General Overview of Membranes & Applications

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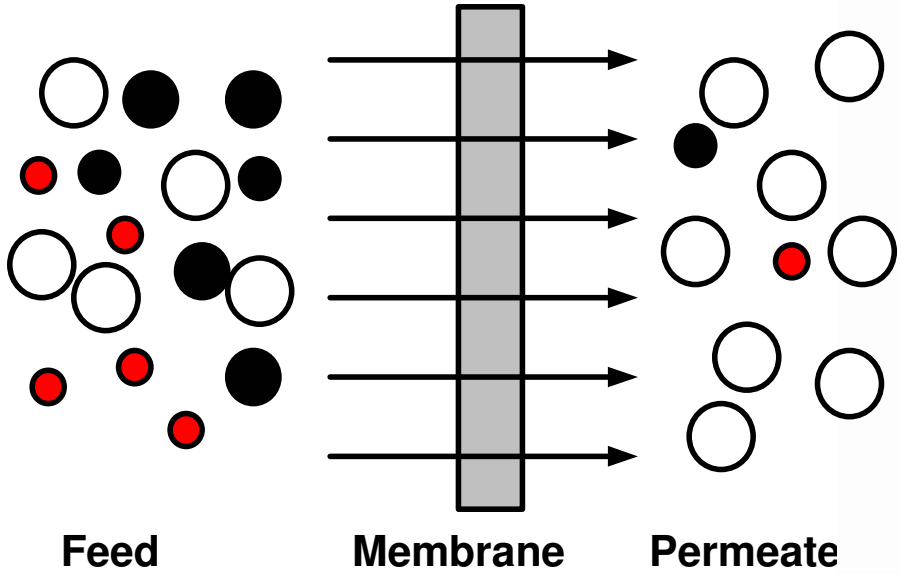
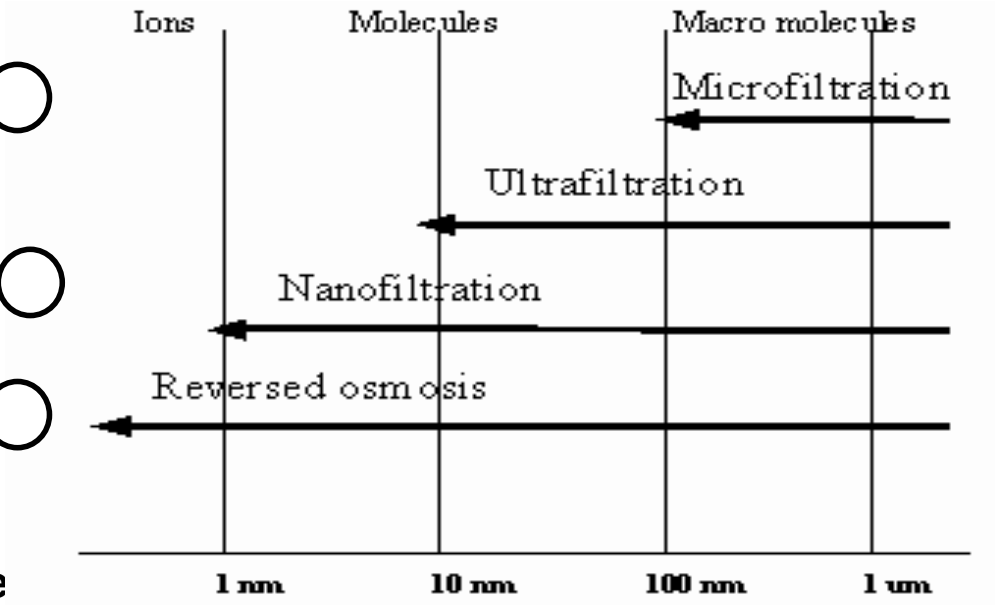
Outline

- My Background
- Basic Membrane Definition
- Membrane Processes
- Applications
- Selection

Basic Membrane Definition

Semi-permeable materials that allow certain selected materials (solutes e.g. molecules or ions) to pass through while retaining others under a driving force.

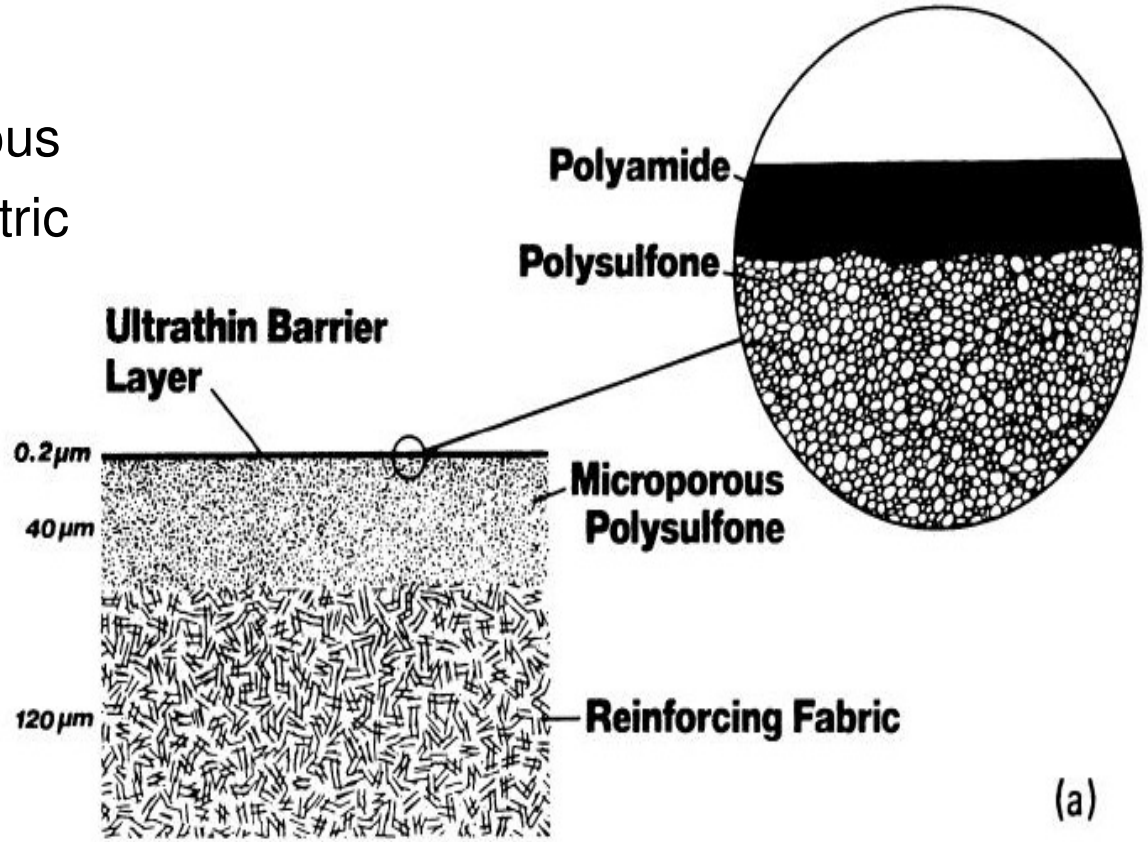




What is a Membrane?

Intervening structure separating two phases and/or acting as an active or passive barrier to the transport of matter between the phases adjacent to it.

- **Structure**:
  - Homo-.or heterogeneous
  - Symmetric or asymmetric
  - Solid or liquid
- **Charge**
  - Negative
  - Positive
  - Neutral
  - Bipolar



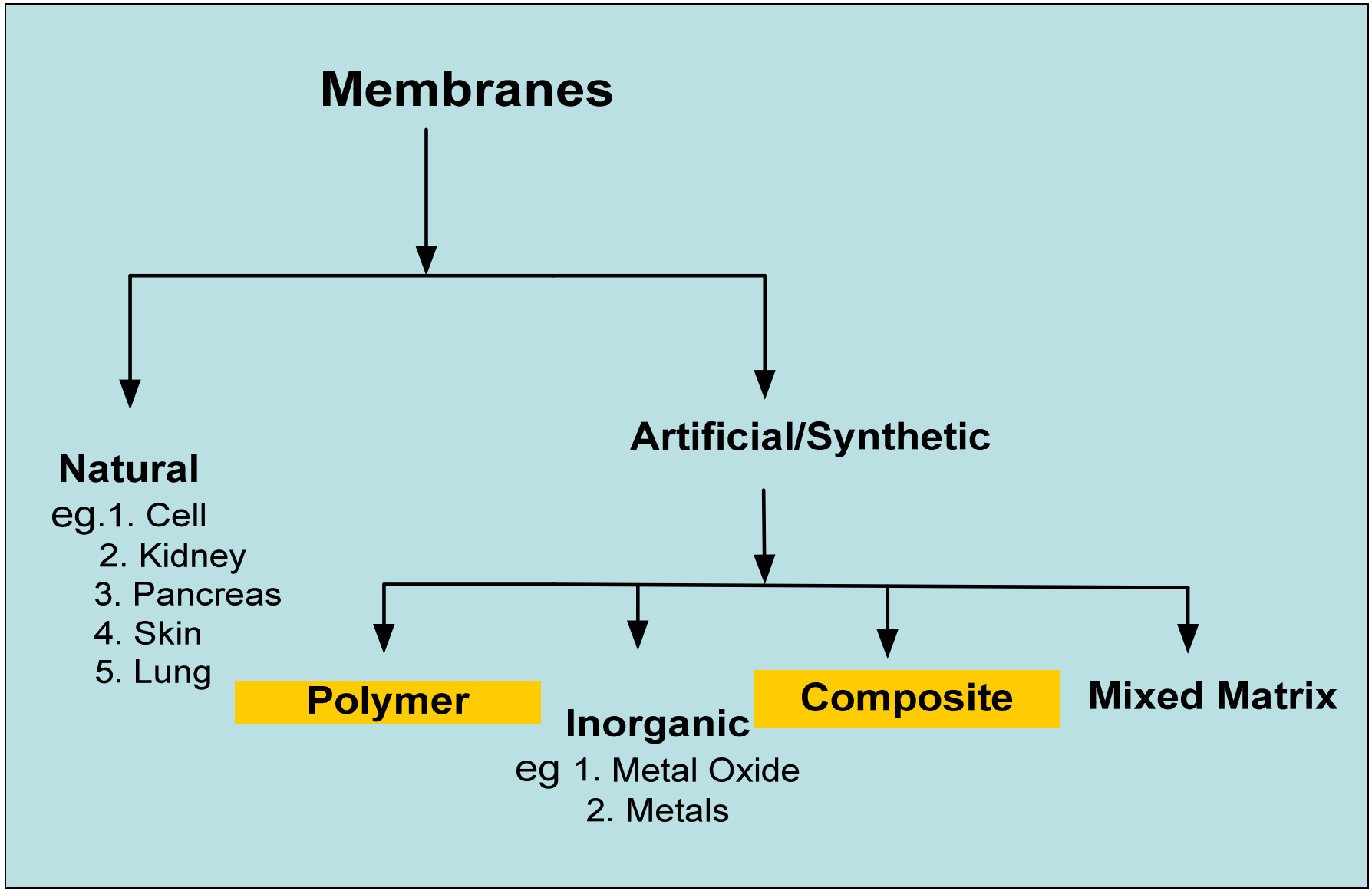
Some Advantages of Membranes

- Competing with niche technologies such as distillation, extraction, adsorption, stripping, degasification, etc
- Green process
- Lower energy consumption & foot print
- High selectivity e.g. for thermal labile products
- Wide range of applications
- Less sophisticated & ease of operation
- Modular expansion & ease of integration
- Linear scale from pilot and bench analysis

