Lecture 4: **Membrane Processes Technology in water treatment** (Part I)

Water Treatment Technology

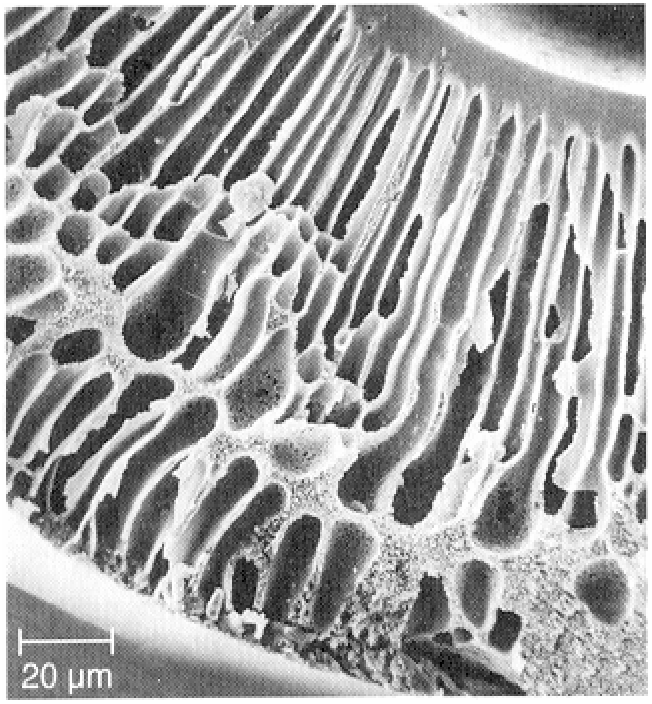
Water Resources Engineering
Civil Engineering
ENGC 6305

Dr. Fahid Rabah PhD. PE.

Membrane Processes Technology

1. Definition:

- Membrane processes are those in which a membrane is used to filter through (i.e. permeate) high quality water while rejecting the passage of dissolved and suspended solids.
- A filtration membrane is a physical boundary over which a solute (TSS or TDS) can be separated from a solvent (water) by applying energy in the form of pressure or electric potential.
- Figure 4.1 is a cross section in a membrane wall, Figure 4.2 illustrates the filtration process.



SEM Image of Membrane Lumen (AWWA, 1996)

Fig. 4.1

Pressure-Driven Membrane Processes

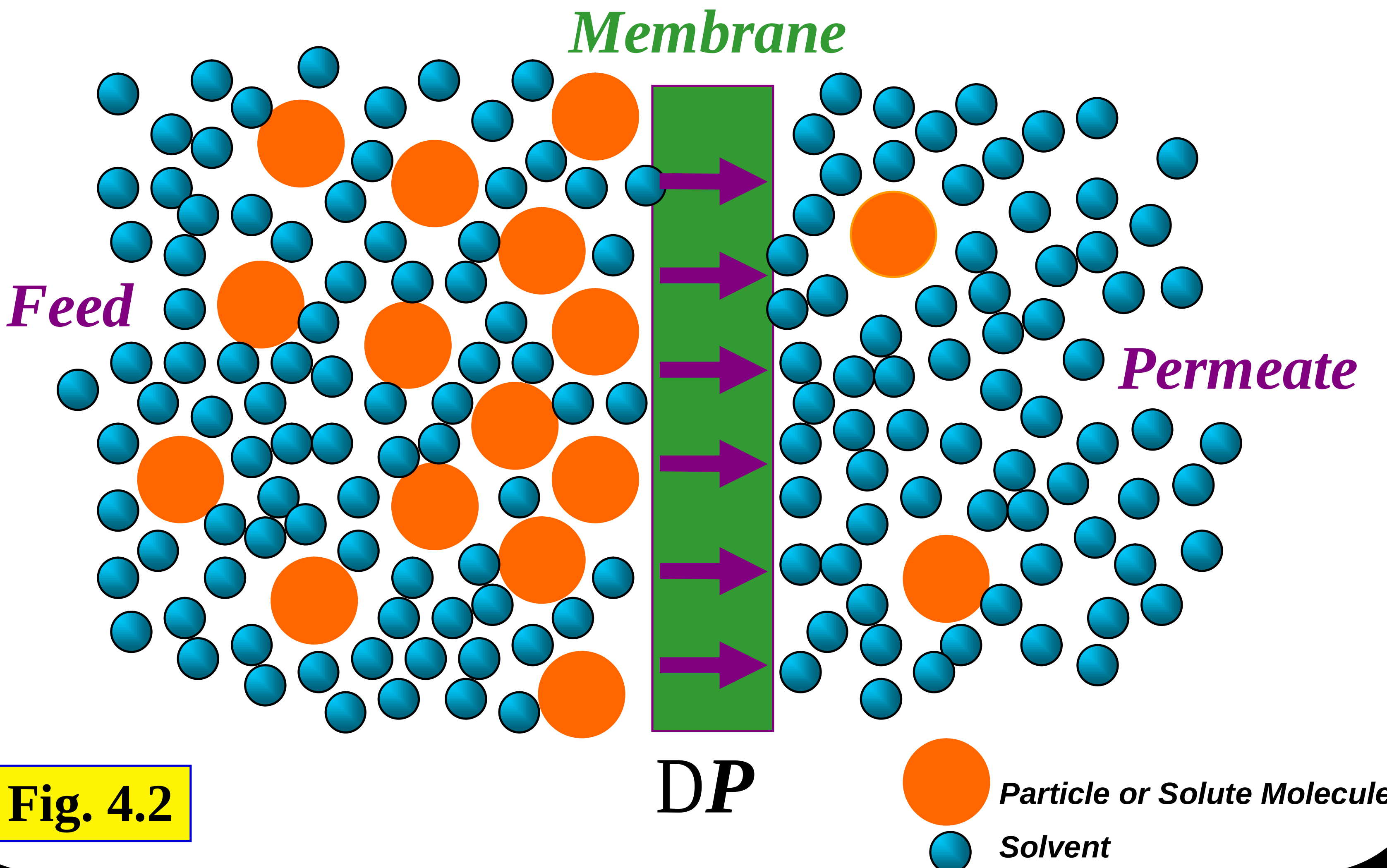


Fig. 4.2

Membrane Processes Technology

2. Membrane process types:

- The main membrane processes used in water treatment are:
  - A. Microfiltation (MF)
  - B. Ultrafiltation (UF)
  - C. Nanofiltration (NF)
  - D. Reverse Osmosis (RO)
  - E. Electrodialysis (ED)
- The classification and comparison between these processes is Based on many characteristics of each such as 1) The driving force [hydrostatic or electrical], 2) The separation mechanism, 3) The nominal size of the separation achieved.
- Tables 4.1, and Figures 4.3 and 4.4 illustrate the difference between the above mentioned membrane methods.
- Table 4.2 shows the operating pressures and the materials used to produce the membranes.

