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William A. McEllhiney Distinguished Lecture Series in Water Well Technology

National Ground Water Research and Educational Foundation's McEllhiney Lecture Series is supported by a grant from Franklin Electric.

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To foster professional excellence in water well technology, the National Ground Water Research and Educational Foundation, has established the William A. McEllhiney Distinguished Lecture Series in Water Well Technology.

Initiated in 2000, the lecture series honors William A. McEllhiney, who was the founding president of the National Ground Water Association in 1948, and a groundwater contractor and civil engineer from Brookfield, Illinois.

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"McEllhiney and the other founders of the Association saw several primary functions for the new national group," explains Foundation Chief Executive Officer Kevin McCray, "including serving as a clearinghouse for information and its dissemination, serving as an intermediary in coordinating advances occurring in different parts of the country, and serving as a place to bring contractors together so that they might have a working knowledge of contracting from all parts of the nation. NGWREF's McEllhiney Lecture series promotes and perpetuates those original aims."

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Starting in May 2005, Franklin Electric Co., the world's largest manufacturer of submersible electric motors and a leading manufacturer of pumping systems, agreed to underwrite this lecture series for a number of years.

Meetings and conventions of state and regional associations are eligible. Foreign associations of groundwater contractors, academic institutions teaching water well technology, gatherings of water well regulators, and other bodies with a direct and identifiable interest in water well design and construction are eligible as well, to host the lecture series.

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Peter S. Cartwright, PE

Groundwater Contaminants and Treatment Options

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INTRODUCTION

Groundwater Supply

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Total Global Groundwater Volume = 23×10^6 cubic kilometers (6×10^{18} gallons)

Of that, 0.35 x 106 cubic kilometers (9×10^{10} gallons) is < 50 years old (1½%)

Science Daily, 16 Nov, 2015

Domestic Well Water

- Supplies 15% of the U.S. population
- Not covered by U.S. EPA Safe Drinking Water Regulations

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WATER RIGHTS

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THINK SAFETY!!!

WHEN YOU ARE LOWERING TOOLS INTO THE HOLE, USE REDUNDANT TETHERING (A.K.A. THE BUDDY SYSTEM)

UTAH DNR WATER RIGHTS


UTAH
DNR
WATER RIGHTS

SUPPLEMENTARY PIPE SPECS

- All pipe is to be made of long hole surrounded by metal centered around the hole.
- All pipe is to be hollow throughout the entire length.
- All pipe is to be of the very best quality, perfectly tubular or popular.
- All acid proof pipe is to be made of acid proof metal.
- The O.D. of all pipe shall exceed the I.D. Otherwise the hole will be on the outside.
- All pipe is to be supplied with nothing in the hole so that water or other stuff can be put in at a later date.
- All pipe is to be supplied without rust, as this can be applied at the job site.

SUPPLEMENTARY PIPE SPECS

- All pipe is to be cleaned free of covering such as mud, tar, barnacles or any form of manure before installation, otherwise it will make lumps under the paint.
- All pipe over 500 feet long must have the words “LONG PIPE” clearly printed on each end so the well driller will know it is long pipe.
- Pipe over two miles long must have the words “LONG PIPE” painted in the middle so that the driller will not have to walk the entire length to determine if it is a long pipe.

SUPPLEMENTARY PIPE SPECS

- All pipe over 6” in diameter is to have the words “BIG PIPE” painted on it so the driller will not confuse it with “SMALL PIPE”.
- All pipe fittings are to be made of the same stuff as the pipe.
- No fittings are to be put on the pipe unless specified. Otherwise straight pipe becomes crooked pipe.
- Fittings come in all sizes. Be sure to indicate the direction you are going when ordering.
- Flanges are to be used on the same pipe. Flanges must have holes for the bolts quite separate from the big hole in the middle of the pipe.
- If flanges are to be blind or blank, the big hole in the middle must be filled with metal.

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Water-Borne Contaminants

USGS National Water-Quality Assessment Program

23% of sampled domestic wells had one or more health-related contaminant above the MCL

Contaminants:

- 80% naturally occurring (e.g. manganese, arsenic, radon)
- 20% human source (e.g. nitrates, solvents, pesticides)

(Circular 1332) 1991-2004

U.S. EPA lists drinking water contaminants by two standards:

- Primary – Health Related
- Secondary – Mainly Aesthetic Related
- Maximum Contaminant Level (MCL).
- Usually in mg/L (ppm) or µg/L (ppb).
- New MCLs starting to be listed in ppt concentrations (1 second in ~ 35,000 years).

