Membrane Separations

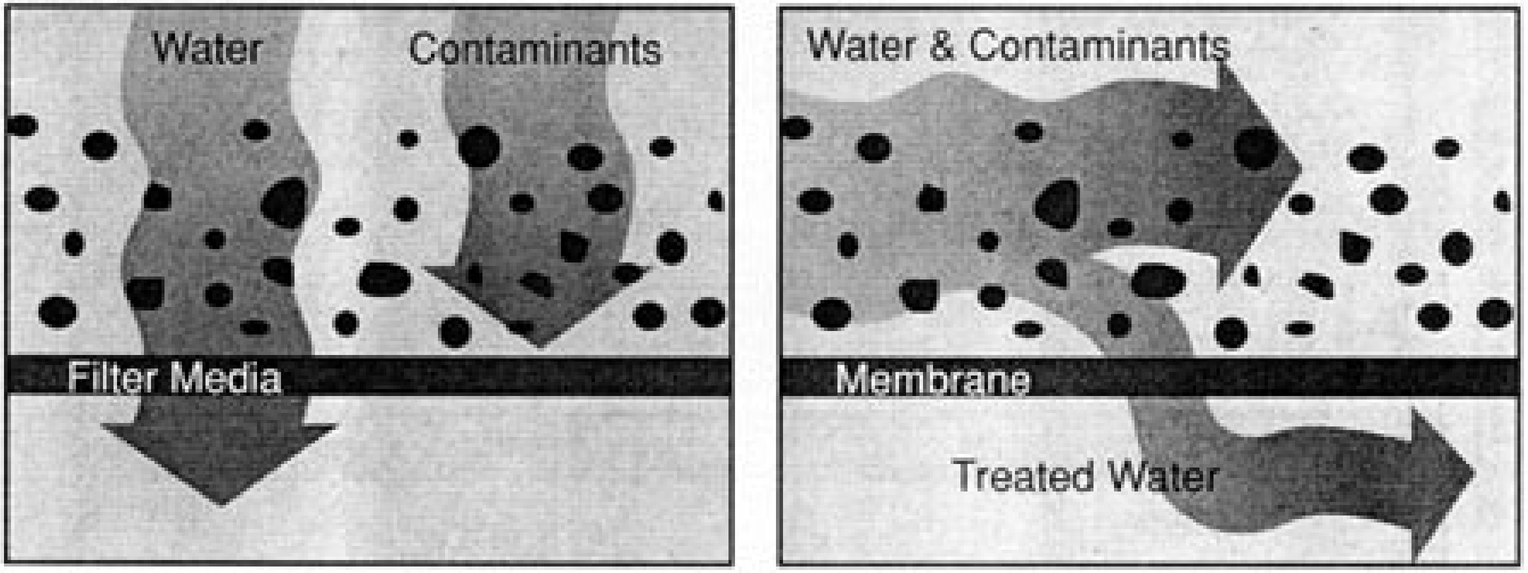
- There are other separation operations where a membrane is the responsible of the la selective separation of the compounds:

- Dialysis.
- Electrodialysis (ED).
- Pervaporation.
- Gas permeation (GP).
- Liquid membranes.

- In others, the membrane is not directly responsible for the separation but it actively participates:

- Membrane extraction.
- Membrane distillation.
- Osmotic distillation.