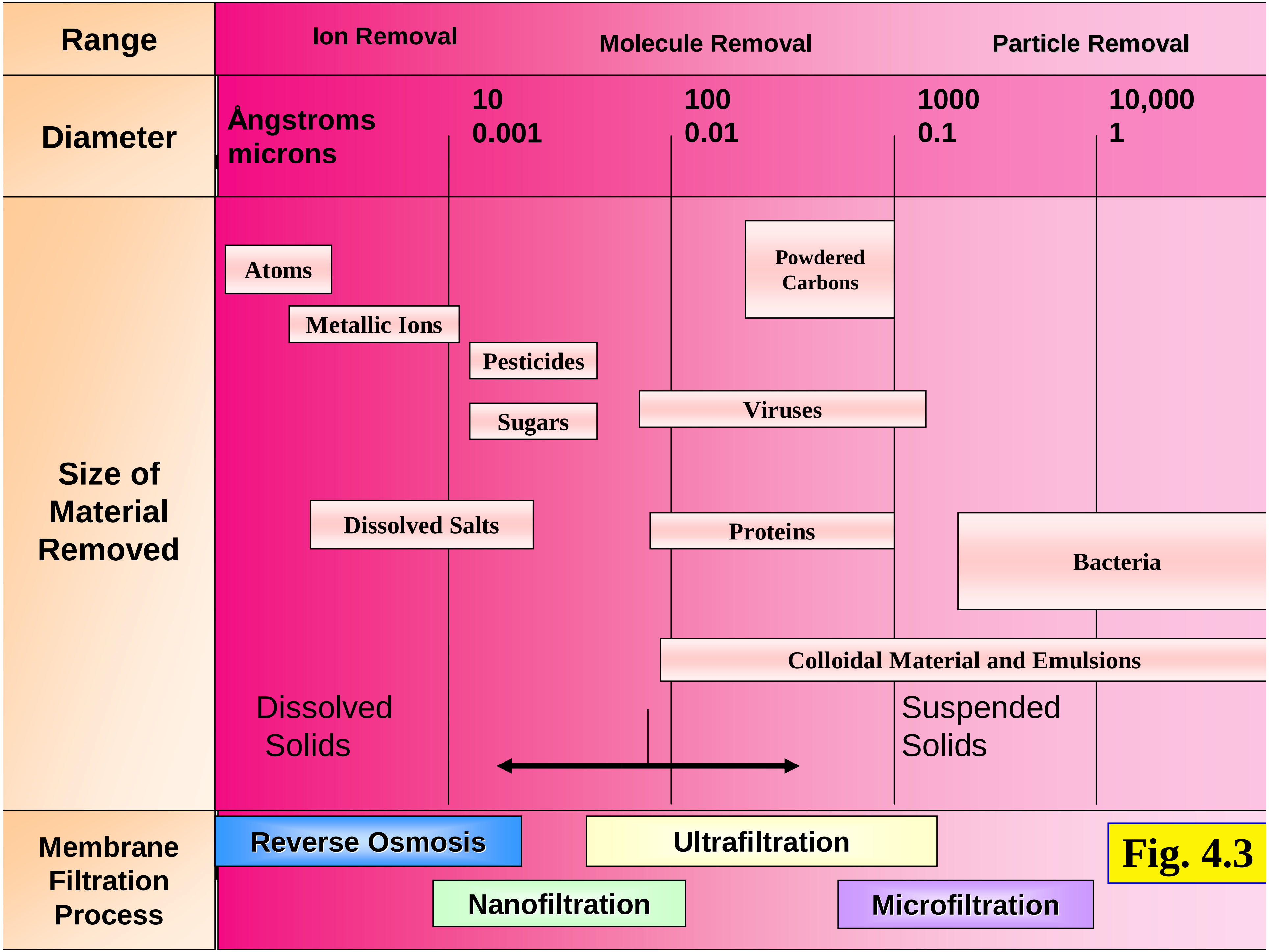

Range
Ion Removal
Molecule Removal
Particle Removal
Diameter
Ångstroms
microns
10
0.001
100
0.01
1000
0.1
10,000
1
Size of Material Removed
Atoms
Metallic Ions
Pesticides
Sugars
Powdered Carbons
Viruses
Dissolved Salts
Proteins
Bacteria
Colloidal Material and Emulsions
Dissolved Solids
Suspended Solids
Membrane Filtration Process
Reverse Osmosis
Ultrafiltration
Nanofiltration
Microfiltration

Fig. 4.3

General characteristics of membrane processes

Table . 4.1

Membrane process	Membrane driving force	Typical separation mechanism	Operating structure (pore size)	Typical operating range, μm	Permeate description	Typical constituents removed
Microfiltration	Hydrostatic pressure difference	Sieve	Macropores (>50 nm) (Note: nm=10^{-9} m)	0.08–2.0	Water + dissolved solutes	TSS, turbidity, protozoan oocysts and cysts, some bacteria and viruses
Ultrafiltration	Hydrostatic pressure difference	Sieve	Mesopores (2–50 nm)	0.005–0.2	Water + small molecules	Macromolecules, colloids, most bacteria, some viruses, proteins
Nanofiltration	Hydrostatic pressure difference	Sieve + solution/ diffusion + exclusion	Micropores (<2 nm)	0.001–0.01	Water + very small molecules, ionic solutes	Small molecules, some harness, viruses
Reverse osmosis	Hydrostatic pressure difference	Solution/ diffusion + exclusion	Dense (<2 nm)	0.0001–0.001	Water, very small molecules, ionic solutes	Very small molecules, color, hardness, sulfates, nitrate, sodium, other ions
Dialysis	Concentration difference	Diffusion	Mesopores (2–50 nm)	—	Water + small molecules	Macromolecules, colloids, most bacteria, some viruses, proteins
Electrodialysis	Electromotive force	Ion exchange with selective membranes	Micropores (<2 nm)	—	Water + ionic solutes	Ionized salt ions

