MASSEY UNIVERSITY
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UNIVERSITY OF NEW ZEALAND

280.371 Process Engineering Operations

Membrane Separation Processes
Lecture 1

Dr Eli Gray-Stuart
Lecture slides by Prof Marie Wong

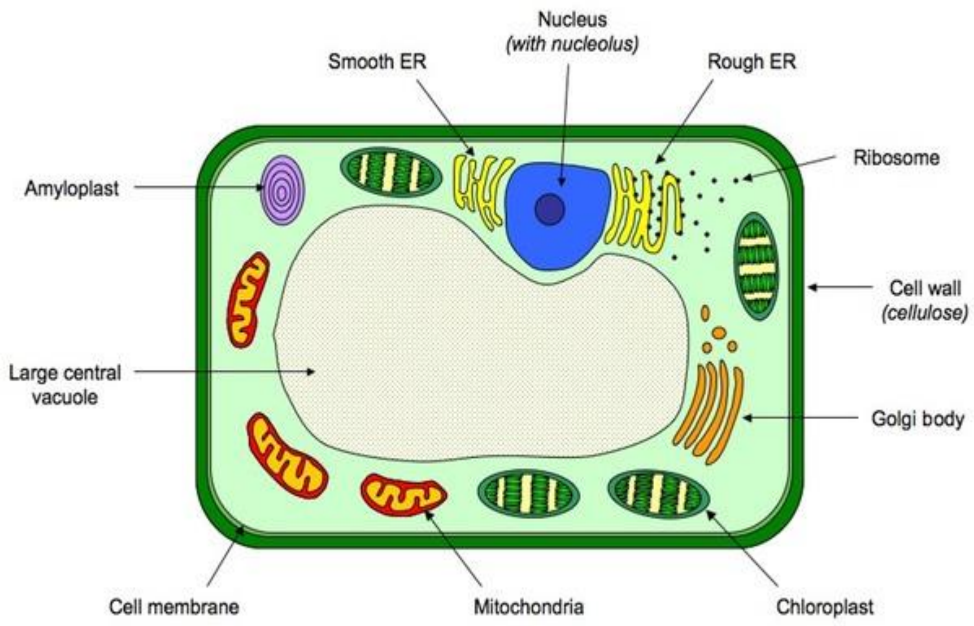
Relevant texts

- Geankoplis, C.J. 2003. Transport Processes and Separation Processes. 4^{th} Edition
- Geankoplis, C.J., Hersel, A.A., Lepek, D.H. 2018. Transport process principles. 5^{th} Edition

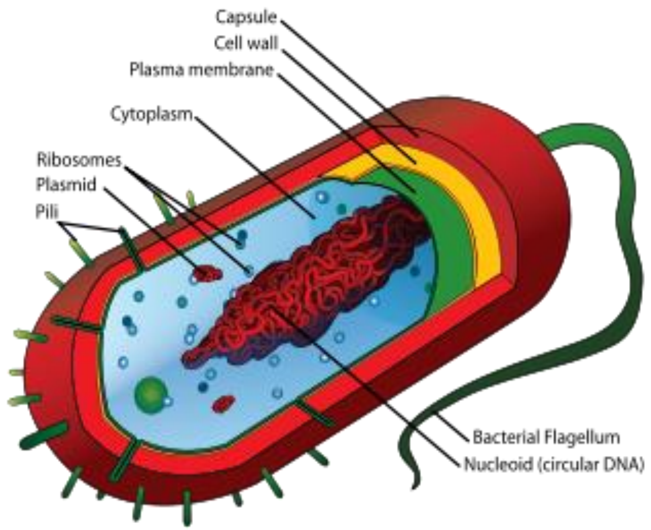
- Kirk-Othmer Encyclopedia of Chemical Technology, 2004. WileyEBS Ebook.