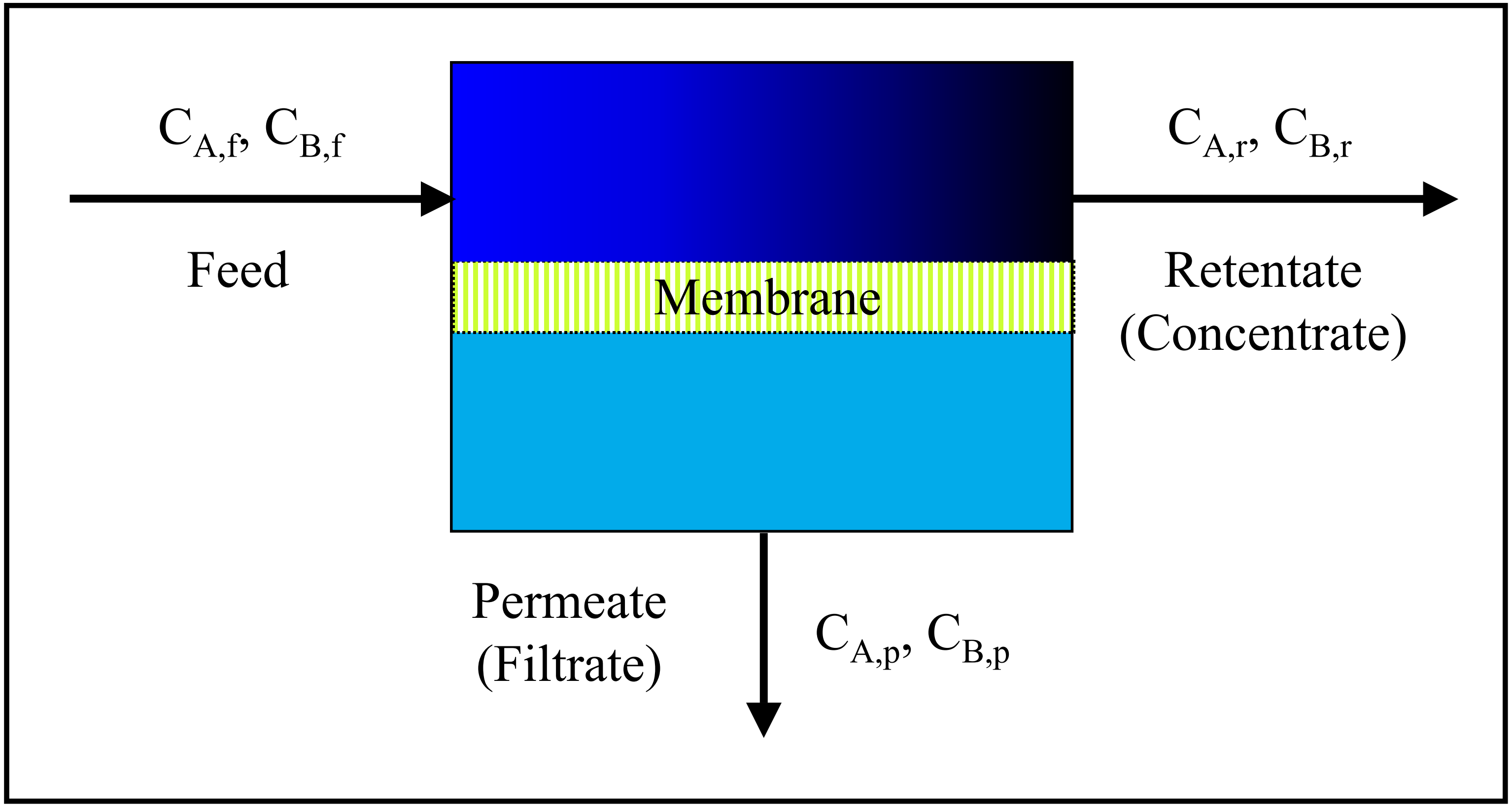
Membrane Separations



Dead-end **Cross-flow**

Type of filtration.

