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MEMBRANE TECHNOLOGIES

By

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CWQA PROFESIONAL DEVELOPMENT SEMINAR

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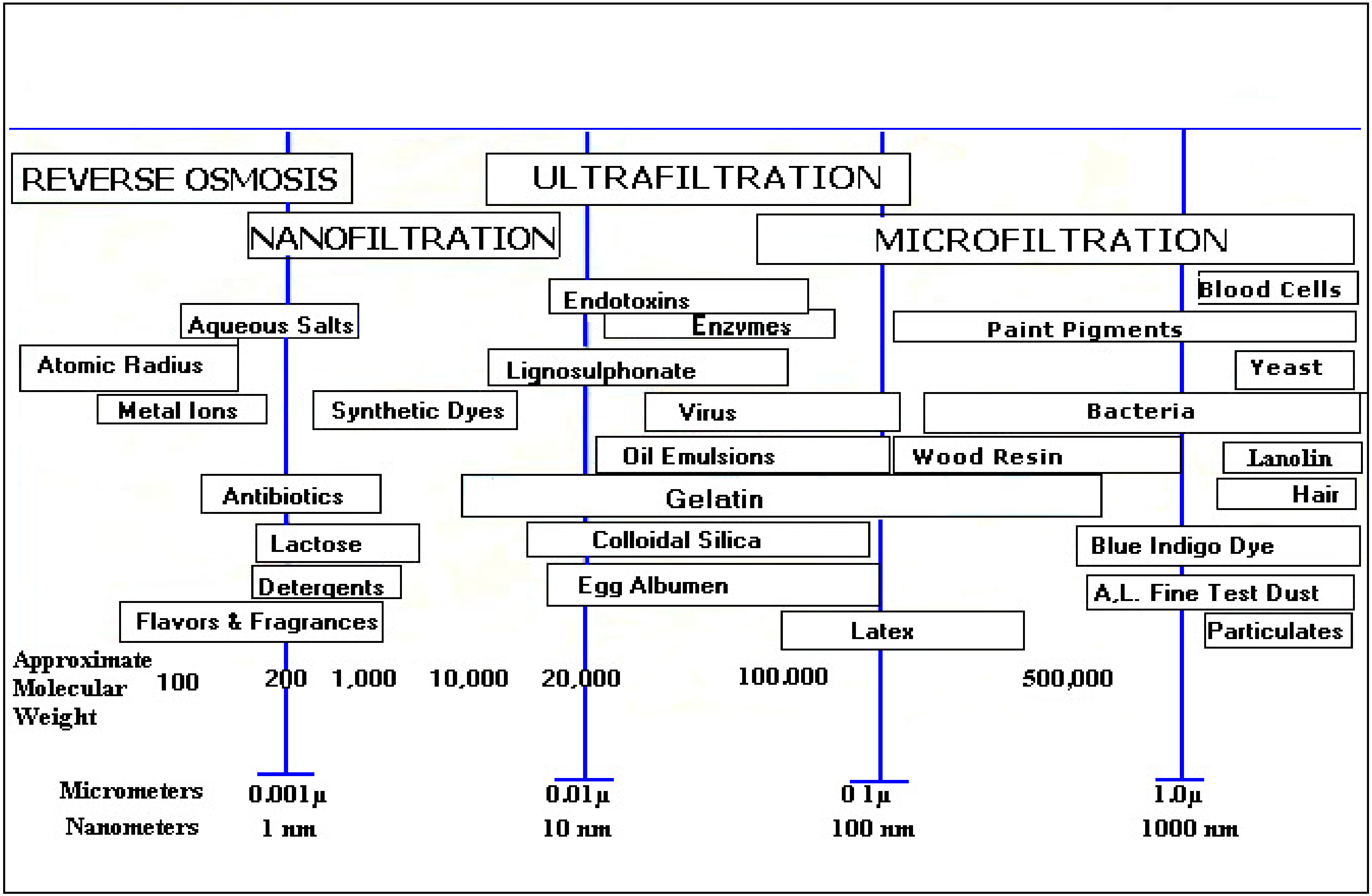
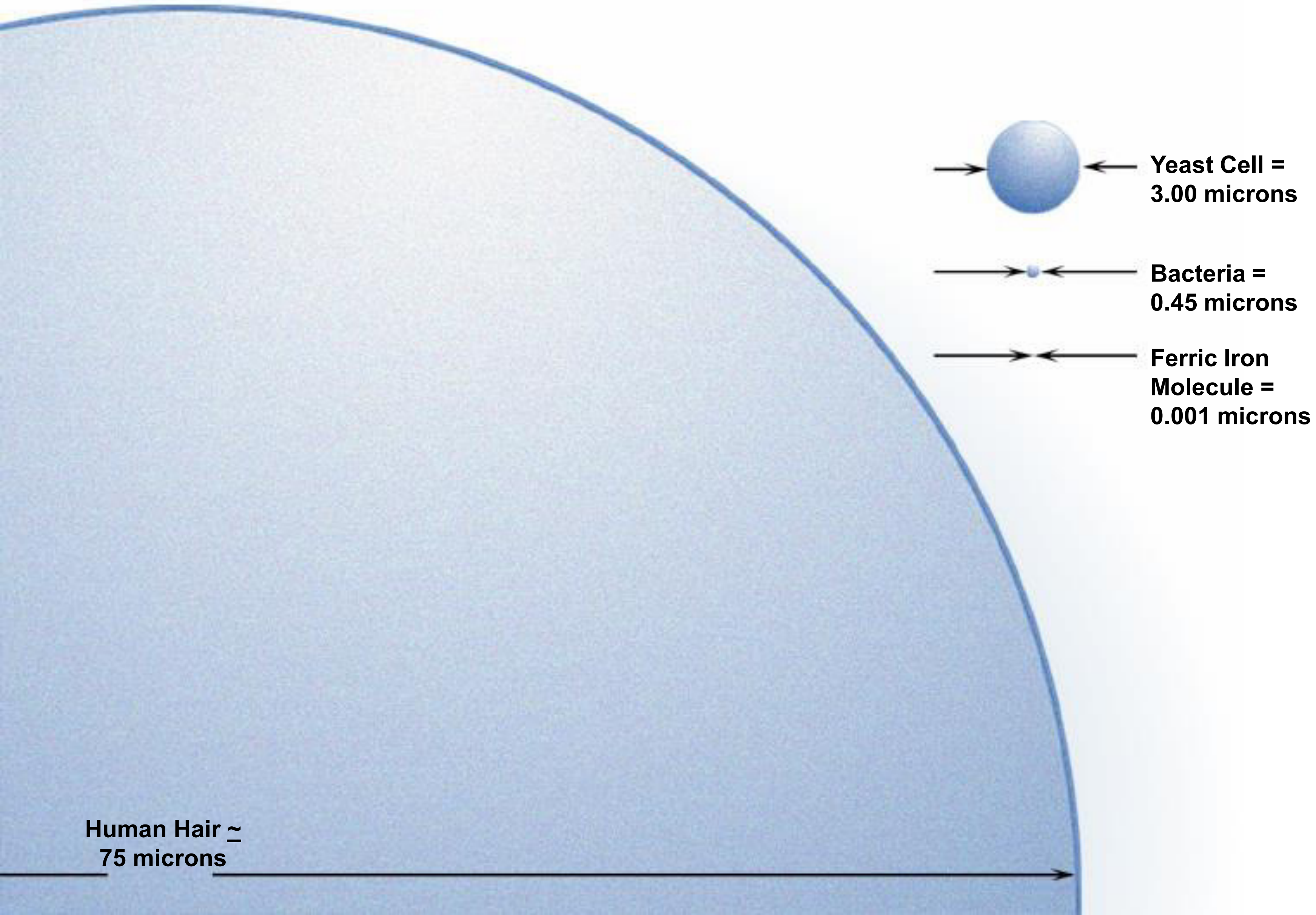
Water Contaminants

Class	Typical Example
Suspended solids	Dirt, clay, colloidal materials
Dissolved organics	Trihalomethanes, synthetic organic chemicals, humic acids, fulvic acids
Dissolved ionics (salts)	Heavy metals, silica, arsenic, nitrate
Microorganisms	Bacteria, viruses, protozoan cysts, fungi, algae
Gases	Hydrogen sulfide, methane, radon

Filtration Range



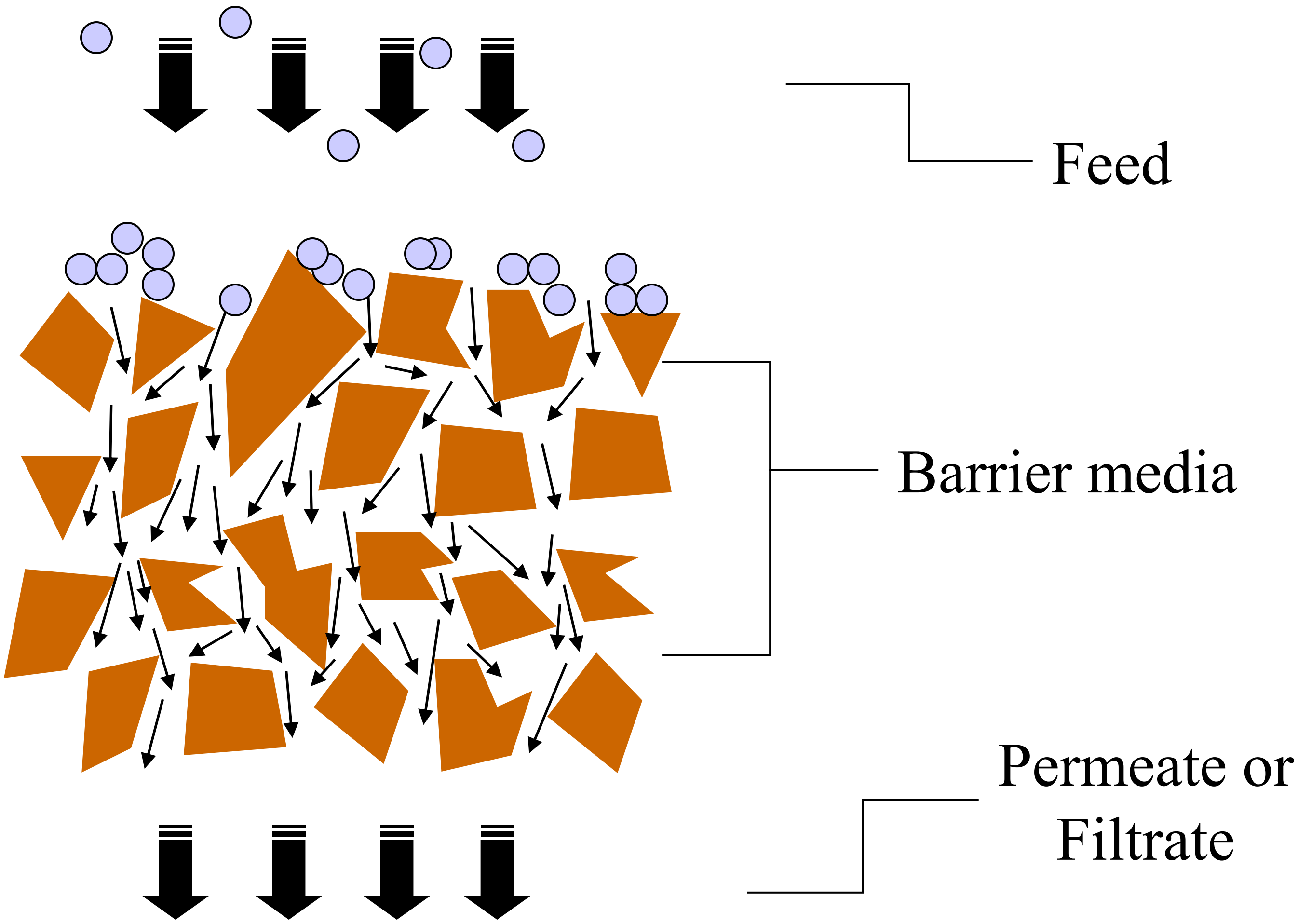
Particle Size



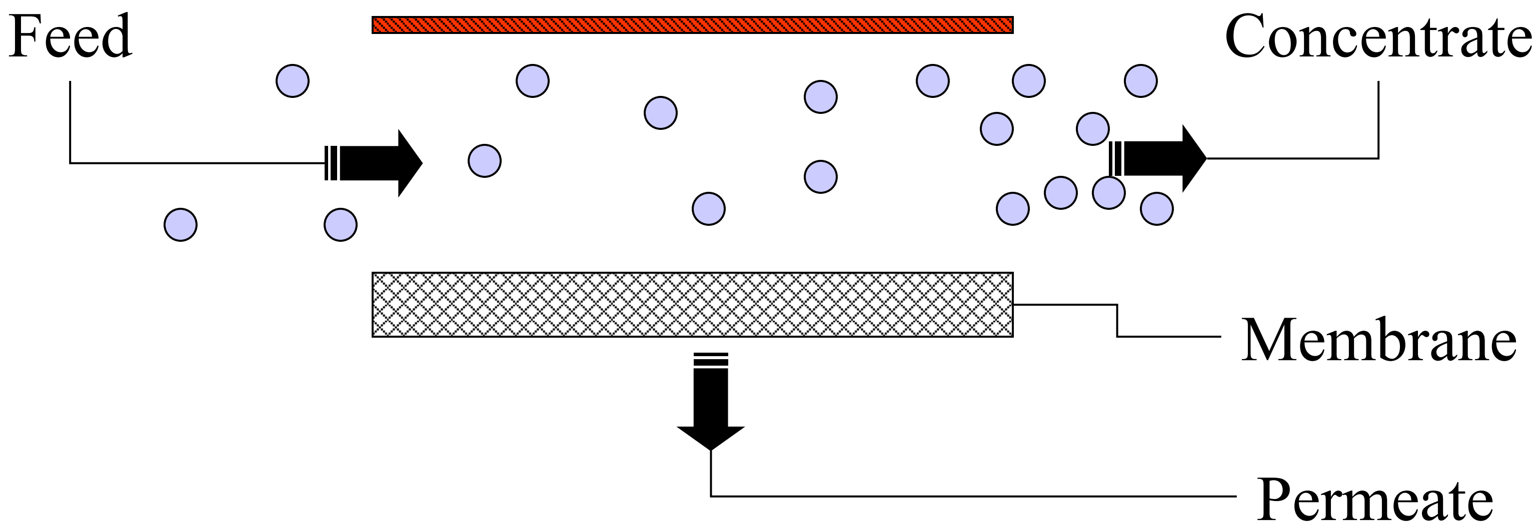
Relative Sizes of Particles

Substance	Microns	Inches
Grain of table salt	100	0.0039
Human hair	80	0.0032
Lower limit of visibility	40	0.0016
Milled flour	25	0.0010
Red blood cells	8	0.0003
Bacteria	2	0.0001