Membranes - natural

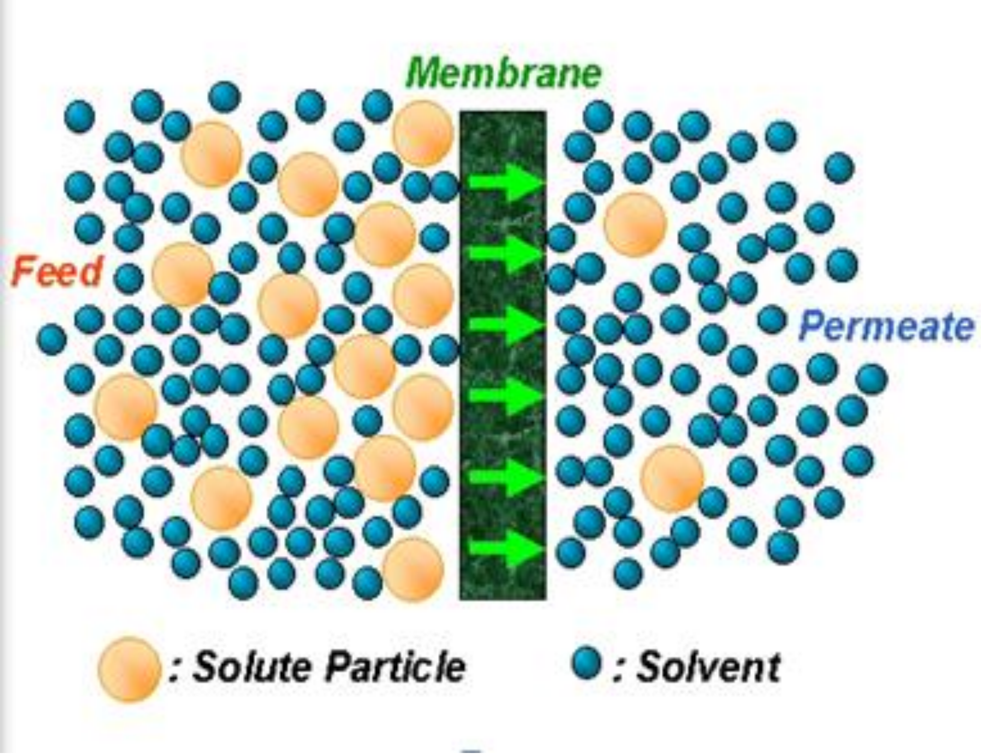
Plant cell



Bacterial cell

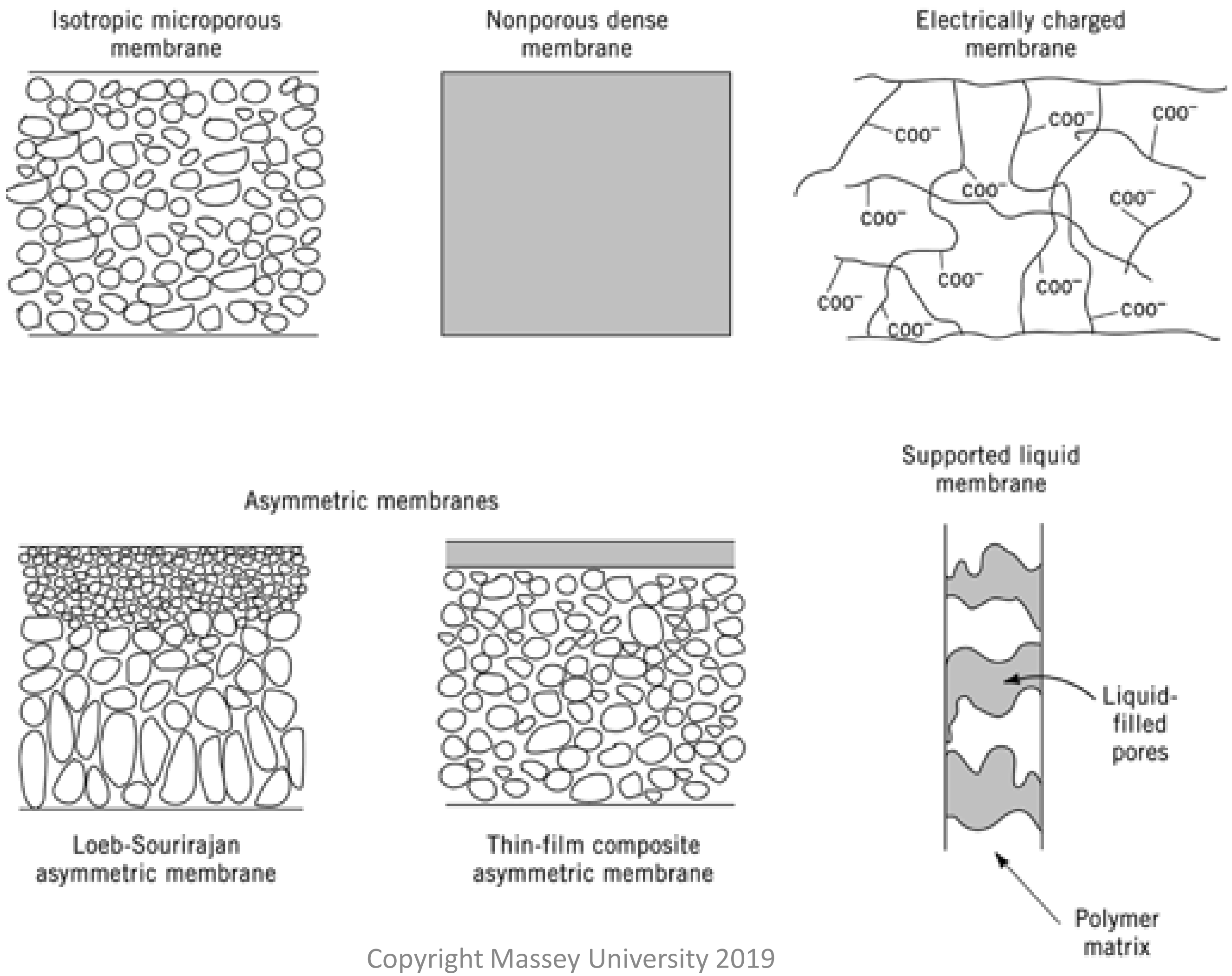


Synthetic membranes



- Barrier
- Semi-permeable
- Selective

Synthetic membrane types



Kirk-Othmer Encyclopaedia of Chemical Technology, 2000

Asymmetric cellulose acetate membrane

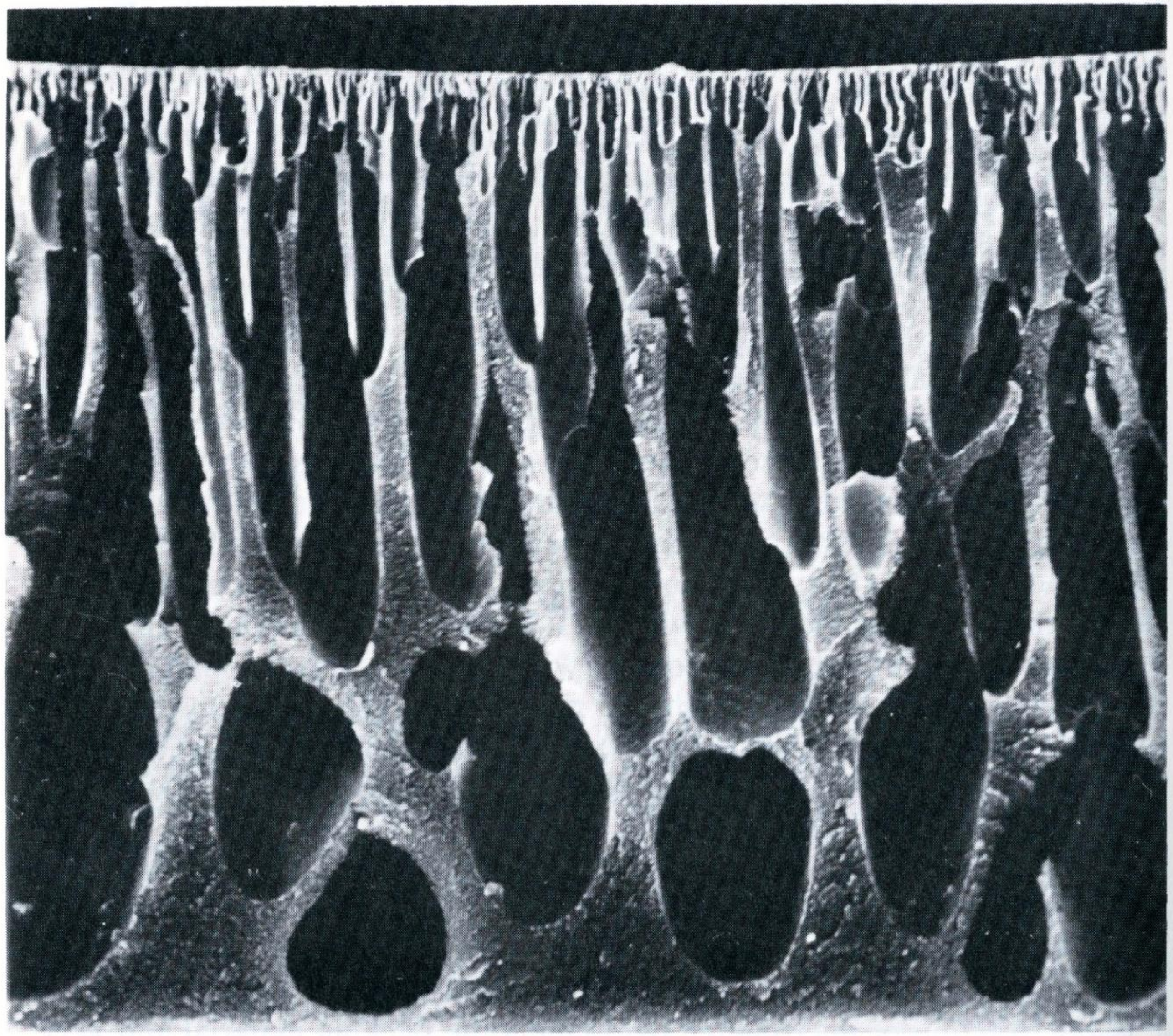
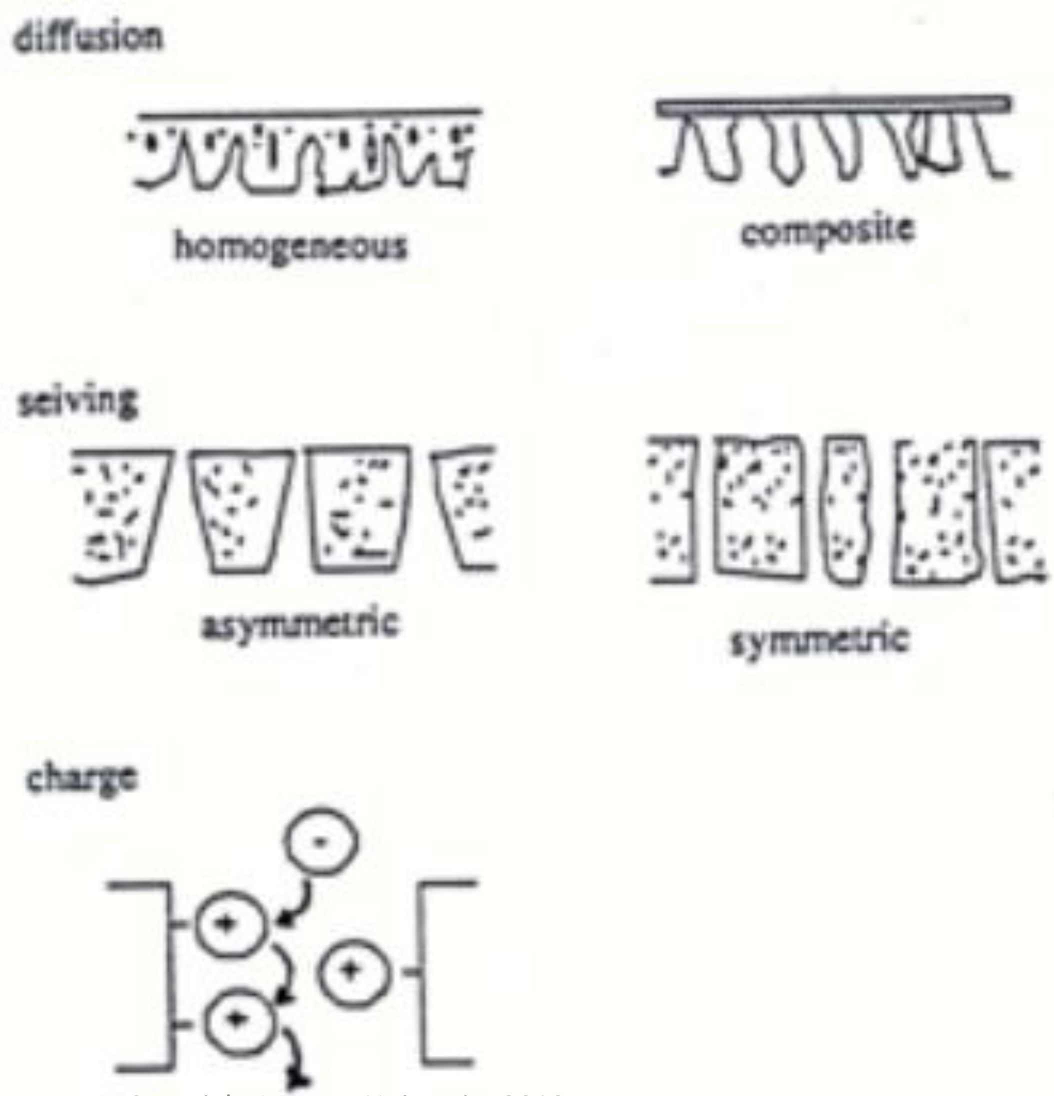


Fig. 2a Scanning electron micrographs of the substructure of asymmetric membranes showing dense skin and porous substructure. Flat cellulose–acetate membrane (total thickness ~100 μm). (ID ~500 μm).

