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Membrane Treatment Technologies for Wastewater Treatment

by

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Distribution of World Water Supply
(cubic miles)

	FRESH	SALINE	TOTAL
Rivers and streams	300		
Freshwater lakes	30,000		
Salt lakes and inland seas		25,000	
Total surface water	**30,300**	**25,000**	**55,300**
Soil moisture and seepage	16,000		
Underground water to ½ mile depth	1,000,000		
Underground water to below ½ mile	1,000,000		
Total ground water	**2,016,000**		**2,016,000**
Glaciers and ice caps	7,000,000		
Oceans		317,000,000	
Total world water supply	**9,046,300**	**317,000,000**	**326,071,300**

U.S. Water Usage

- 39%   Energy Production
- 40%   Agriculture
- 11%   Industry
- 10%   Everything Else

Usage Requirements

- Food for each person = 800 gpd
- 1 bottle of beer = 470 gallons
- 1 gallon of gasoline = 7-10 gallons
- 1 gallon of ethanol = 5-7 gallons
- 1 watermelon = 100 gallons

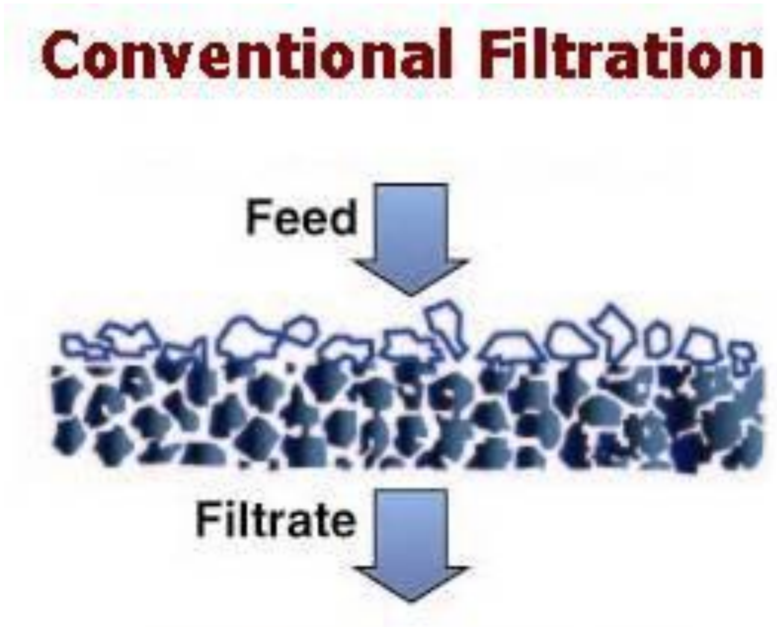
Water Contaminants

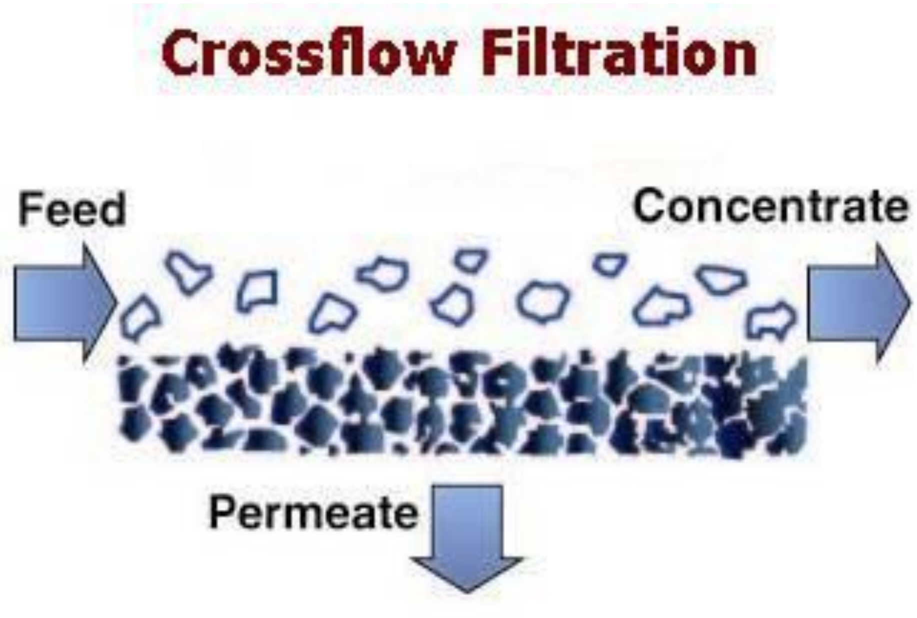
Class	Examples
Suspended solids	Dirt, clay, colloidal materials, silt, dust, insoluble metal oxides and hydroxides
Dissolved organics	Trihalomethanes, synthetic organic chemicals, humic acids, fulvic acids
Dissolved ionics (salts)	Heavy metals, silica, arsenic, nitrate, chlorides, carbonates
Microorganisms	Bacteria, viruses, protozoan cysts, fungi, algae, molds, yeast cells
Gases	Hydrogen sulfide, methane, radon, carbon dioxide

Membrane Technologies

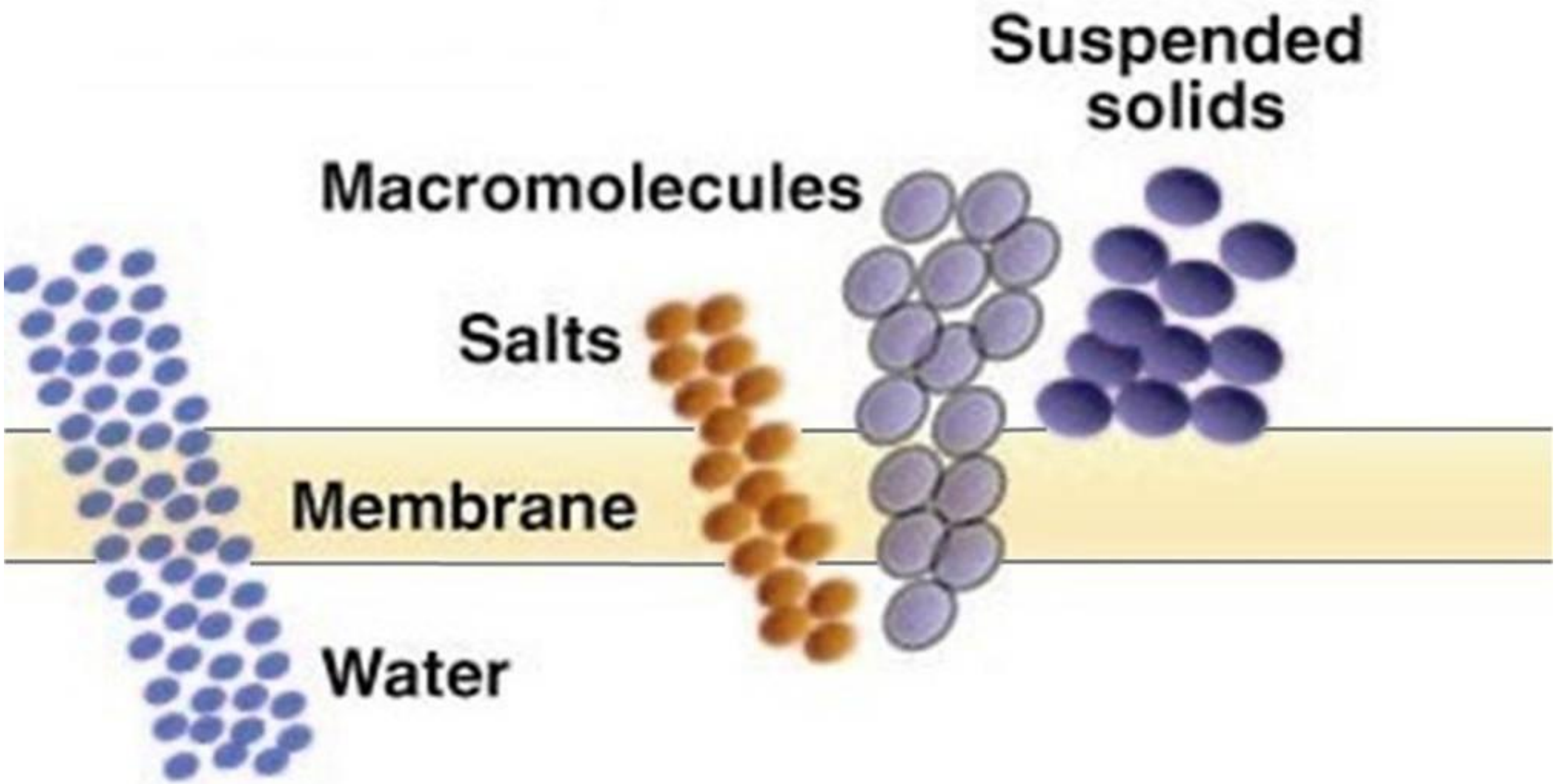
- Continuous process, resulting in automatic and uninterrupted operation.
- Low energy utilization involving neither phase nor temperature changes.
- Modular design – no significant size limitations.
- Minimal moving parts with low maintenance requirements.
- No effect on form or chemistry of contaminants.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