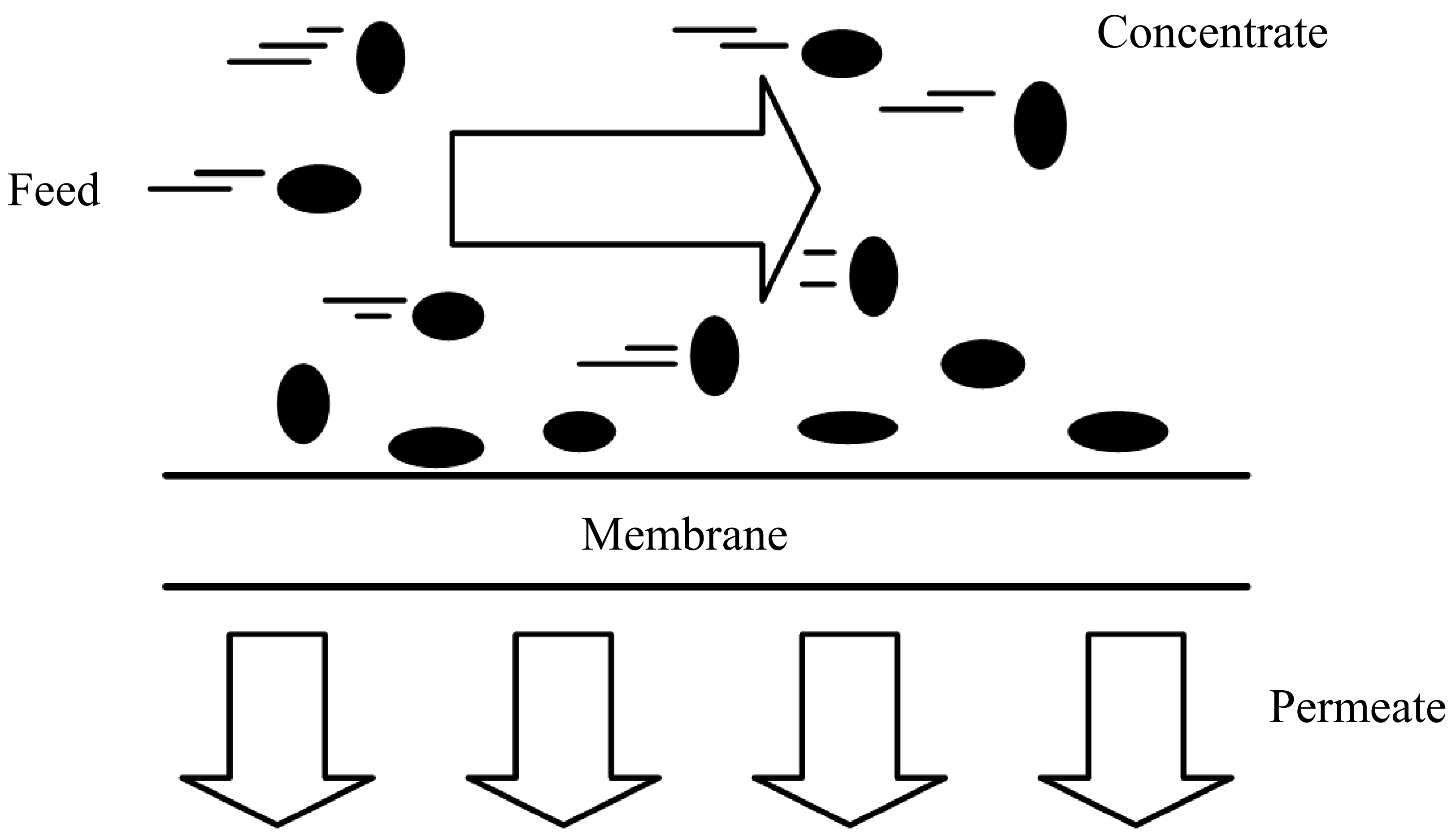
Conventional “dead-end” Filtration



Crossflow Filtration



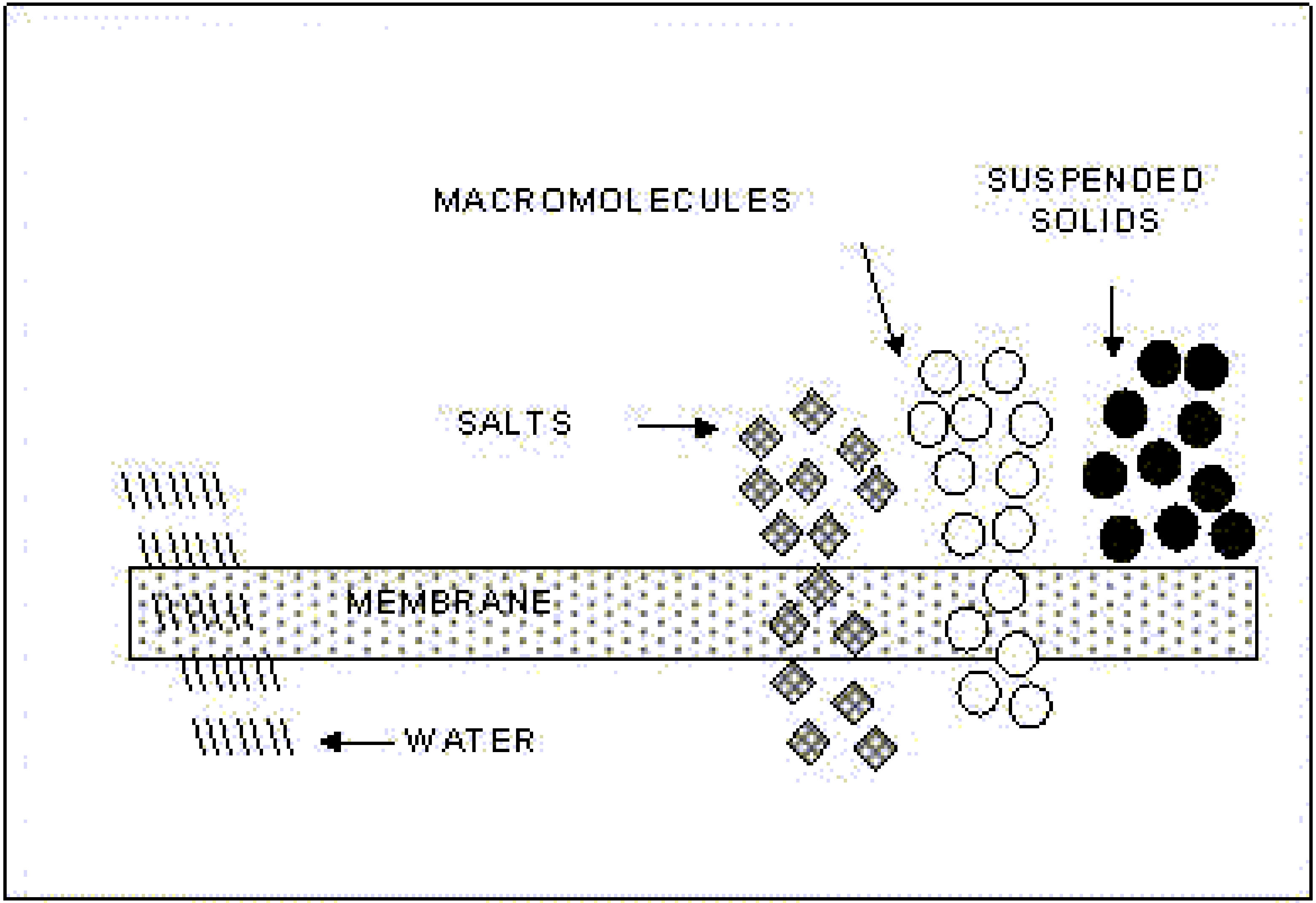
"Sweeping" by Tangential Flow



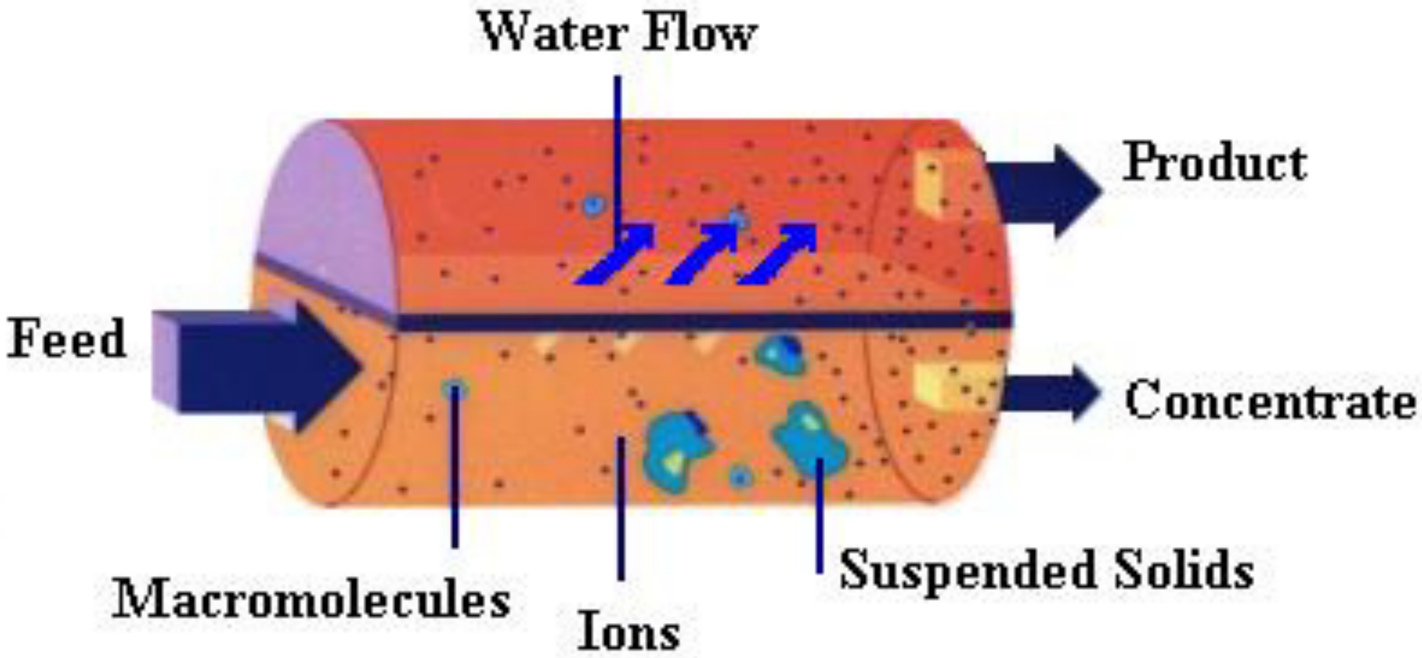
Membrane Separation Technologies Features

- Continuous process resulting in automatic and uninterrupted operation
- Low energy utilization involving neither phase nor temperature changes
- Modular design – no significant size limitations
- Minimal moving parts with low maintenance requirements
- No effect on form or chemistry of the contaminant
- Discrete membrane barrier to ensure physical separation
- No chemical addition requirements