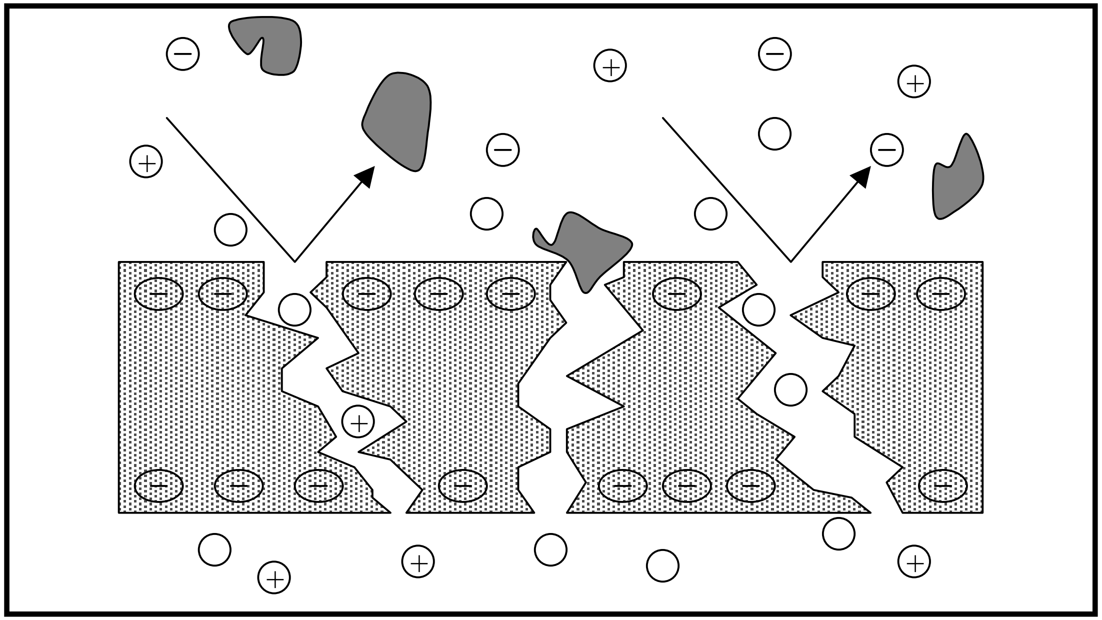
Membrane Separations



Simple scheme of a membrane module.

Membrane Separations

- Synthetic membranes are solid barriers that allow preferentially to pass specific compounds due to some driving force.



(Very) Simple scheme for some mechanisms of selective separation on a porous membrane.

Membrane Separations

- The separation ability of a synthetic material depends on its physical, chemical properties.

  - Pore size and structure
  - Design
  - Chemical characteristics
  - Electrical charge

Membrane Separations

- The membranes can be roughly divided in two main groups: porous and non porous.

- Porous membranes give separation due to...

  - size
  - shape
  - charge

...of the species.

- Non porous membranes give separation due to...

  - selective adsorption
  - diffusion

...of the species.

Main parameters.

- Rejection, R, if there is just one component (RO)

$$R(\%) = 100 \cdot \left(\frac{C_{A,f} - C_{A,p}}{C_{A,f}} \right) = 100 \cdot \left(1 - \frac{C_{A,p}}{C_{A,f}} \right)$$

- Separation factor

$$\alpha_{A,B} = \frac{C_{A,p}/C_{B,p}}{C_{A,f}/C_{B,f}} = \frac{\beta_A}{\beta_B}$$

- Enrichment factor

$$\beta_A = \frac{C_{A,p}}{C_{A,f}}$$

for two or more component

Main parameters.

- In RO, often we use the Recovery (Y)

$$Y(\%) = \frac{Q_p}{Q_f} \cdot 100$$

Q_p: Permeate flowrate (m^3/s)

Q_f: Feed flowrate (m^3/s)

Main parameters.

- Passive transport in membranes. The permeate flux is proportional to a given driving force (some difference in a property).

$$\text{Flux}(J) = \text{Constant}(A)\cdot$$
$$\cdot\text{Driving Force}(X)$$

Driving forces:

- Pressure (total o partial)
- Concentration
- Electric Potential

Main parameters.

Membrane processes and driving force.

Process	Feed phase	Permeate phase	Driving Force
Microfiltration	L	L	ΔP
Ultrafiltration	L	L	ΔP
Nanofiltration	L	L	ΔP
Reverse Osmosis	L	L	ΔP
Dialysis	L	L	Δc
Electrodialysis	L	L	ΔE
Pervaporation	L	G	ΔP
Gas Permeation	G	G	ΔP

Main parameters.

- Permeate flux.