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Primary drinking water standards constantly evolving – virtually always getting tighter

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NGWA – currently 12 BSP documents - Best Suggested Practices – addressing water-borne contaminants

These Cover:

- Iron and Manganese
- Strontium
- Boron
- Arsenic
- Uranium
- Fluoride
- Nitrate
- Perchlorate
- Radon
- Methane
- Hydrogen Sulfide
- Microorganisms

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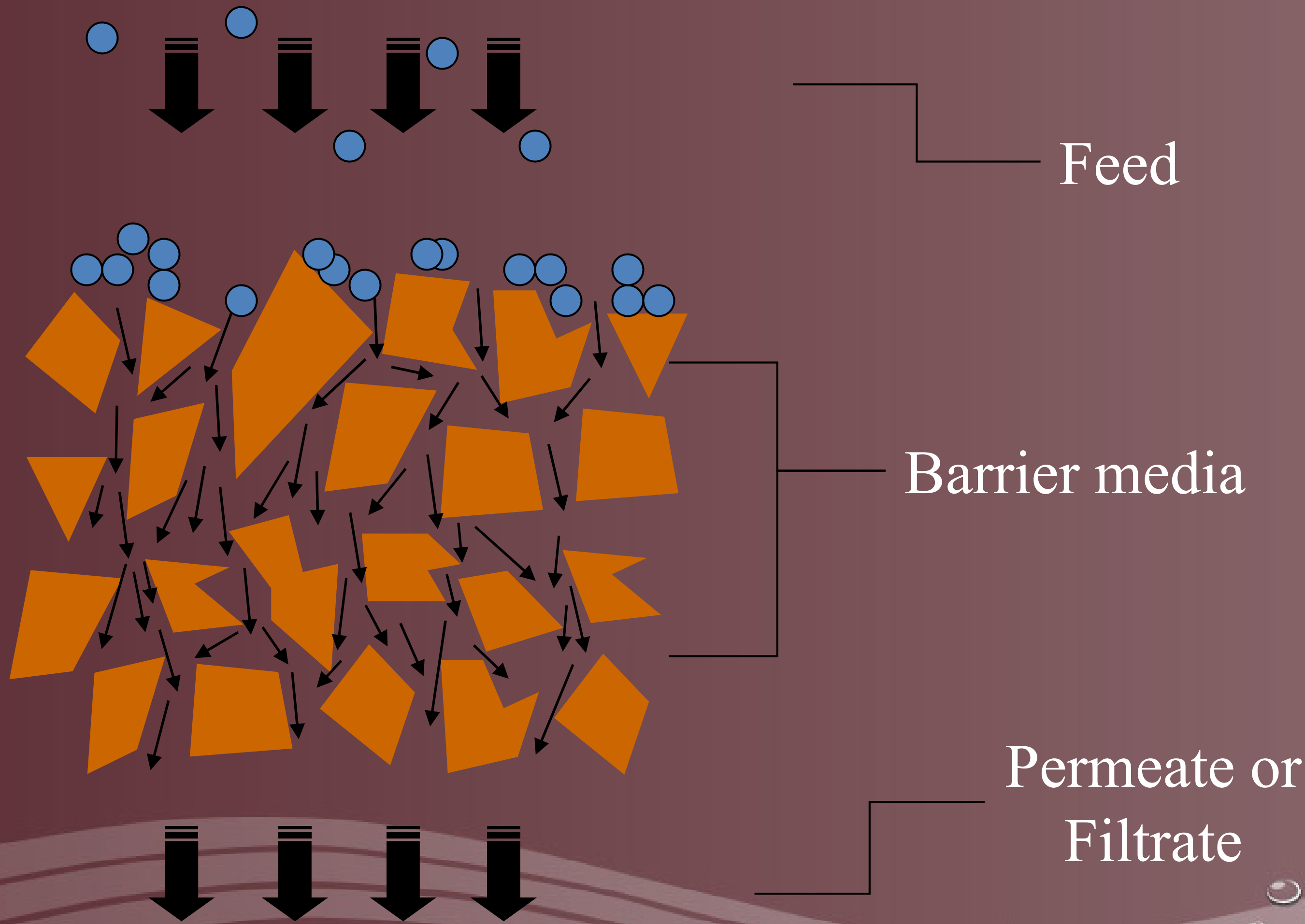
ROAD SALT (NaCl) (e.g. Cl^-) CONTAMINATION