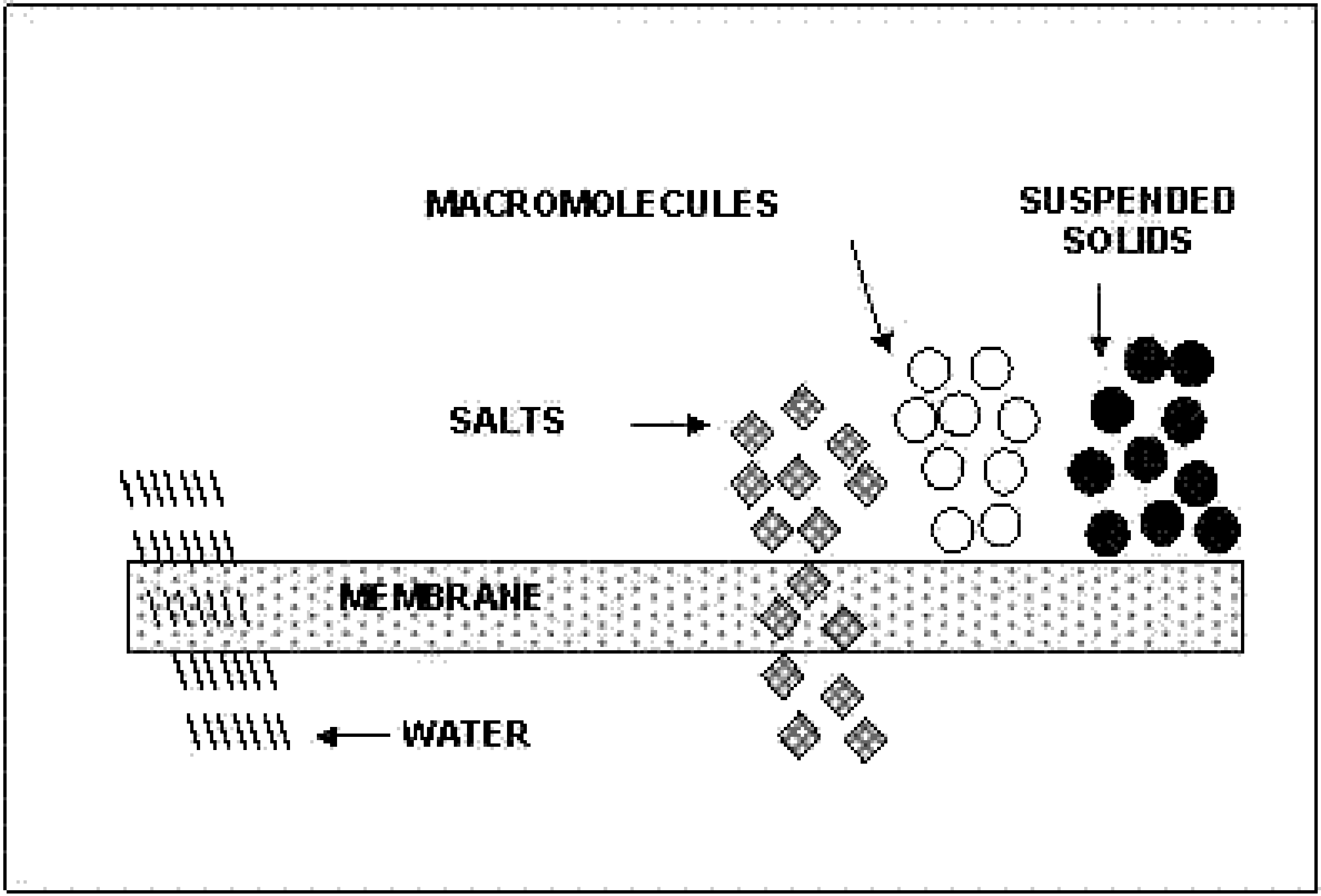
Microfiltration



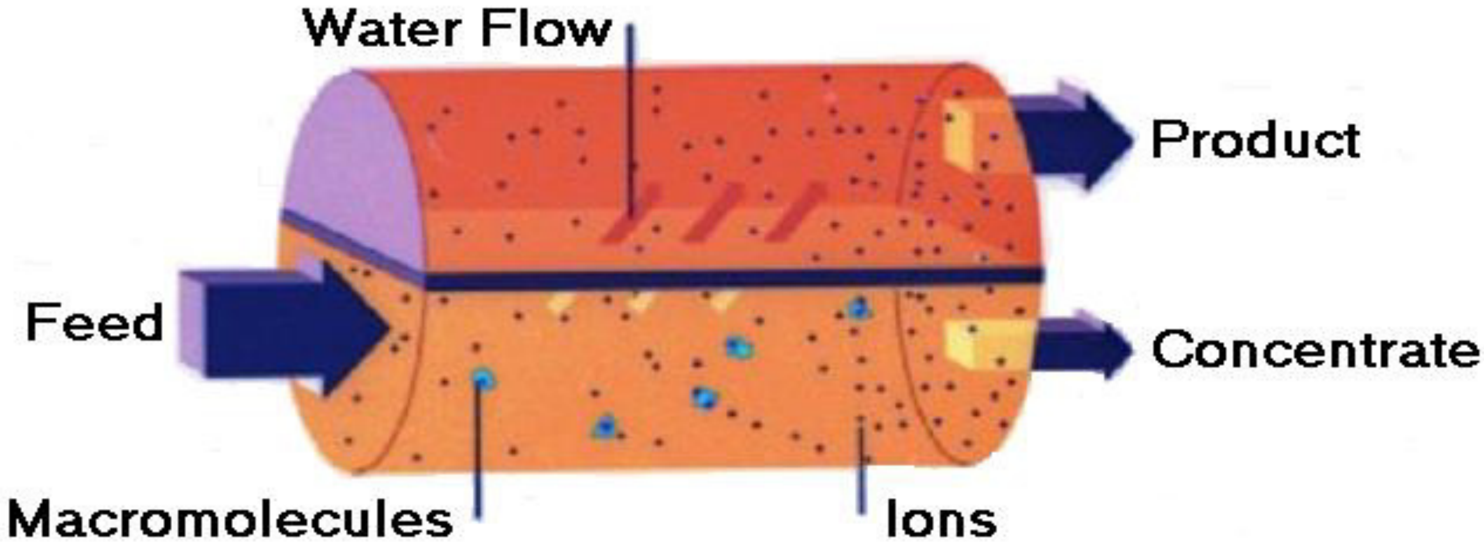
Microfiltration



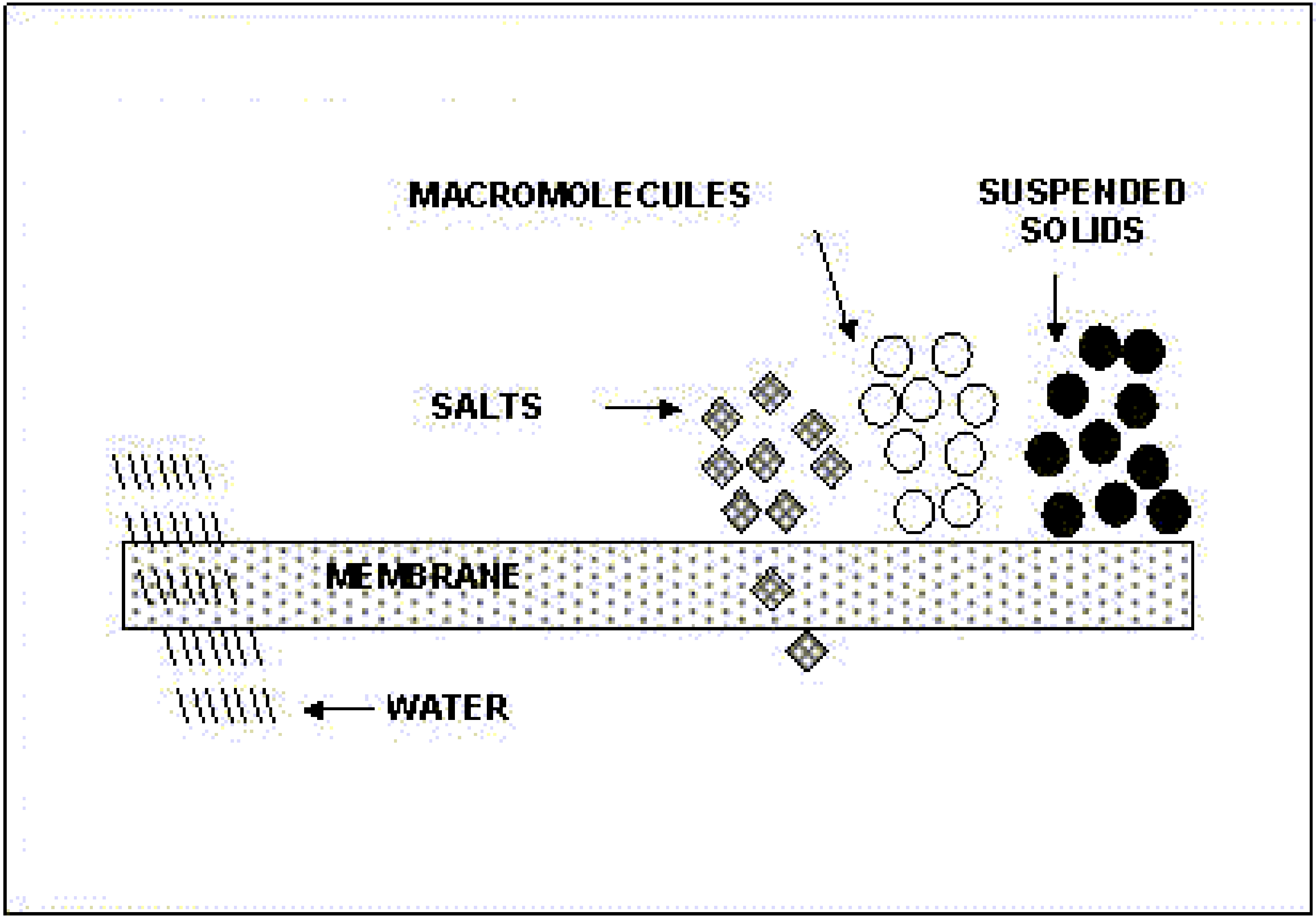
Ultrafiltration



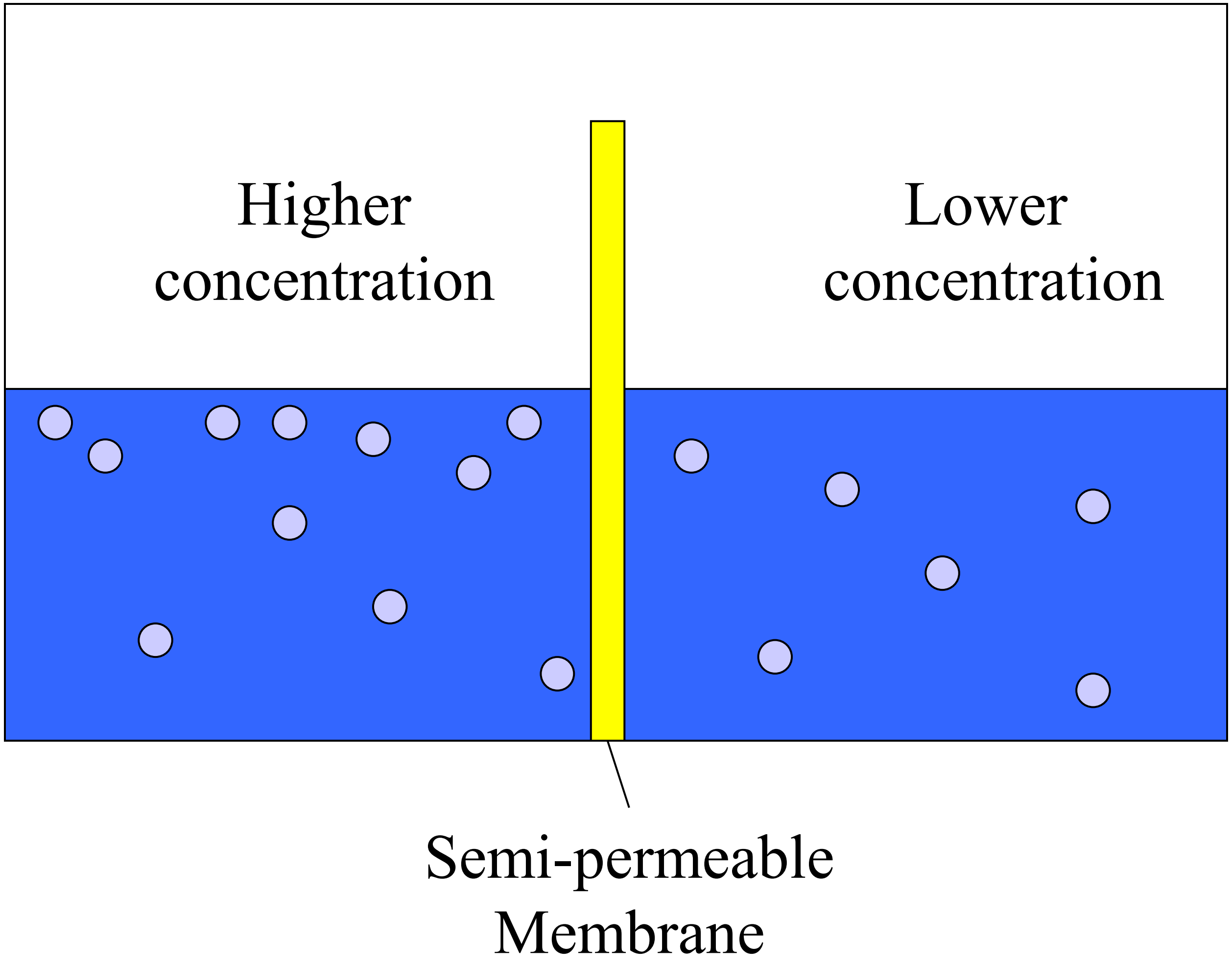
Ultrafiltration



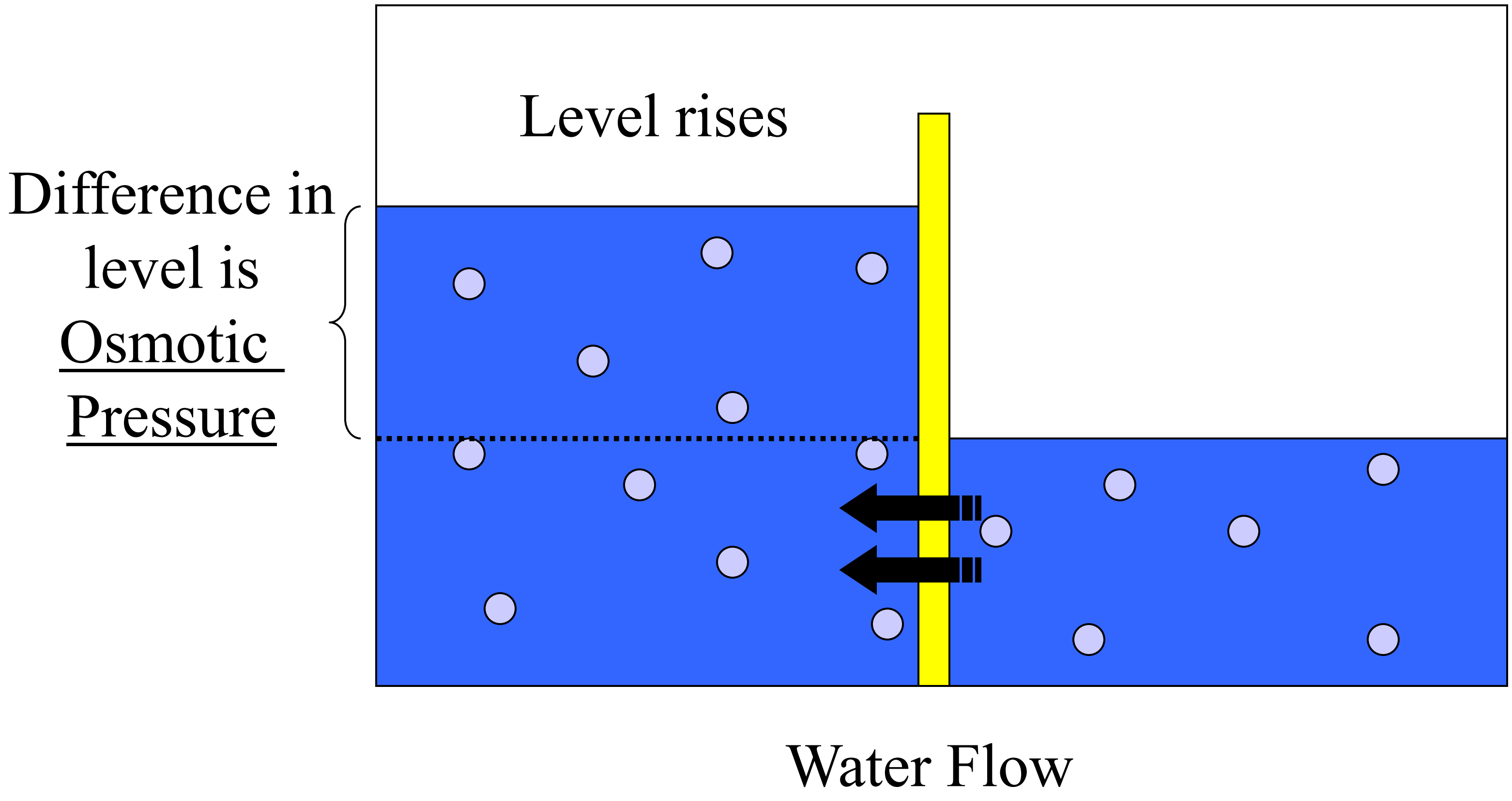