Conventional vs. Crossflow Filtration

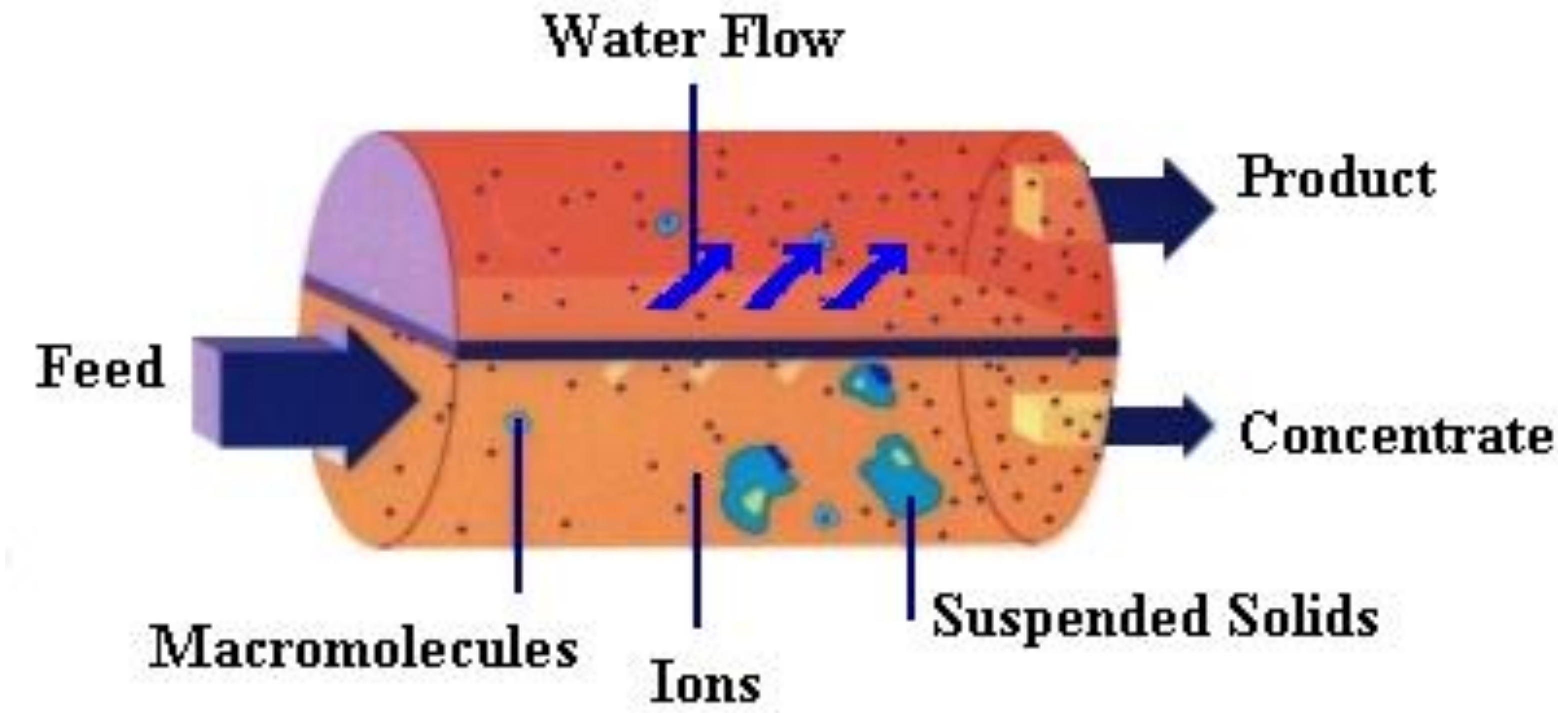




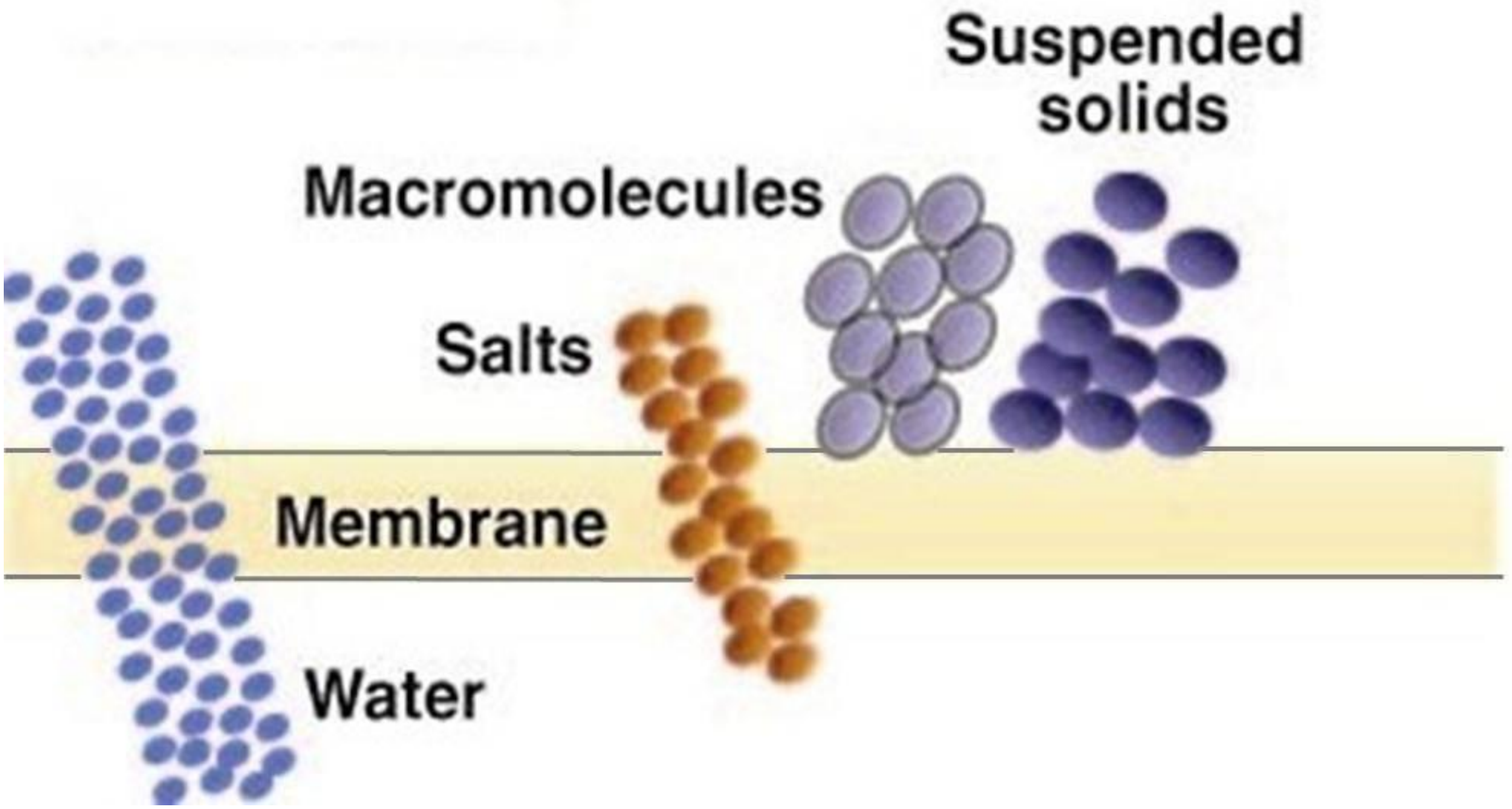
Microfiltration



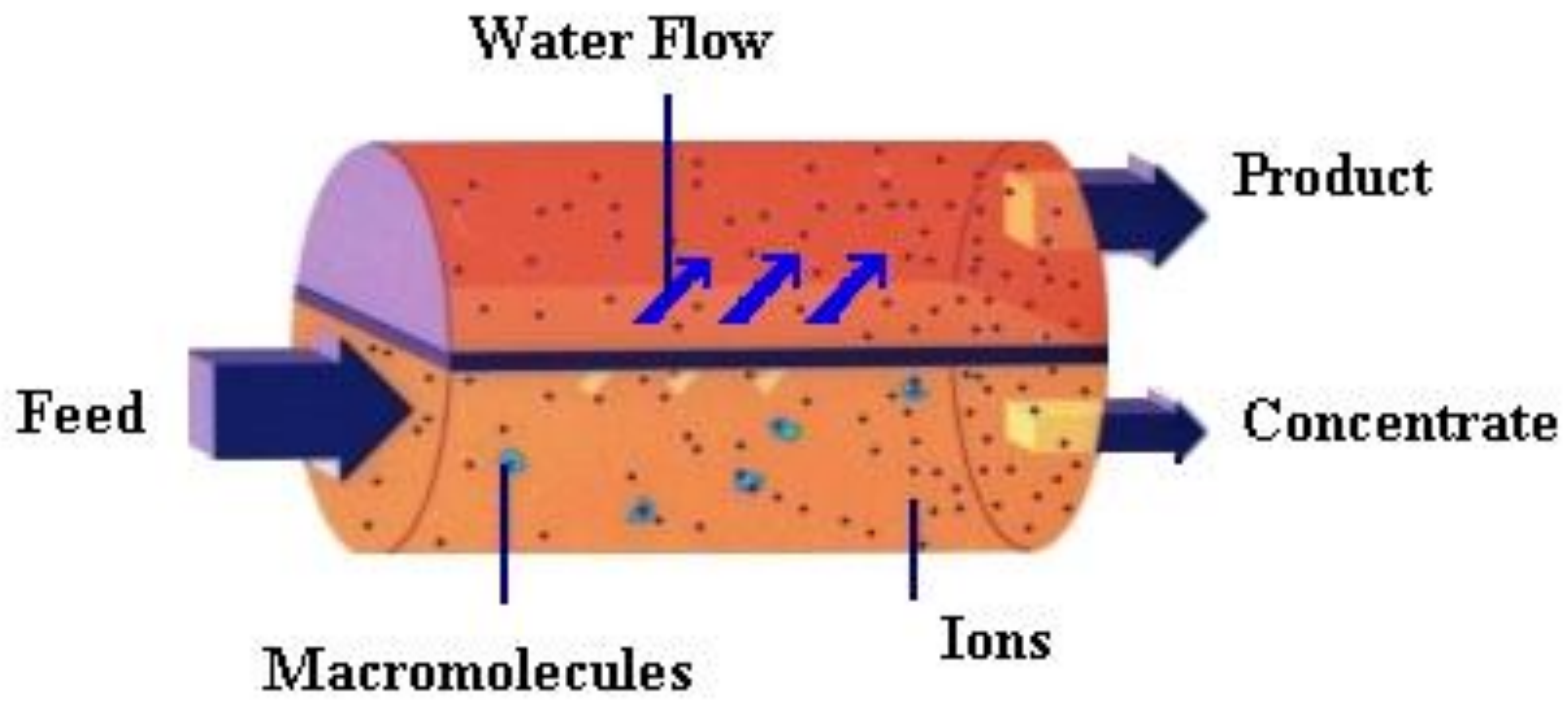
Microfiltration



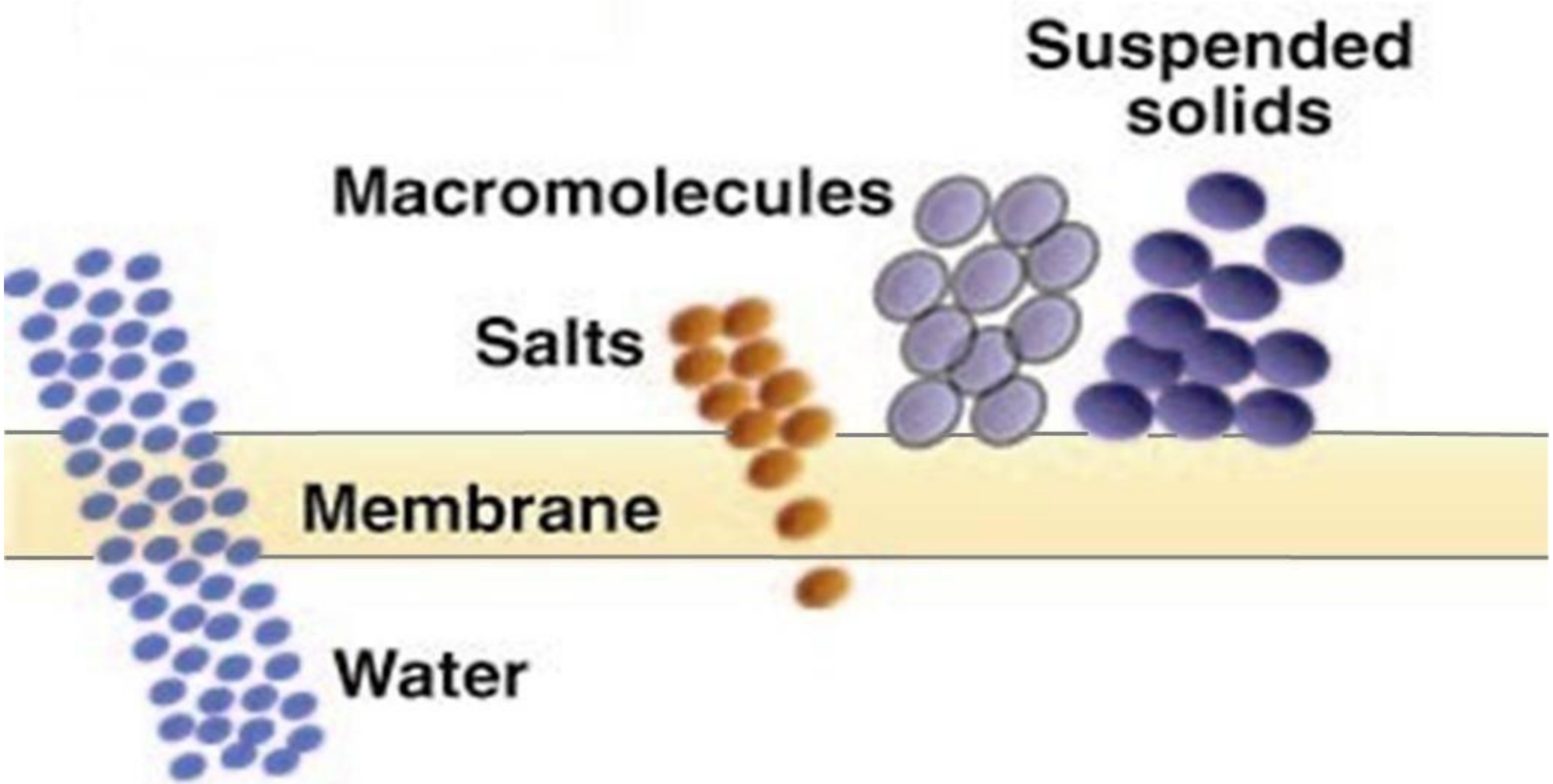
Ultrafiltration



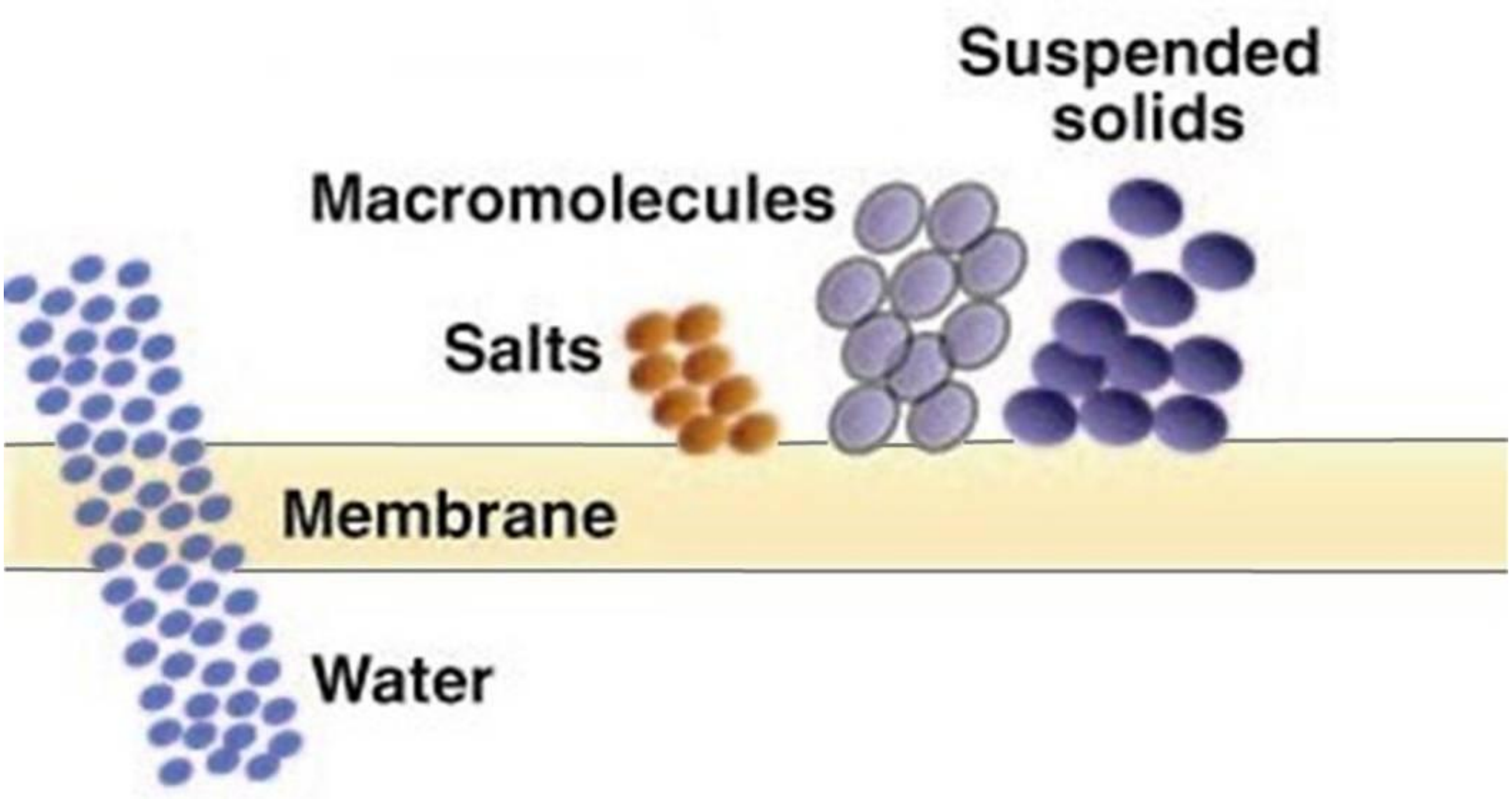
Ultrafiltration



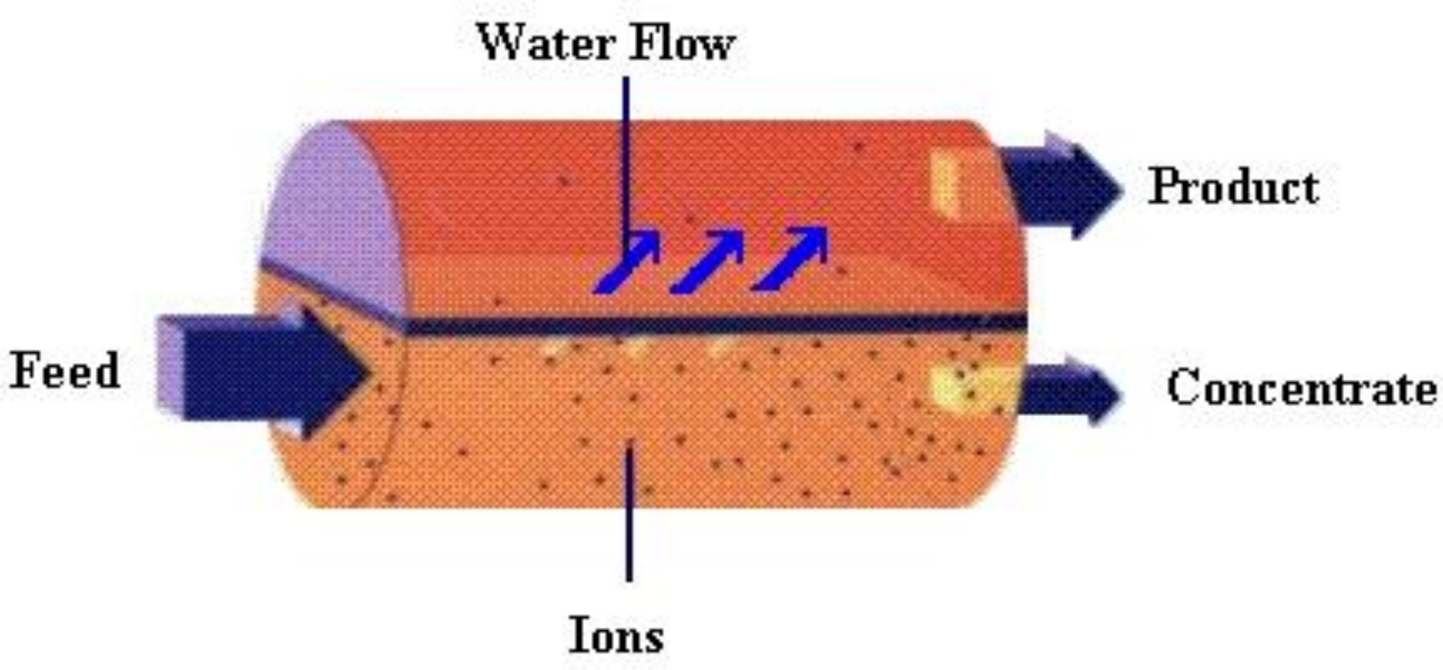
Nanofiltration