Membrane Technologies

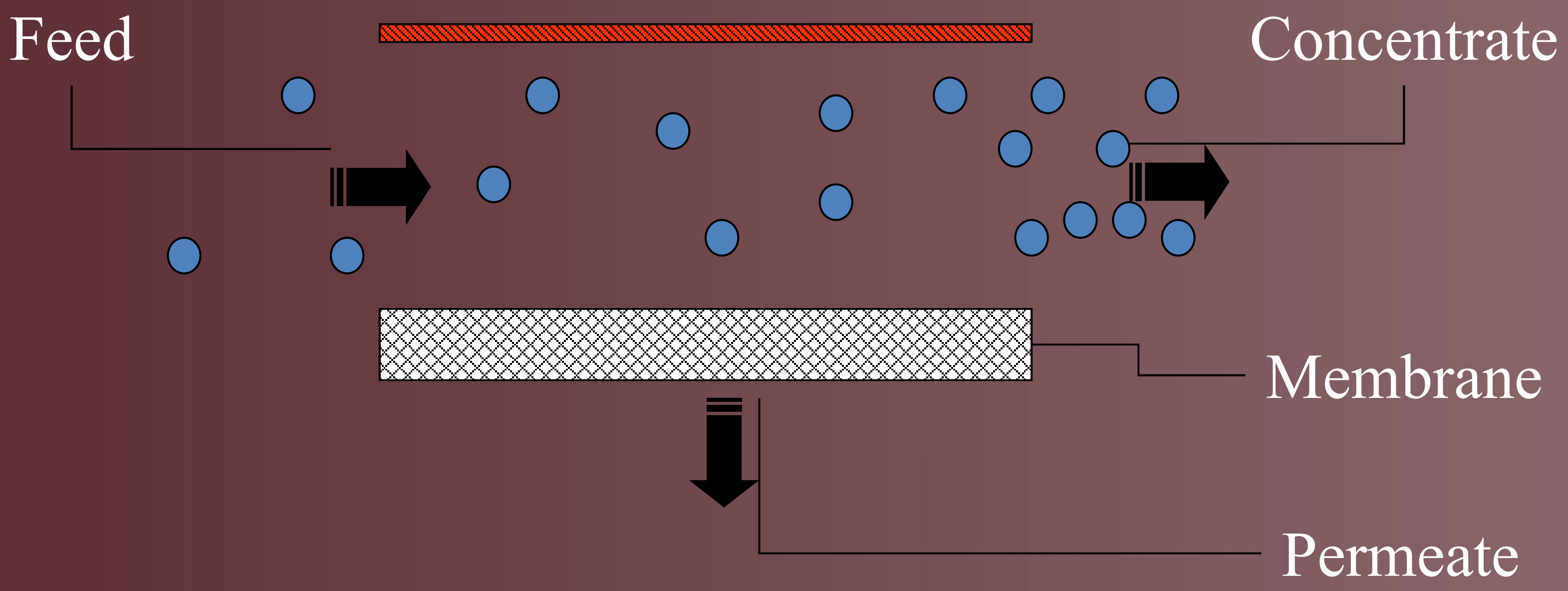
Membrane Separation Technologies Features

- 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 of contaminants.
- No chemical addition requirements to effect separation.

