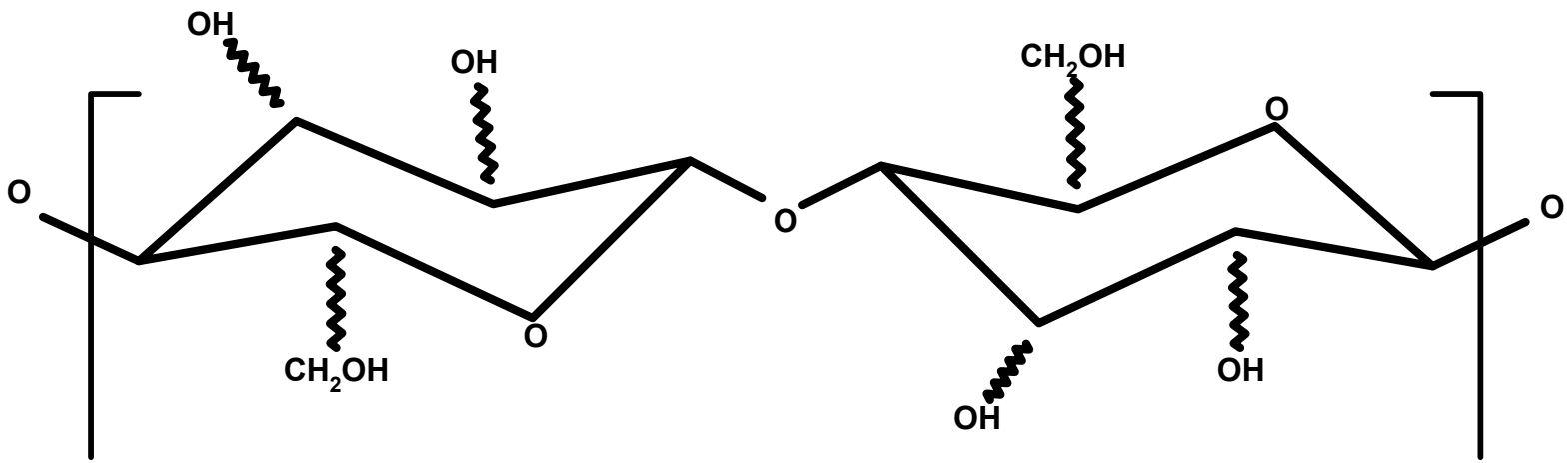
Terms & Formulas

Recovery	Concentration Factor
95%	20X
90%	10X
80%	5X
75%	4X
66.66%	3X

Feed conductivity X concentration factor = concentrate conductivity

Appendix

Cellulose Acetate (CA) Structure



Characteristics of CA membrane

- Chlorine tolerant--1ppm on continuous basis
- Tight pH range--hydrolysis of membrane
  - approximate service pH 5.4-5.7
  - pH 2.5-8.0 for cleaning
- Typical rejection 95-98%
- Higher operating pressure (28 bar)

Pressure Definitions

Primary Pressure (Inlet) - P_I

- Pressure of the feed stream prior to the membrane elements

Final Pressure (outlet) - P_O

- Pressure of the concentrate stream after the elements

Back Pressure (Permeate Pressure) - P_B

- Pressure of the permeate stream after the elements

Pressure Definitions

Osmotic Pressure - P_p

- Natural energy present as a result of difference in concentration across a "semi-permeable" membrane:

  $\prod$ = Osmotic Pressure

  Ex : 1000 ppm NaCl => $\prod$=10 psig=0.8 Bar

Average Operating Pressure

$P_{AVG} = (P_I + P_O)/2$

Pressure Definitions

Effective Pressure (Transmembrane)

$P_{EFF} = P_{AVG} - (P_B - P_p)$

> The effective pressure is the net pressure after permeate back pressure and osmotic pressure losses - i.e. the pressure difference across the membrane