Nanofiltration



Osmosis

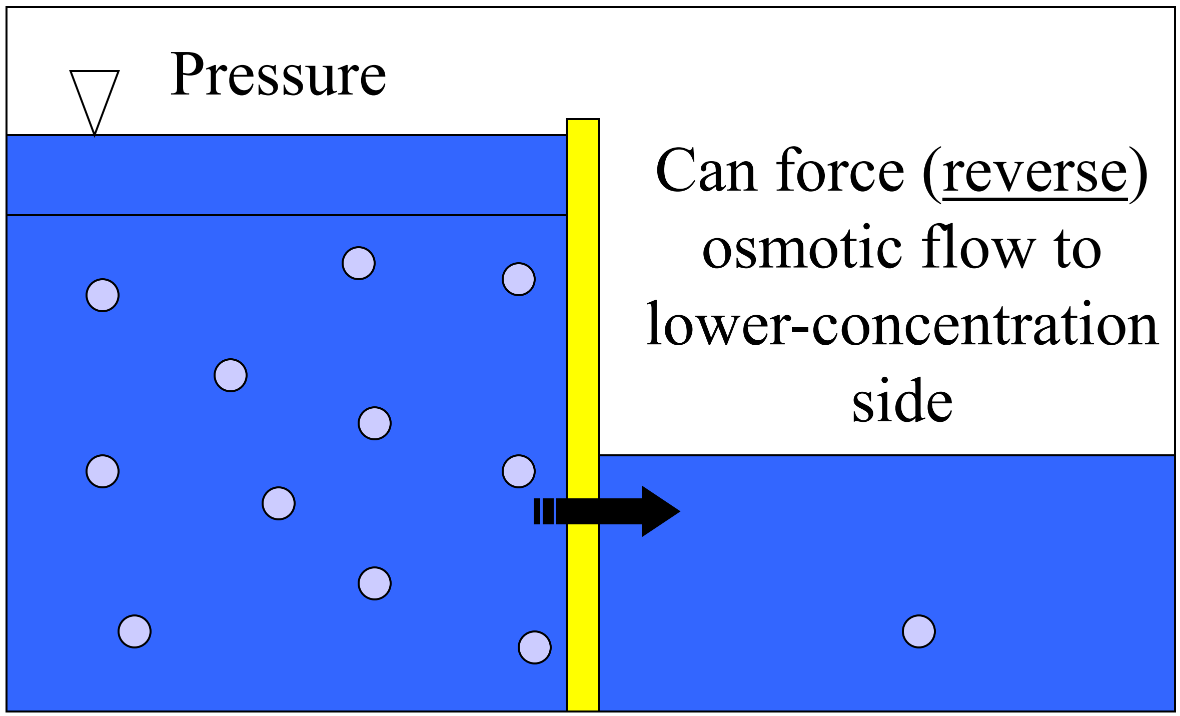

Higher
concentration
Lower
concentration
Semi-permeable
Membrane

Osmosis



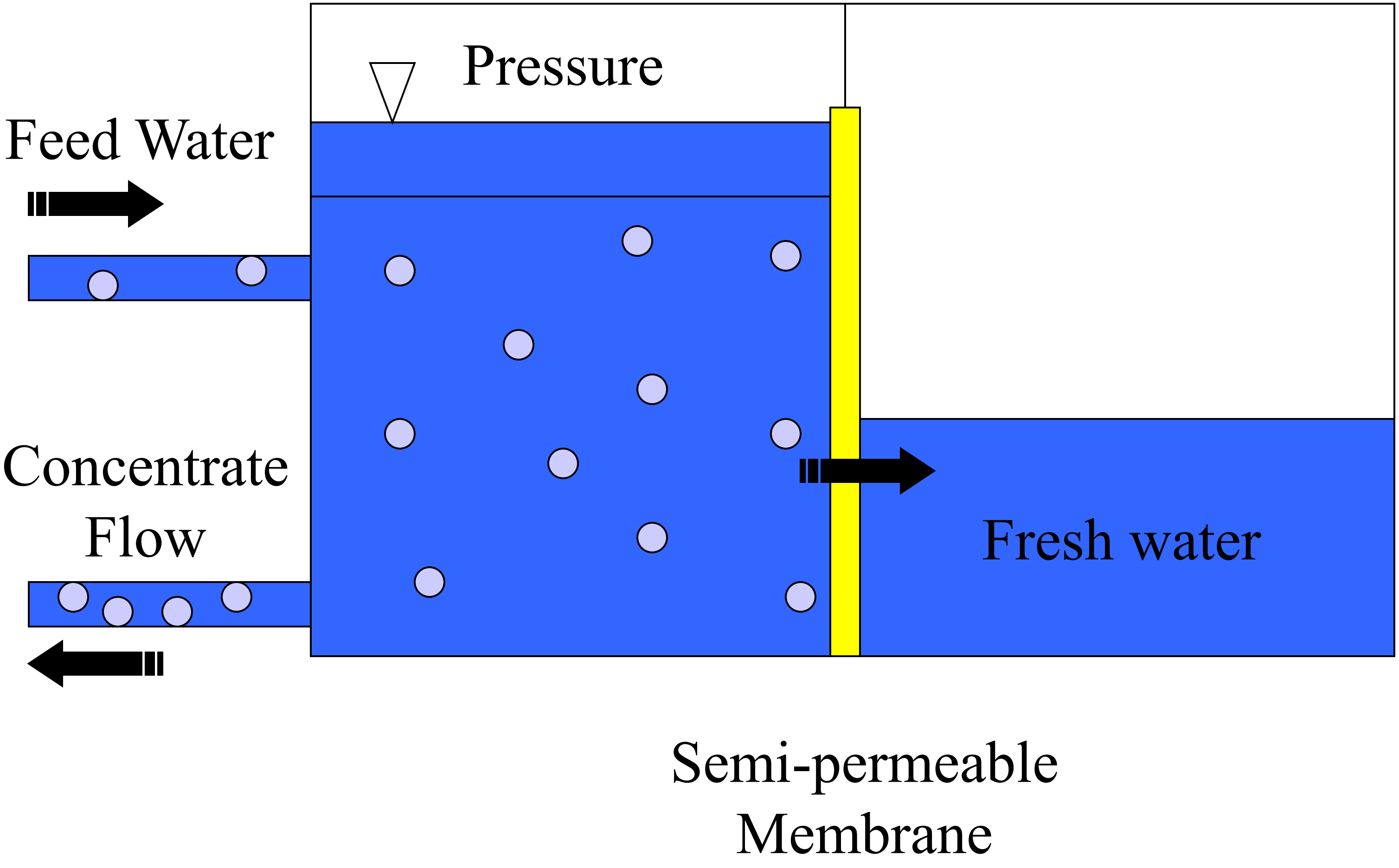
Level rises
Difference in level is Osmotic Pressure
Water Flow