Conventional “dead-end” Filtration



Crossflow Filtration



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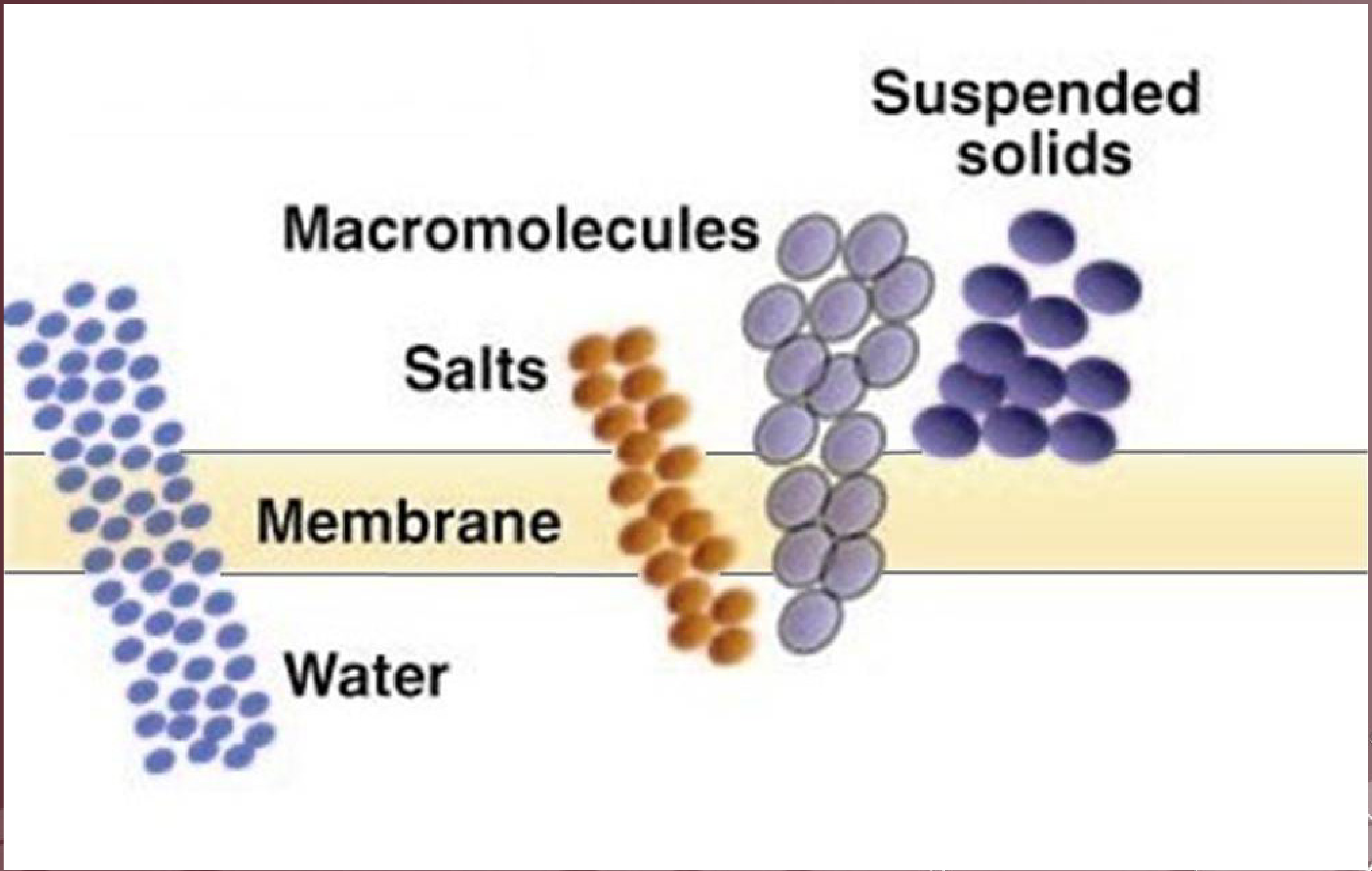
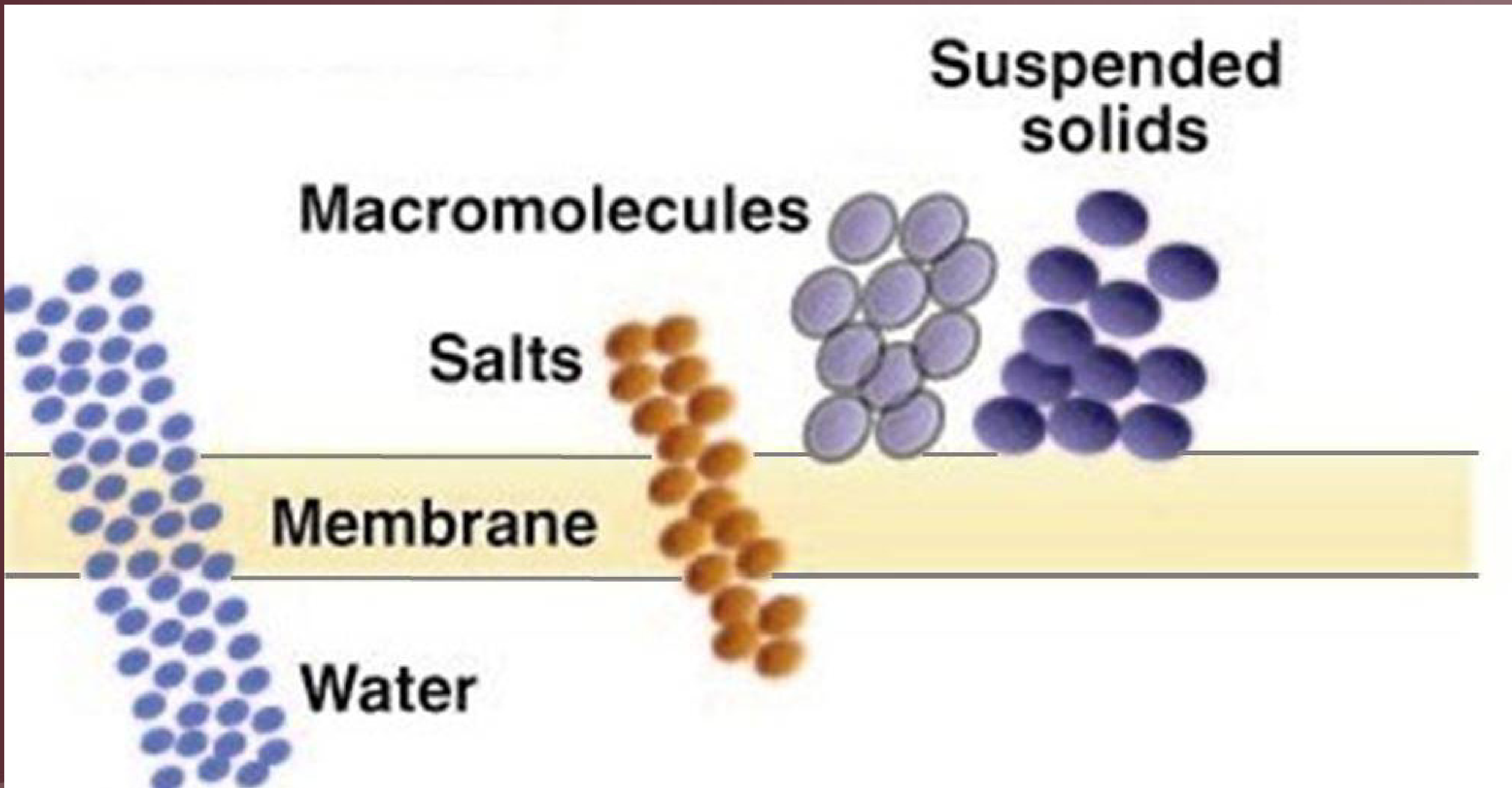
Microfiltration