Some Disadvantages

- Newer Technology
- Fewer people with in-depth knowledge
- Could be expensive - polymer vs. ceramic
- Poor selection can heavily affect performance

Types of Membranes



Basic Functions of Membranes

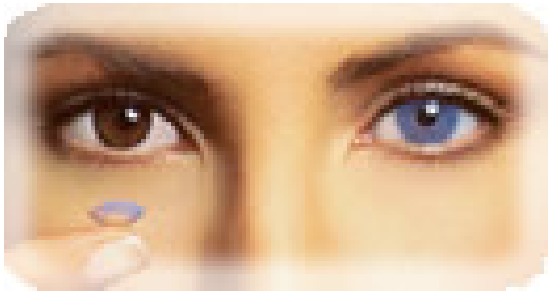
- Separation e.g. water and ethanol purifications
- Discrimination e.g. pH meter, blood glucose meters
- Selective Transport e.g. contact lenses
- Delivery e.g. control drug delivery

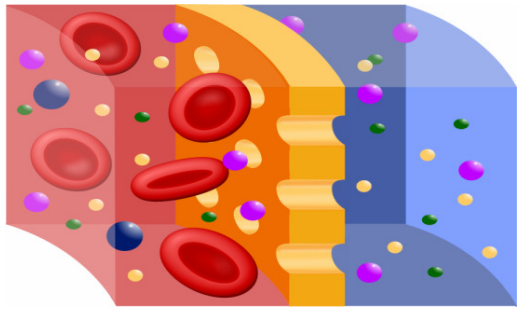
Membranes: Delivery Role

Control drug delivery e.g. patches such as nicotine patches, and some drugs, some oral or anal drugs, etc.

Membranes: Selective Transport Role

Applications includes contact lenses, artificial kidney, artificial liver and artificial pancreas, artificial lung (oxygenators), dialysis and hemodialysis.





Membranes: Discriminatory Role

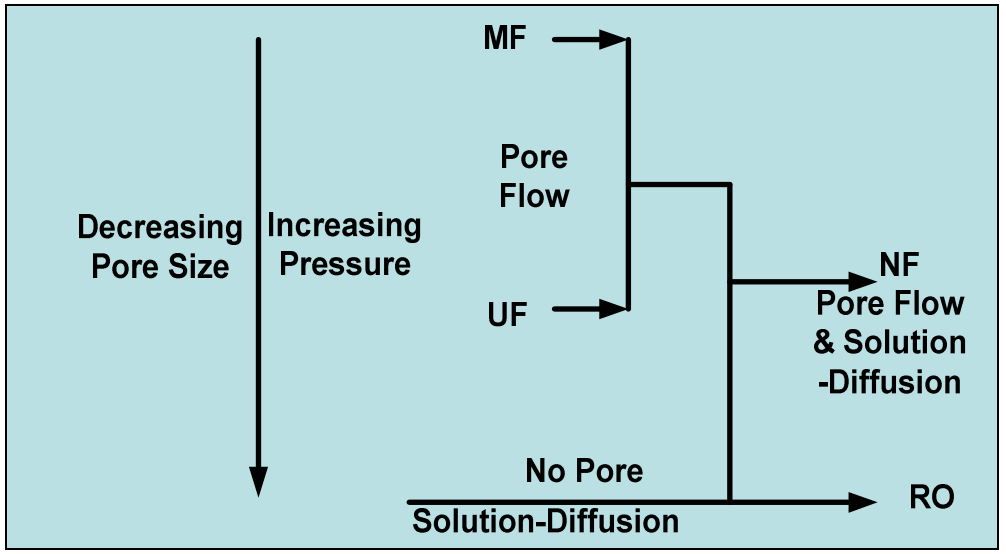
Applications include batteries, fuel cells, and sensors. Sensors have been used for the detection of chemical and biological agents.

Membranes: Separation Role

- Water purification and waste water treatments
- Seawater desalination and brackish water purification
- Petroleum and petrochemical industries for separations
- Purification and recovery involving solvents.
- Sterilization: removal of viruses, bacteria, fungi and unwanted microbes

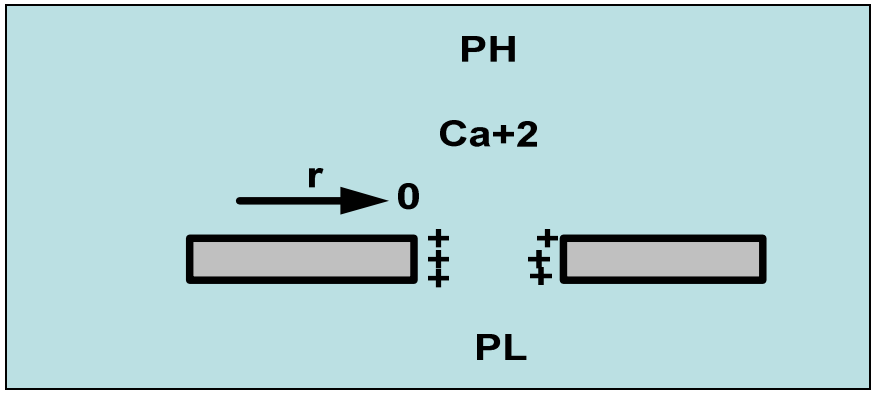
Some Common Membrane Processes

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse Osmosis (RO)
- Pervaporation (PV)
- Vapor/Gas Permeation
- Dialysis
- Hemodialysis
- Electrodialysis



$$E = k\frac{q_1 q_2}{r^2}$$

$$\Delta P = \frac{2\gamma \, Cos\beta}{r}$$

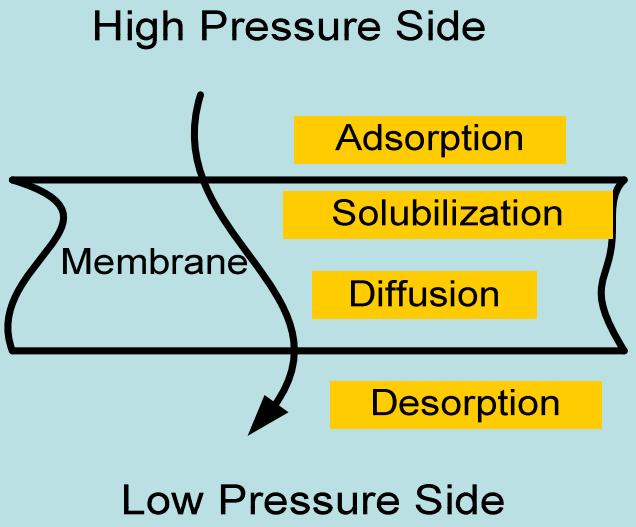


Separation Mechanisms

- ❑ Size
- ❑ Charge
- ❑ Shape
- ❑ Affinity
- ❑ Combination

Affinity- Cohesive Energy

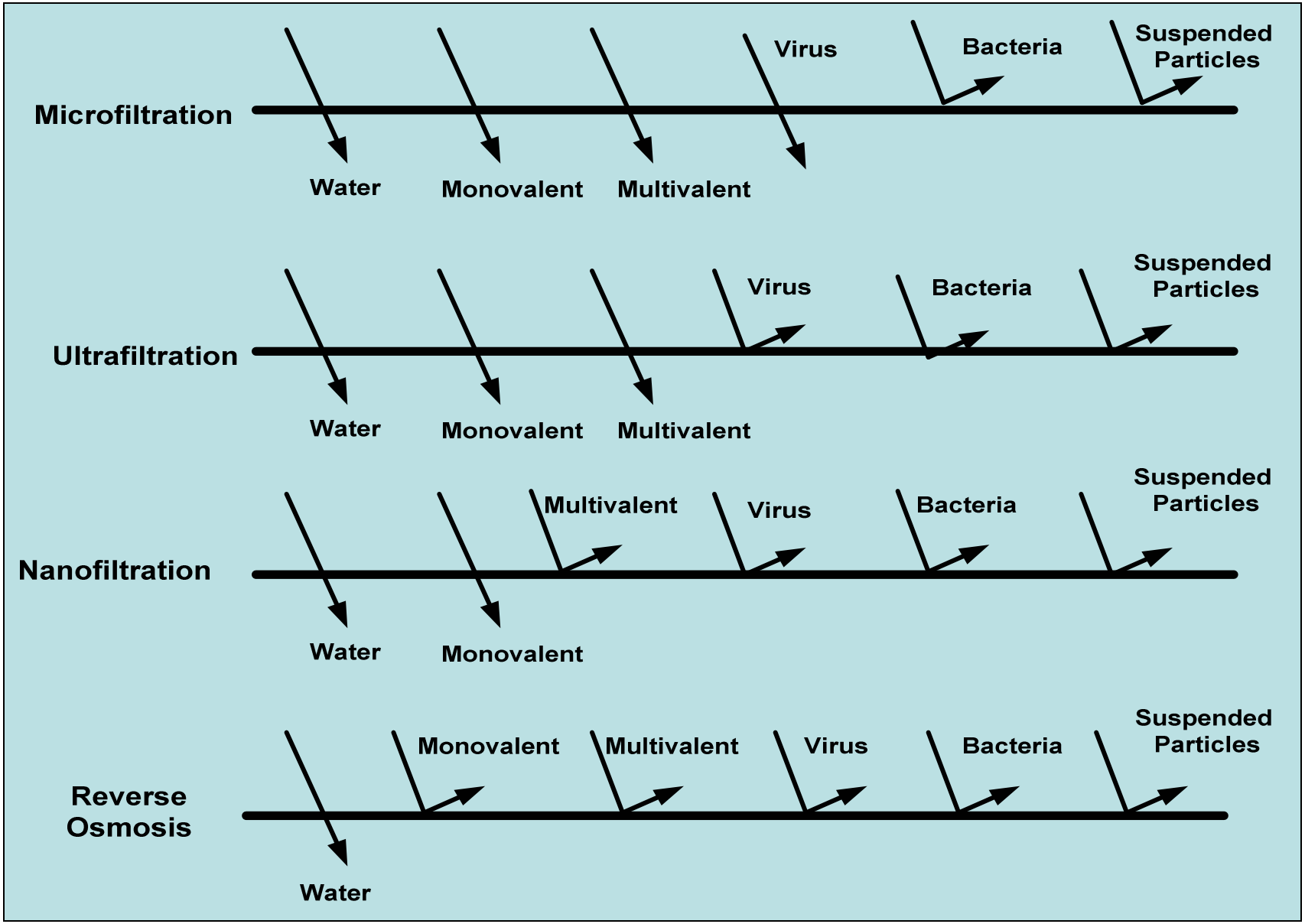
- o Adsorption
- o Solubilization
- o Diffusion
- o Desorption