Reverse Osmosis

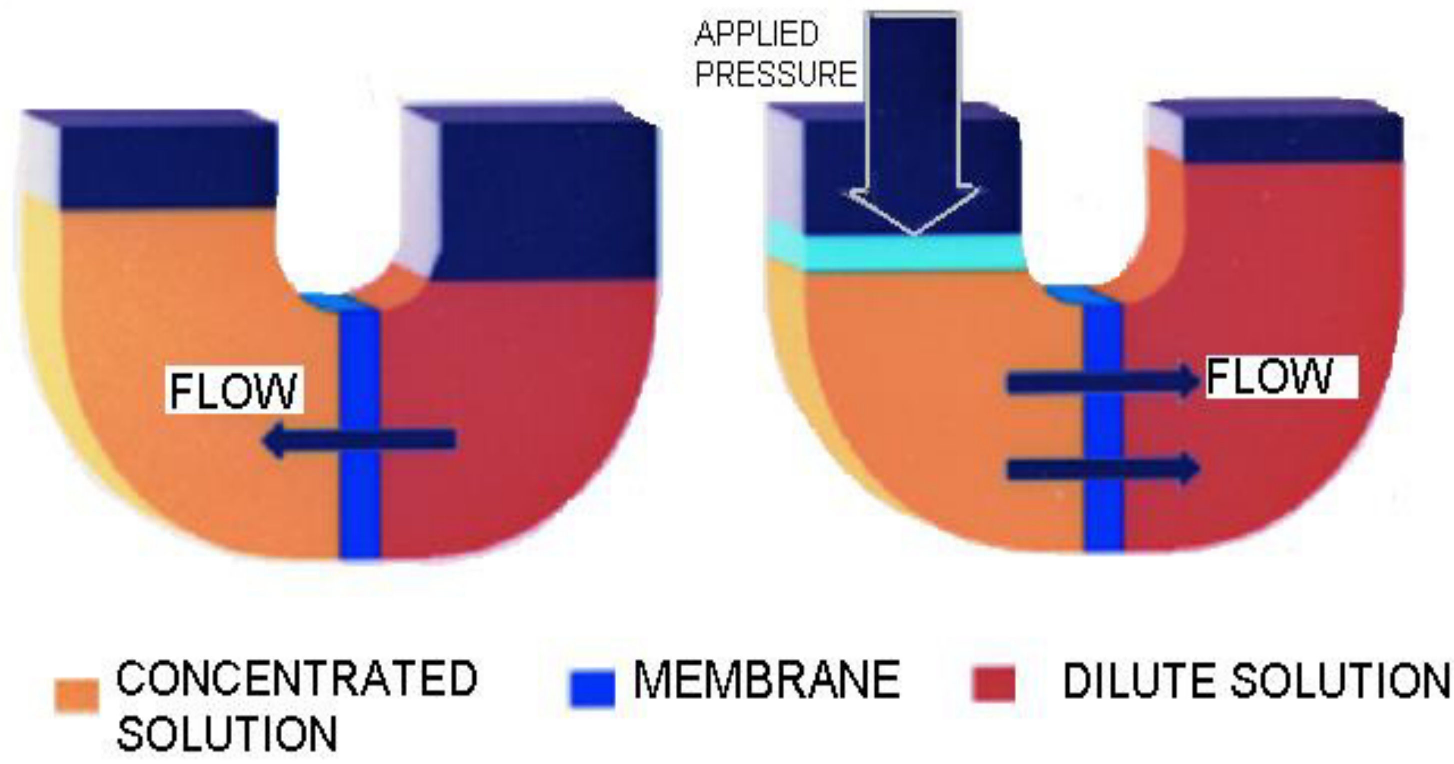


Semi-permeable Membrane

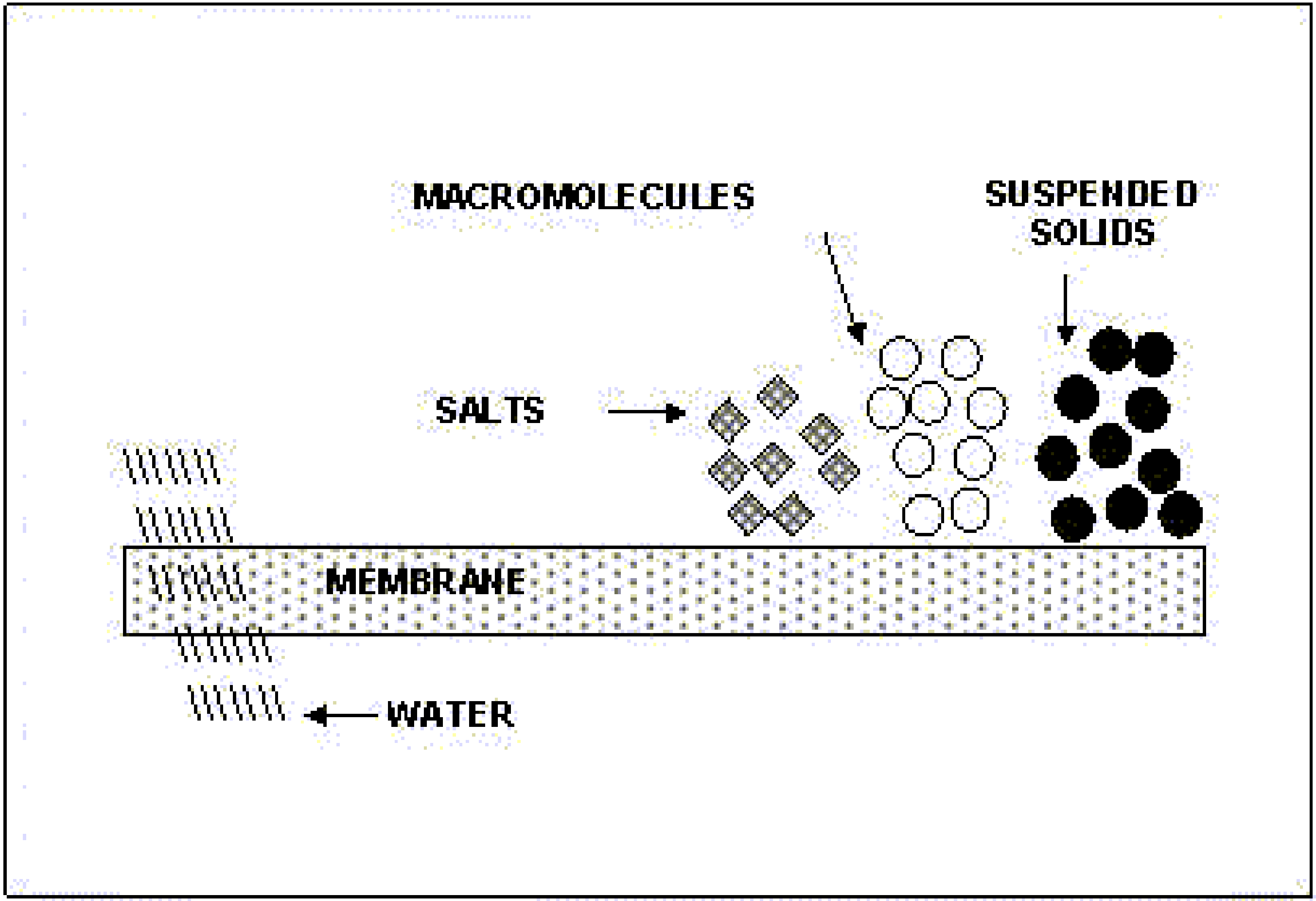
Reverse Osmosis Applied



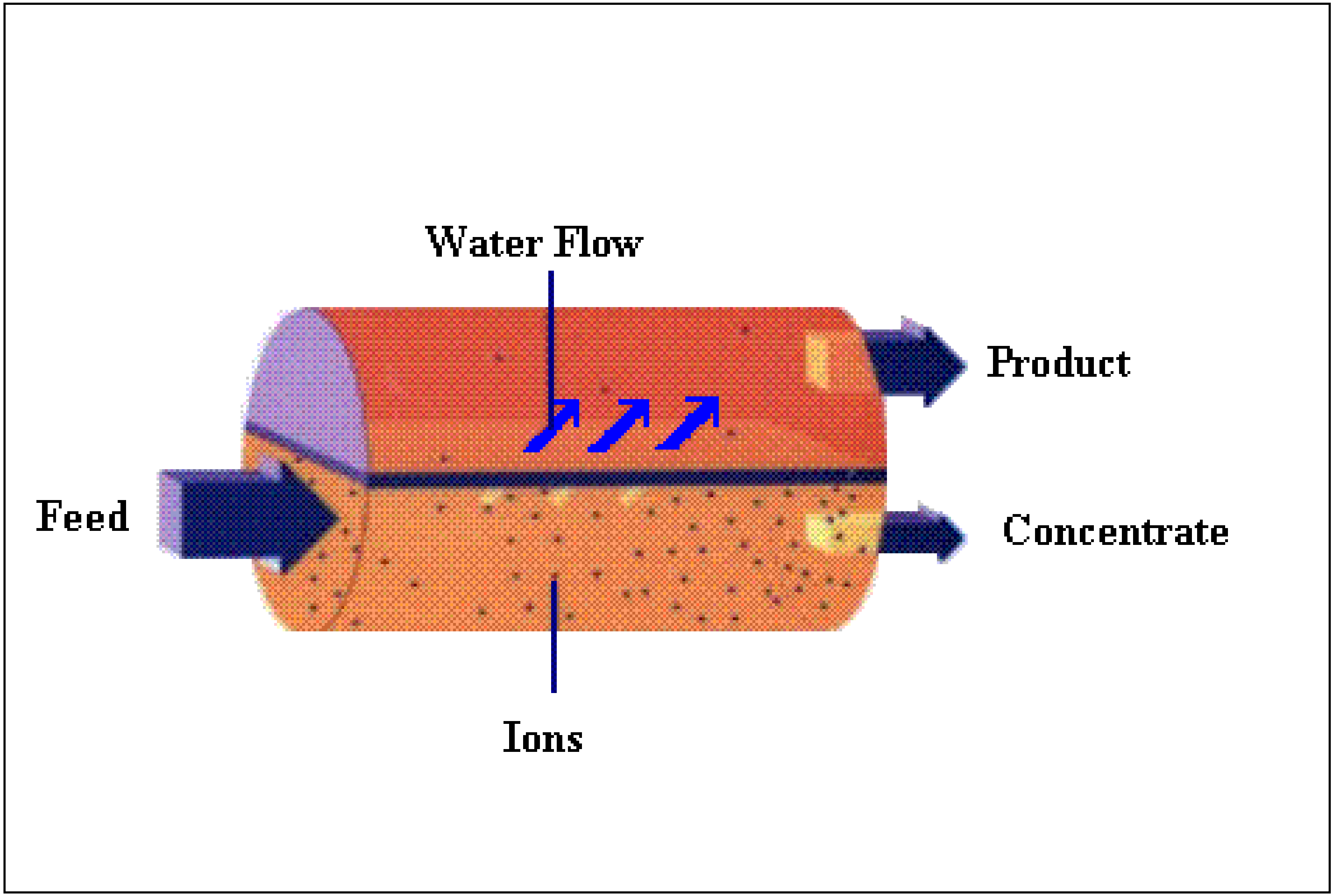
Reverse Osmosis



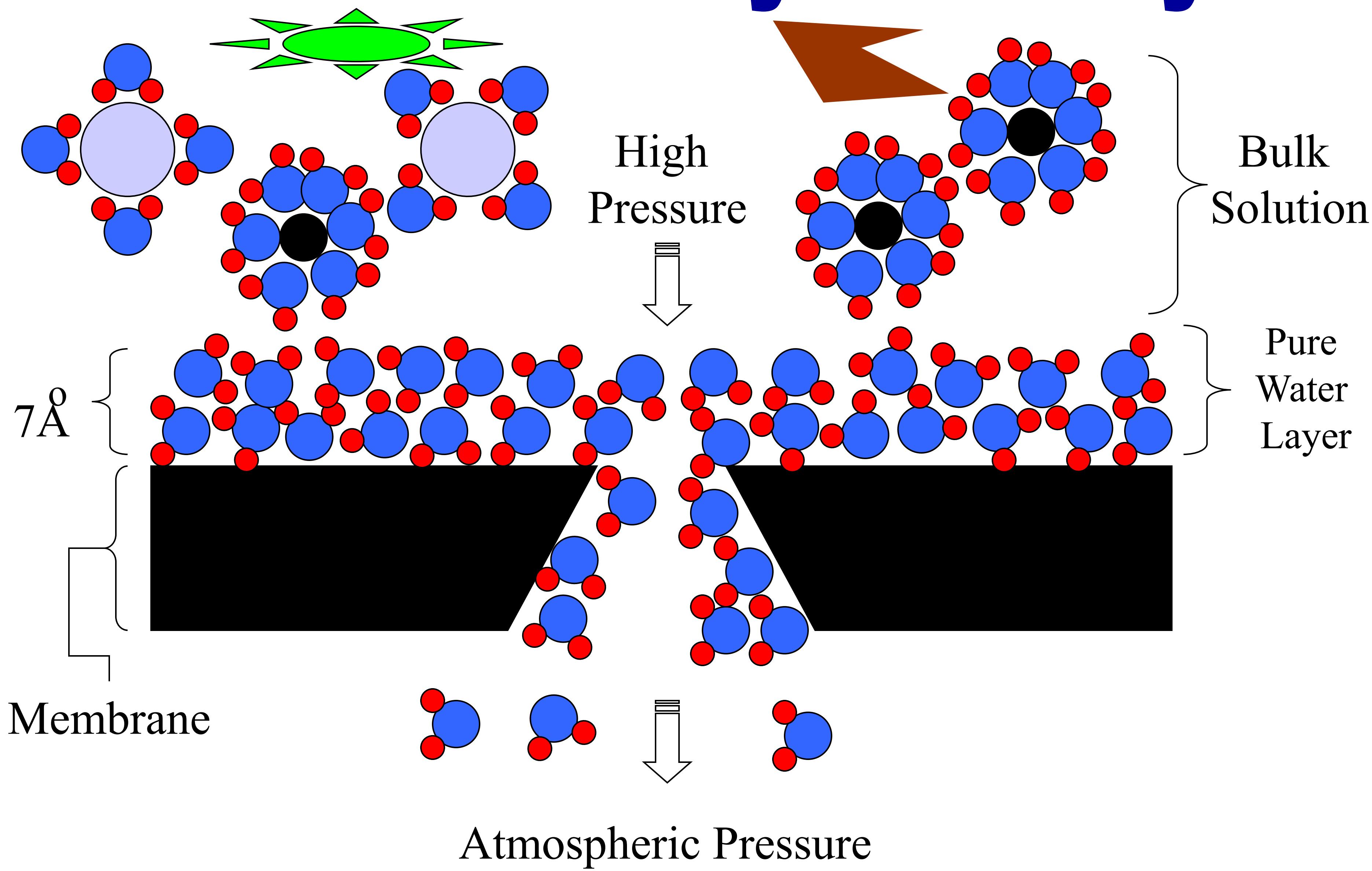
Reverse Osmosis



Reverse Osmosis



Pure Water Layer Theory



RO Fundamentals

- Semi-permeable membrane uses two mechanisms for removal of impurities:

  Rejection (repels mineral salts involving dielectric and molecular forces)

  Sieving (does not allow particulate matter to pass on a small scale ~0.0005 microns. Tiny organics and gas molecules can pass.)

Osmotic Pressure

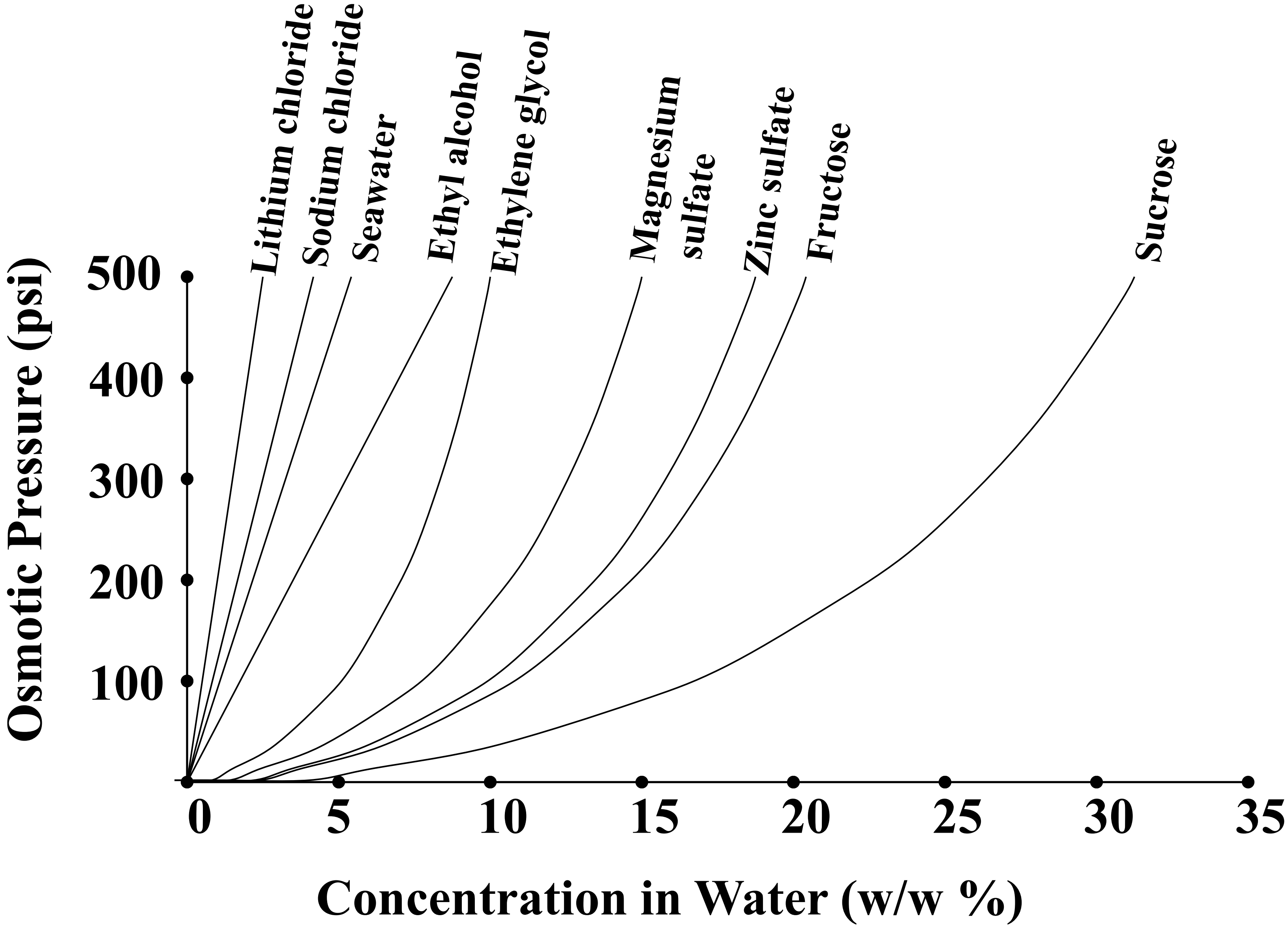
Equation

$$\pi = 1.19(T + 273)\ \sum M_i$$

π = Osmotic Pressure (psi)
T = Water Temperature (^{o}C)
M_i = Molar Concentration of
individual ions (gmol/L)