Microfiltration (MF)

- Particle (suspended solids) removal only.
- Pore sizes in the submicron range (<1.0μ).
- Removal mechanism is sieving.

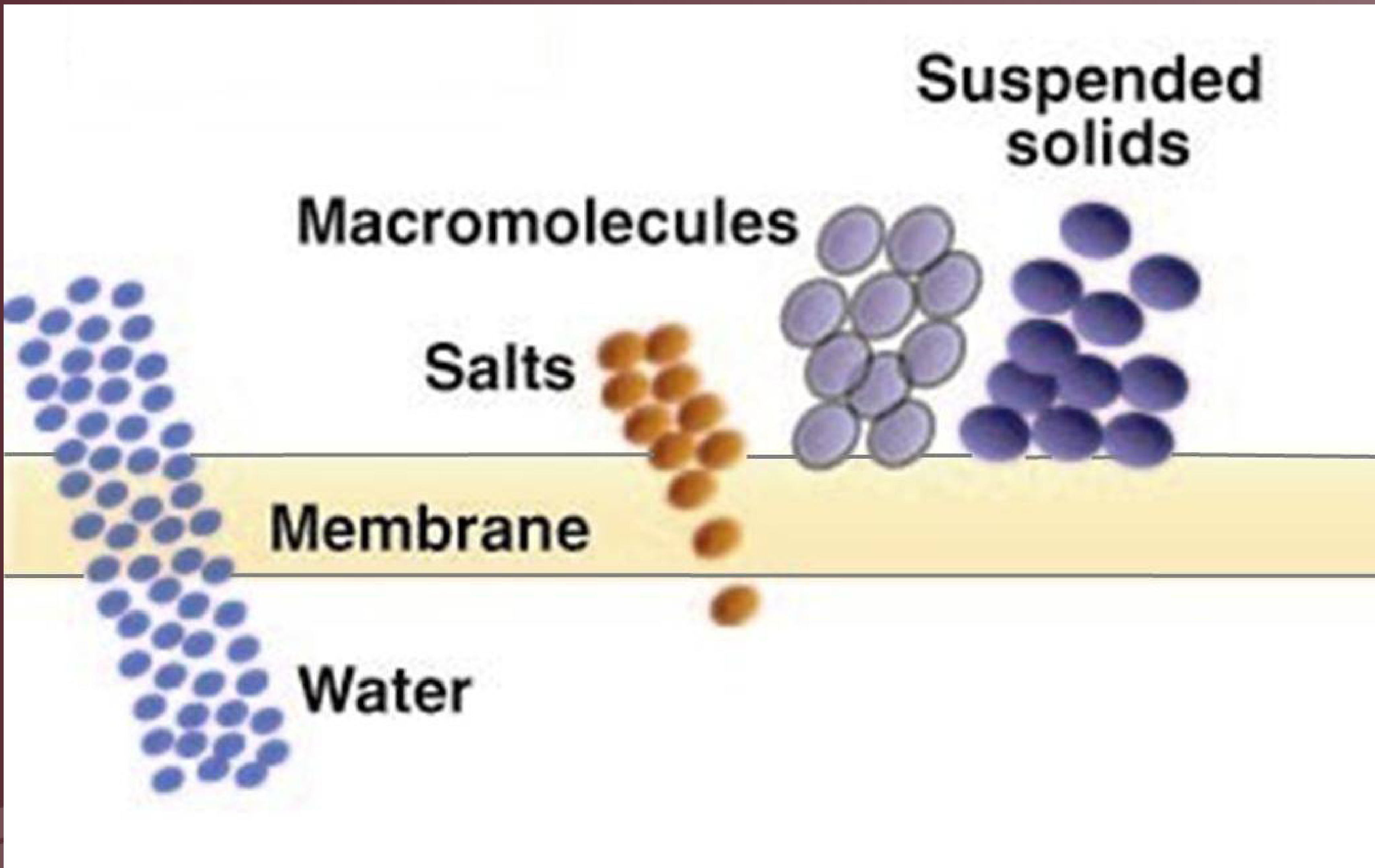
Ultrafiltration



Ultrafiltration (UF)

- Dissolved organic (macromolecule) removal.