(Belfort, 1984)

Separation mechanisms

- Diffusion
- Sieving
- Charge

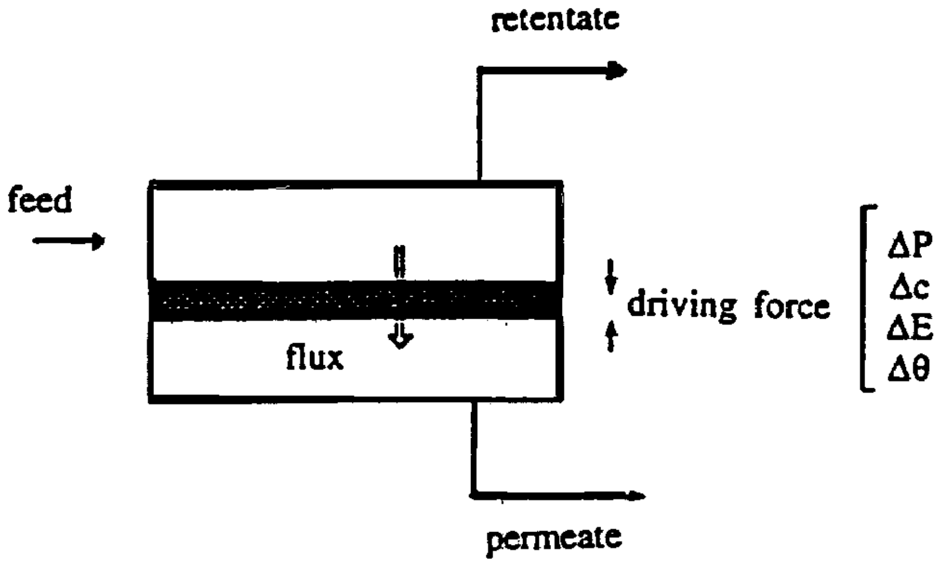


Membranes: Desirable features

- High selectivity
- High permeability
- Mechanical stability
- Temperature stability
- Chemical resistance
- Ease and reproducibility of manufacture
- Low cost

Terminology

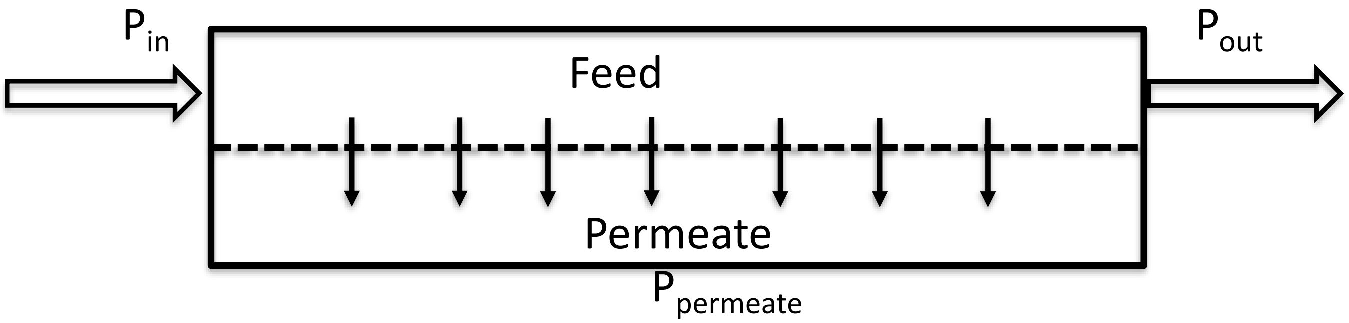
- Membrane
- Feed (F)
- Retentate (R)
- Permeate (P)
- F = R + P
- Flux (J)
  - Volumetric or mass flow rate per unit membrane area
- Driving force
- Rejection coefficient (SRC)



Pressure driving force

ΔP_{TM} Trans-membrane pressure

$$\Delta P = P_{in} - P_{out}$$



$$\Delta P_{TM} = \left(\frac{P_{in} + P_{out}}{2} \right) - P_{permeate}$$

- P_{in} is the inlet pressure on feed/retentate side
- P_{out} is the outlet pressure on feed/retentate side
- $P_{permeate}$ is the pressure on the permeate side