Typical Osmotic Pressures (25°C)			
Compound	Conc. (mg/L)	Conc. (mol/L)	Osmotic Pressure (psi)
NaCl	35,000	0.6	398
NaCl	1,000	0.0171	11.4
$NaHCO_3$	1,000	0.0119	12.8
Na_2SO_4	1,000	0.00705	6
$MgSO_4$	1,000	0.00831	3.6
$MgCl_2$	1,000	0.0105	9.7
$CaCl_2$	1,000	0.009	8.3
Sucrose	1,000	0.00292	1.05
Dextrose	1,000	0.00555	2.0

Solute Concentration as a Function of Osmotic Pressure



RO Performance Equations

- Osmotic Pressure: The pressure, due to the effect of TDS in the feed water, that must be overcome in order to generate product water flow.
- For monovalent salts, assume 1 psi of osmotic pressure per 100 mg/L of TDS.
- For multivalent salts, assume ½ psi of osmotic pressure per 100 mg/L of TDS.

R.O. Contaminant Rejection

Inorganics	CTA Rejection	TFC Rejection	inorganics	CTA Rejection	TFC Rejection
Sodium	85-90%	90-95%	Fluoride	85-90%	90-95
Calcium	90-95%	93-98%	Phosphate	90-95%	93-98%
Magnesium	90-95%	93-98%	Chromate	85-90%	90-95%
Potassium	85-90%	90-95%	Cyanide	85-90%	90-95%
Iron	90-95%	93-98%	Sulfate	90-95	93-98%
Manganese	90-95%	93-98%	Boron	30-40%	55-60%
Aluminum	90-95%	93-98%	Arsenic+3	60-70%	70-80%
Copper	90-95%	93-98%	Arsenic+5	85-90%	93-98%
Nickel	90-95%	93-98%	Selenium	90-95%	93-98%
Zinc	90-95%	93-98%	Radioactivity	90-95%	93-98%
Strontium	90-95%	93-98%	Biological&Particles		
Cadmium	90-95%	93-98%	Bacteria	>99%	>99%
Silver	90-95%	93-98%	Protozoa	>99%	>99%
Mercury	90-95%	93-98%	Amoebic Cysts	>99%	>99%
Barium	90-95%	93-98%	Giardia	>99%	>99%
Chromium	90-95%	93-98%	Asbestos	>99%	>99%
Lead	90-95%	93-98%	Sediment/Turbidity	>99%	>99%
Chloride	85-95%	90-95%	Organics		
Bicarbonate	85-90%	90-95%	Organics MW>300	>90%	>99%
Nitrate	40-50%	85-90%	Organics MW<300	0-90%	0-99%

CTA-Cellulosic Membrane
TFC-Thin Film Composite

All rejections nominal for 60 psi net pressure and at 77^{o}F

Membrane Comparisons

	Cellulosic	Thin Film Composite
Effect of Bacteria	Some bacteria will attack	Very bacteria resistant
pH Range	4.0 – 8.5	2.0 – 11.0
Chlorine Tolerance	Excellent Resistance	Poor Resistance 200 - 1000 ppm hrs.
% Rejection Nominal TDS dependence	92% Decreases as TDS Increases	95% Constant
Nitrate Rejection	0% - 65%	40% - 90%
Temperature Limit	87^{o}F (31^{o}C)	112^{o}F (45^{o}C)

Membrane Technology Comparison Chart

Feature	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Polymers	Ceramics, sintered metals, polypropylene, polysulfone, polyethersulfone, polyvinylidene fluoride, polytetrafluoroethy-liene	Ceramics, sintered metals, cellulosics, polysulfone, polyethersulfone, polyvinylidene fluoride	Thin film composites, cellulosics	Thin film composites, cellulosics
Pore Size Range (micrometers)	0.01 - 1.0	0.001 - 0.01	0.0001 - 0.001	<0.0001
Molecular Weight Cutoff Range (Daltons)	>100,000	2,000 - 100,000	300 - 1,000	100 - 200
Operating Pressure Range	<30	20 - 100	50 - 300	225 - 1,000
Suspended Solids Removal	Yes	Yes	Yes	Yes
Dissolved Organics Removal	None	Yes	Yes	Yes
Dissolved Inorganics Removal	None	None	20-85%	95-99%
Microorganism Removal	Protozoan cysts, algae, bacteria*	Protozoan cysts, algae, bacteria*	All*	All*
Osmotic Pressure Effects	None	Slight	Moderate	High
Concentration Capabilities	High	High	Moderate	Moderate
Permeate Purity	High	High	Moderate-high	High
Energy Usage	Low	Low	Low-moderate	Moderate
Membrane Stability	High	High	Moderate	Moderate

Membrane Devices

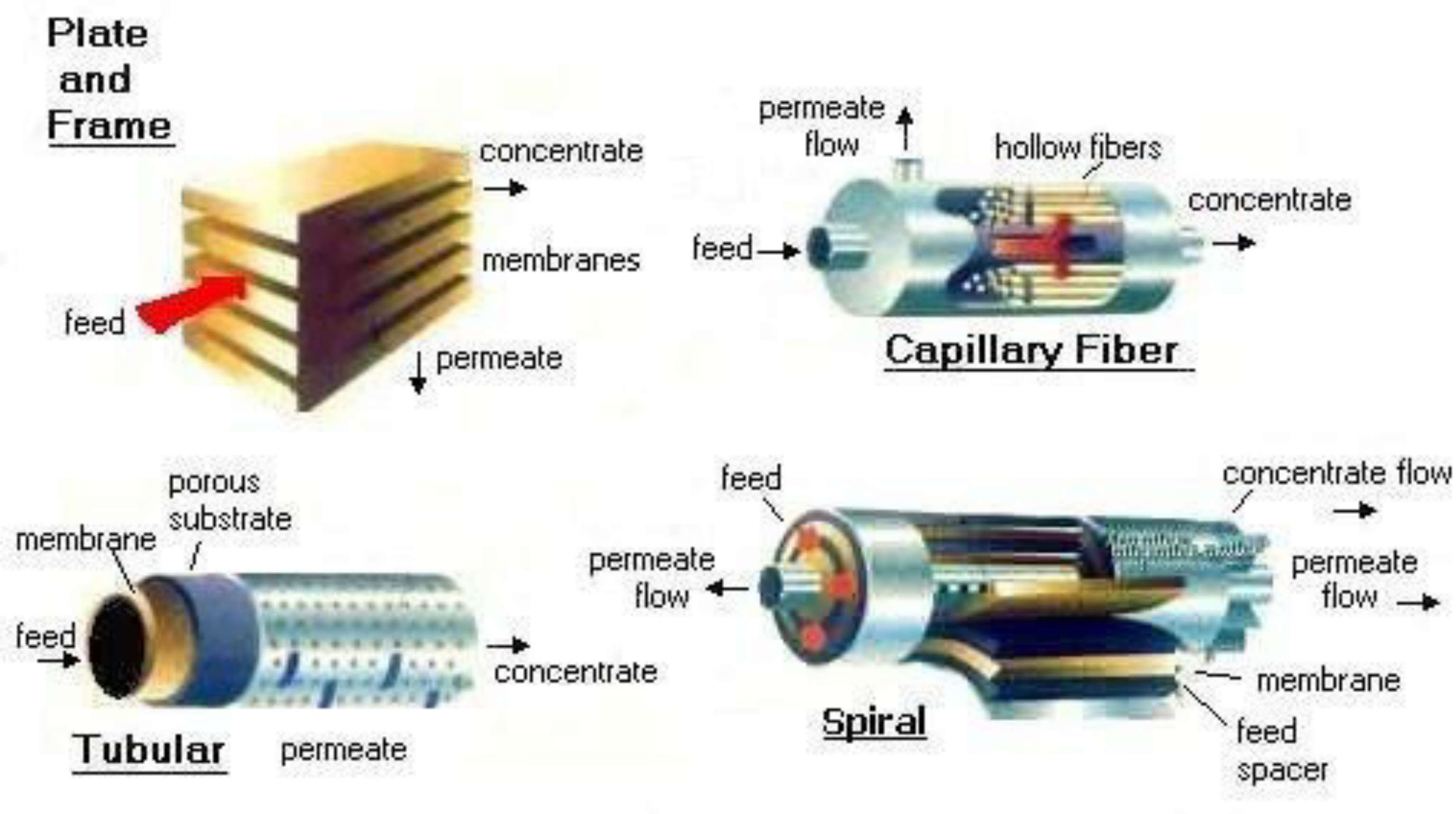
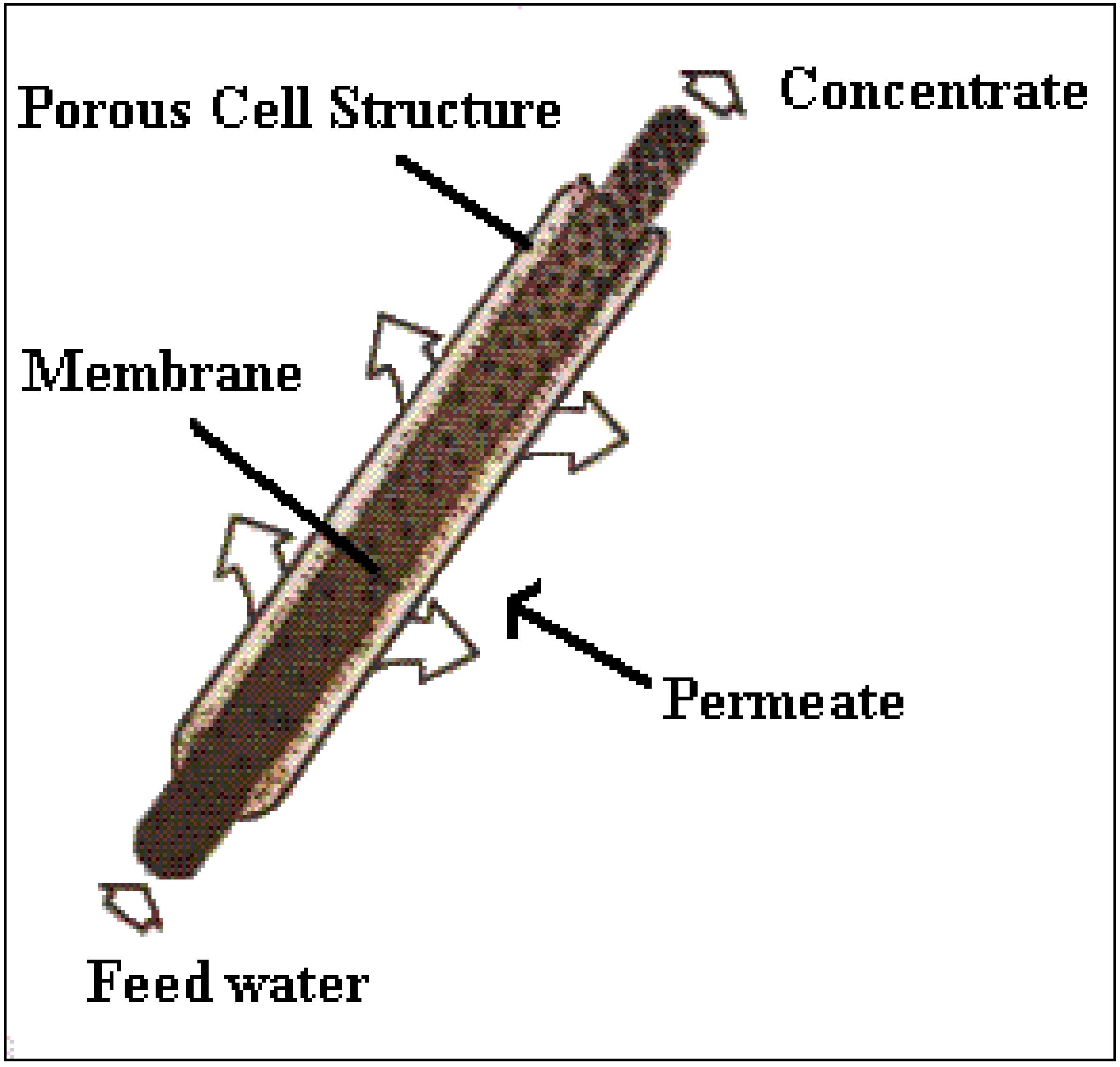