- Pore sizes in the submicron range, and generally smaller than MF.
- Removal mechanism is sieving.

Nanofiltration



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Nanofiltration (NF)

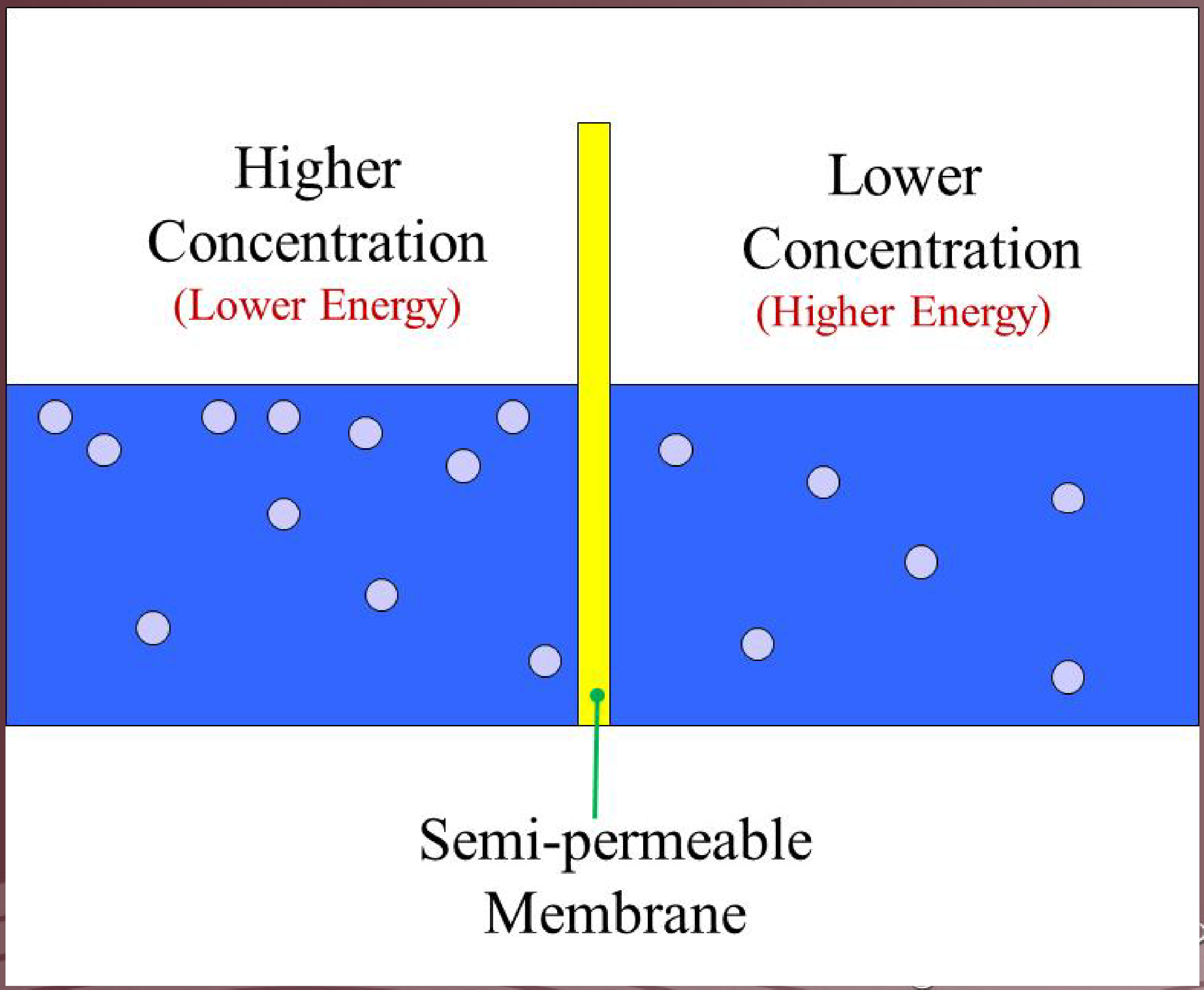
"Loose RO"