Membrane Processes Technology

Table . 4.2

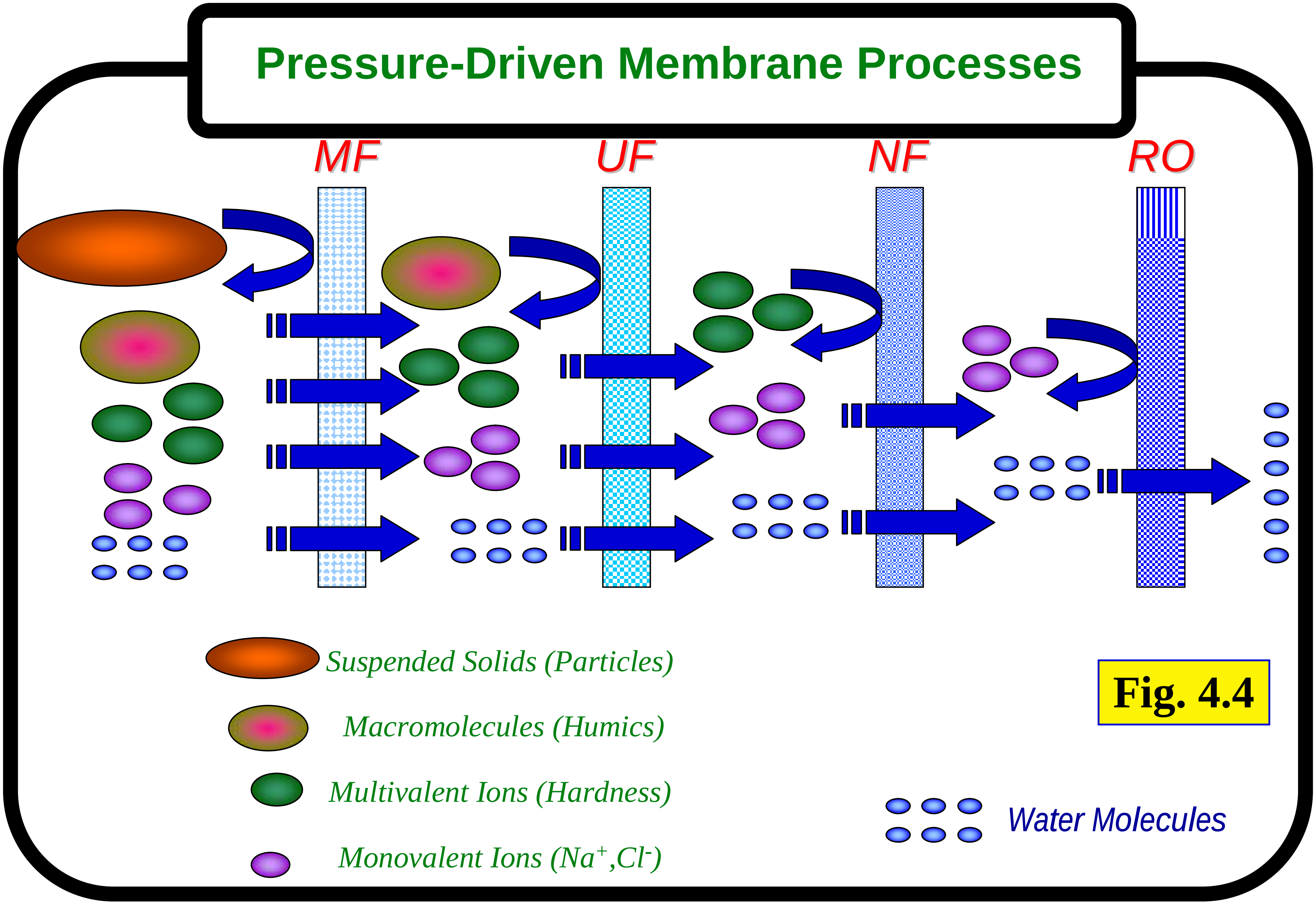
Typical characteristics of membrane technologies used in wastewater-treatment applications[a]

Membrane technology	Typical operating range, µm	Operating pressure		Rate of flux		Membrane details	
		lb/in^2	kPa	gal/ft^2·d	L/m^2·d	Type	Configuration
Microfiltration	0.08–2.0	1–15	7–100	10–40	405–1600	Polypropylene, acrylonitrile, nylon, and polytetrafluoroethylene	Spiral wound, hollow fiber, plate and frame
Ultrafiltration	0.005–0.2	10–100	70–700	10–20	405–815	Cellulose acetate, aromatic polyamides	Spiral wound, hollow fiber, plate and frame
Nanofiltration	0.001–0.01	75–150	500–1000	5–20	200–815	Cellulose acetate, aromatic polyamides	Spiral wound, hollow fiber
Reverse osmosis	0.0001–0.001	125–1000	850–7000	8–12	320–490	Cellulose acetate, aromatic polyamides	Spiral wound, hollow fiber, thin-film composite

[a] Adapted from Crites and Tchobanoglous (1998).

Note: kPa × 0.1450 = lb/in^2

L/m^2·d × 0.024542 = gal/ft^2·d


Pressure-Driven Membrane Processes
MF
UF
NF
RO
Suspended Solids (Particles)
Macromolecules (Humics)
Multivalent Ions (Hardness)
Monovalent Ions (Na+,Cl-)
Water Molecules
Fig. 4.4

3.Membrane Configurations:

The principal types of membranes are:

3.1Tubular Modules:

- In this type the membrane is cast on the inside of a support tube.
- A number of tubes are then placed in a pressure vessel.
- The feed water is pumped through the feed tube and the product water is collected on through the skin of the membrane.
- The concentrate continues to flow through the feed tube.
- This type is used for water with high suspended solids content since it is the easiest to clean. Cleaning can be accomplished by circulating chemicals and pumping a " foamball" or " spongeball". See Figures 4.5, 4.6

Tubular Membrane Module

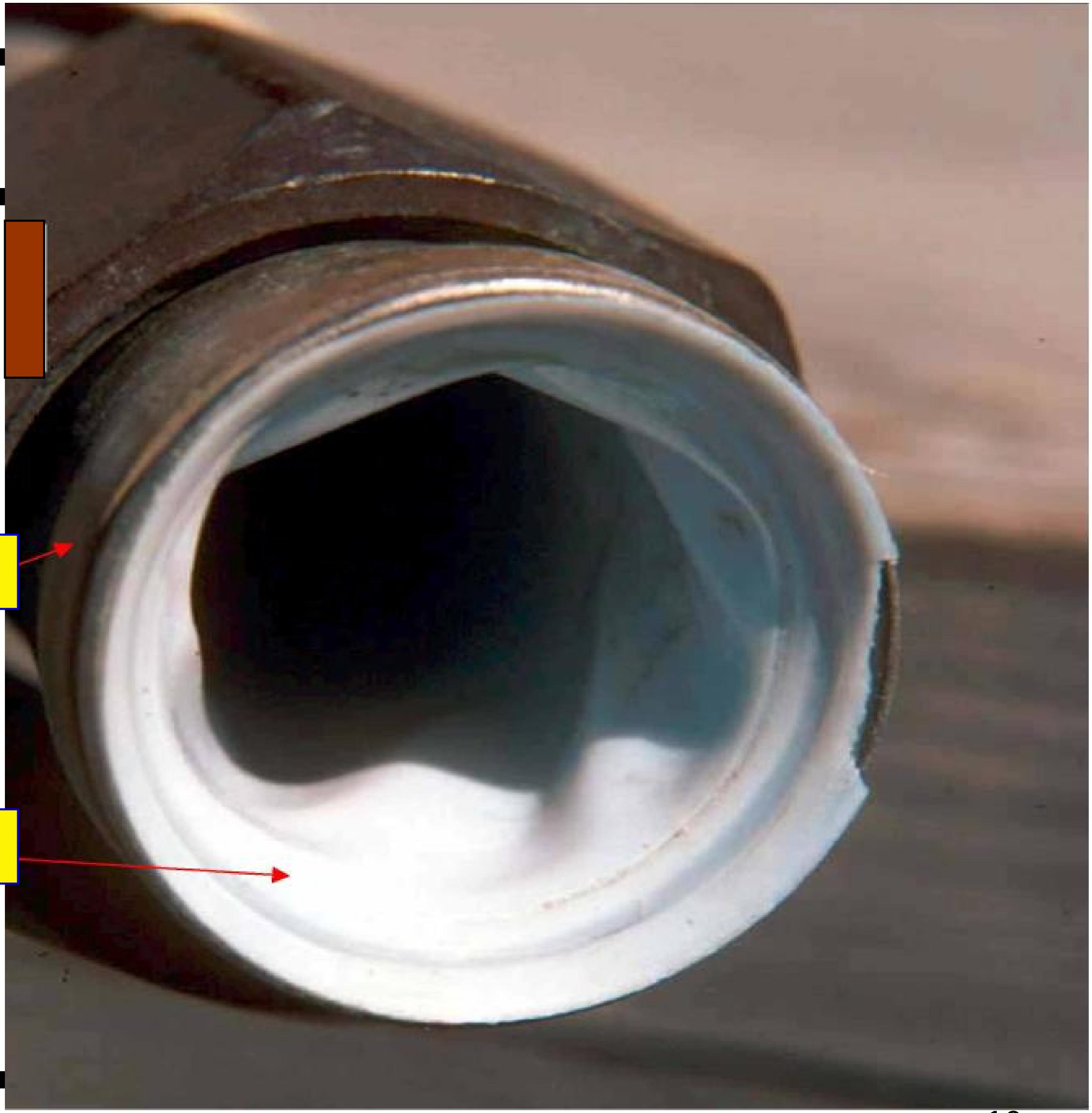


Fig. 4.5

Tubular Membrane Module

Fig. 4.6

3.2 Hollow Fiber :

- In hollow fiber modules hundreds to thousands of hollow fibers are bundled together to form a module

- The entire assembly is inserted into a pressure vessel.