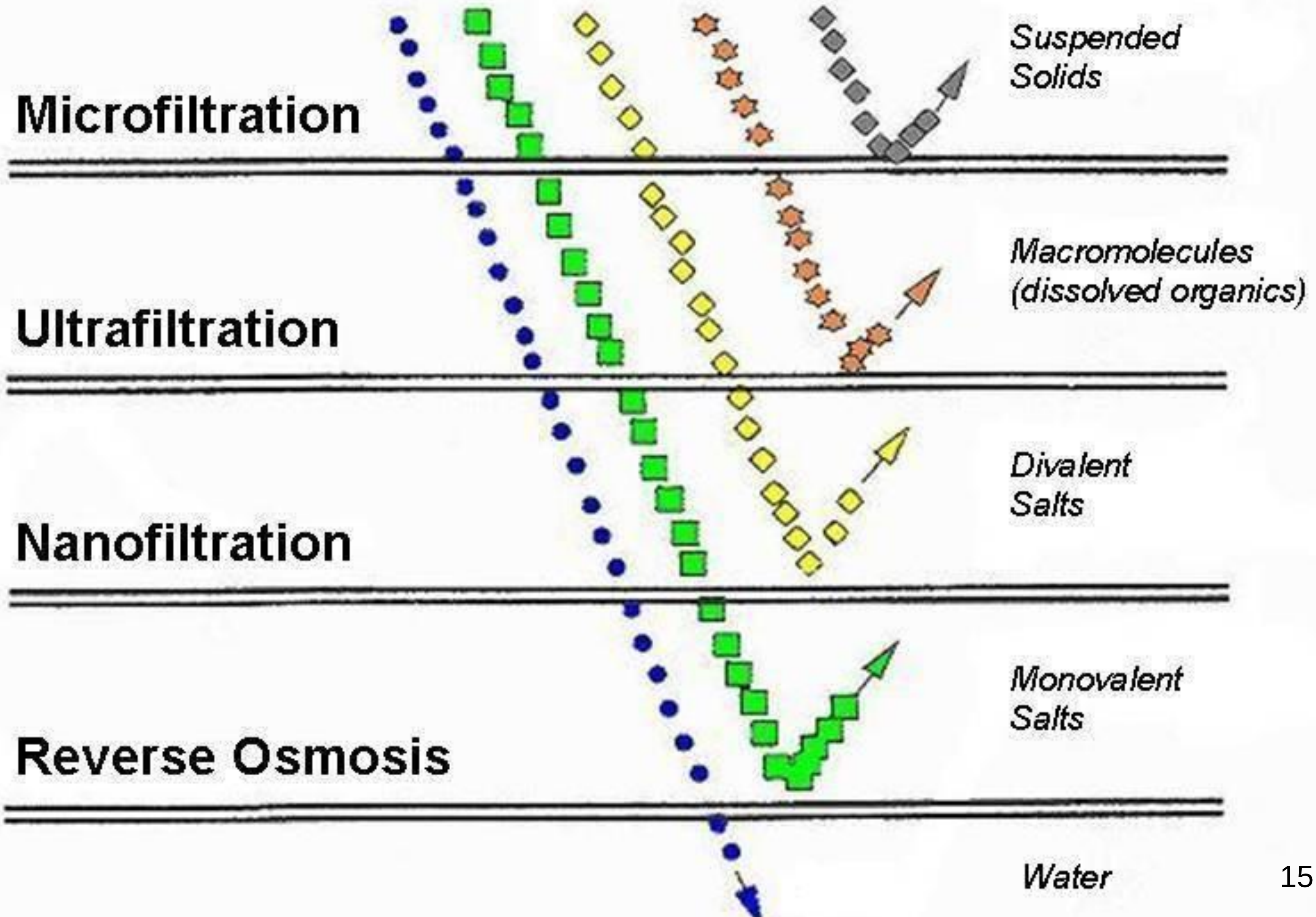
Reverse Osmosis



Reverse Osmosis



Membrane Technologies

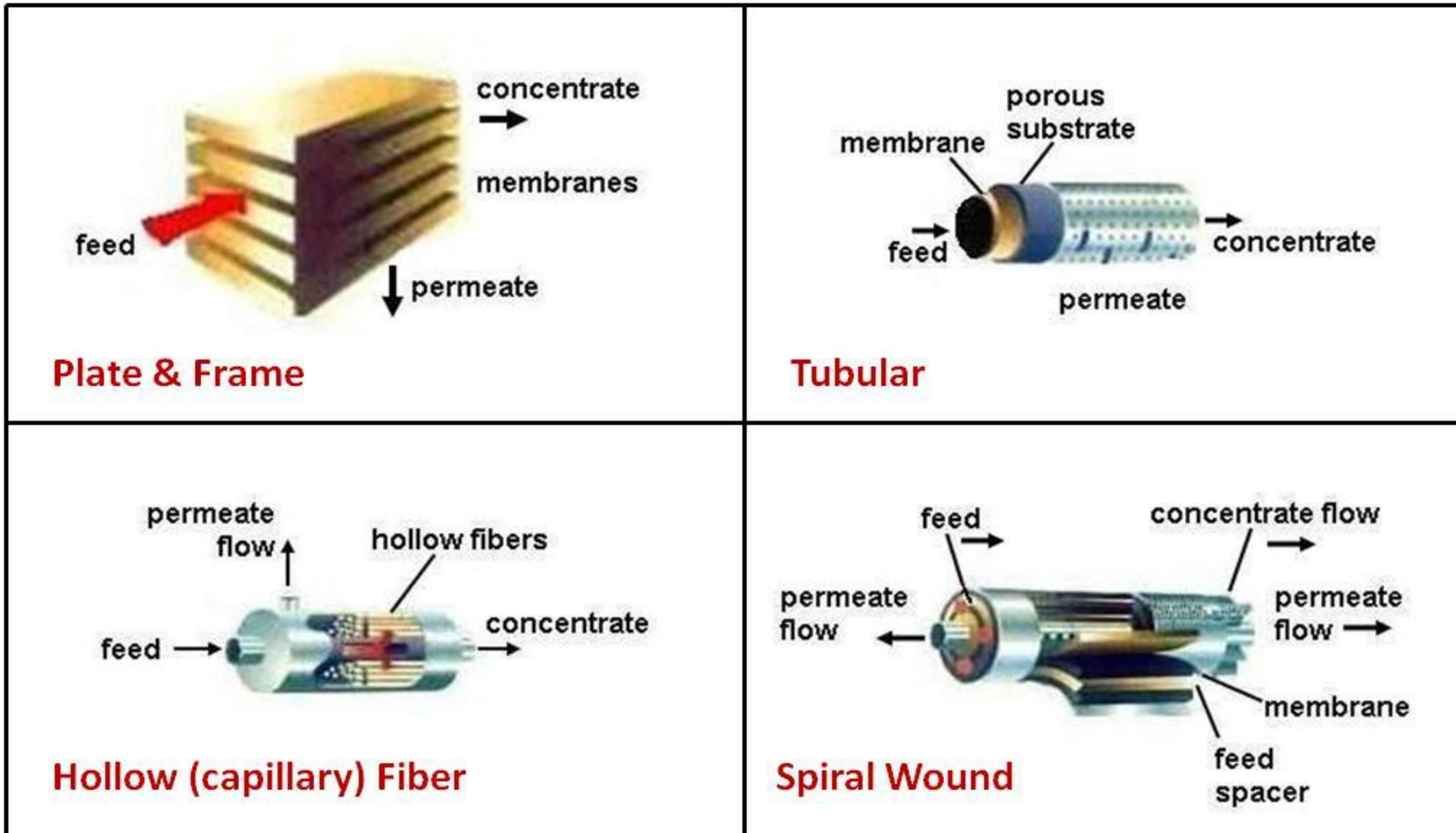


Membrane Technologies Compared

Feature	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Polymers	Ceramics, Sintered metals, Polypropylene, Polysulfone, Polyethersulfone, Polyvinylidene fluoride, Polytetrafluoroethyliene	Ceramics, Sintered metals, Polypropylene, Polysulfone, Polyethersulfone, Polyvinylidene fluoride	Thin film composites, Cellulosics	Thin film composites, Cellulosics
Pore Size Range (microns)	0.1 - 1.0	0.001 - 0.1	0.0001 - 0.001	<0.0001
Molecular Weight Cutoff Range (Daltons)	>100,000	1,000 - 100,000	300 - 1,000	50 - 300
Operating Pressure Range (psi)	<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	20-95%	95-99+%
Microorganism Removal	Protozoan cysts, algae, bacteria*	Protozoan cysts, algae, bacteria*, viruses	All*	All*
Osmotic Pressure Effects	None	Slight	Moderate	High
Concentration Capabilities	High	High	Moderate	Moderate
Permeate Purity (overall)	Low	Moderate	Moderate-high	High
Energy Usage	Low	Low	Low-moderate	Moderate
Membrane Stability	High	High	Moderate	Moderate