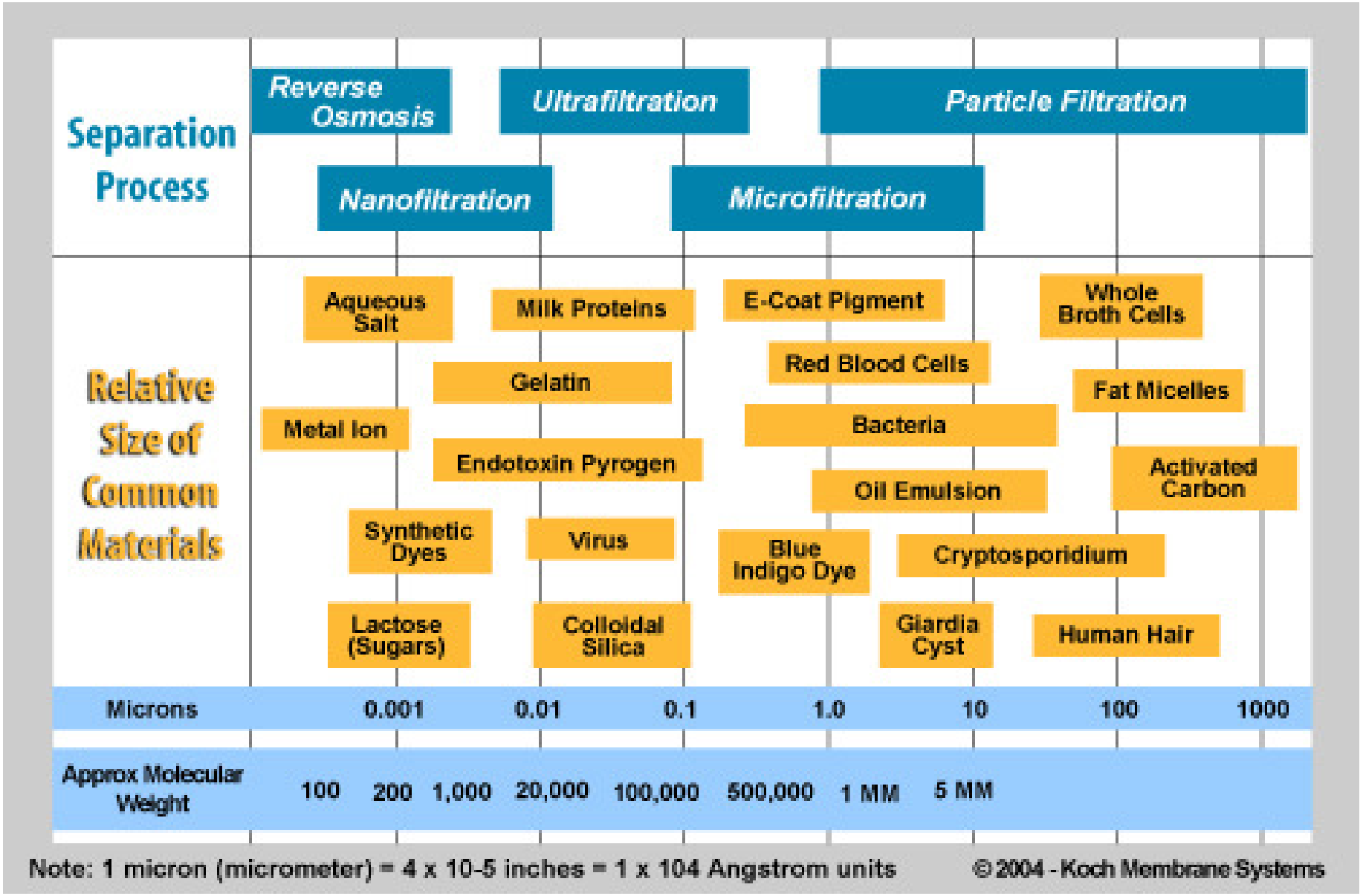
Driving Forces

- Pressure
- Concentration
- Partial Pressure
- Osmotic Pressure
- Electric Field
- Magnetic Field
- Temperature

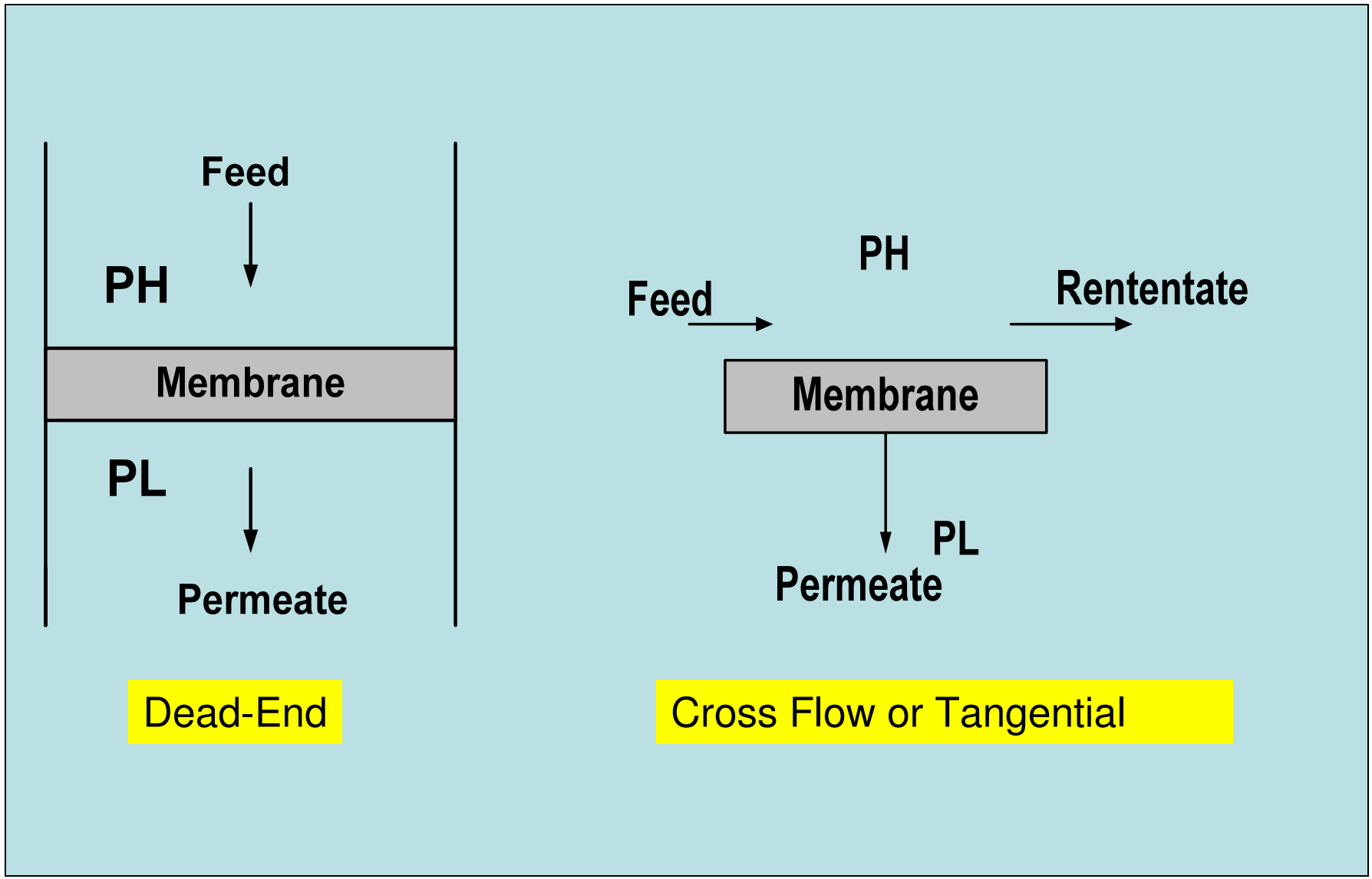
Membrane Process Capabilities



Membrane Process Capabilities

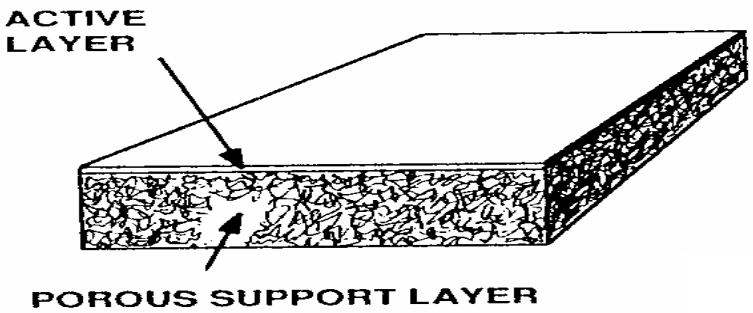


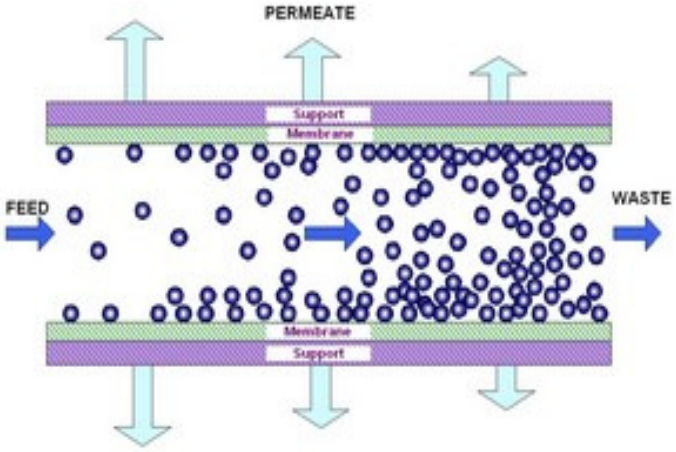
Flow Modes

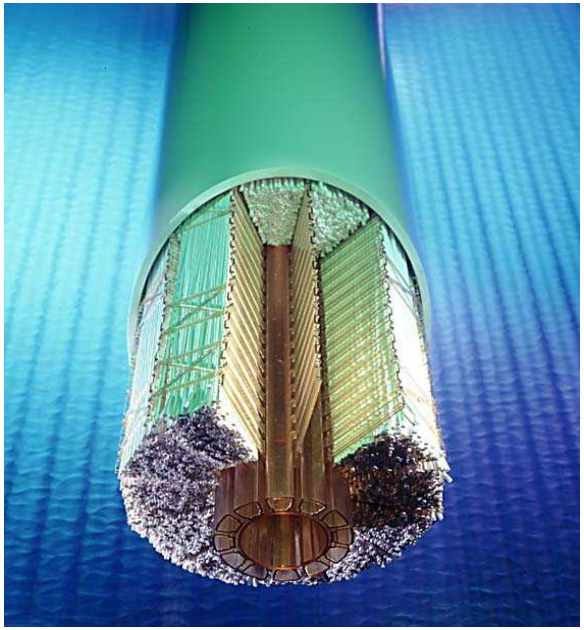

Feed
PH
Membrane
PL
Permeate
Dead-End
PH
Feed
Rententate
Membrane
PL
Permeate
Cross Flow or Tangential