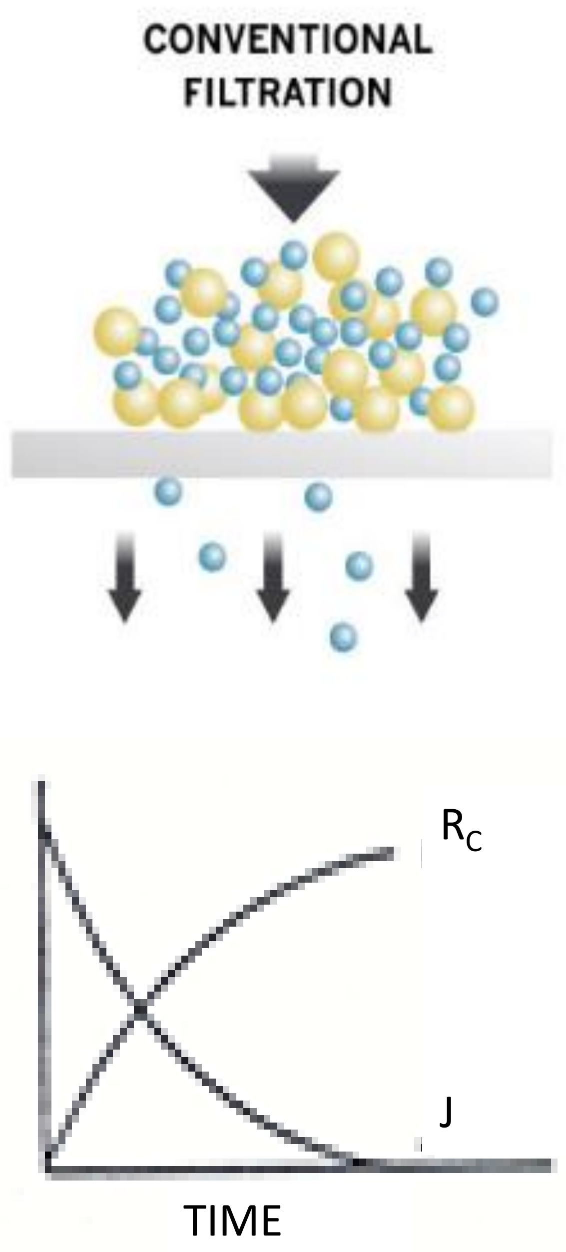
Recap

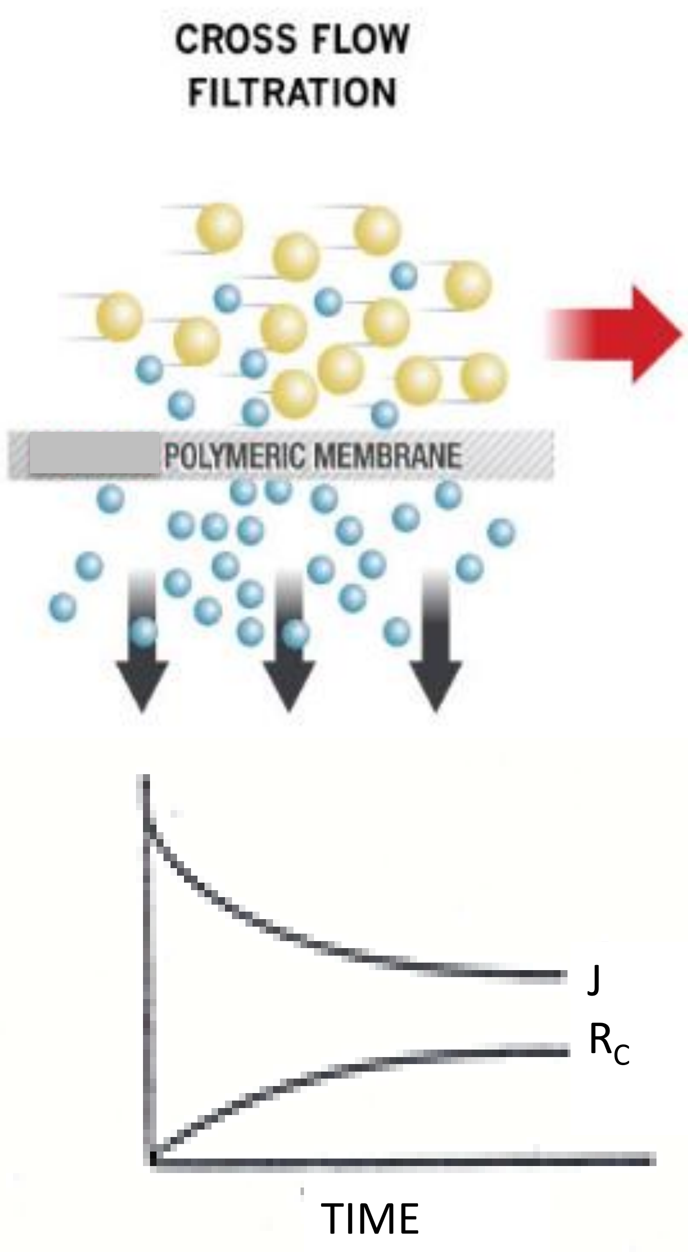
$$Q = v \times A$$

Q = volumetric flow rate m^3 s^{-1}
v = velocity m^2 s^{-1}
A = cross sectional area of flow m^2

$$Re = \frac{d_h v \rho}{\mu}$$

d_h = hydraulic diameter m
v = velocity m^2 s^{-1}
ρ = density m^3 s^{-1}





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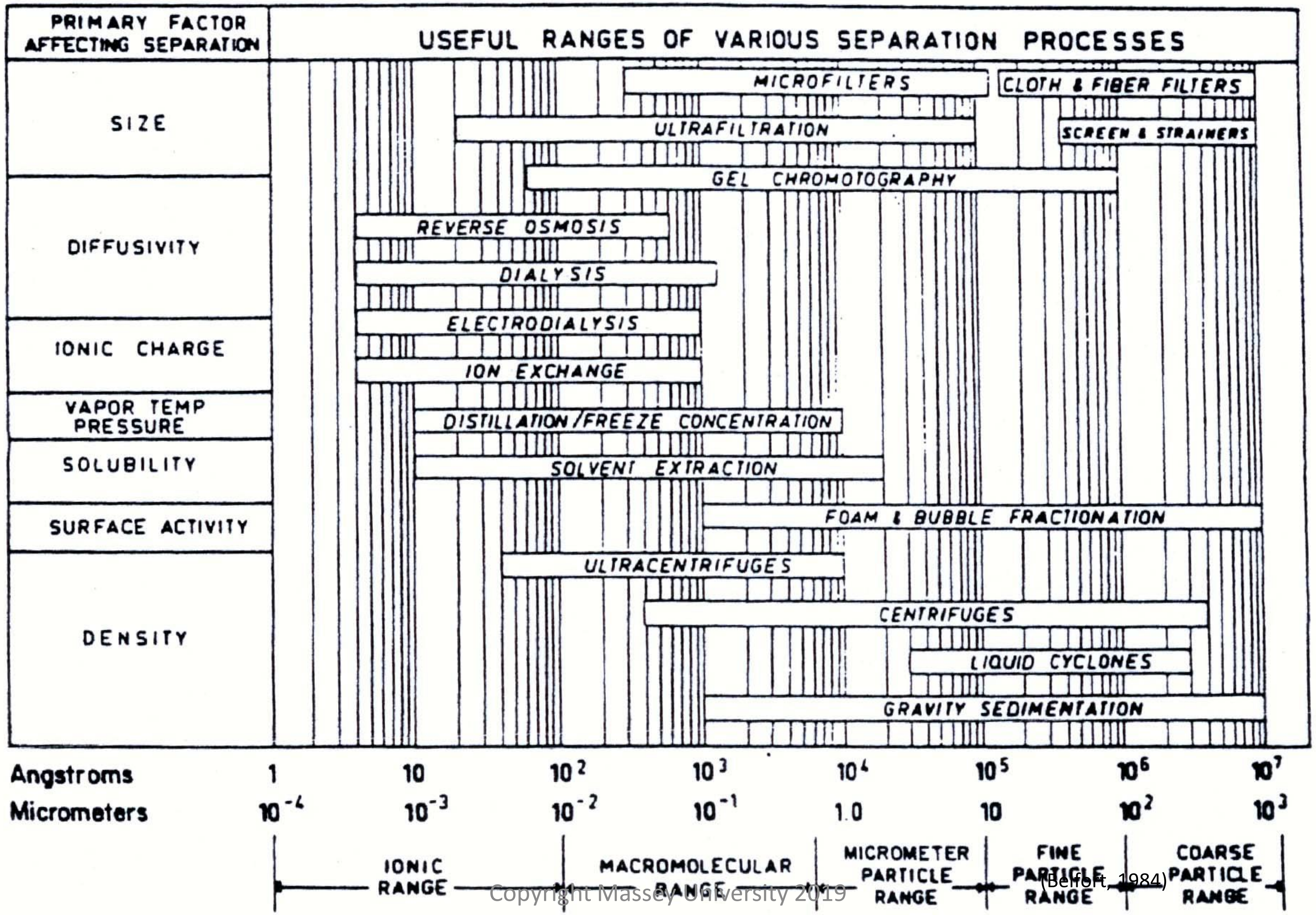
Membrane separation processes categorized by driving force

Driving Force	Membrane separation process	Feed phase	Permeate phase
Pressure	Reverse osmosis (RO)	L	L
	Ultrafiltration (UF)	L	L
	Microfiltration (MF)	L	L
	Gas separation (GS)	G	G
Concentration	Pervaporation (PV)	L	G
	Dialysis (D)	L	L
	Liquid membrane (LM)	L	L
Electrical Potential	Electrodialysis/electrolysis (ED)	L	L
Temperature	Membrane distillation (MD)	L	L

L – Liquid phase, G – gas phase

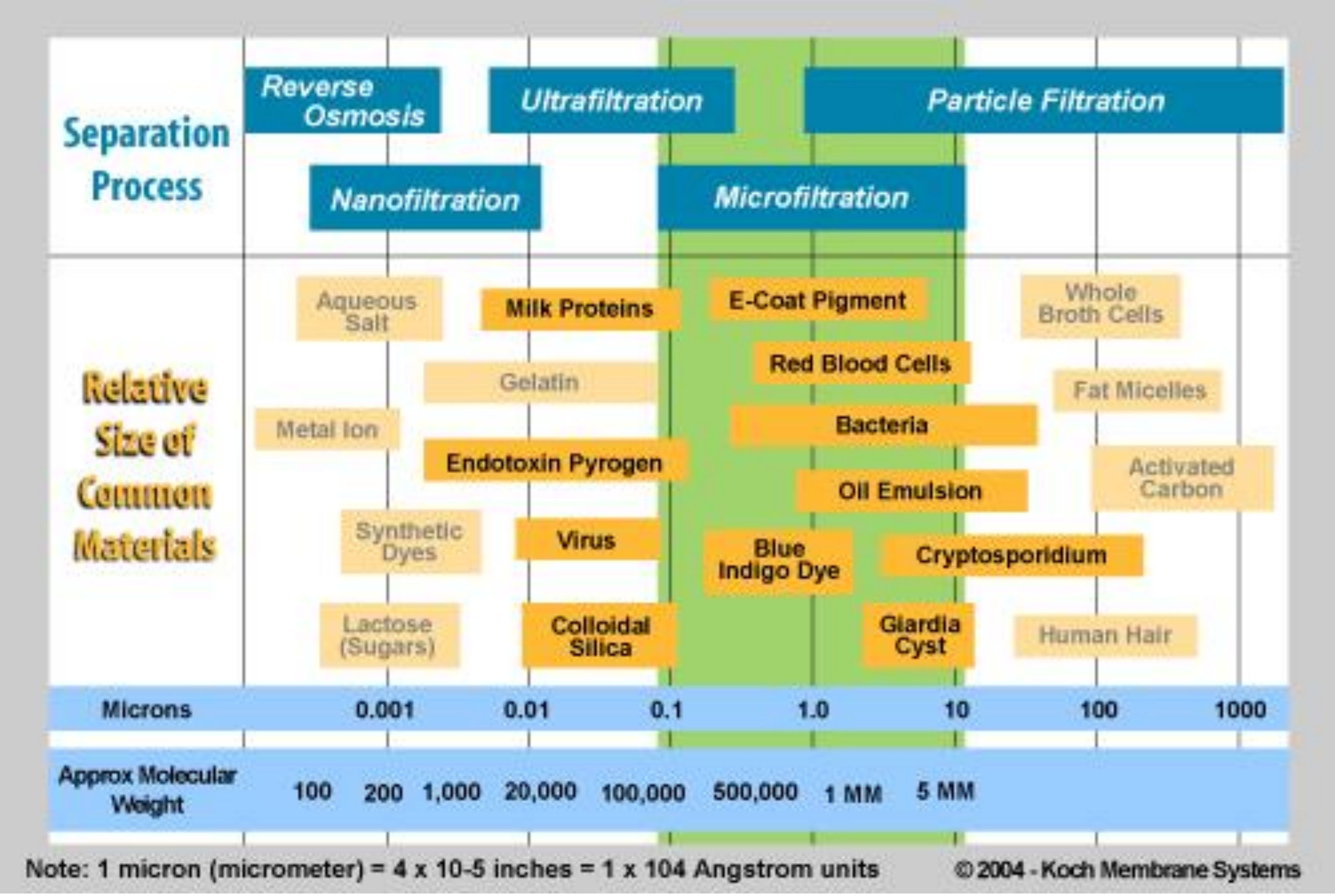
Classification of membrane process:
comparison to other separation processes