Rejects salts as with RO

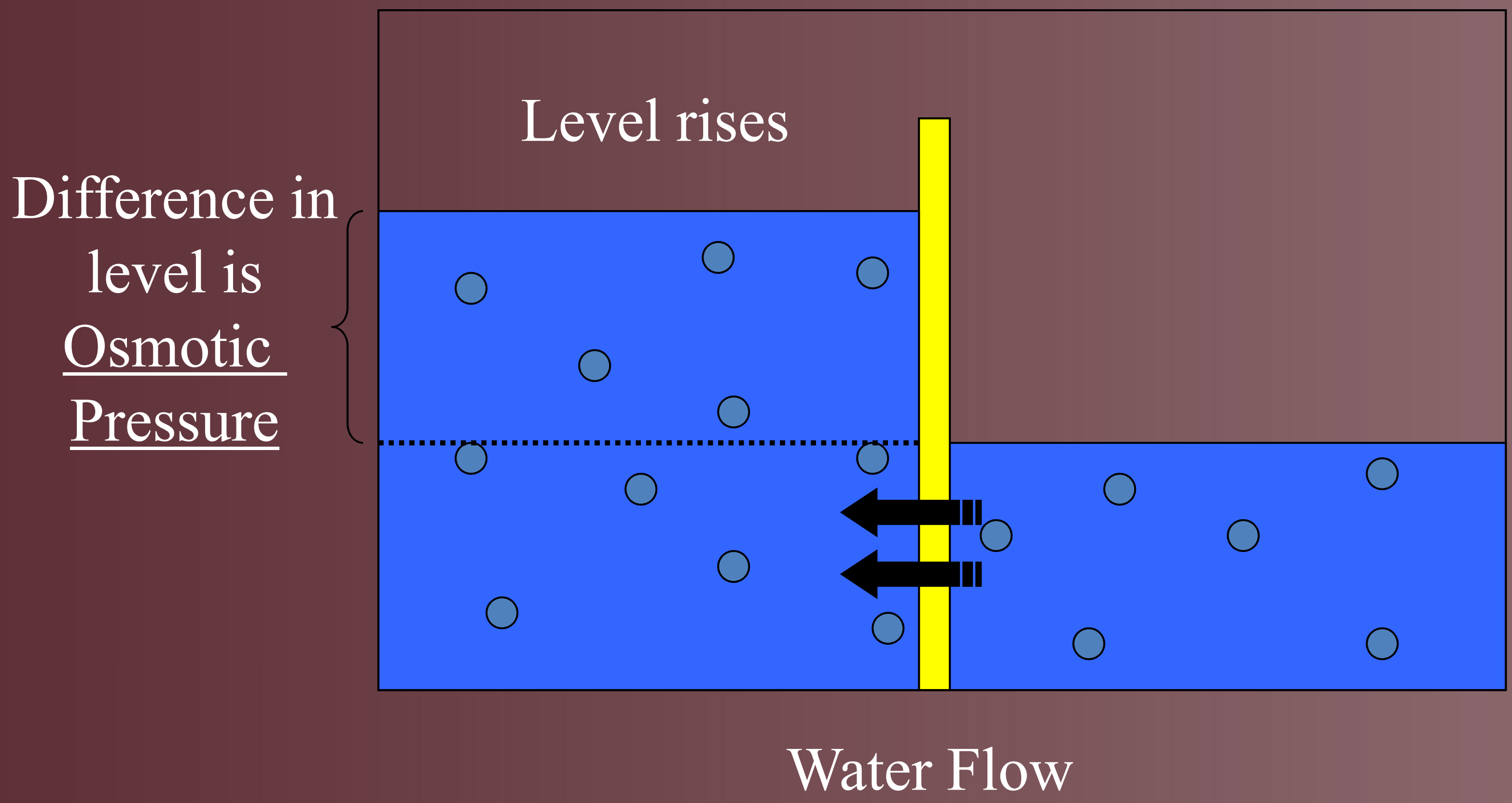
- But -

Rejects multivalent salts to a much higher degree than monovalent salts