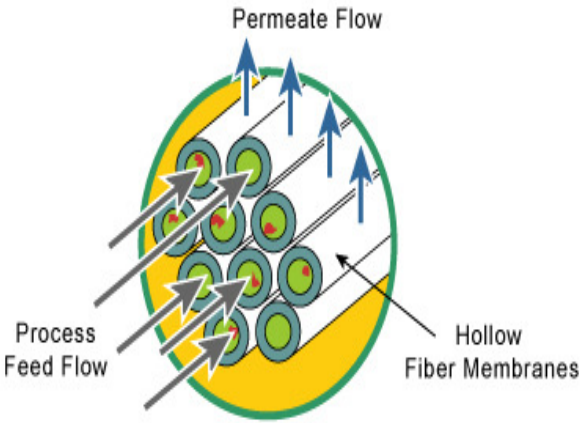
Configuration

- Flat Sheet
- Tubular
- Hollow Fiber
- Spiral Wound

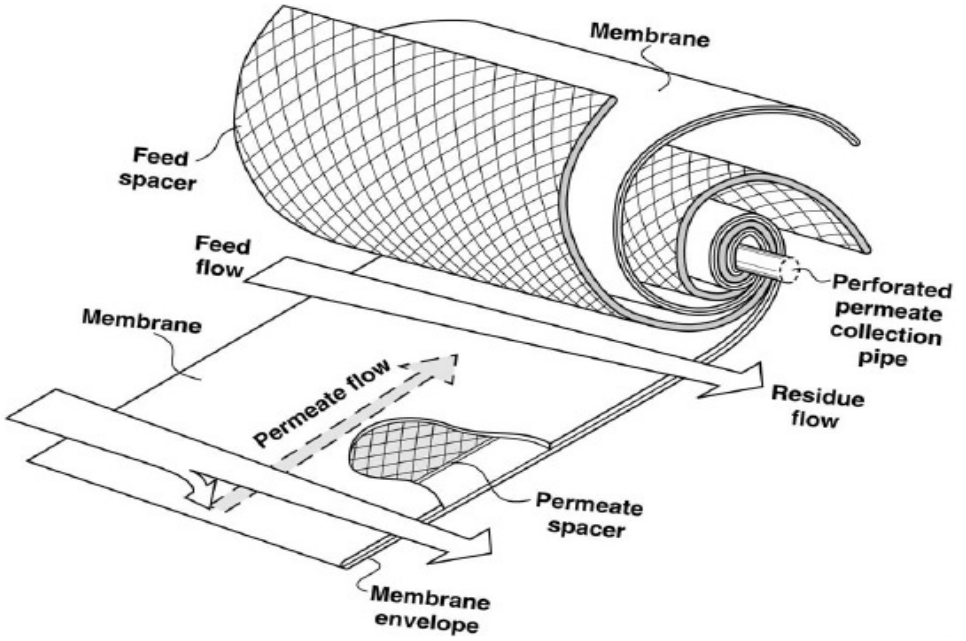




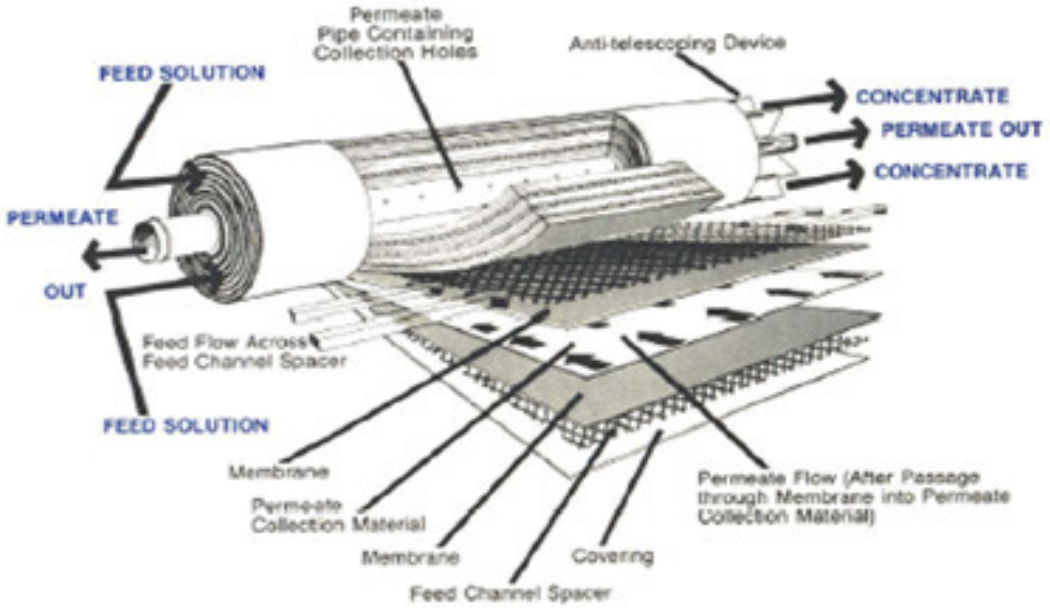




Configuration



Awesome Size. Awesome Savings.



- Spiral Wound

Some Industrial Application of Membranes

- Water and Pharmaceutical Purification
- Waste Water Treatment
- Seawater Desalination
- Food & Beverage
  - Dairy processing
  - Clarification, Debittering
  - Bottled water
  - Dealcoholization of wine

- Solvent Purification and Recovery
- Biofuel Separation – Bioethanol, Biodiesel, etc
- Petroleum & Petrochemical
  - Catalyst recovery, NPG purification
  - Petroleum & Petrochemical
- Gas Separation & Purification
  - CO_2/H_2, NPG & LPG Purification

Membrane Applications: Petroleum & Petrochemical

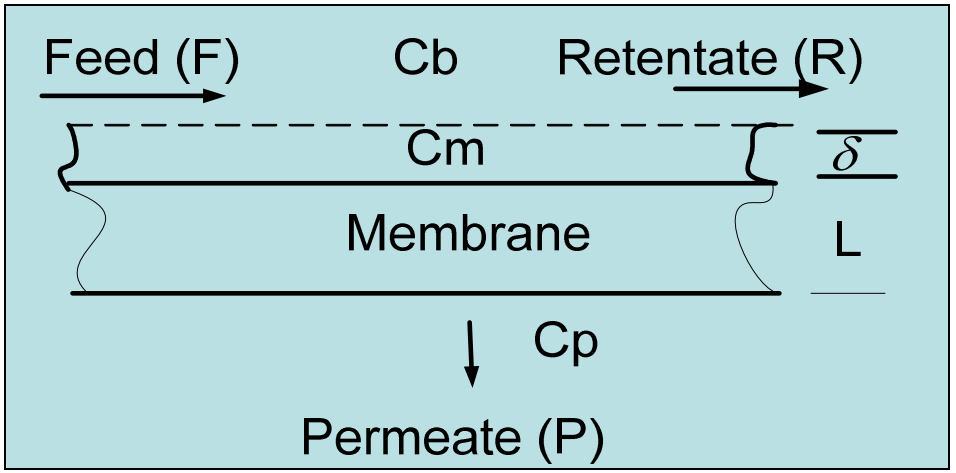
- **Petrochemical:** Hydrocarbon and nitrogen recovery from vent streams in polypropylene production, ethylene oxide and vinyl acetate monomer production and polyvinyl chloride (PVC) production.

- **Natural Gas:** Fuel gas conditioning, natural gas liquids conditionings (NGL), recovery/dew point control, and nitrogen, carbon dioxide, and hydrogen sulfide removal

- **Refinery and Syngas:** Hydrogen purification and liquid petroleum gas (LPG) recovery from refineries, hydrogen separation in syngas processes and CO2 removal from syngas.