(Belfort, 1984)

Classification of membrane process:

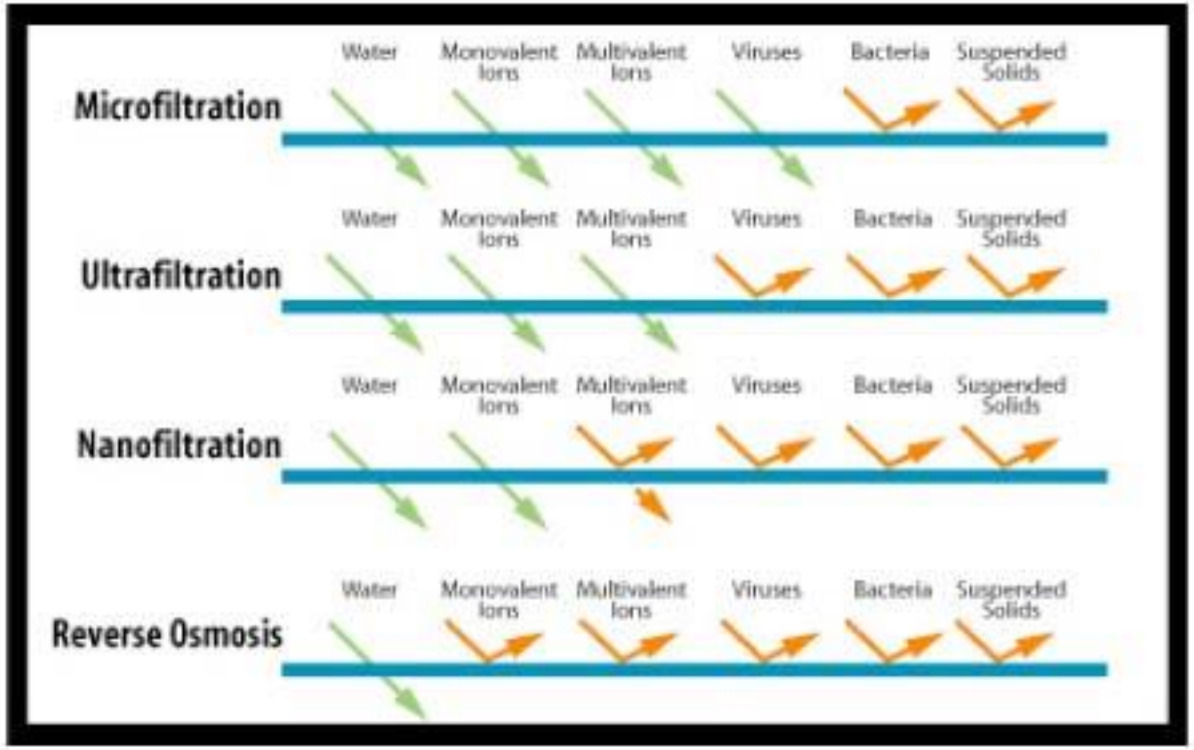
particle size range



www.kochmembrane.com

In this course we will focus on the pressure driven membrane processes

- Reverse Osmosis (Hyperfiltration)
- *Nanofiltration (not covered)*
- Ultrafiltration
- Microfiltration



Membrane Process Characteristics

www.kochmembrane.com

Membrane materials

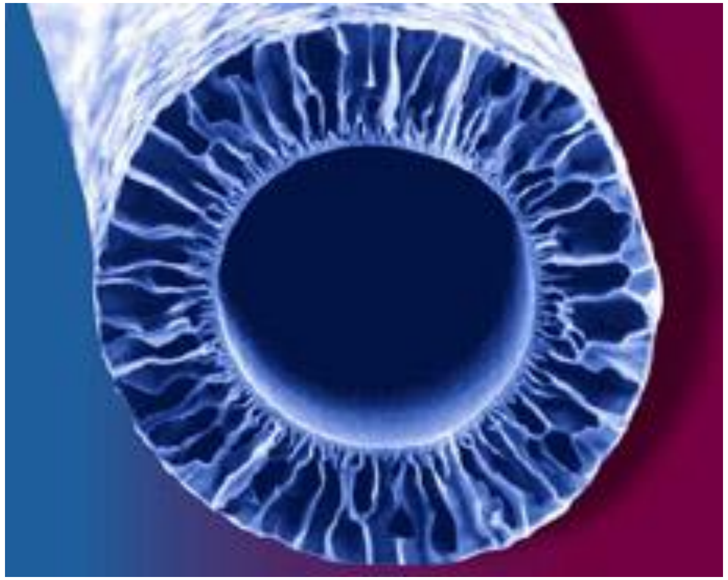
Process	Major membrane materials
RO	Cellulose acetate (CA), cellulose esters, polyamide (PA), composite polymers
UF	Cellulosics, polysulphone (PS), polyether sulphone (PES), polyacrylonitrile (PAN)
MF	CA, PA, PS, PES, polyvinylidene difluoride, polyimide, polypropylene (PP), polytetrafluoroethylene (PTFE), zirconia, alumina, sintered stainless steel, borasilicate glass, ceramics
GS	Cellulosics, polymethylsiloxane (PMDS), silicone rubber, PS, polyaramide, polyphenyleneoxide
PV	PMDS, PAN, CA, polyvinylalcohol (PVA)
LM	Organic solvents
D	Cellulosics, PS, PA, PVA
ED	Polystyrene, divinylbenzene, sulphonated polysulphone