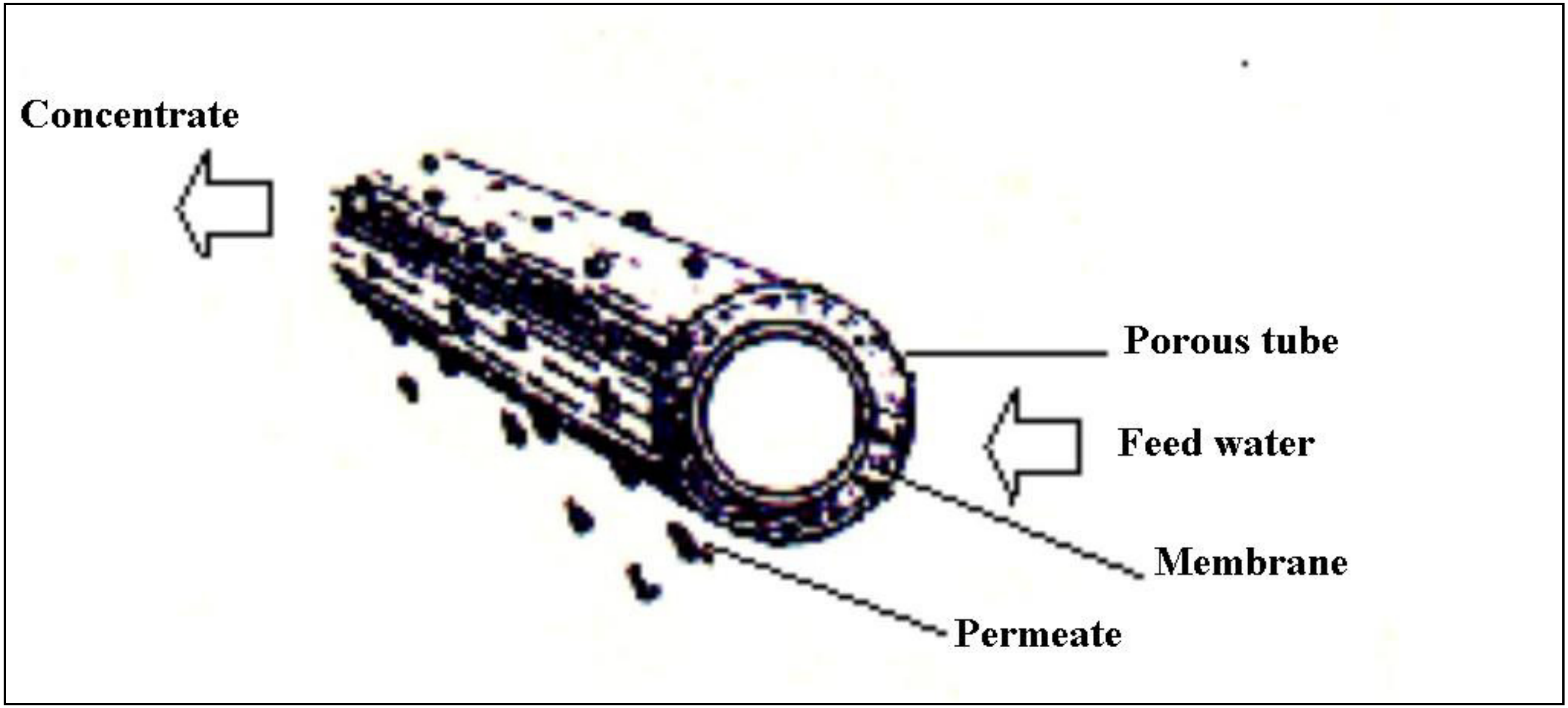
Plate & Frame

Capillary (Hollow) Fiber



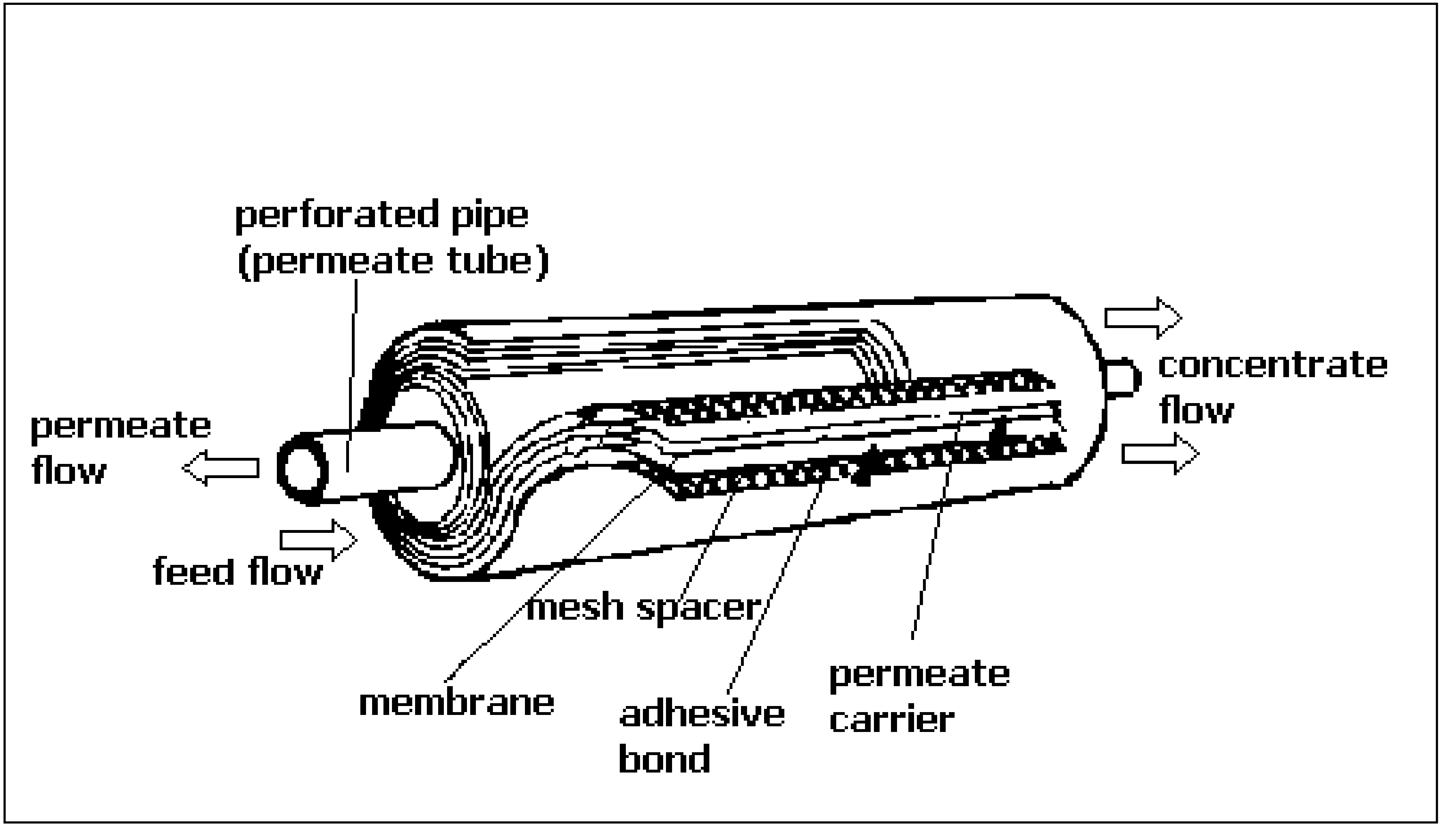
Hollow Fiber UF

Tubular



Tubular Membrane Elements

Spiral Wound



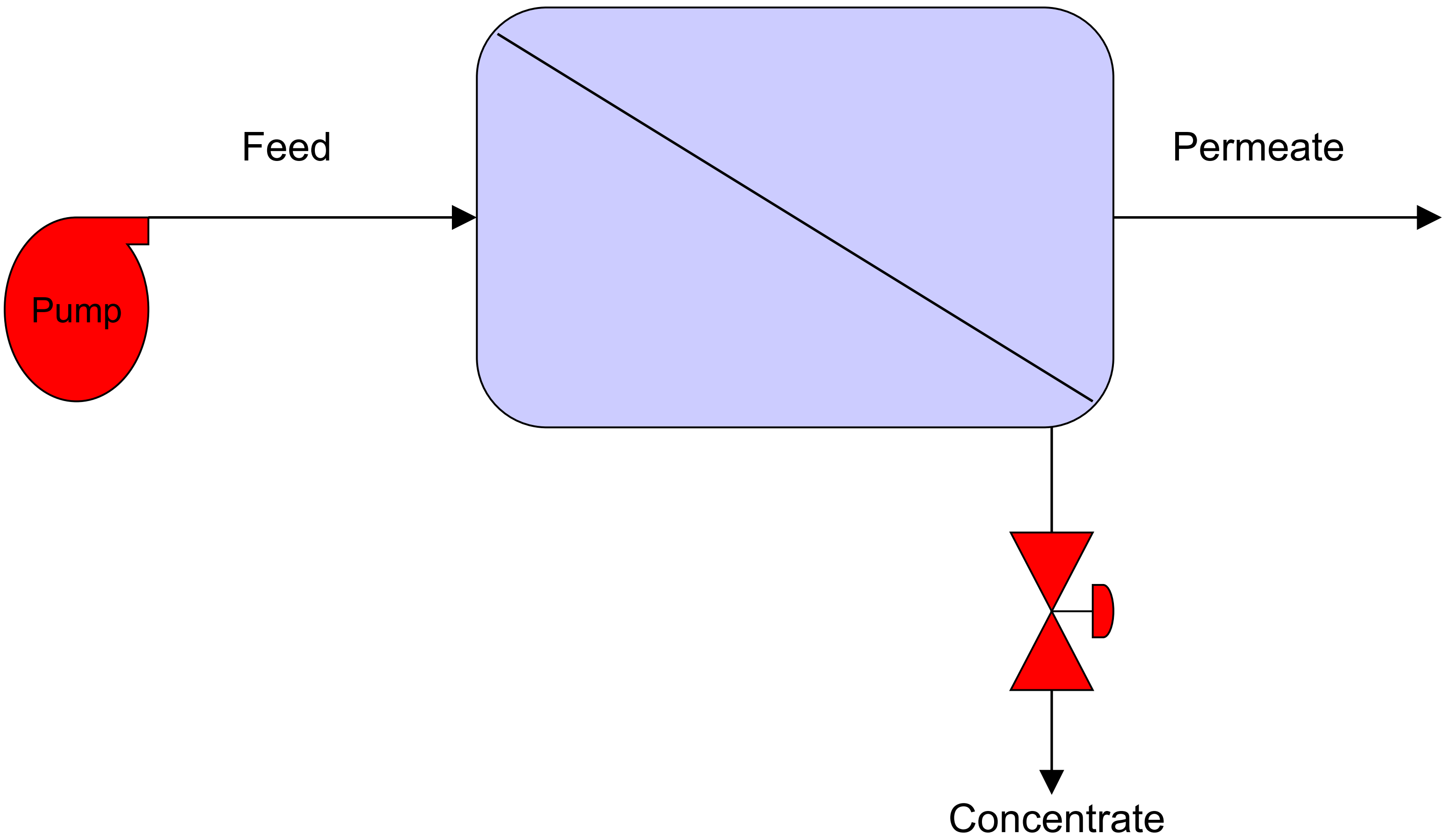
Membrane Element Configuration Comparison

Element Configura-tion	Packing Density *	Fouling Resistance **
Capillary Fiber	Medium	High
Plate and Frame	Low	High
Spiral Wound	Medium	Moderate
Tubular	Low	high

* Membrane area per unit volume of element

** Tolerance to suspended solids

Membrane Schematic



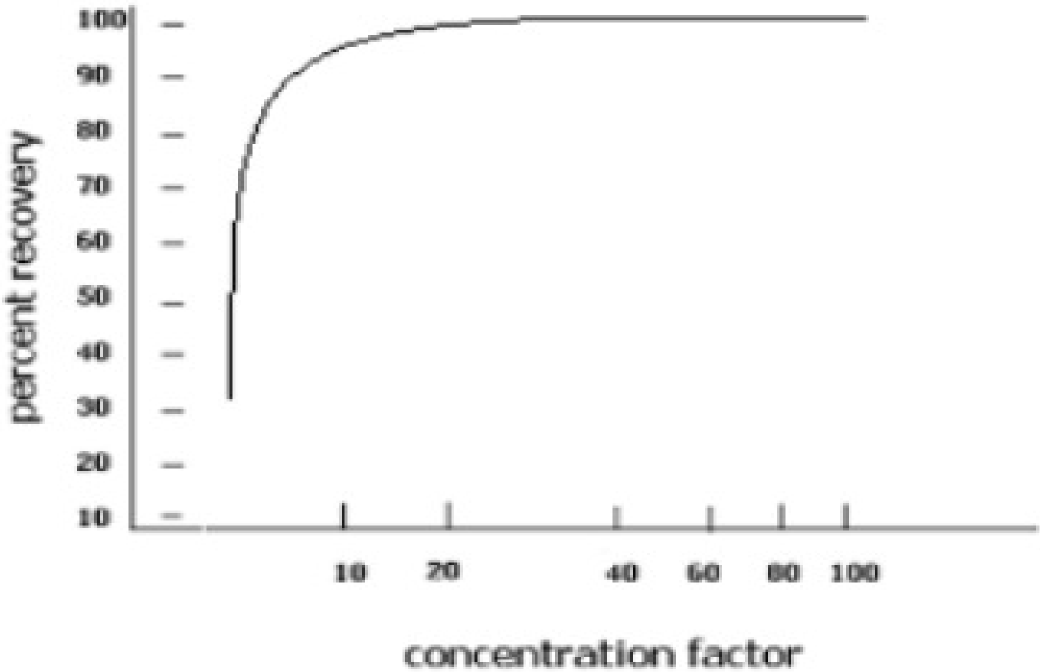
Concentration Effects

$$C_C \approx \frac{C_F}{1 - \text{Recovery}} = XC_F$$

$$X \equiv \textit{Concentration Factor}$$

Percent Recovery	X
33%	1.5
50%	2
67%	3
75%	4
80%	5
90%	10
95%	20
97.5%	40
98%	50
99%	100