- The feed water can be applied to the inside of the fiber (inside-out flow), or the outside of the fiber (outside-in flow).

- See Figures 4.7, 4.8

Membrane Processes Technology

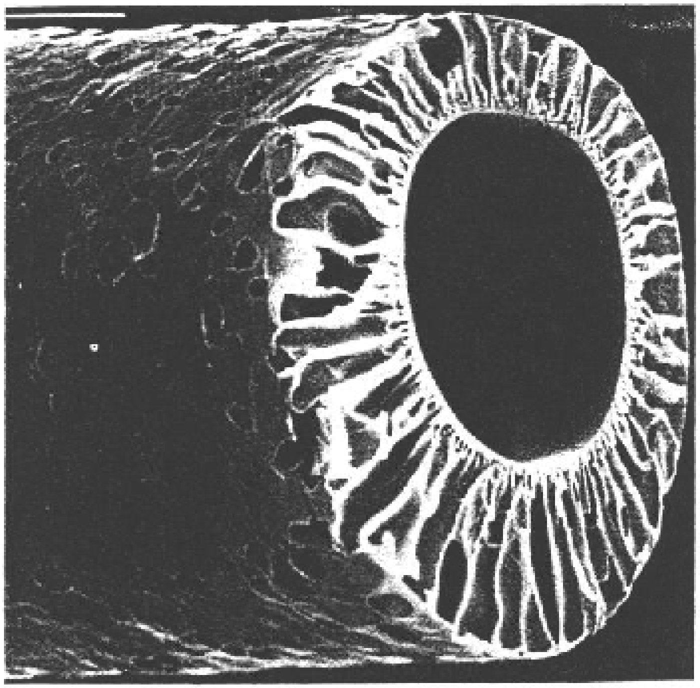


FIGURE 1.2. Capillary ultrafiltration membrane (Amicon).
(Kesting)

Fig. 4.7

Endview of Hollow Fiber Module


Hollow Fiber module
ROMICON®
P/N : RDB0269
S/N : SS050059-5016
KOCH
850 Main Street Wilmington, MA

Fig. 4.8

Membrane Processes Technology

Fig. 4.9 **Hollow Fiber membrane**

3.3 Spiral Wound Modules :

- In hollow the spiral-Wound membrane, a flexible permeate spacer is placed between two flat membrane sheets.
- The membranes are sealed on three sides.
- The fourth open side is attached to a perforated pipe.
- A flexible feed spacer is added and the flat sheets are rolled into tight circular configuration.
- The term spiral is derived from the fact that the flow in the rolled-up arrangement of membranes and support sheets follows a spiral flow pattern.
- The feed water can be applied to the inside of the fiber (inside-out flow), or the outside of the fiber (outside-in flow).
- See Figures 4.9 trhogh 4.13

Spiral RO Element

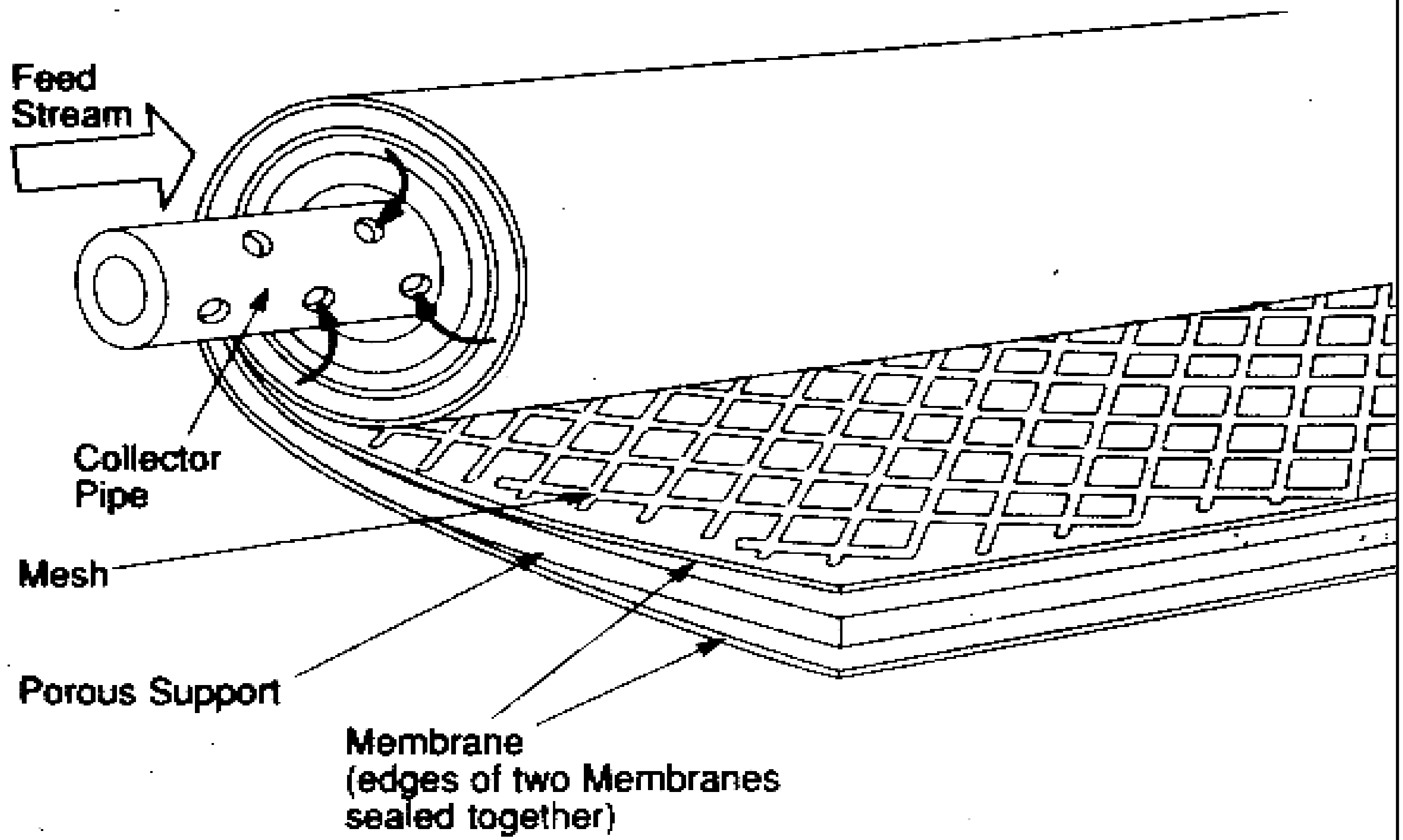
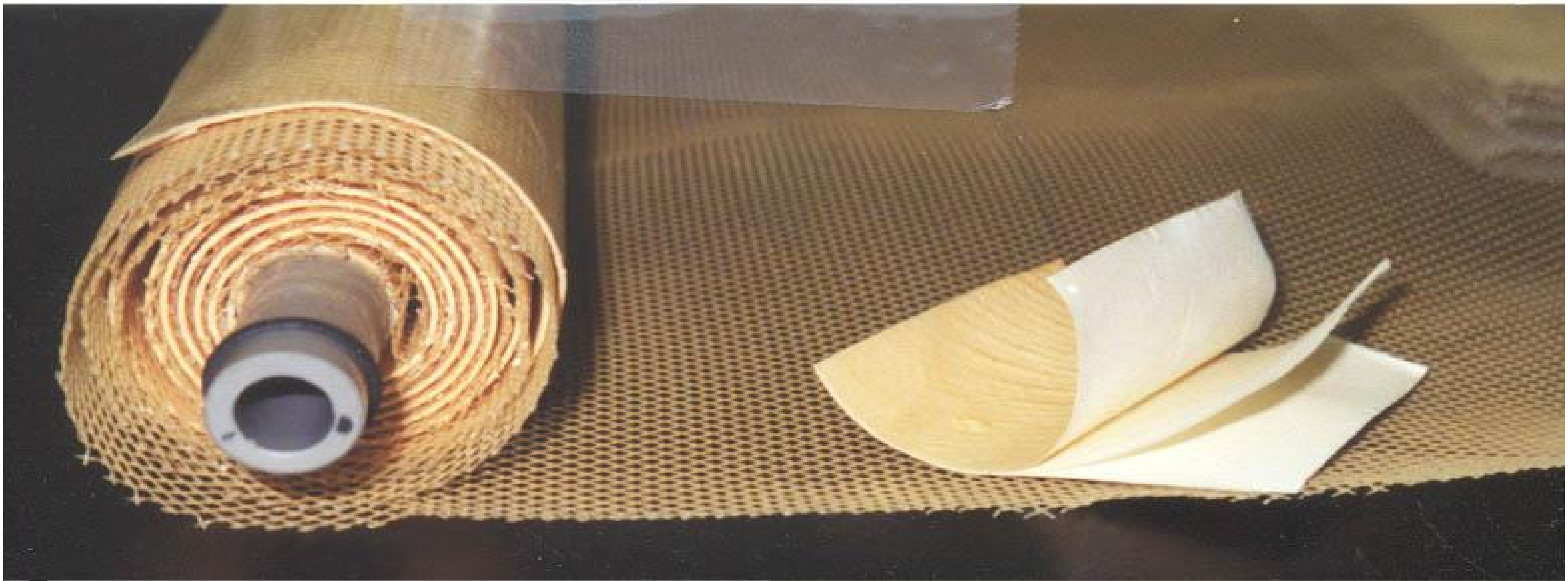