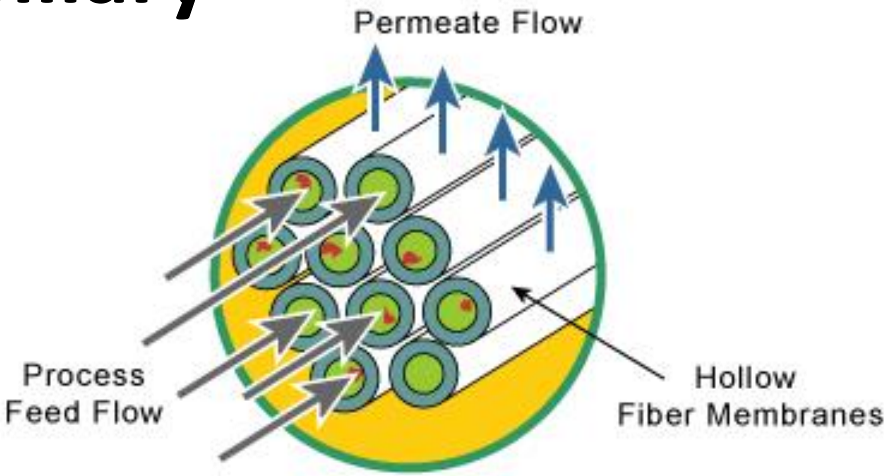
Membrane Modules

- Hollow fibre or capillary
- Tubular
- Plate and Frame
- Spiral Wound

Membrane modules designed for cross flow filtration

Hollow fibre or Capillary





Hollow fibre polyamide membrane, asymmetric

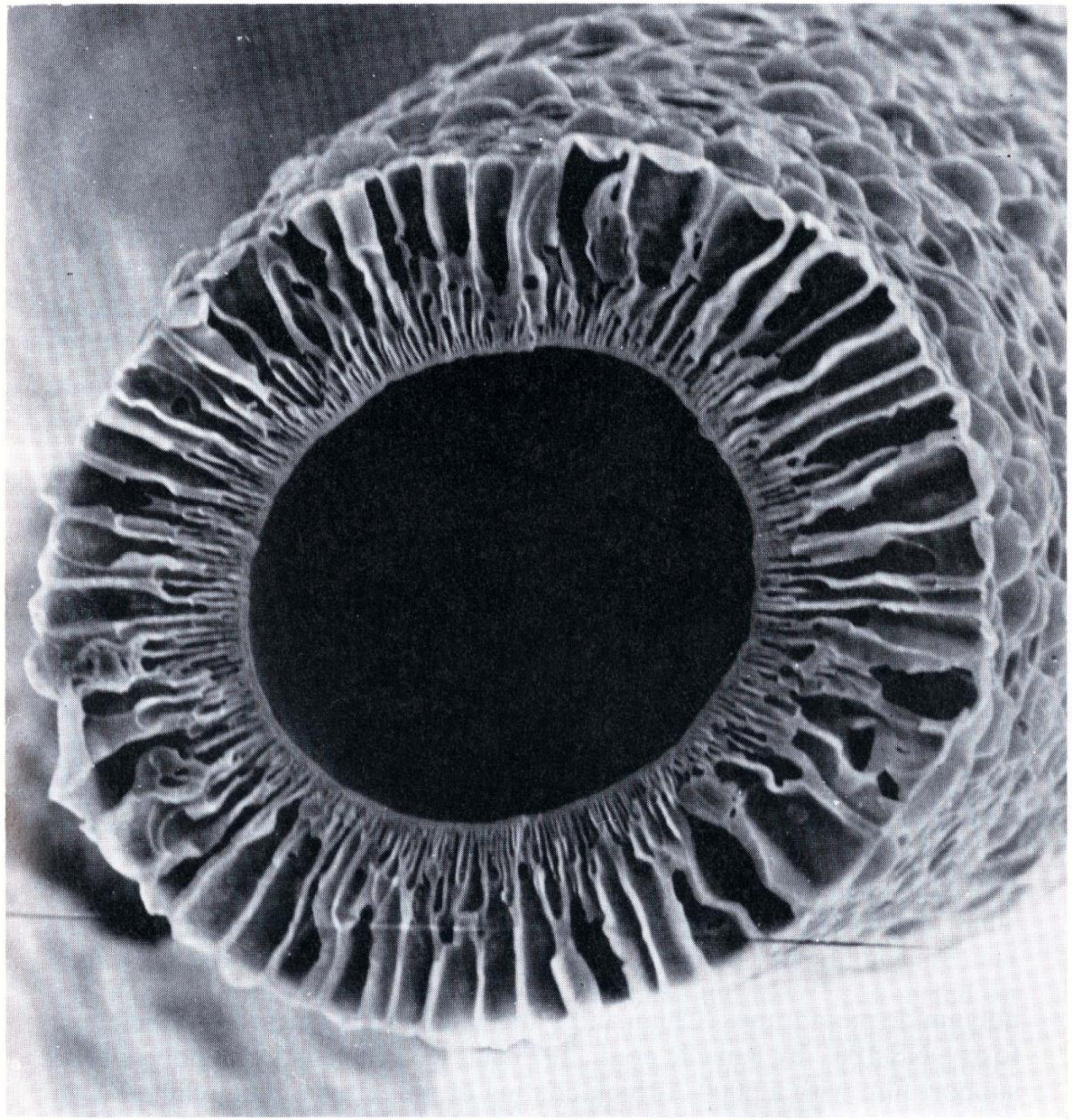
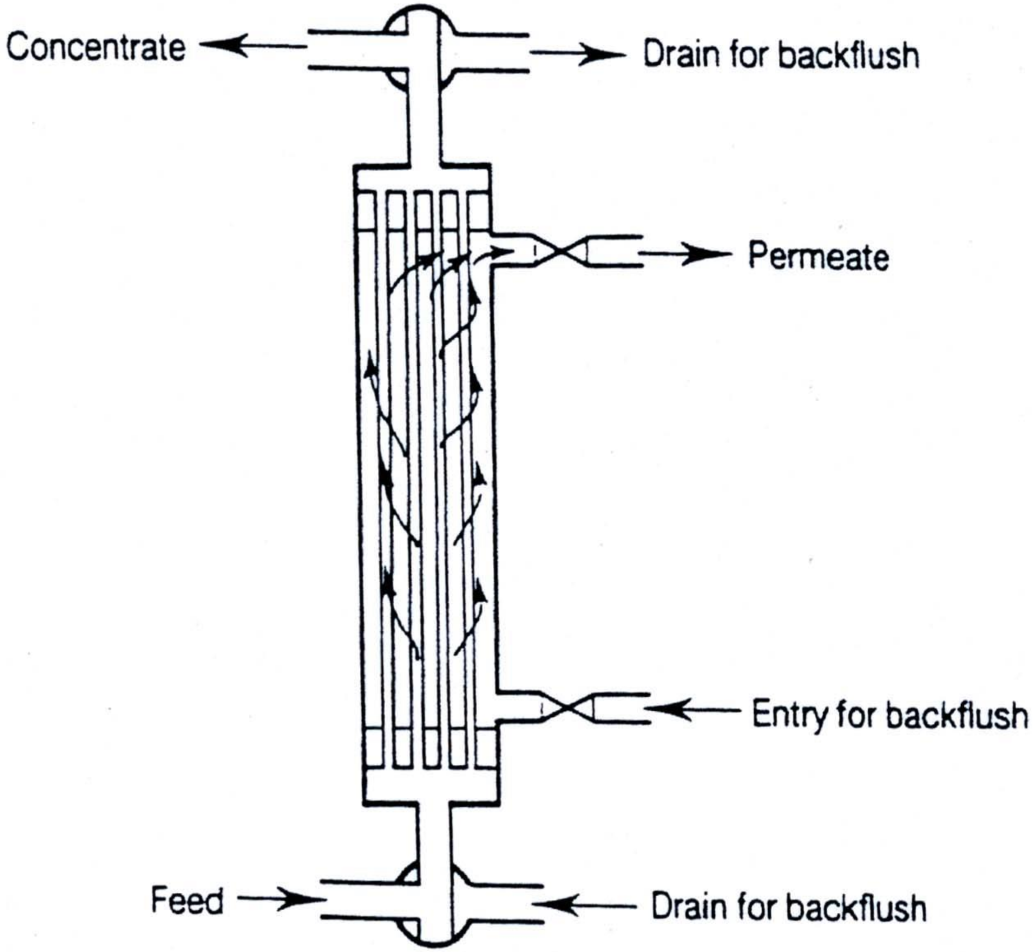
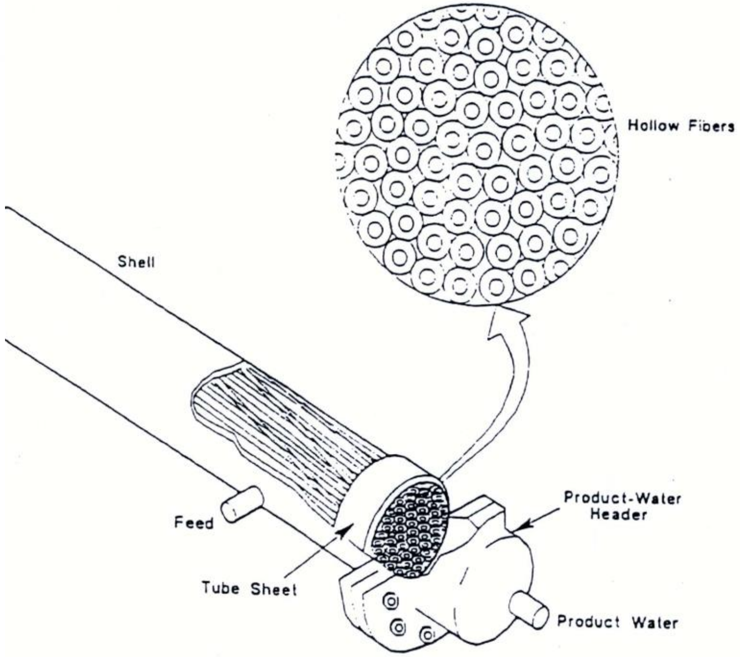


Fig. 2b Scanning electron micrographs of the substructure of asymmetric membranes showing dense skin and porous substructure. Hollow fiber polyamide membrane (ID ~500 μm). (Courtesy of H. Strathmann, Forschungsinstitute, Berghof Gmb, West Germany.)