Propylene and Isobutane Recovery Membrane Unit at a Polyolefins Plant

Membrane Performance Characterization



$$1.\ \text{Flux}\ (q) = \frac{\text{Volume}}{\text{Area} \times \text{Time}}$$

$$2.\ \text{Permeability}\ (Lp) = \frac{\text{Flux}\ (q)}{\text{Transmembrane Pressure}\ (\Delta P)}$$

$$3.\ \text{Observed Rejection}\ (OR) = \left[1 - \frac{Cp}{Cb}\right] \times 100\ \%$$

$$4.\ \text{Intrinsic Rejection}\ (r) = \left[1 - \frac{Cp}{Cm}\right] \times 100\ \%$$

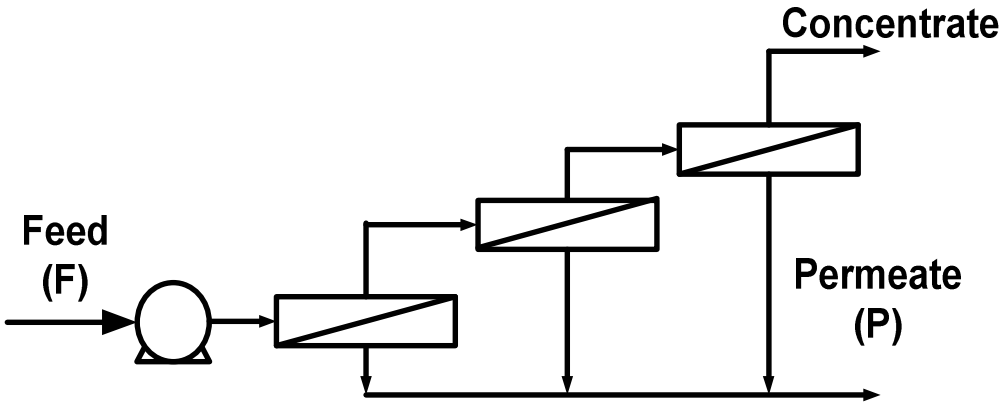
Factors Affecting Membrane Performance

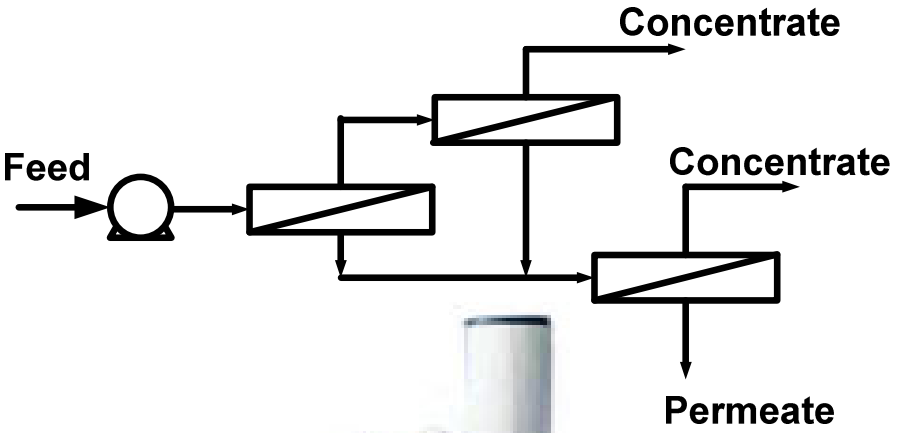
- Nature of the feed
  - Gas-liquid mixture
  - Liquid mixture
  - Solid and liquid mixture
  - Fouling feed, viscosity, density, etc
- Flow Rate
- Concentration
- Temperature
- Driving Force e.g. pressure, concentration, etc
- Type of Membrane Process and Material
- Module Configuration

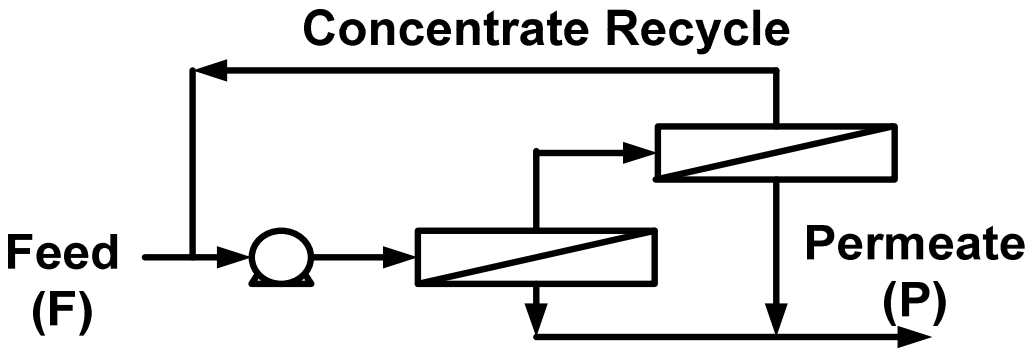
Problems Facing Membrane Performance

- Concentration Polarization
- Fouling
- Swelling
- Compaction

Membrane System Design

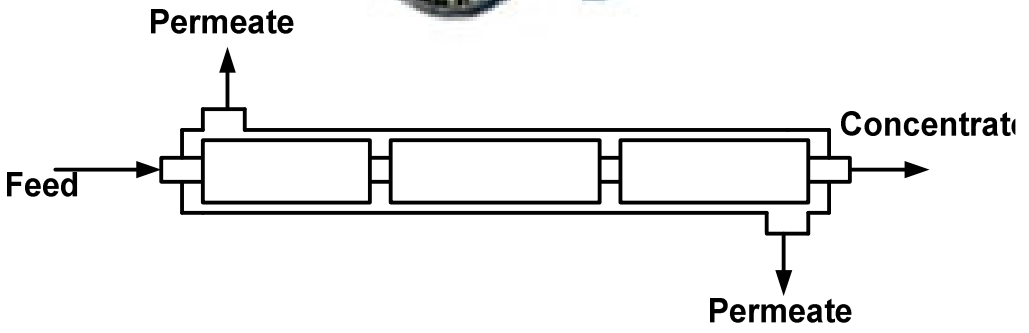




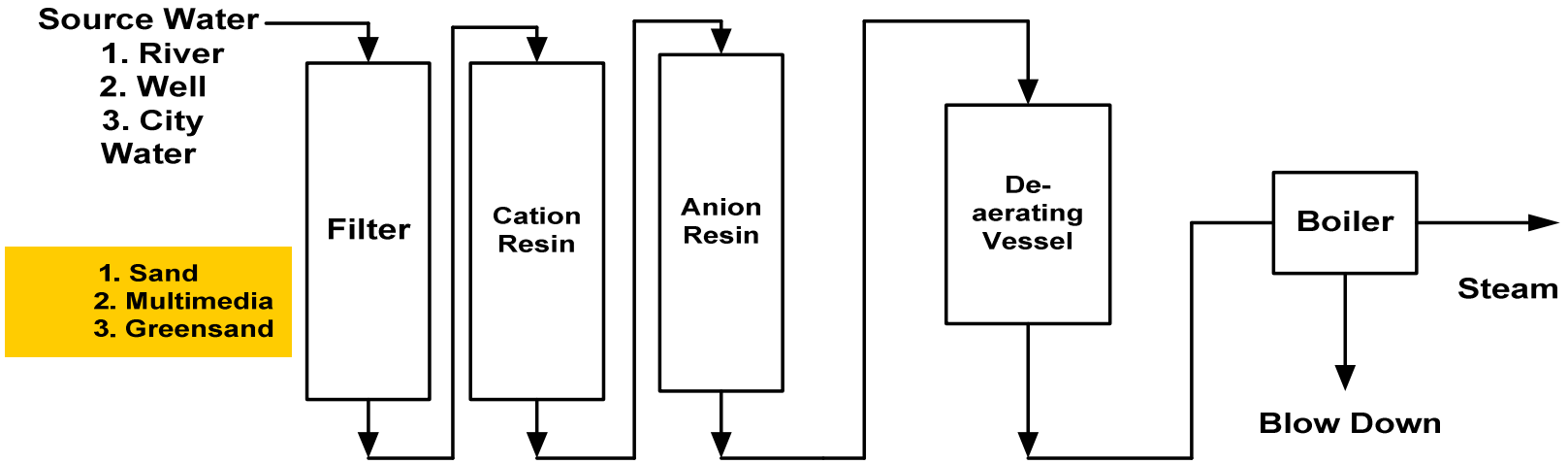


System Design Software Demo

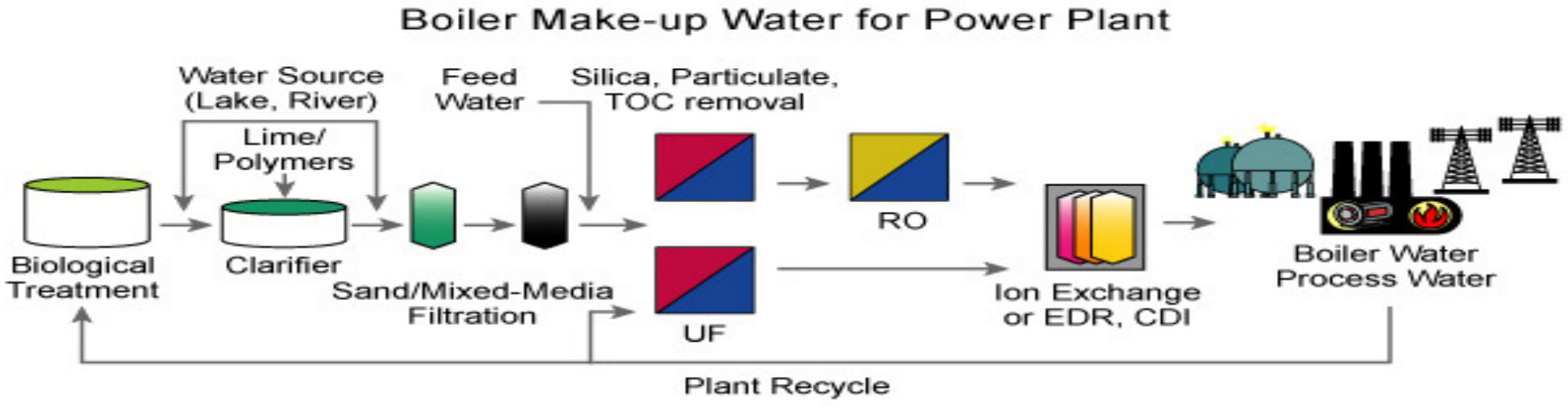
- o For MF, UF, NF and RO
- o Recovery (P/F)
- o Stages
- o Passes