Fig. 4.10



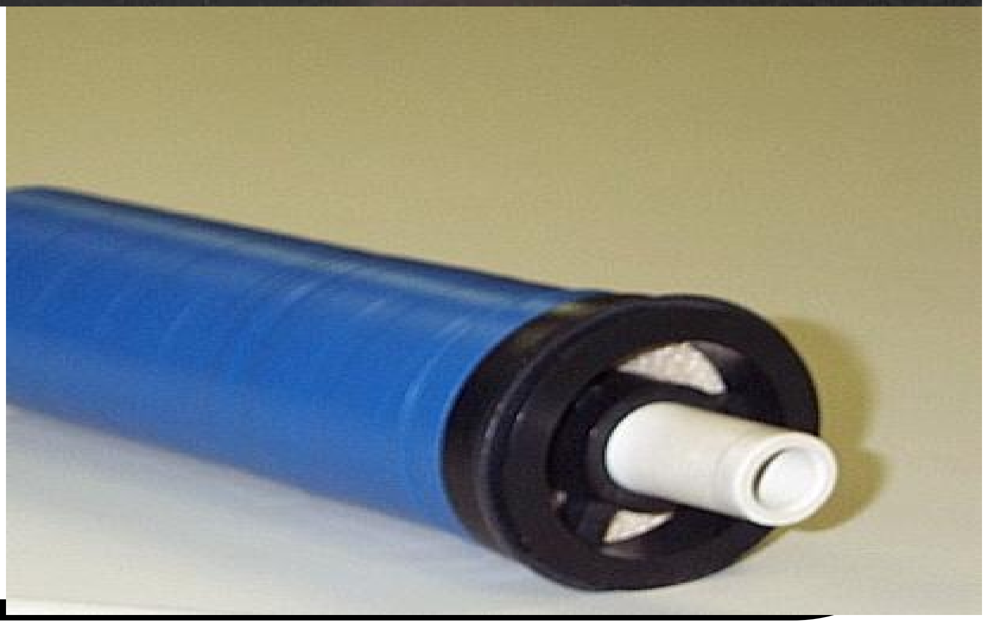


Fig. 4.11

Fig. 4.12

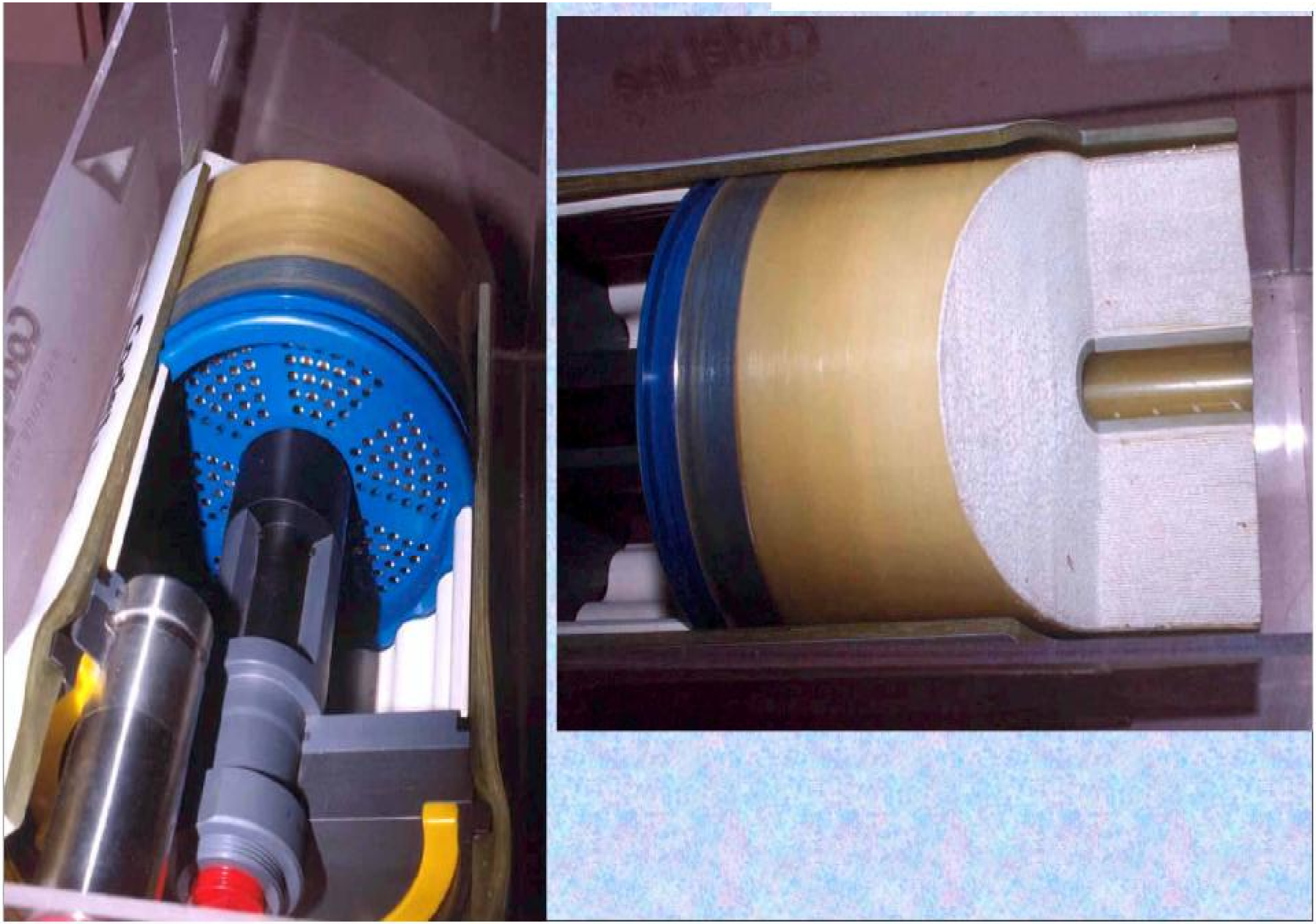


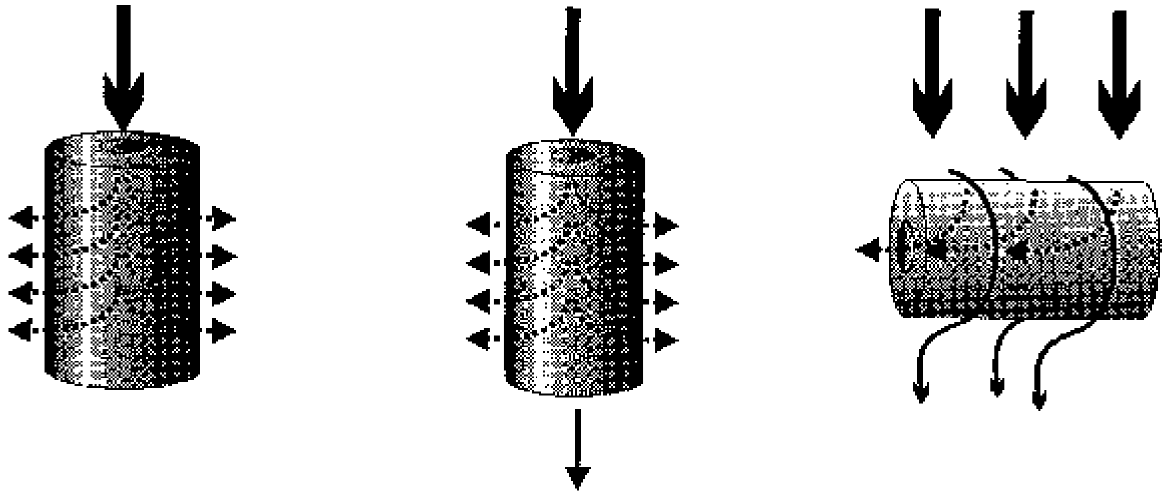
Fig. 4.13 Cut-way photo in a Spiral wound membrane module

4. Terminology

The following is a brief description of some of the terms used in the membrane processes:

- Feed stream : the influent water to the membrane.
- Concentrate or Retentate: the portion of the feed water that dose not pass the membrane that contains higher TDS than the feed stream.
- Permeate: the portion of the feed stream that passes through the membrane that contains lower TDS than the feed water.
- Flux: mass or volume rate transfer the rough the membrane.
- Solvent: Liquid containing dissolved matter, usually water.
- Solute: Dissolved matter in raw, feed, permeate and concentrate water.
- Recovery rate: the ratio between the product water to the feed water.
- Rejection rate: percent removal of the solute from water.
- Fouling: deposition of solids on the feed side of the membrane.
- Filtration mode terms are shown on Figure 4.14.

Filtration Mode Terms



Dead end flow: All water passes through the membrane, particles are trapped within the membrane structure.

Cross flow: Feed water passes parallel to the membrane surface, product water permeates through the membrane, the concentrated stream helps carry particles out of the system.

Transverse flow: Feed water meets the membrane surface at right angles, product water permeates through to the inside of the tube, concentrate washes over the outside of the tube removing particle build-up.

Fig. 4.14

5. Membrane Operation:

5.1 Key factors that directly impact membrane operation in water treatment:

- **Flux**
- **Fouling**
- **Rejection rate**
- **Recovery rate**
- **Temperature - Viscosity of Water**

(Note: Change from 20°C to 4°C results in a ~50% decrease in production for similar membrane area and pressure)

Membrane Processes Technology

5.2 Membrane fouling:

A. Definition:

• It is the deposition and accumulation of solid from the feed water on the membrane.

• It is an important design and operation membrane as it affects:

- Pretreatment needs
- Cleaning requirements
- Operating conditions
- Cost and performance

B. Forms of Fouling:

• Formation of chemical precipitates "Scaling".

• Buildup of solids in the feed-water.

• Damage of the membrane due to the reaction between chemicals in the feed water and the membrane. See Figure 4.15.