** Under certain conditions, bacteria may grow through the membrane.*

Membrane Element Devices

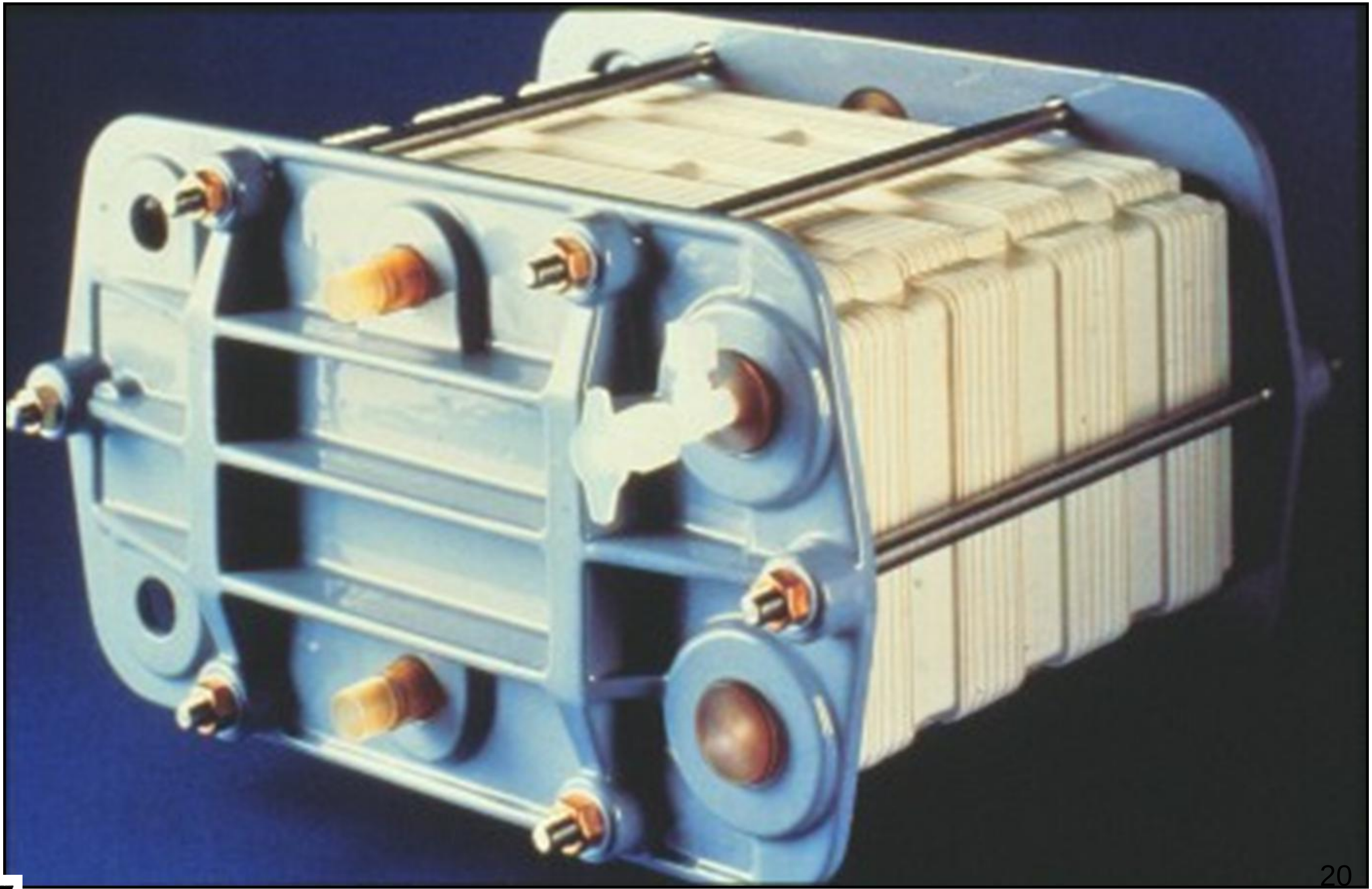


Membrane Element Devices

- **Plate and Frame**
- Tubular
- Hollow (Capillary) Fiber
- Spiral Wound

Plate and Frame

Plate and Frame



Membrane Element Devices

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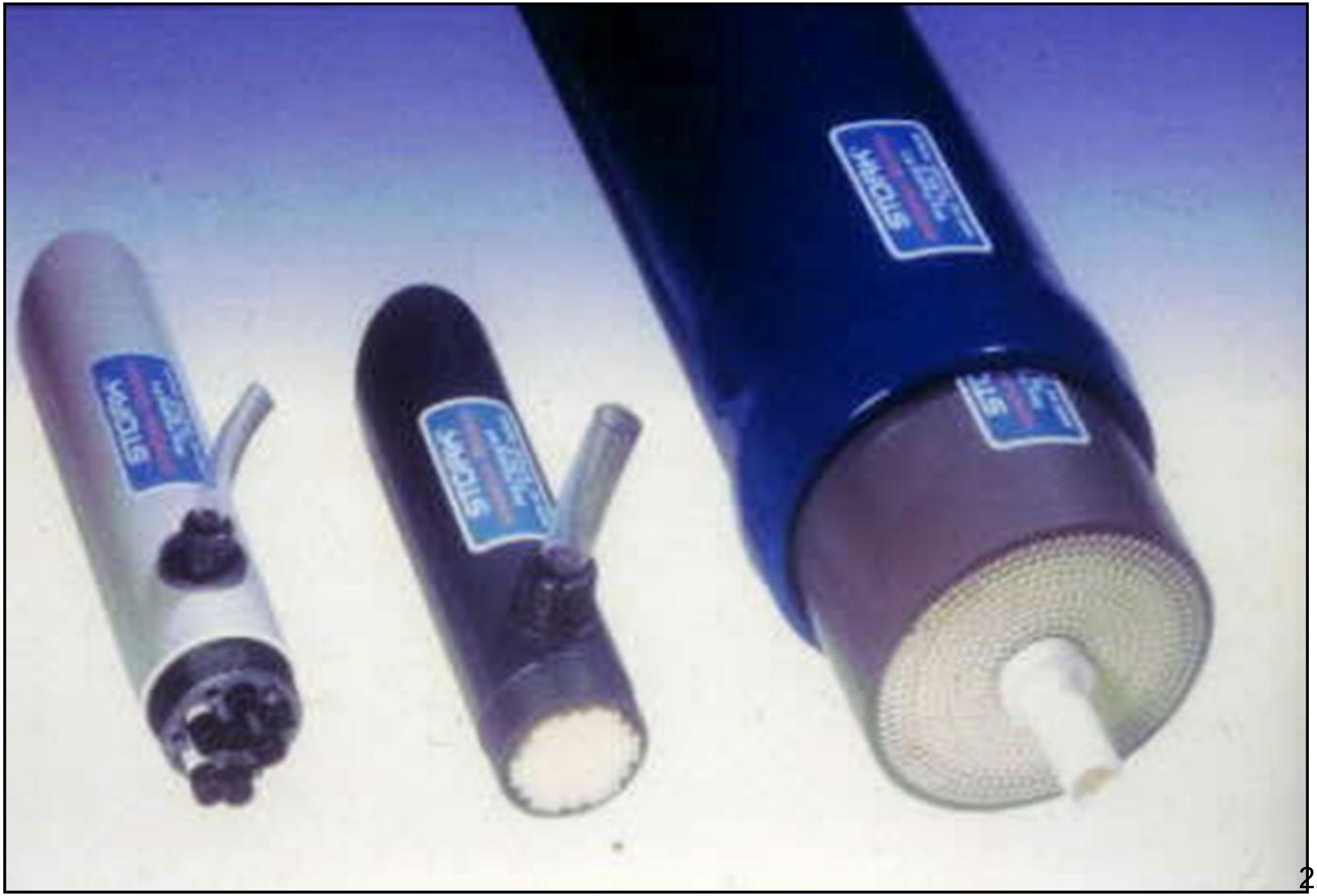
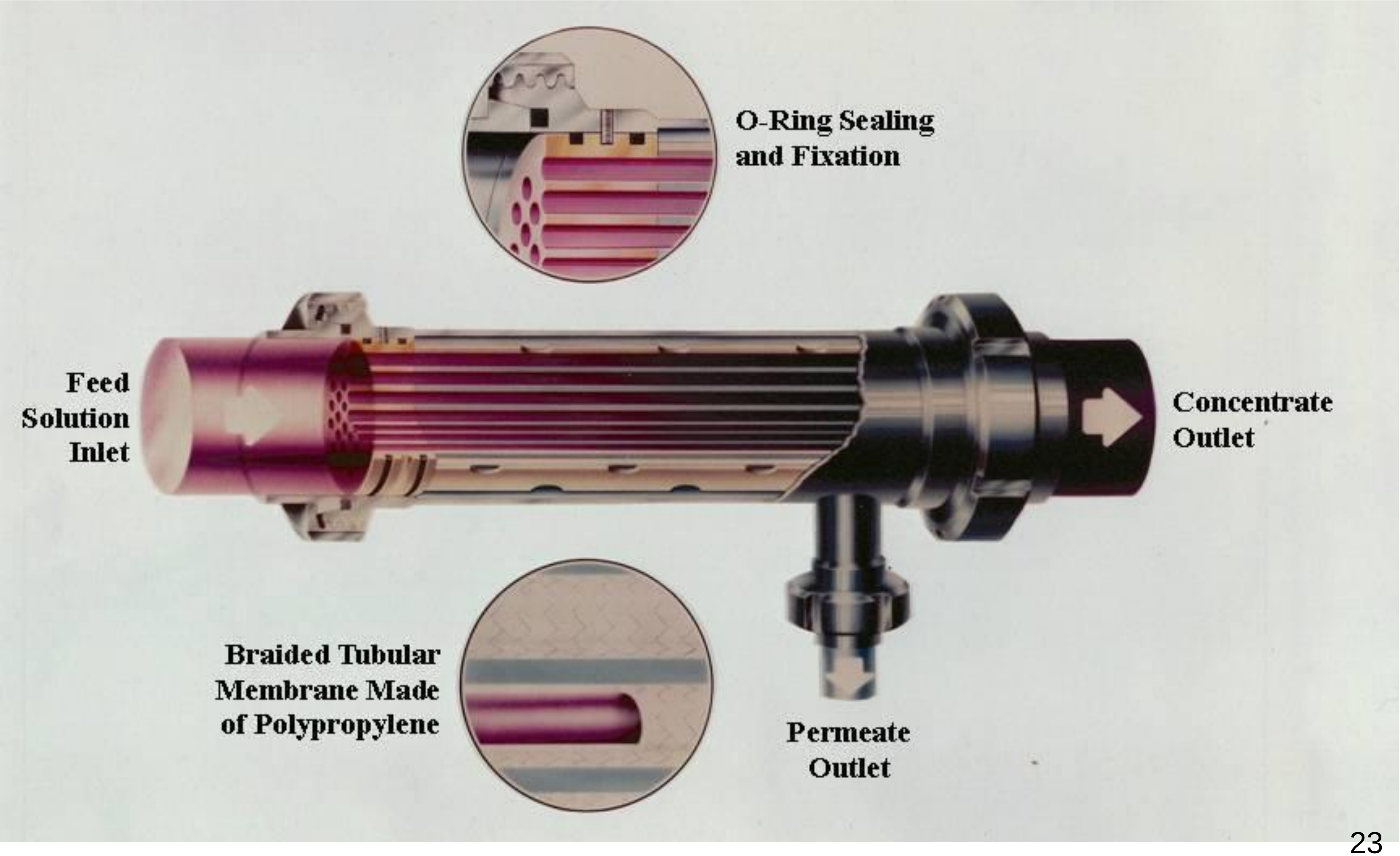
Tubular