Boiler Water Treatment Process

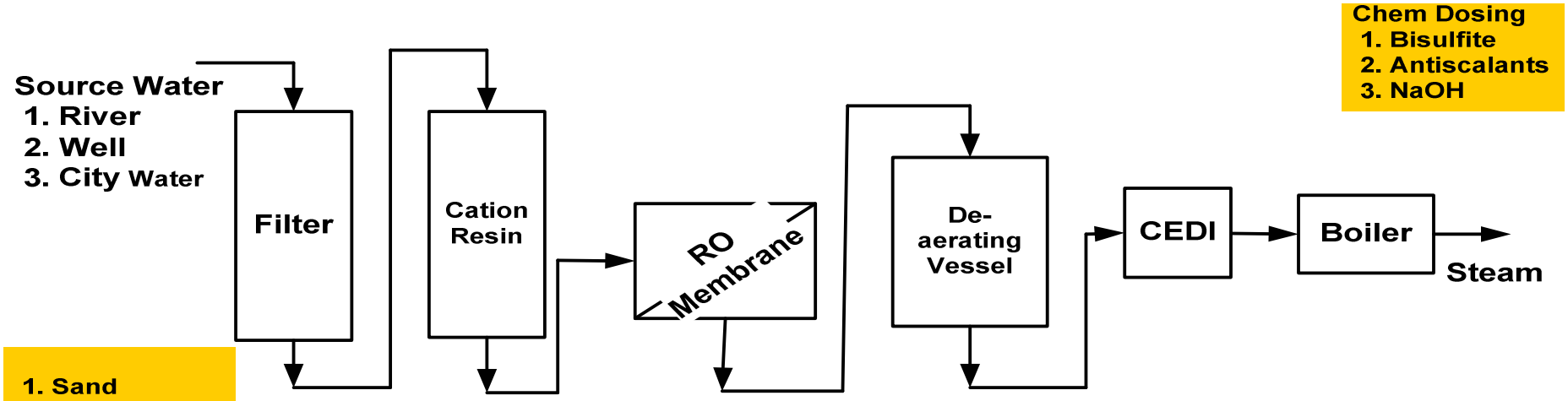


Cold lime softening before the filters depending on the hardness



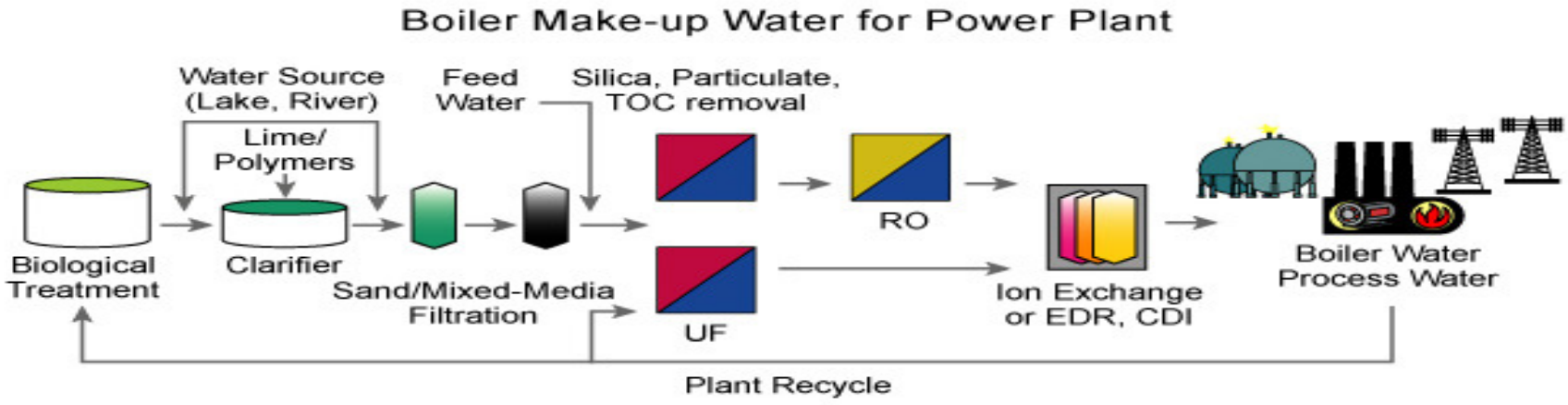
- Alternative to chemical and physical based RO pretreatment
- Provides higher quality product water for improved RO operation
- Option to reuse municipal wastewater or boiler blow down water

Boiler Water Treatment Process



Easier to treat well water river water

- First pass normally fed to demin. system
- Second pass fed to the boiler



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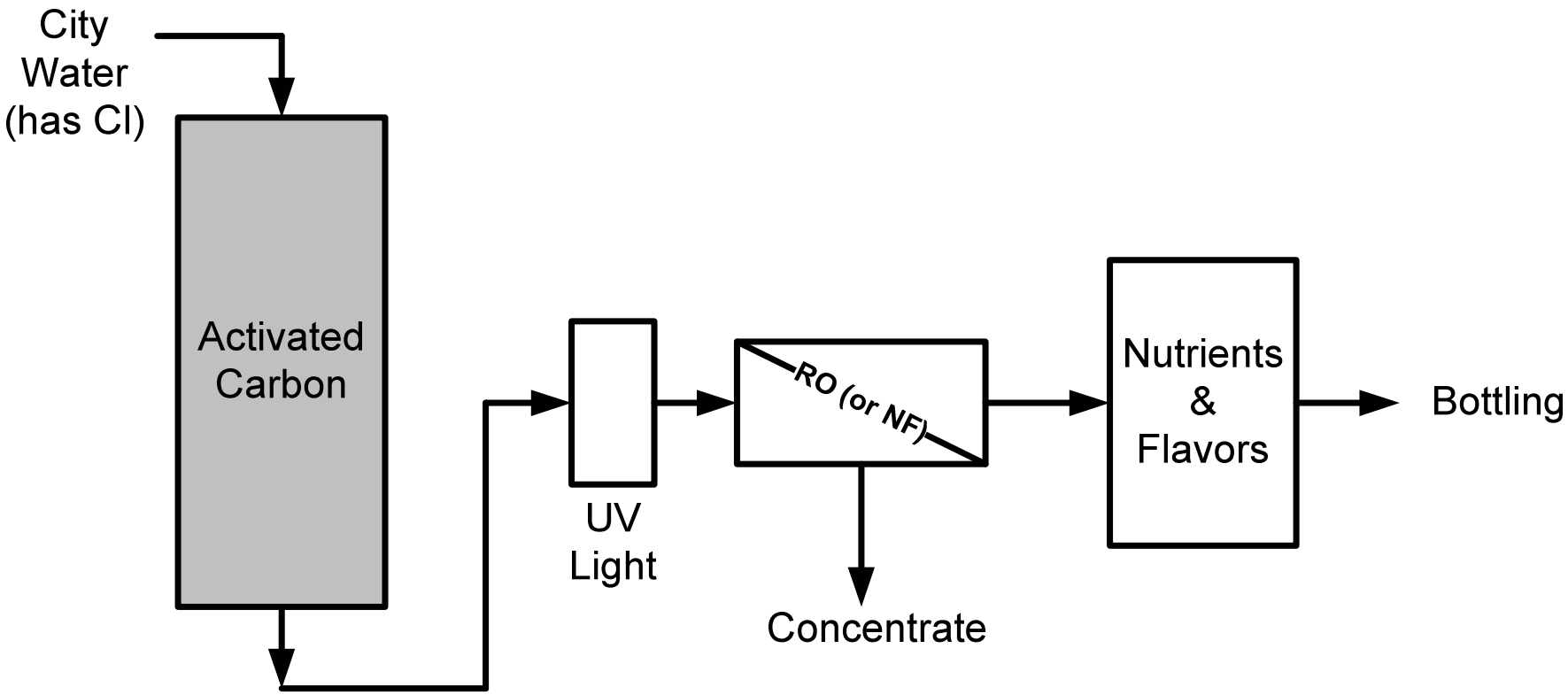
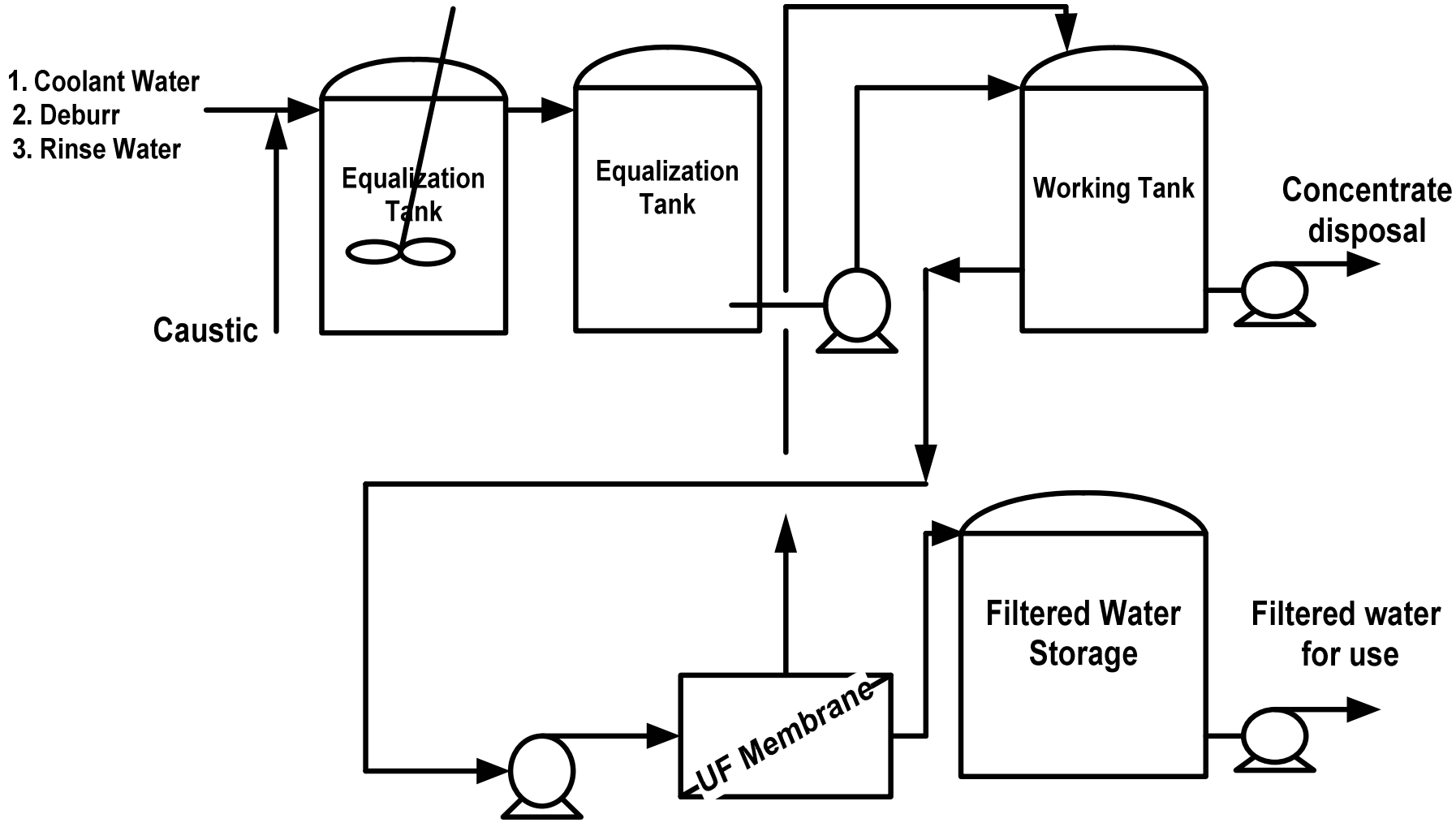
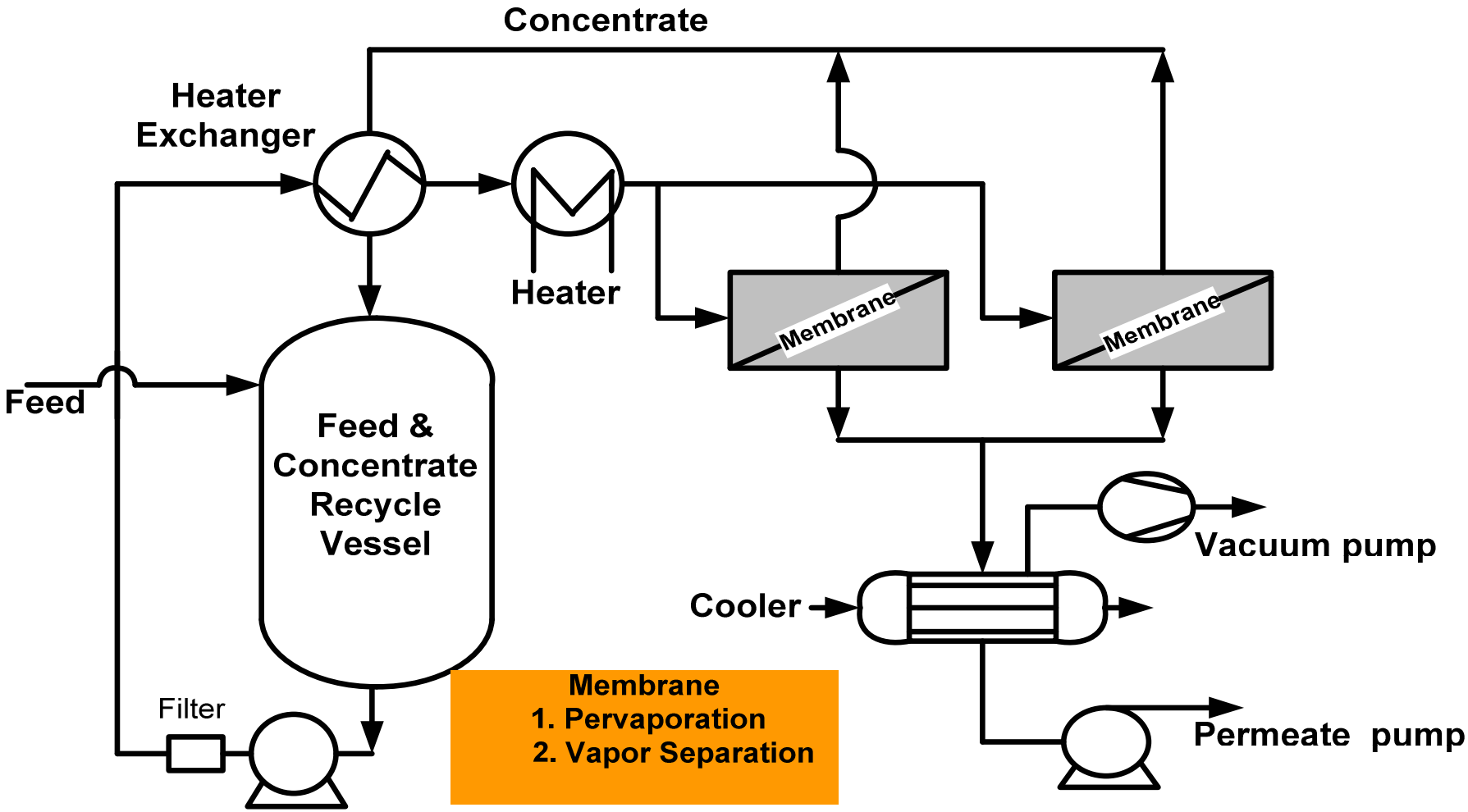
Purified Water Treatment Process