In MF and UF, porous membrane model is assumed, where the a stream freely flows through the pore. Then, the transport law follows the Hagen-Poiseuille equation.

$$J_w = \frac{Q_w}{A_m} = \frac{\varepsilon \cdot r^2}{8 \cdot \mu \cdot \tau} \cdot \frac{\Delta P}{d}$$

J_w: Solvent flux ($m^3/s \cdot m^2$)

Q_w: Solvent flowrate (m^3/s)

A_m: Membrane area (m^2)

d: Membrane thickness (m)

μ: Viscosity (Pa ·s)

ΔP: Hydraulic pressure difference (Pa)

r: Pore radius (m)

ε: Porosity

τ: Tortuosity

Main parameters.

- The above model is good for cylindrical pores. However, if the membrane is rather formed by a aggregated particles, then the Kozeny-Carman relation works much better.

$$J_W = \frac{Q_W}{A_m} = \frac{\varepsilon^3}{K \cdot \mu \cdot S^2 \cdot (1-\varepsilon)^2} \cdot \frac{\Delta P}{d}$$

J_W: Solvent flux ($m^3/s \cdot m^2$)

Q_W: Solvent flowrate (m^3/s)

S: Particle surface area (m^2/m^3)

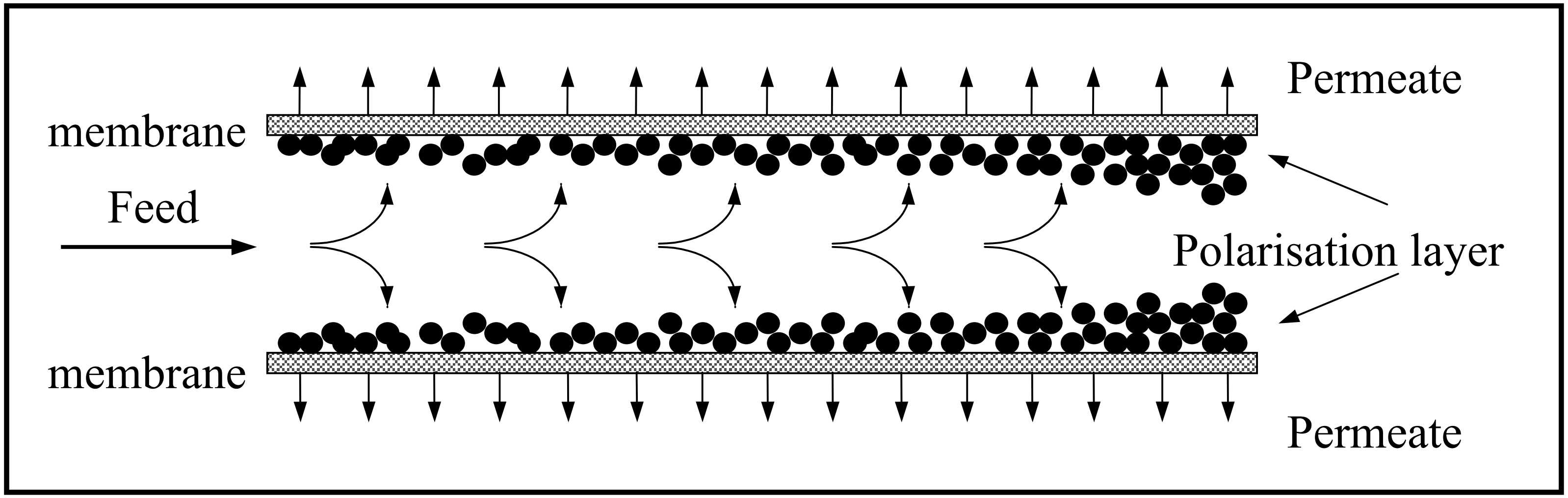
K: Kozeny-Carman constant

A_m: Membrane area (m^2)

d: Membrane thickness (m)

μ: Viscosity (Pa ·s)