Membrane Fouling

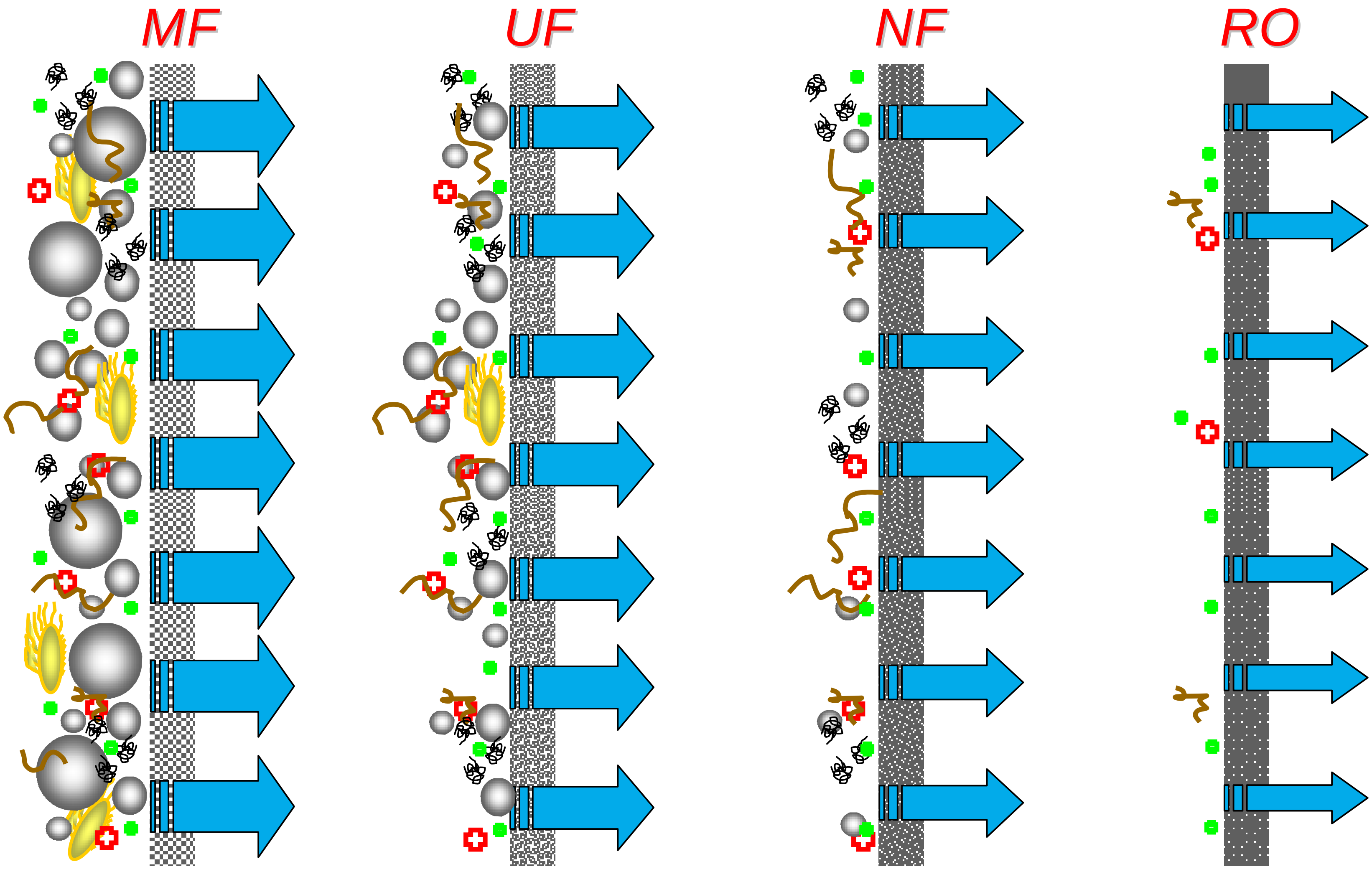


Fig. 4.15

Membrane Processes Technology

C. Control of membrane fouling:

There are three approaches are used to control fouling:

1. Pretreatment of the feed water Buildup of solids in the feed-water. The following are some examples on pretreatment:
   - using conventional filtration, microfiltration or ultrafiltrtion.
   - disinfecting the feed water to limit the bacterial activity using either chlorine, ozone or UV.
   - removal of iron and manganese to prevent scaling.
   - adjusting the pH of the feed water in the range (4 to 7.5) using sulfuric acid to prevent the formation of calcium carbonate, and using hexametaphosphate to prevent the formation of calcium sulfate. Other chemicals called antiscallants are added instead of sulfuric acid.

2. Membrane back-flushing with water.
3. Chemical cleaning of membranes.

Membrane Processes Technology

5.3 Disposal of concentrate waste stream "Brine" :

Disposal of the concentrated waste streams produced by membrane processes represents the major problem in membrane operations.

The principal methods used for the concentrate disposal:

1. Ocean discharge
2. Surface water discharge
3. Discharge to wastewater collection system.
4. Deep-well injection
5. Evaporation bonds
6. Controlled thermal evaporation

Each disposal option has it's own use conditions and should be studied carefully.

5.4 Infrastructure of membrane processes:

The operation of membrane processes is simple:

- A pump is used to pressurize the feed solution and to circulate it through the module.
- A valve is used to maintain the pressure of the concentrate (retentate).
- The permeate is withdrawn typically at atmospheric pressure.
- See Figure 4.16.
- Units are arranged in parallel to meet the flow requirements, and arranged in series to increase the treatment efficiency, see Figures 4.17, 4.18, 4.19,and 4.20 .