Tubular



O-Ring Sealing
and Fixation
Feed
Solution
Inlet
Concentrate
Outlet
Braided Tubular
Membrane Made
of Polypropylene
Permeate
Outlet

Membrane Element Devices

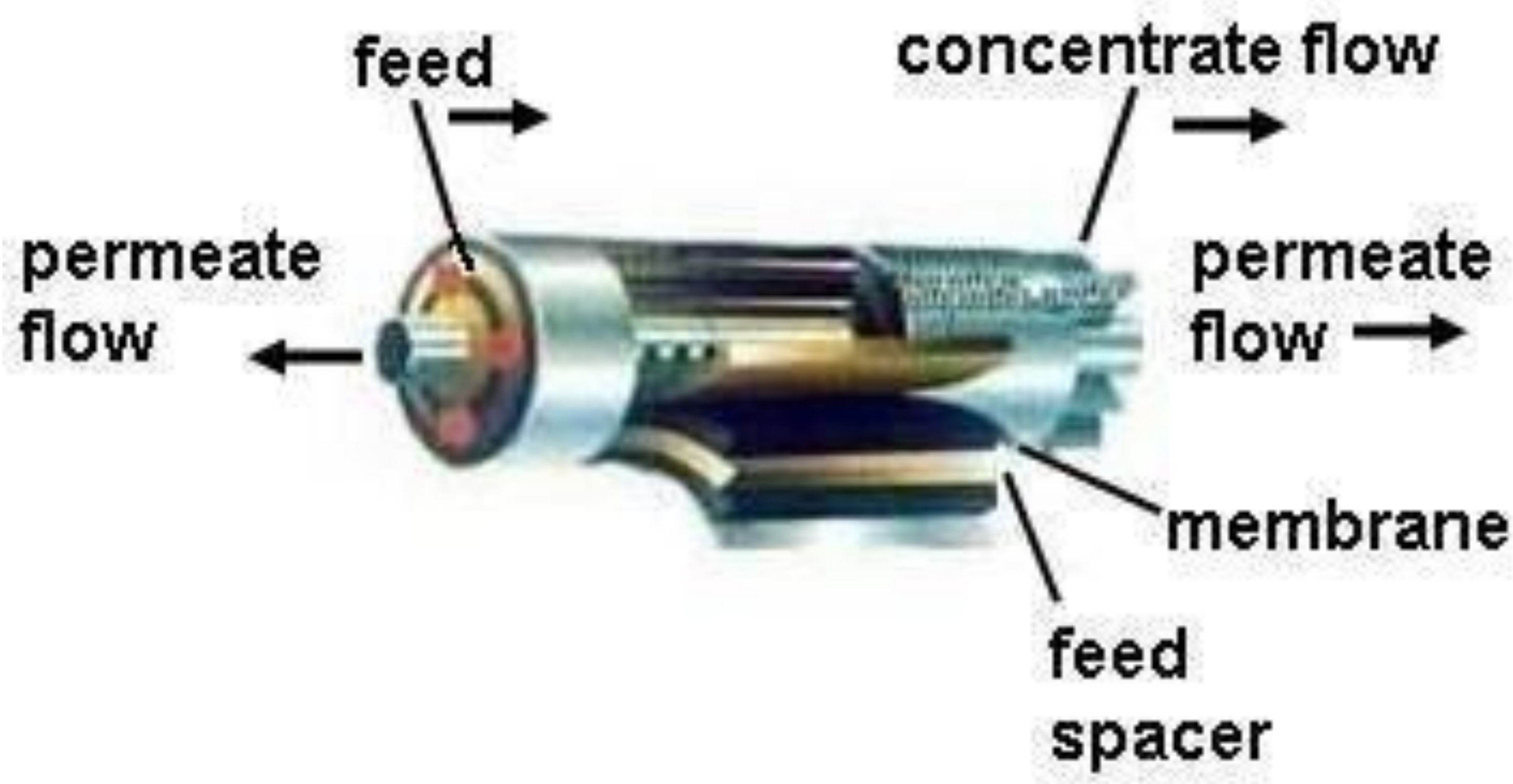
- Plate and Frame
- Tubular
- **Hollow (Capillary) Fiber**
- Spiral Wound

Hollow (Capillary) Fiber

Membrane Element Devices

- Plate and Frame
- Tubular
- Hollow (Capillary) Fiber
- **Spiral Wound**

Spiral Wound



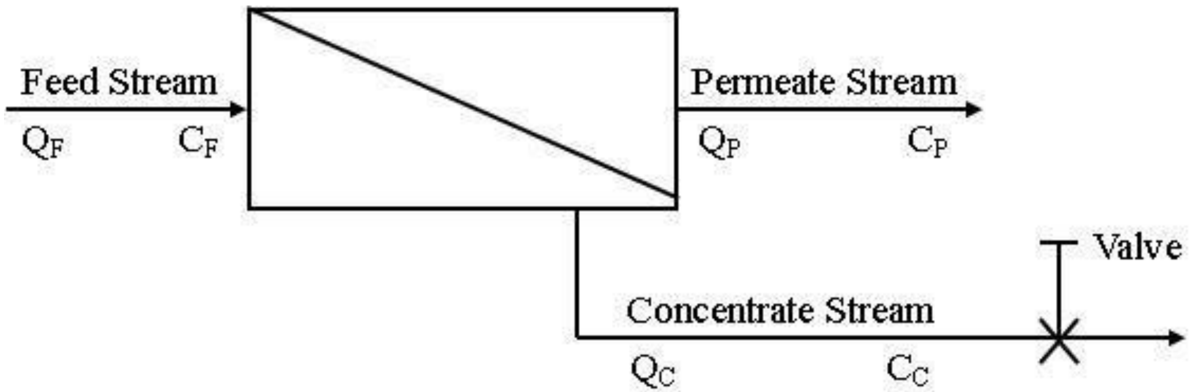
Membrane Element Configuration Comparison

Element Configuration	Packing Density *	Fouling Resistance **
Plate & Frame	Low	High
Tubular	Low	High
Hollow (Capillary) Fiber	Medium	Moderate
Spiral Wound	Medium	Low

** Membrane area per unit volume of element*

*** Tolerance to suspended solids*

Membrane System Schematic



Q_F - Feed Flow Rate
C_F - Solute Concentration in Feed
Q_P - Permeate Flow Rate
C_P - Solute Concentration in Permeate
Q_C - Concentrate Flow Rate
C_C - Solute Concentration in Concentrate

$$\text{Recovery} = \frac{Q_P}{Q_F}$$

(Expressed as Percent)

TDS = Total Dissolved Solids: Usually considered the total of the ionic contaminants (salts) in solution.

mg/L (milligrams per liter) is the same as ppm (parts per million)