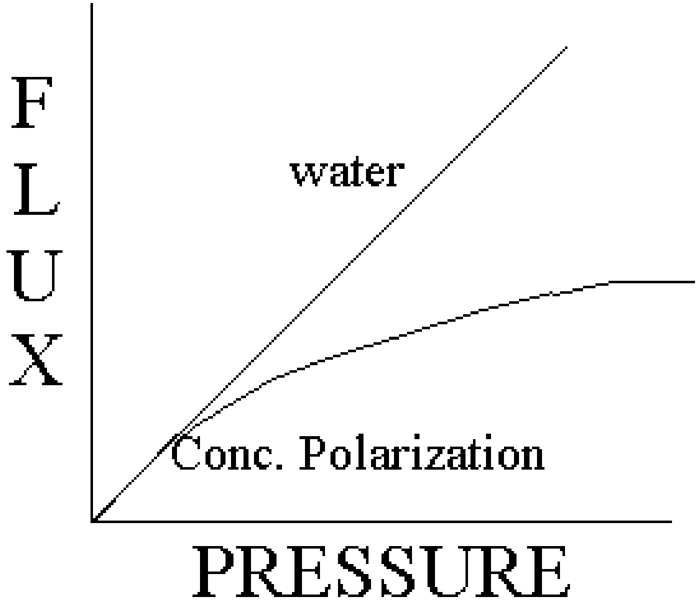
- In the operations governed by the pressure, a phenomenon called <u>concentration polarisation</u> appears, which must be carefully controlled. This is due to the solute accumulation neighbouring the membrane surface.



Formation of the polarisation layer.

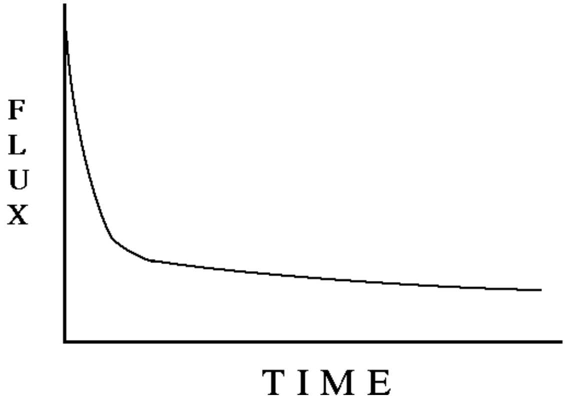
- Concentration polarisation.

Flux vs. Pressure



(It is not fouling!!!)

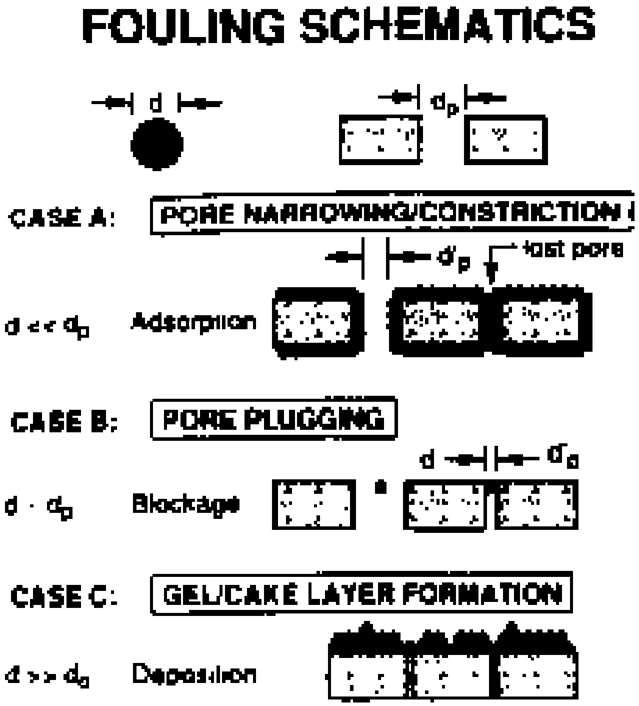
- Fouling: Irreversible reduction of the flux throughout the time.