(Belfort, 1984)

Hollow fibre or capillary membrane holder





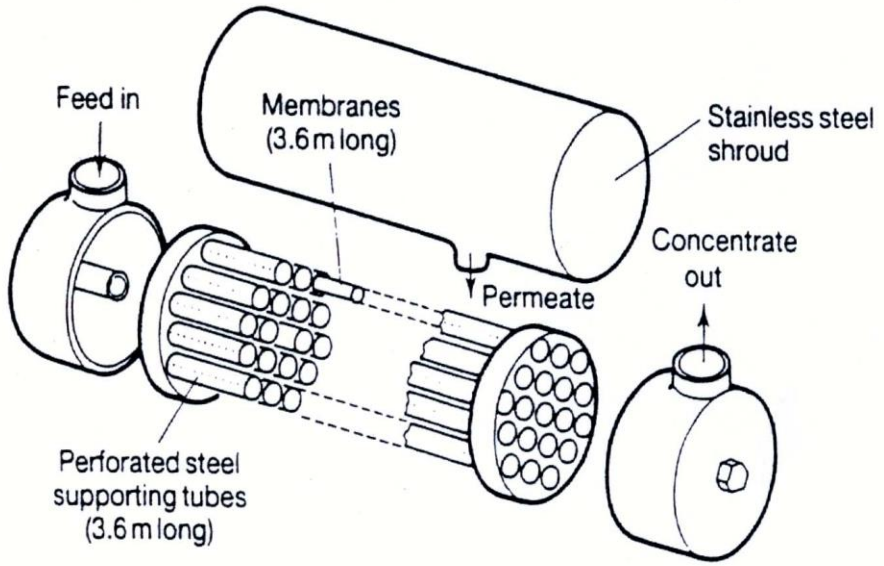
(Lewis, 1996; Bhattacharyya & Williams, 1992)

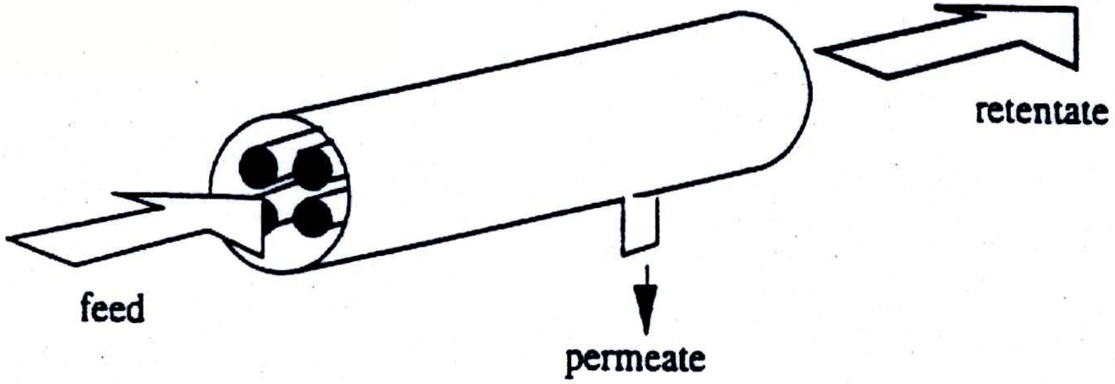
Hollow fibre cartridges at Newater, Singapore

Tubular

www.kochmembrane.com

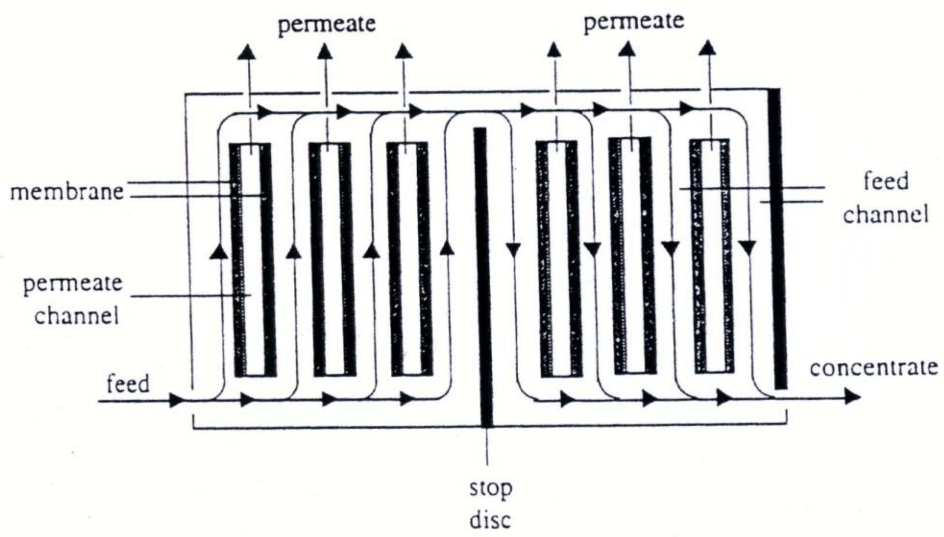
Tubular

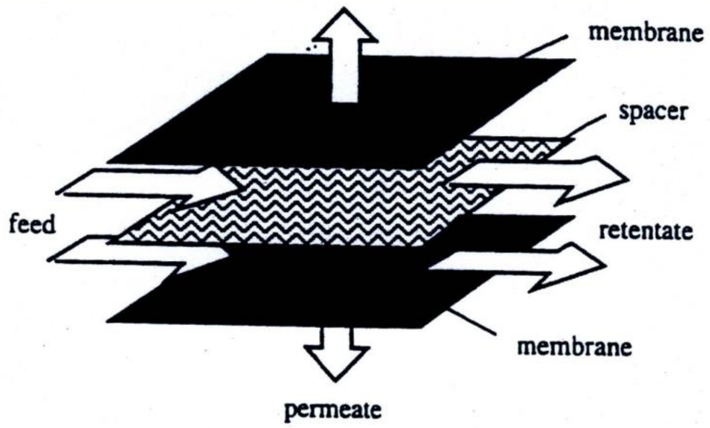




(Mulder, 1996; Lewis, 1996)

Plate & Frame

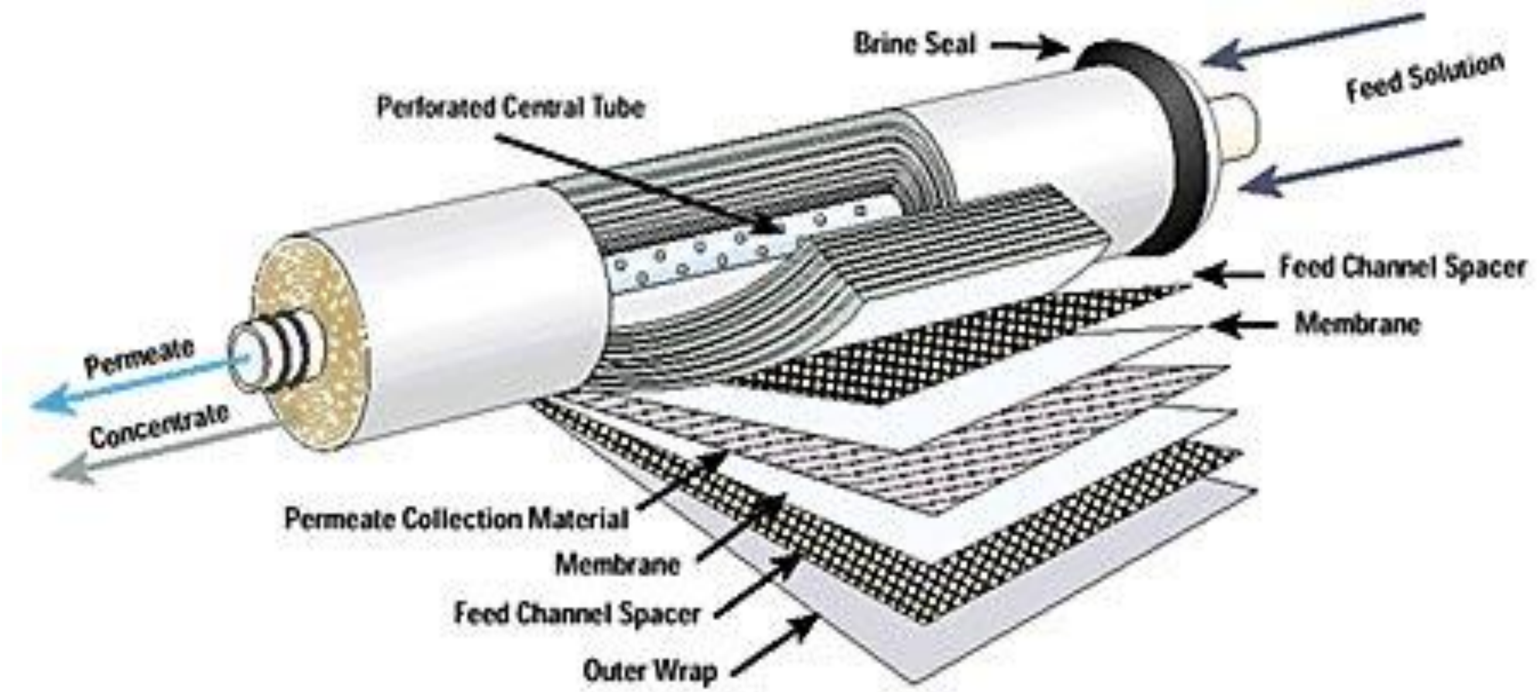




- http://www.alfalaval.com/ecoreJava/WebObjects/ecoreJava.woa/wa/showNode?siteNodeID=6843&contentID=-1&languageID=1