Waste Water Treatment for Re-use

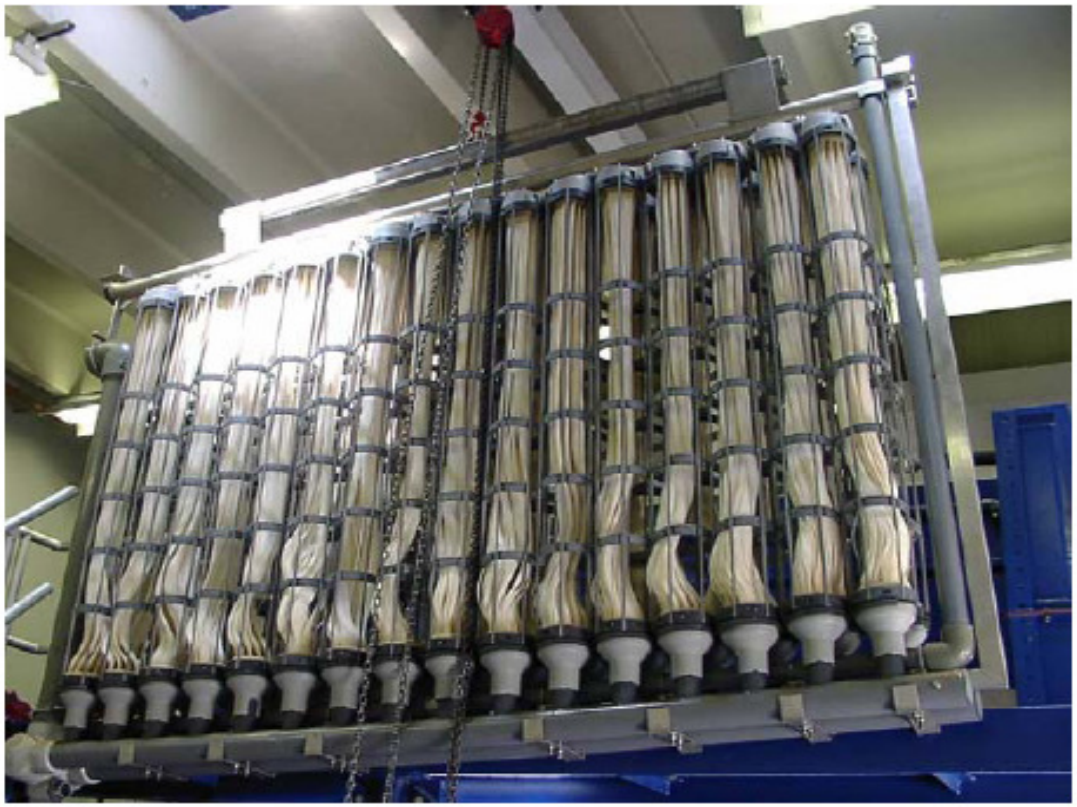


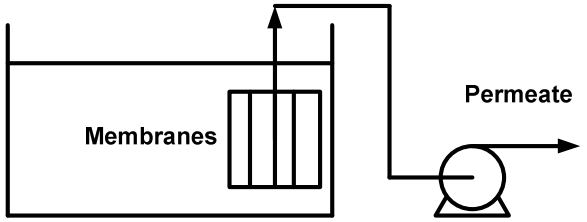
Biofuel & Solvent Dehydration & Purification



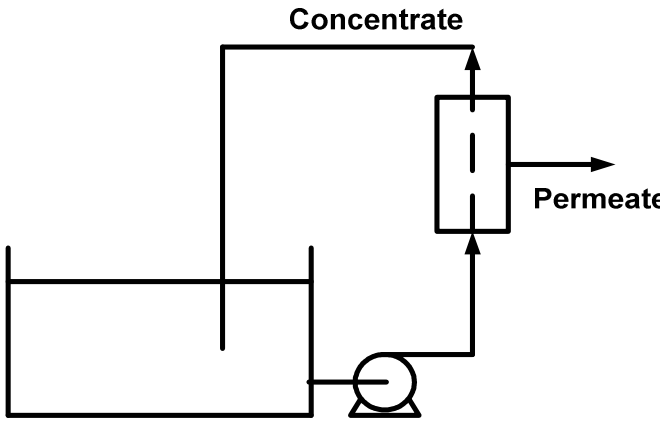
Desalination/Brackish Water Purification Process