- Pore size reduction by irreversible adsorption of compounds.

- Pore plugging.

- Formation of a gel layer over the membrane surface (cake).



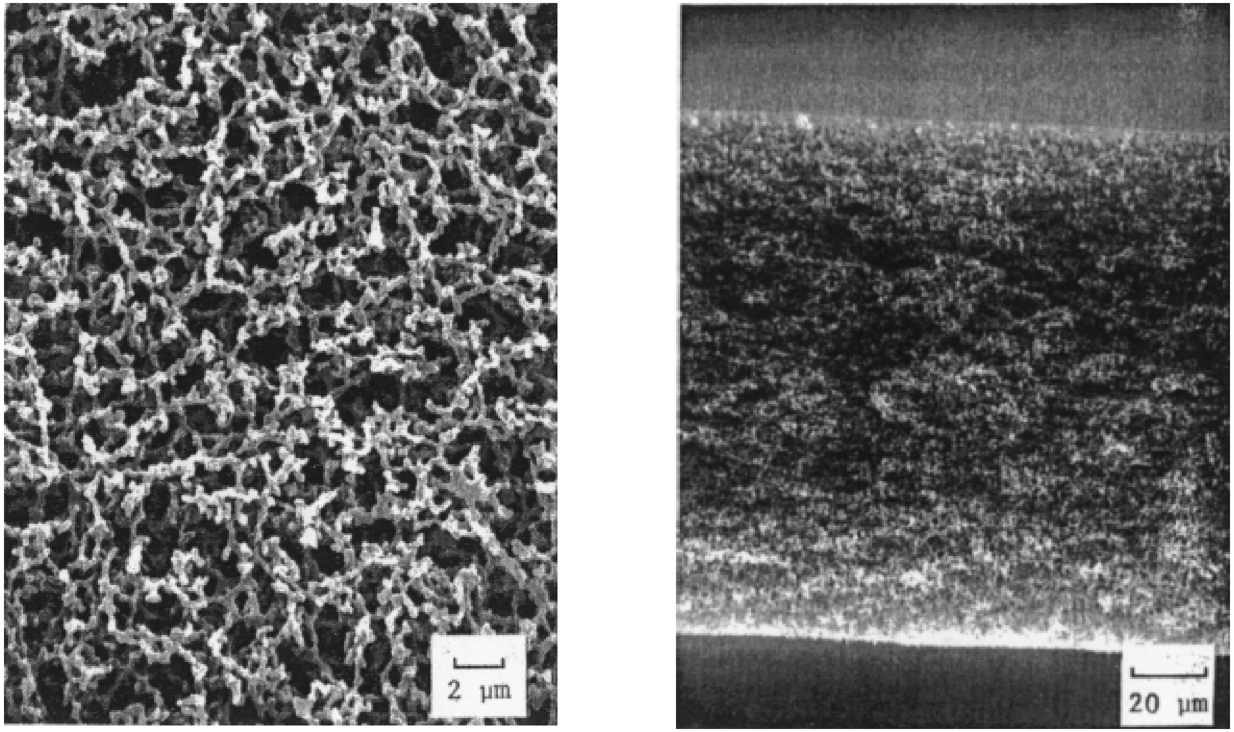
Membrane Separations

- Membrane can be classified in several ways, but always there are arbitrary classifications.

- Structure: symmetric, asymmetric
- Configuration: flat, tubular, hollow fiber
- Material: organic, inorganic
- Surface charge: positive, negative, neutral
- ...and even other divisions and subdivisions