Spiral wound

[Spiral] wound membrane cartridge

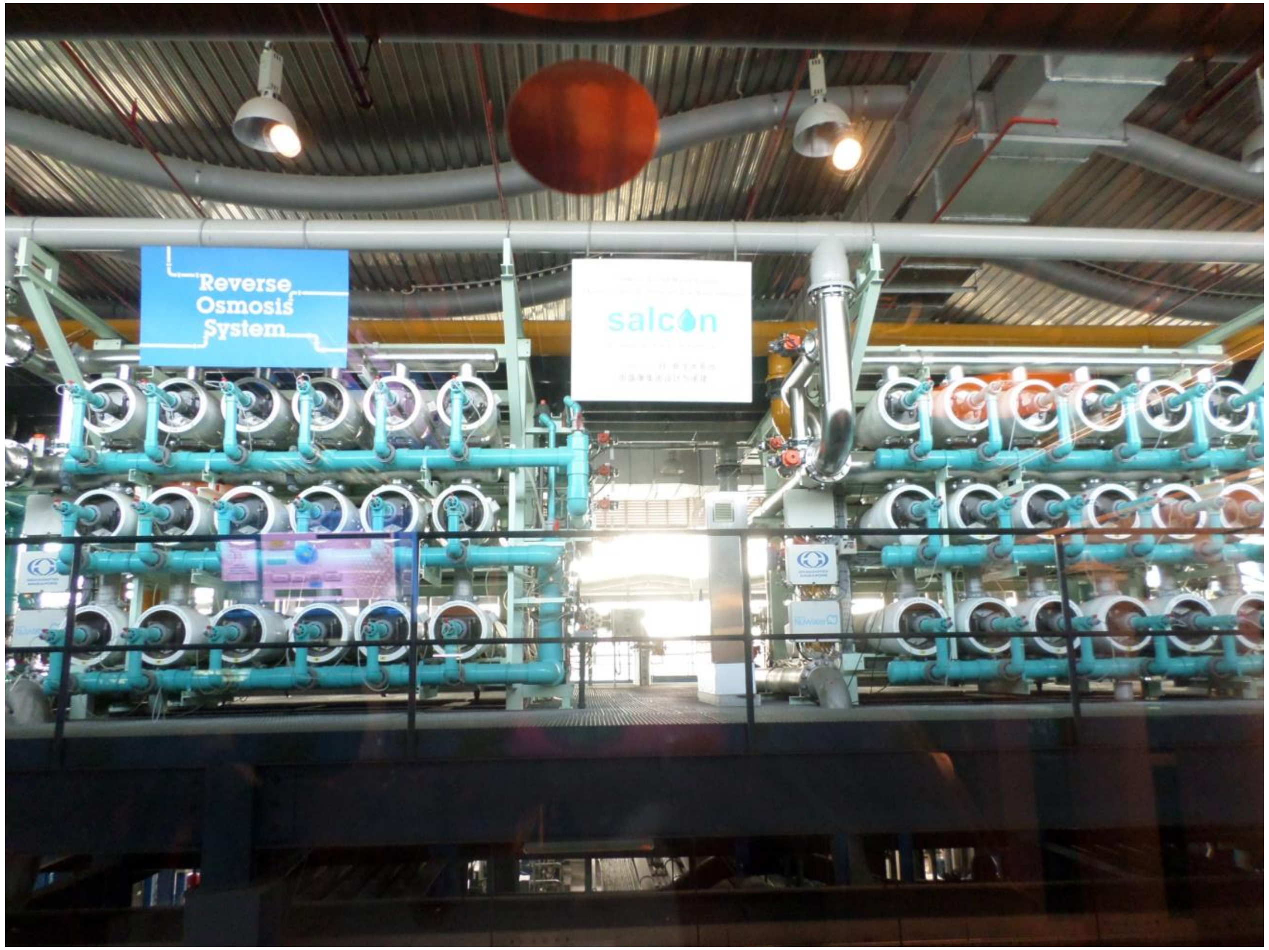


- http://www.alfalaval.com/ecoreJava/WebObjects/ecoreJava.woa/wa/showNode?siteNodeID=6844&contentID=-1&languageID=1

Video on spiral wound membranes
[http://www.youtube.com/watch?v=YlMGZWmh_Mw]


NITTO DENKO
SWC4

Desalination plants with spiral wound membranes



Newater, Singapore

Water treatment plant, Middle East

Module and Membrane Selection

Key factors dictating module and membrane selection

- Ability of membrane to reliably produce required specifications
- Overall cost of membrane process
  - $/unit volume of permeate
  - $/unit volume (or mass) of product

Qualitative comparison of membrane configurations

	Tubular	plate-and-frame	Spiral wound	capillary	hollow fiber
Packing density	low	------------------------	------------------------	------------------------→	very high
Investment	high	------------------------	------------------------	------------------------→	low
Fouling tendency	low	------------------------	------------------------	------------------------→	very high
Cleaning	good	------------------------	------------------------	------------------------→	poor
Operating cost	high	------------------------	------------------------	------------------------→	low
Membrane replacement	yes/no	yes	No	no	no

(Mulder, 1996)

Membrane Processes Categorized by:

- Driving force for mass transfer
- Separation mechanism (solubility, size, charge)
- Characteristic solute size range which can be separated
- Structural and chemical properties of the membrane (porous/non-porous; hydrophilic/hydrophobic)
- Mode of operation of the process

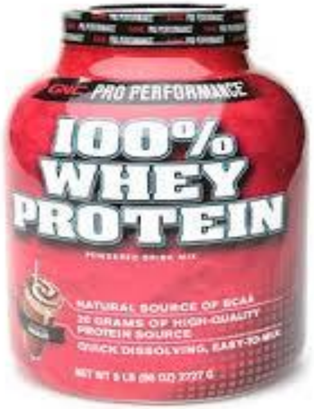
Applications of membrane processes in the food industry :

- Primarily separation of components in a fluid

Major objectives are

- Purification
  - Removal of one or more components from the feed
- Concentration
  - Removal of the solvent liquid from the feed
- Fractionation
  - Separation of two components in a feed

Applications of membrane processes in the food industry :



$$\Delta P = P_{in} - P_{out}$$

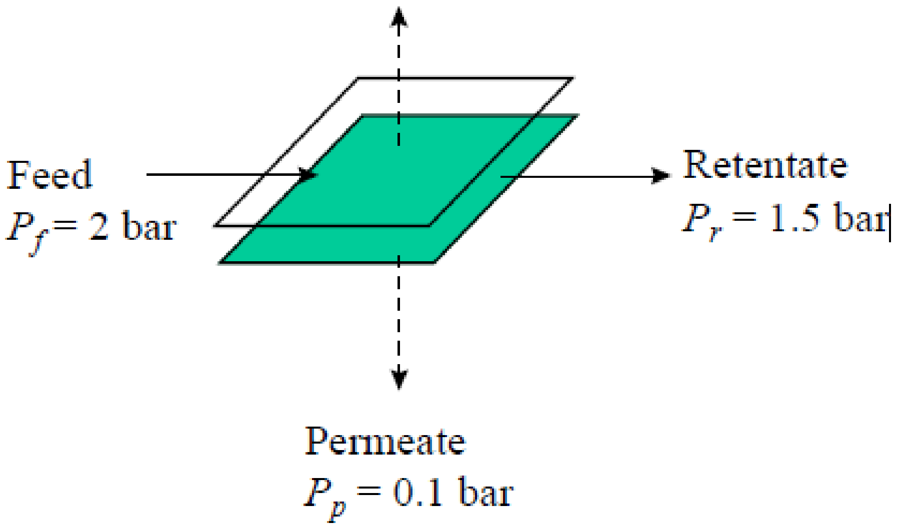
$$\Delta P_{TM} = \left[\frac{P_{in} + P_{out}}{2}\right] - P_{permeate}$$

Overall mass balance

$$F = R + P$$

Problem 1

1. For the filter module shown below, calculate the pressure drop on the feed side and the transmembrane pressure.



Problem 1a

The transmembrane pressure for the case shown below is