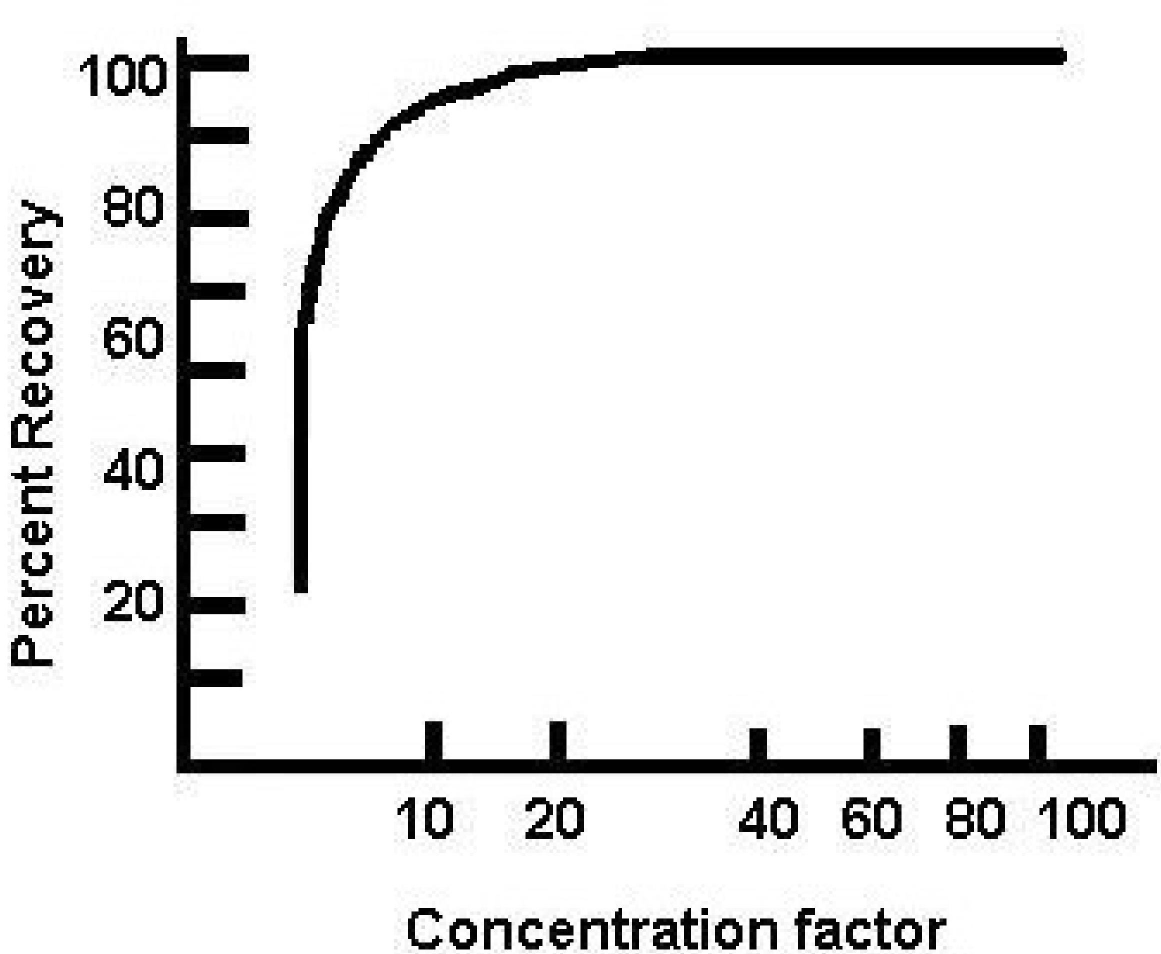
Effect of Recovery on Concentration

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

$$X = \frac{1}{1 - \text{Recovery}} = \text{Concentration Factor}$$

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

Effect of Recovery on Concentration Factor



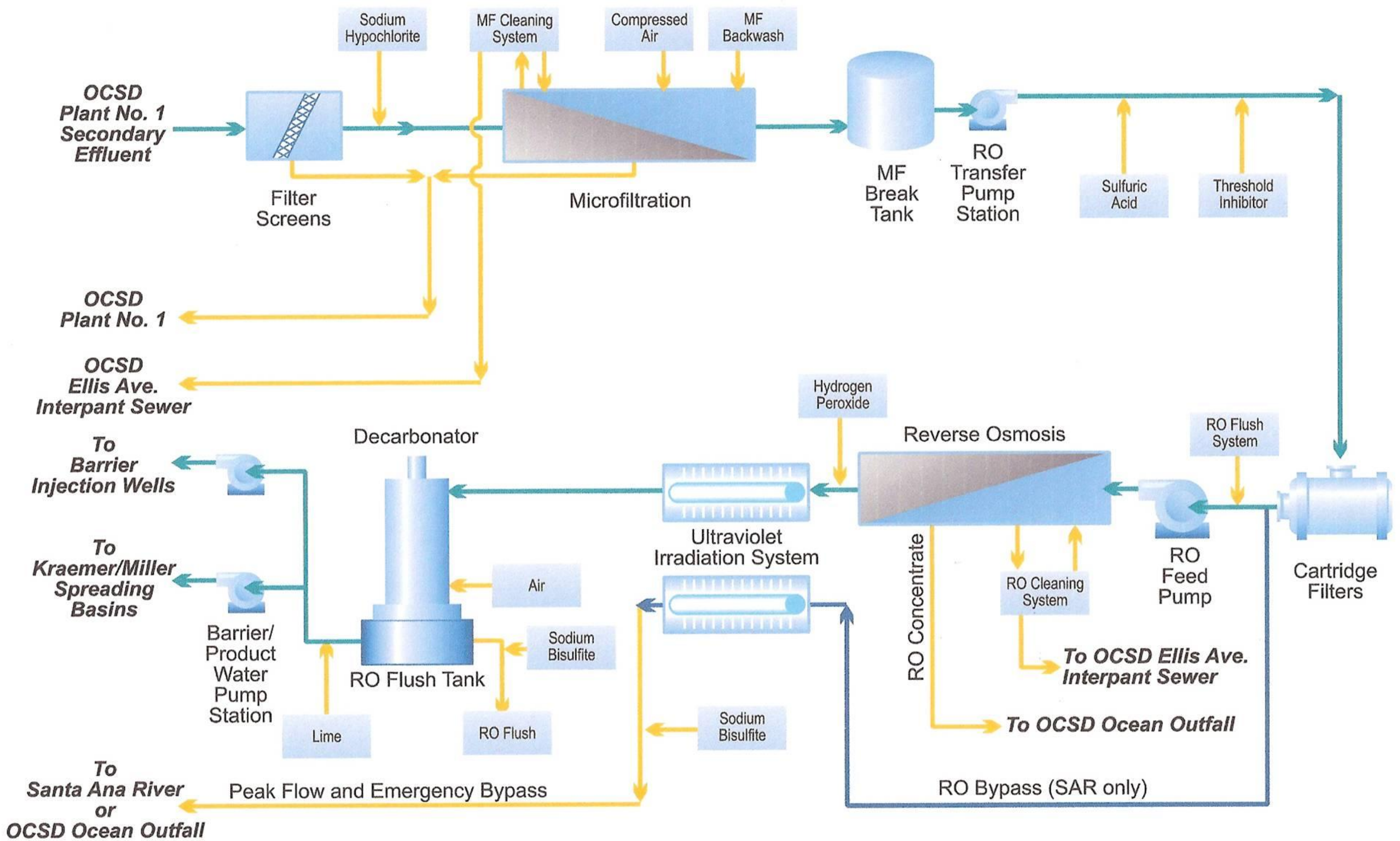
System Performance

- Higher concentration of contaminants can result in precipitation and greater propensity for fouling.
- In nanofiltration and reverse osmosis applications, the concentrated salts will result in higher osmotic pressure, requiring a higher pressure pump and a more pressure resistant system.
- Also with RO and NF, as recovery is increased, the ionic purity of the permeate decreases.
- As higher recoveries reduce the quantity of concentrate to be discharged, the higher concentration of this concentrate stream can itself present discharge problems.

CHEMICAL REQUIREMENTS

1) Addition of specific dispersants/anti-scalants minimize precipitation of slightly soluble salts for RO treatment.
2) Pretreatment may require surfactants and/or emulsifying agents.
3) Cleaning chemicals range from acids and bases to enzymatic chemicals and depend on the nature of the membrane foulant.
4) Disinfectants include chlorine compounds, ozone, hydrogen peroxide and peroxyacetic acid.

GWR System Schematic



Conclusions

WATER – CRITICAL TO LIFE

Conservation, Collection & Conversion

are practical, economical and essential

Water Recovery & Reuse

is an achievable goal

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