Membrane Processes Technology

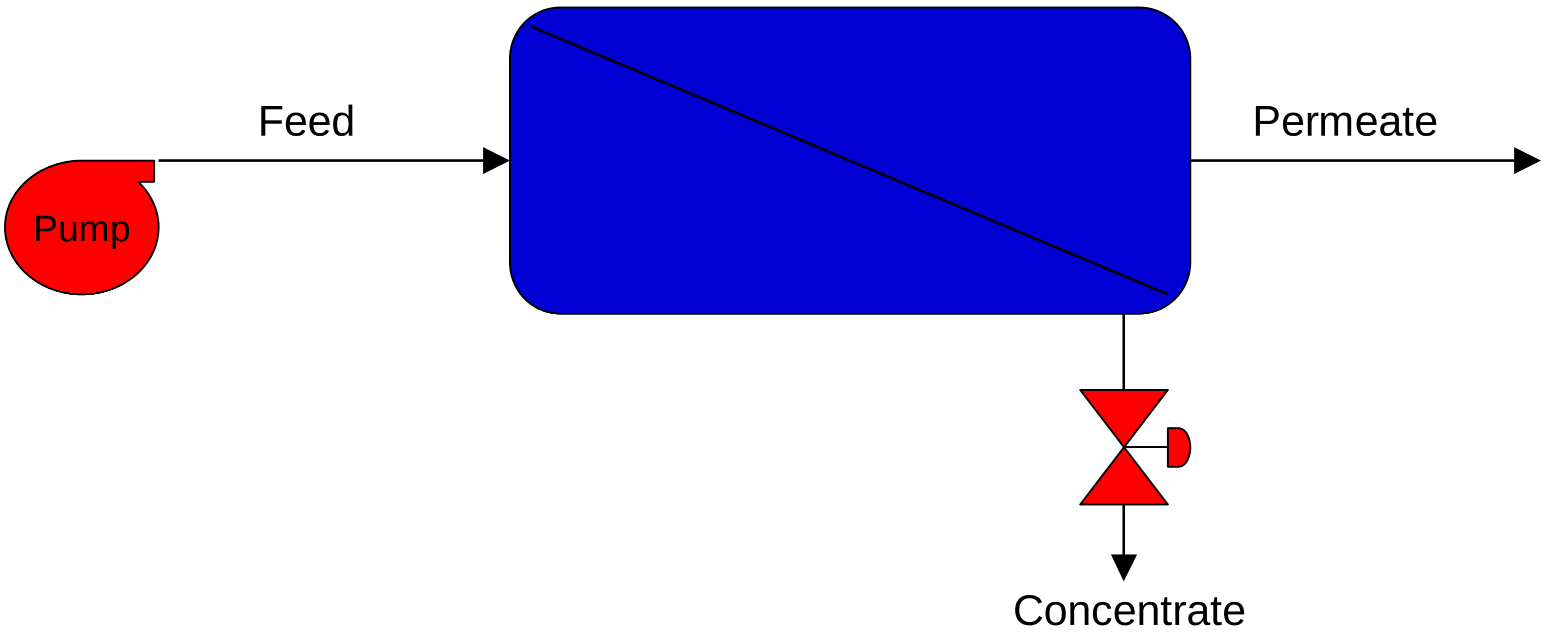


Fig. 4.16 **Membrane operation Schematic layout**

Membrane Processes Technology

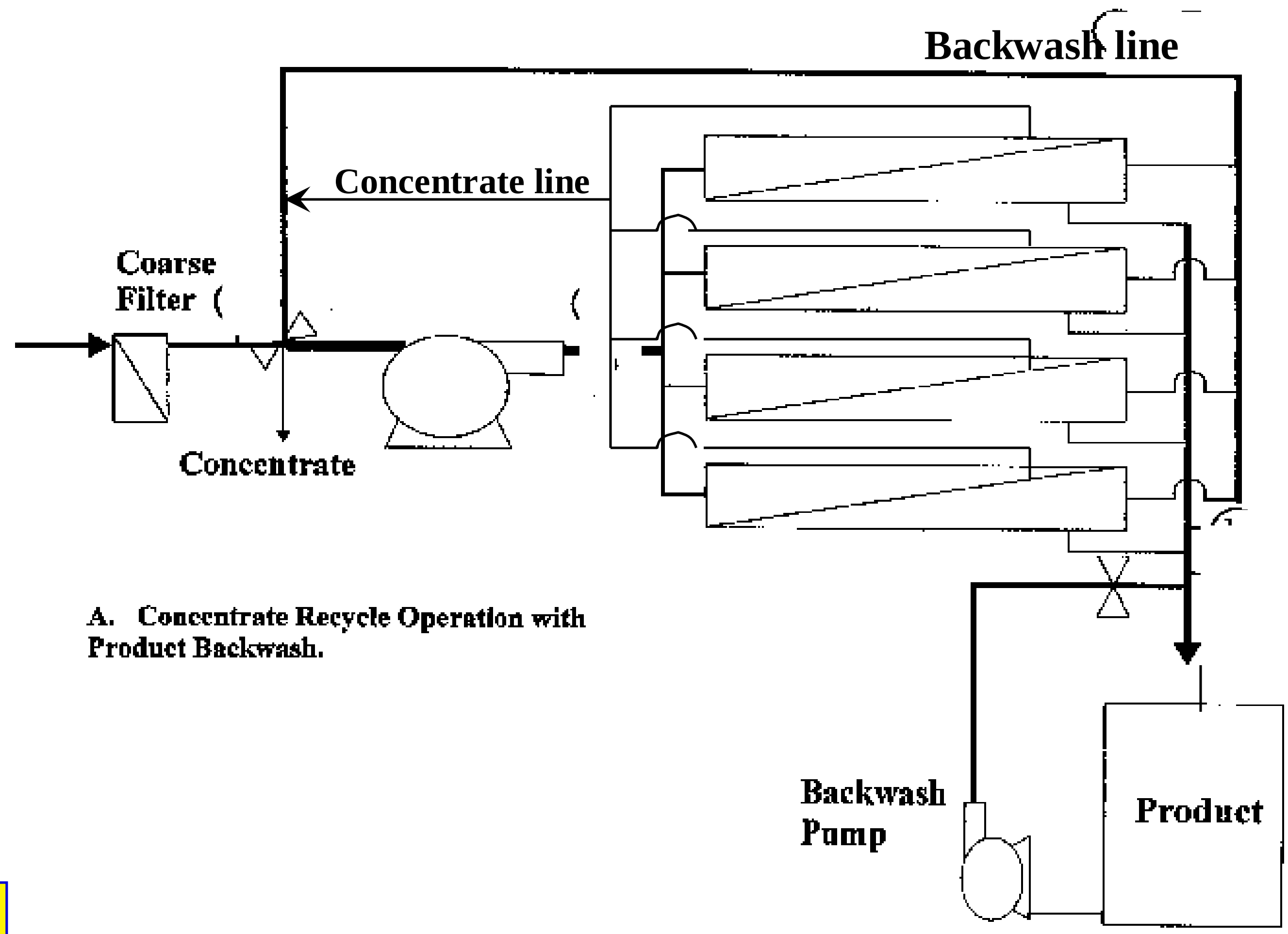


Fig. 4.17

Membrane units arranged in parallel one stage system

Membrane Processes Technology

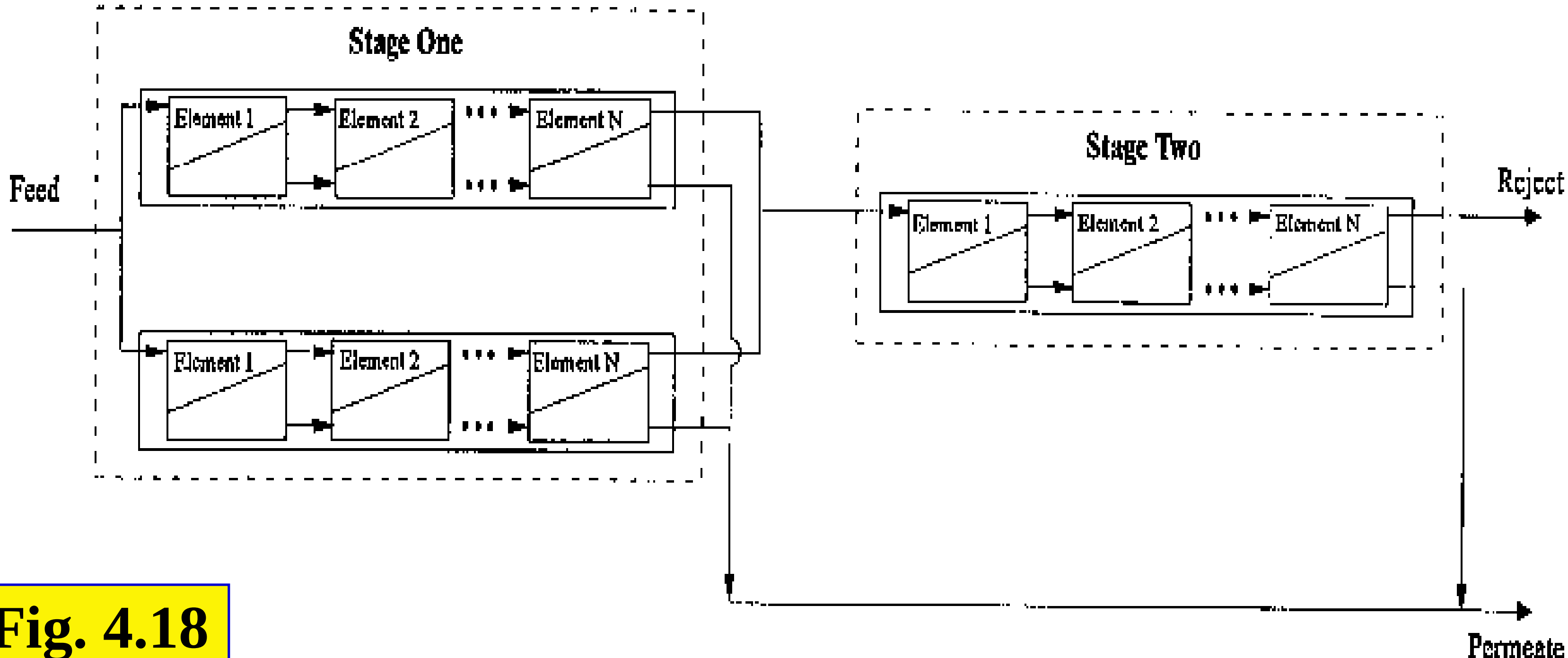


Fig. 4.18

Membrane units arranged in parallel and in series in a two stage system

Fig. 4.19

0.1 MGD RO Package System

Fig. 4.20

6. Membrane applications in water treatment:

- MF can remove suspended solids, turbidity, crypto and giardia. Not color, virus, or dissolved solids.
- UF can remove color and odor causing organics, virus, and other microbiological pests. Not dissolved salts.
- RO and NF systems should be used to remove only **dissolved** solids - they need VERY clear feed water.
- ED removes IONS from water - it does NOT remove crypto, giardia, uncharged molecules, suspended solids etc.

Visit this web site:
http://www.diwater.net/Animation_Library_Listing.htm