Membrane Bioreactors





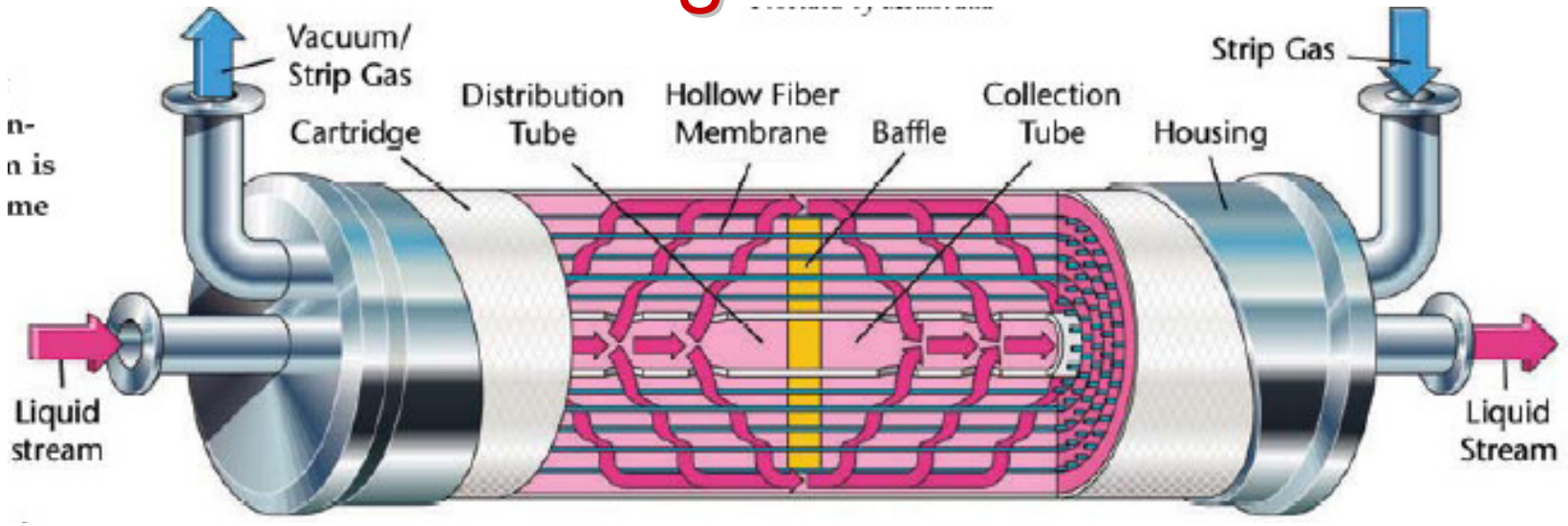
❑Submerged & vacuum

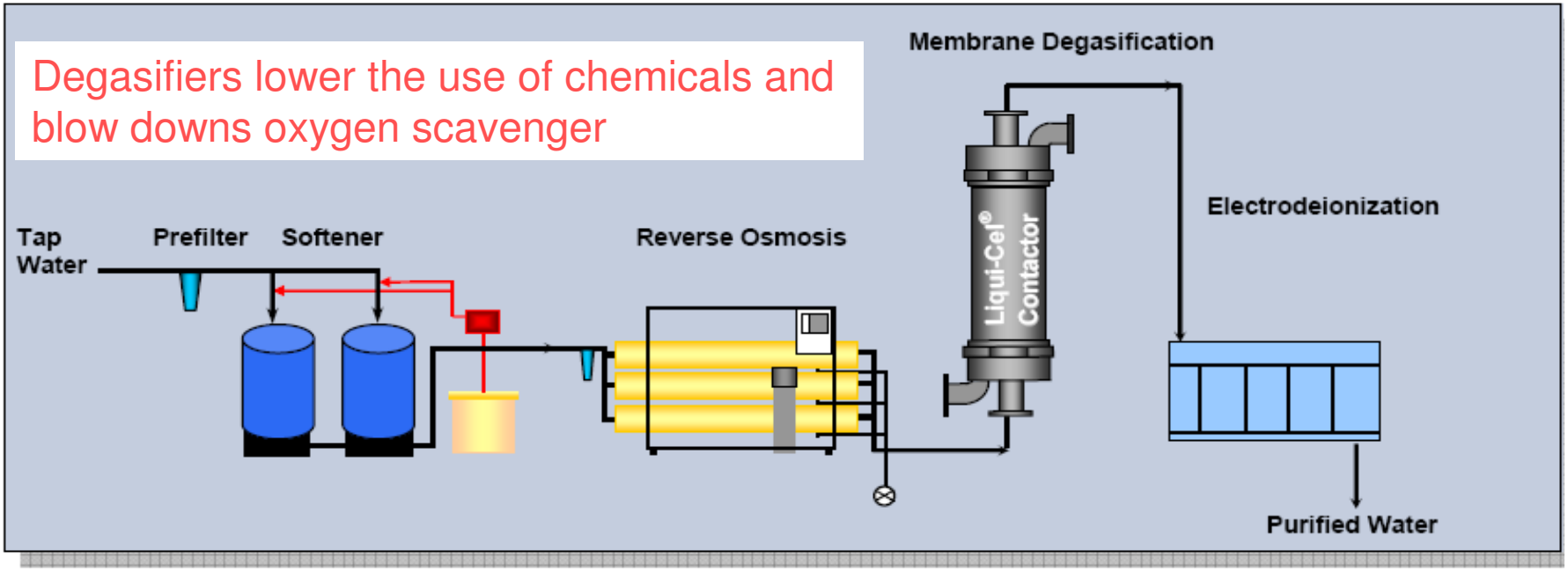


❑Pressure Driven

- ❑ For waste treatment e.g. organic waste, enzymatic or bacteria decomposition
- ❑ For biofuel separation e.g. Bioethanol & bio-butanol from fermentation broth
- ❑ For pharmaceutical separation application e.g. antibiotics from fermentation broth

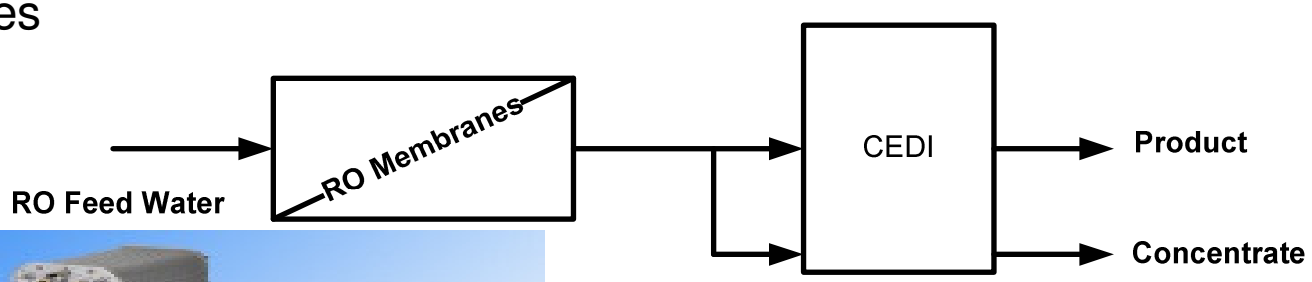
Membrane Contactors: Gasification & Degasifiers

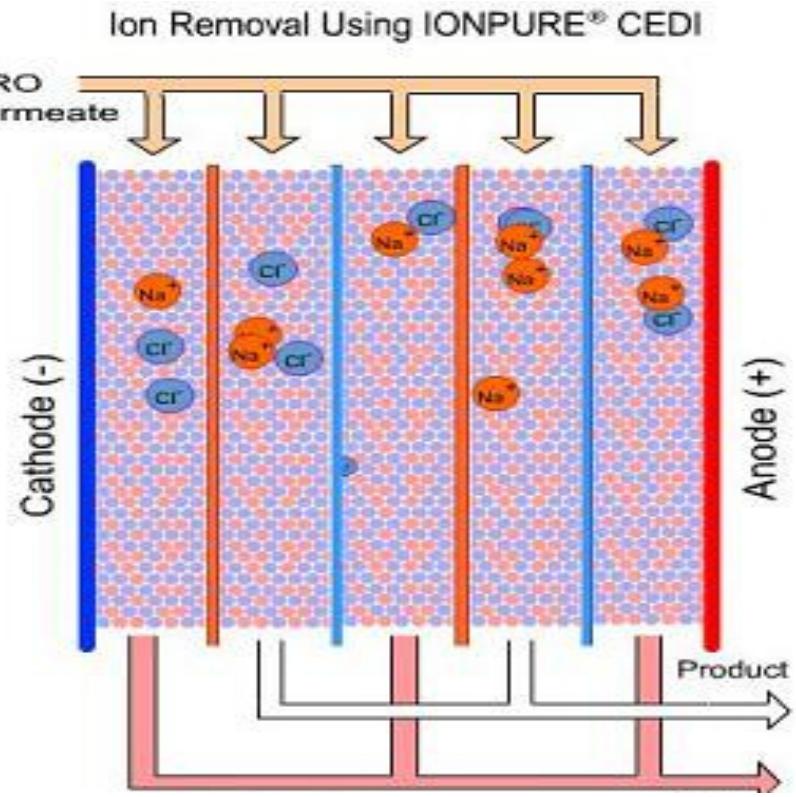




Pharmaceutical and Microelectronic Grade Water

- RO membranes followed by Continuous Electrodeionization (CEDI)
- CEDI principles - Ion exchange resin + charged (cationic and anionic) membranes





Conclusions

- Membranes have wide and varied applications.
- Proper selection of membrane processes, materials, feed rate, driving forces and configuration are pertinent for designing an effective membrane system.
- Membranes also has very specialized applications.
- Could provide effective solution to the current quality water problems in Africa.


THANK YOU!

Questions ?

Large RO Systems

Degasifiers: Economic Benefits

Boiler Operating Details		
	Chemically Treated Feed Water	Degassed Feed Water
Boiler capacity	10,000 lb/hr	10,000 lb/hr
Pressure	50 psig	50 psig
Efficiency	80%	80%
Fuel	Natural Gas	Natural Gas
Fuel cost	4.5 USD/ 1000 ft³	4.5 USD/ 1000 ft³
Fuel efficiency	1000 BTU/ft³	1000 BTU/ft³
Condensate return	30%	30%
Boiler blow down rate	10%	5%
Hours of operation	6600 hrs/yr (275 days/yr)	6600 hrs/yr (275 days/yr)
Feed water costs	1.2 USD/1000 gallons	1.2 USD/1000 gallons
Sodium Sulfite cost	0.5 USD/lb	0.5 USD/lb
Feed water temperature	60° F	60° F
Inlet Dissolved	9.0 ppm	0.5 ppm

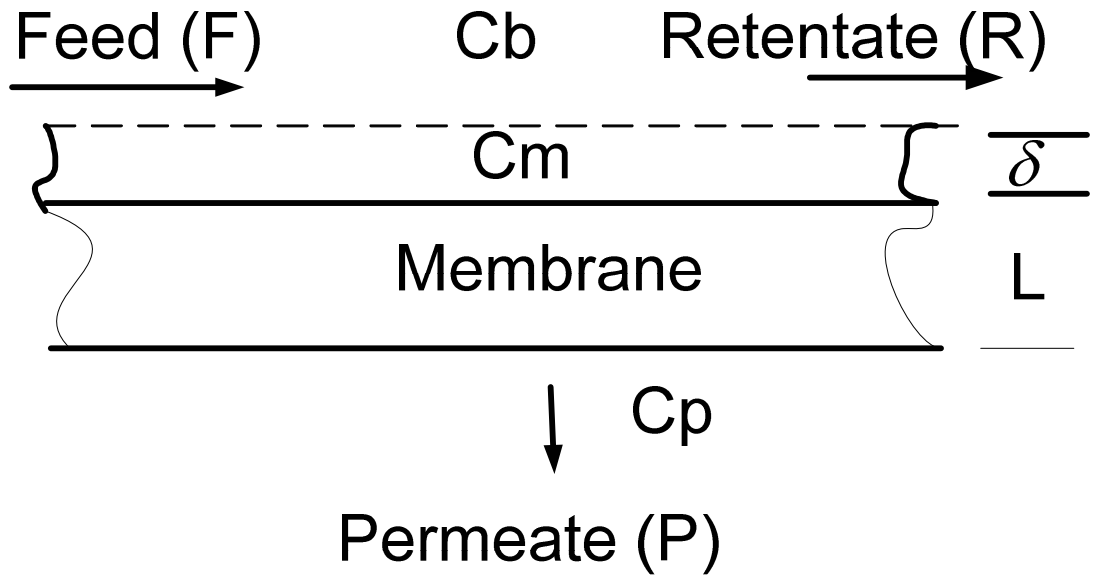
Comparison of Chemical Treatment System to Degassing System			
	Chemically Treated Feed Water	Degassed Feed Water	Savings
Chemical cost (US$)	$2,299.00	$128.00	$2,171.00
Blow down water costs	$1,055.00	$500.00	$555.00
Energy cost due to heat loss in blow down	$11,095.00	$5,256.00	$5,839.00
Total yearly costs/savings	$13,997.00	$5,669.00	$8,565.00

Membrane Performance Characterization

$$q = \frac{Q}{A} = k\frac{\Delta P.}{\mu L}$$

$$q = Lp(\Delta p - \sigma\Delta\pi)$$

$$\Delta\pi = \varphi(Cm - Cp)RT$$



$$q = \frac{Q}{A}$$

$$\text{Permeability (Lp)} = \frac{\text{Flux (q)}}{\text{Transmembrane Pressure } (\Delta P)}$$