Concentration Factor vs. Percent Recovery



POU RO Performance Equations

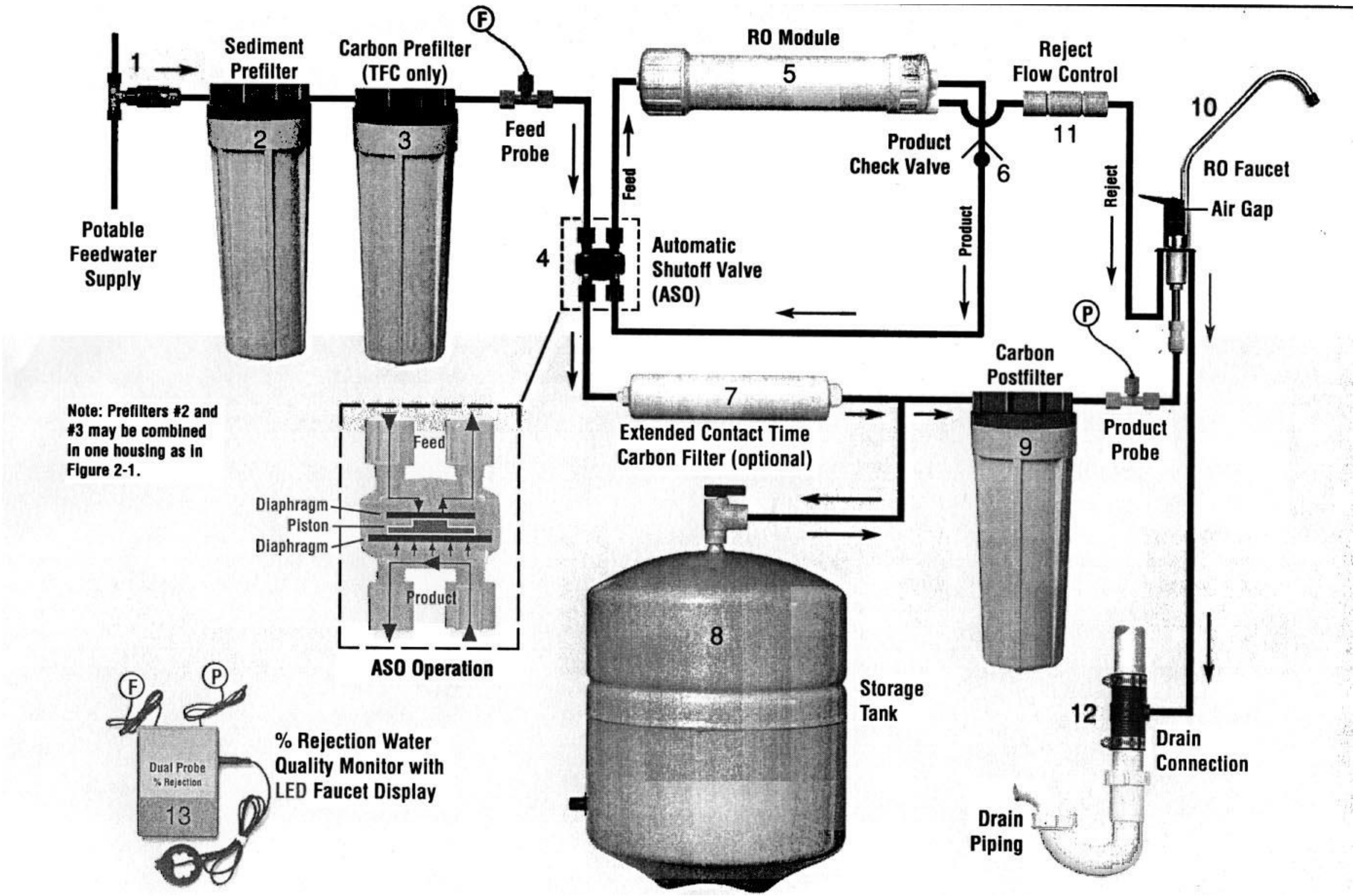
- Production Rate: The rate at which product water is made directly from the RO membrane. It is customarily expressed at Standard Operating Conditions (50-60 psi for POU at 77°F) by applying the appropriate conversion factors.
- Conversion Factor: ml/min x 0.38 = gal/day

Reverse Osmosis Recovery

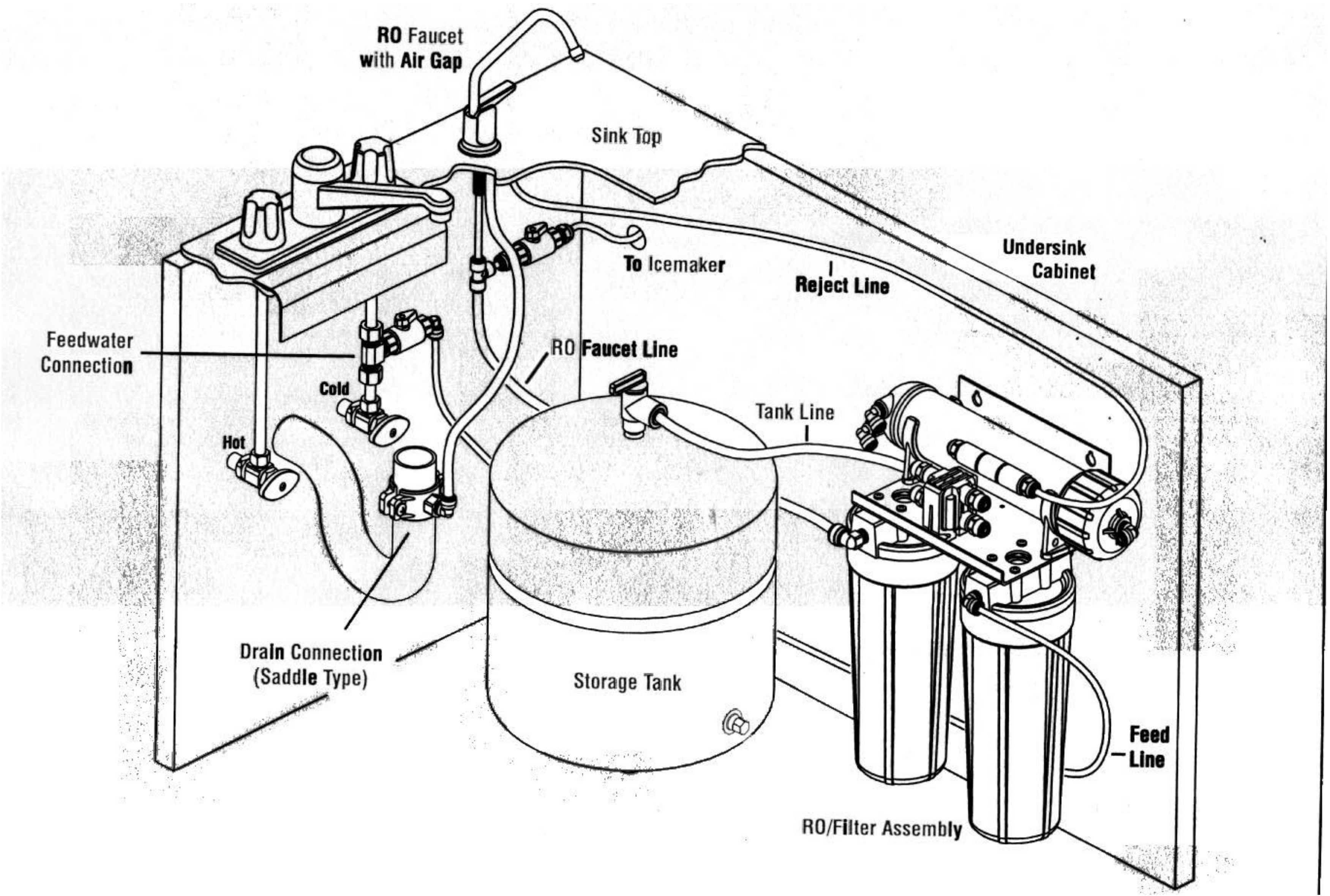
- Recovery: the percentage of feed water that passes through the membrane as product water. (i.e. how efficiently water is being used to make product water)

Reverse Osmosis Recovery

- Example: A membrane is making 10 gallons per day as product, while 40 gallons go to drain. What is the recovery?
- Feed Water = product + reject = 10 + 40 = 50
- Recovery = product/feed = 10/50 = <u>20%</u>
- Note: at 50% recovery, reject water TDS is double that of the feed water



Generic POU RO System Flow Diagram

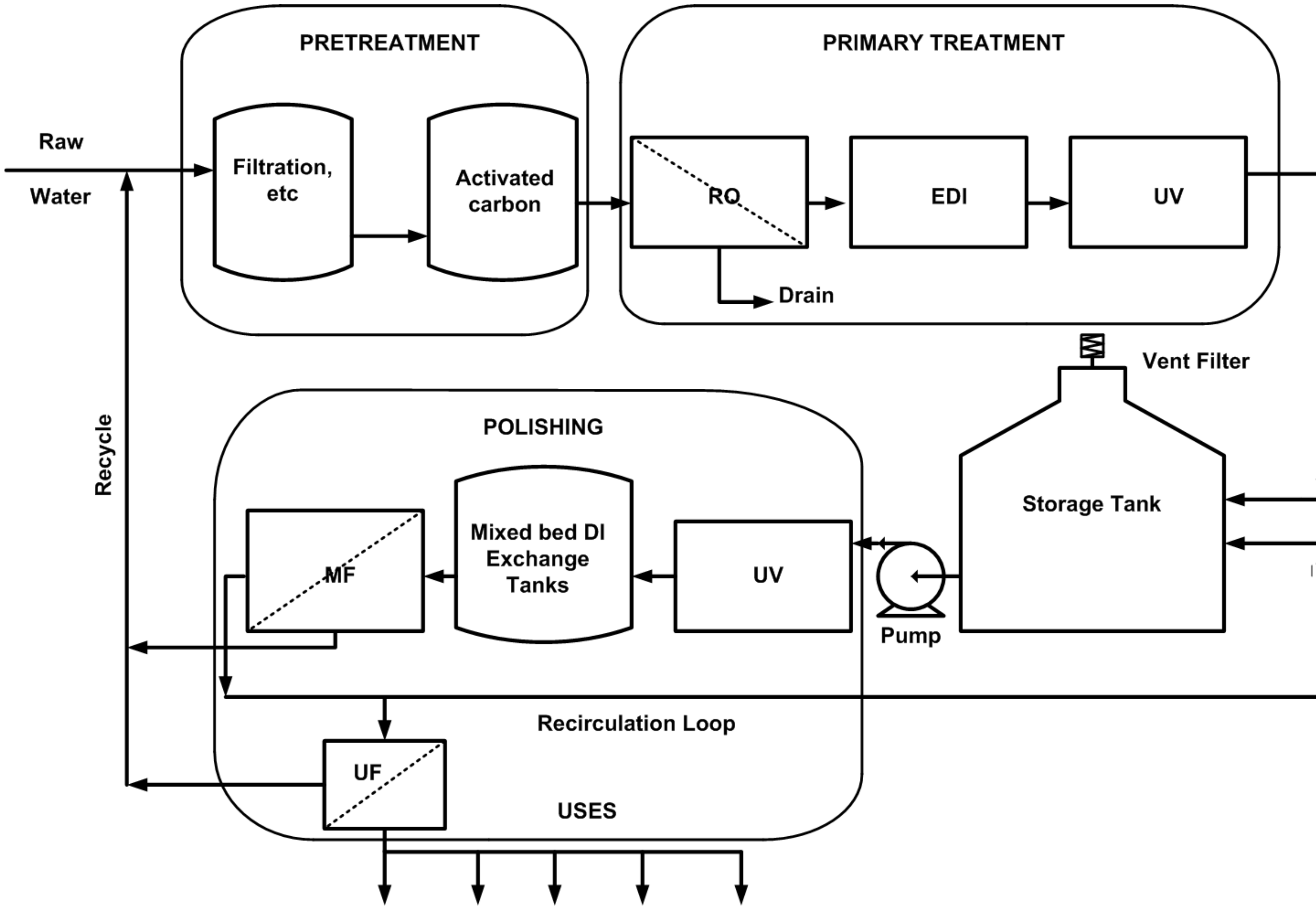


Generic Undersink RO Installation

RO System Controls

- Product Water Check Valve: Protects membrane from back pressure.
- Automatic Shut-off Valve: Maintains storage tank pressure between ½ to 2/3 feed line pressure.
- Brine Flow Restrictor: Maintain reject rinse flow at 3x to 5x product flow; Membrane life and water quality; Prevent water wasting.

Typical Pure Water System



Aerobic MBR Applications