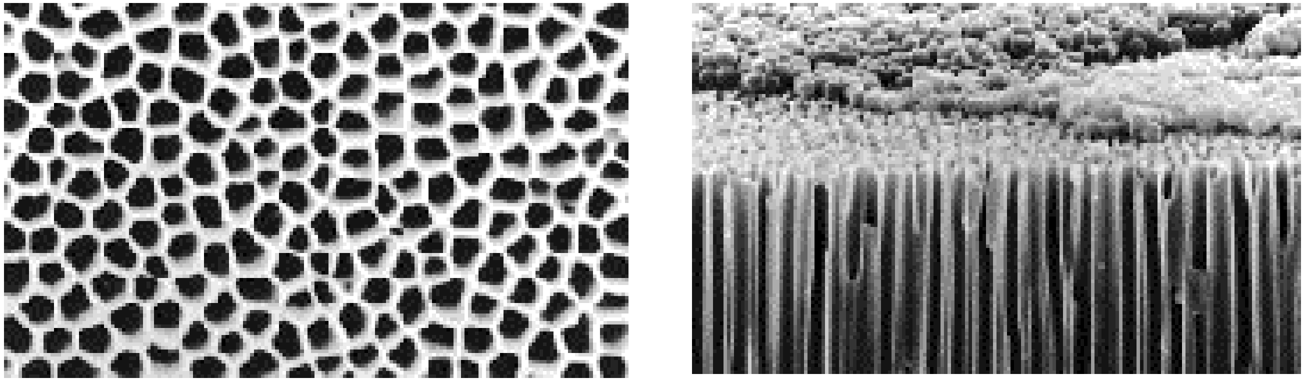
- Structure:
  - Symmetric. Also called homogeneous. A cross section shows a uniform porous structure.
  - Asymmetric. In a cross section, one can see two different structures, a thin dense layer and below a porous support layer.
    - Integral: the layers are continuous.
    - Composites: the active layer (thickness 0.1-0.5 μm) is supported over a highly porous layer (50-150 μm), sometimes both layers are of different materials.

Membrane Separations



Symmetric UF membrane of 0.45 μm made of cellulose acetate (Millipore).

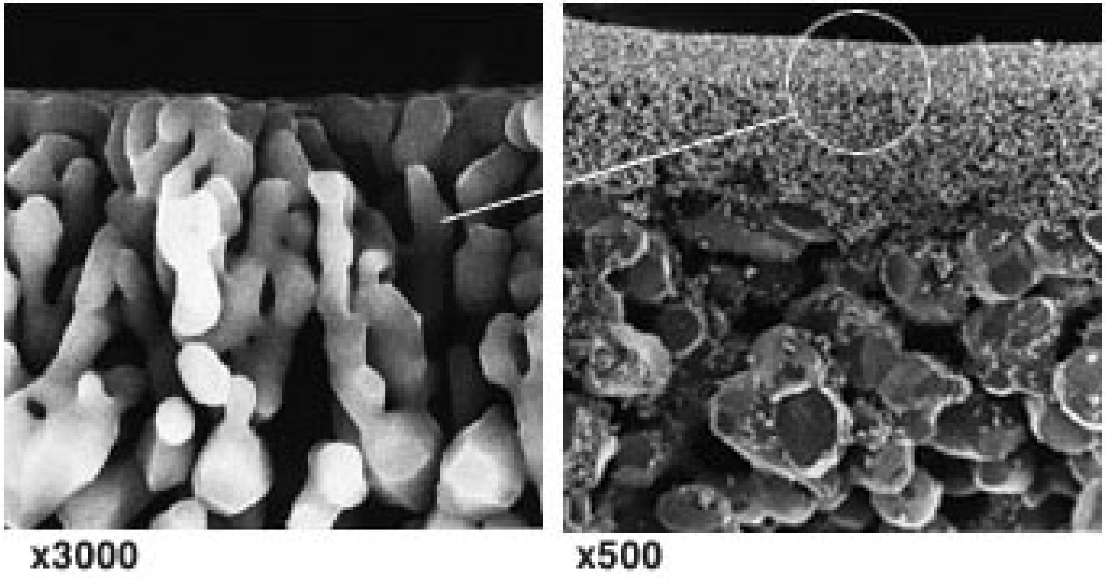
Membrane Separations



Surface **Cross section**

Symmetric ceramic membrane of 0.2 μm made of alumina (Al_2O_3) (Anopore^{TM}).

Membrane Separations



Asymmetric ceramic membrane made of γ-Al_2O_3 (Membralox).