Osmosis

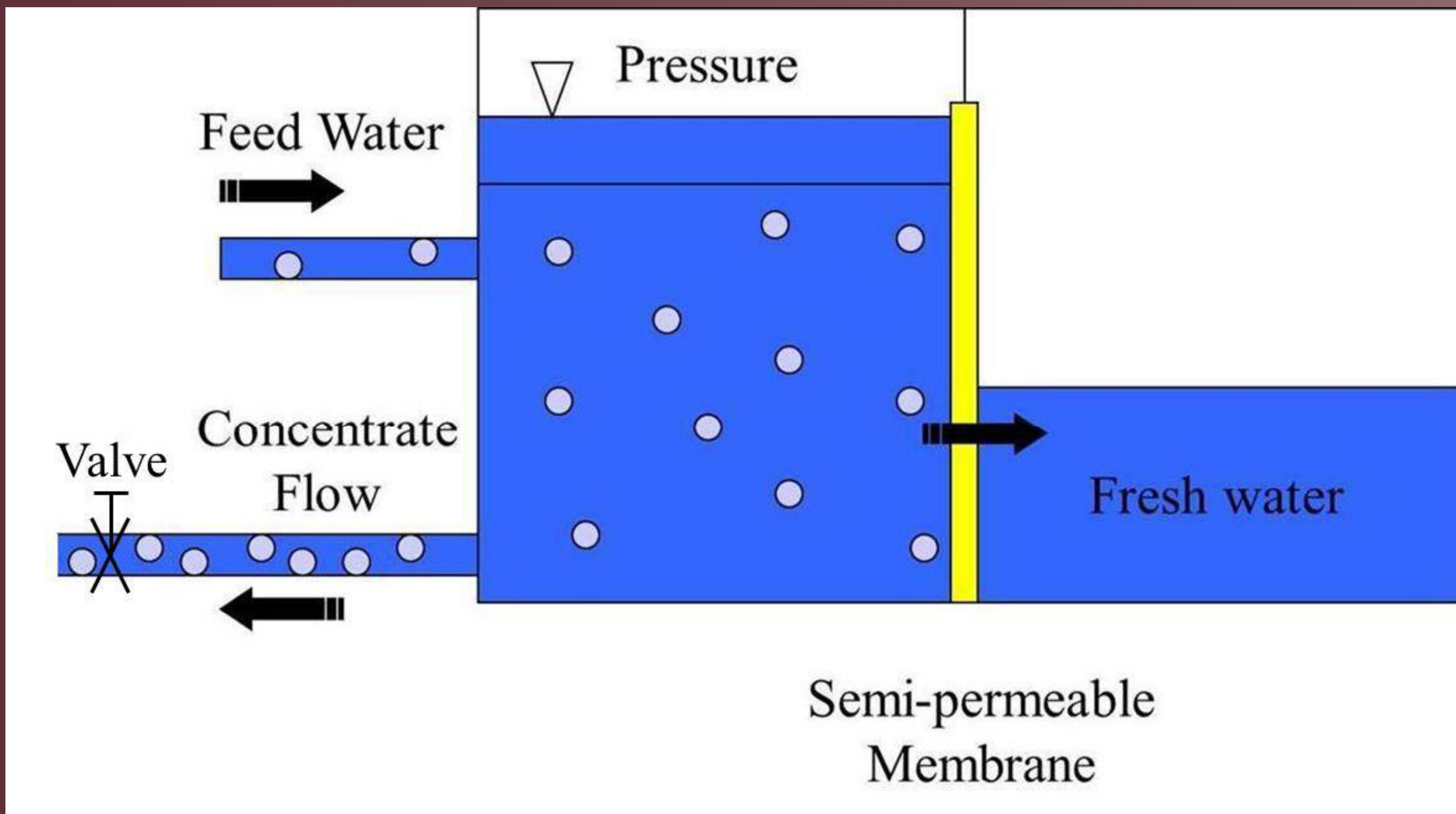

Higher Concentration
(Lower Energy)
Lower Concentration
(Higher Energy)
Semi-permeable Membrane

Osmosis

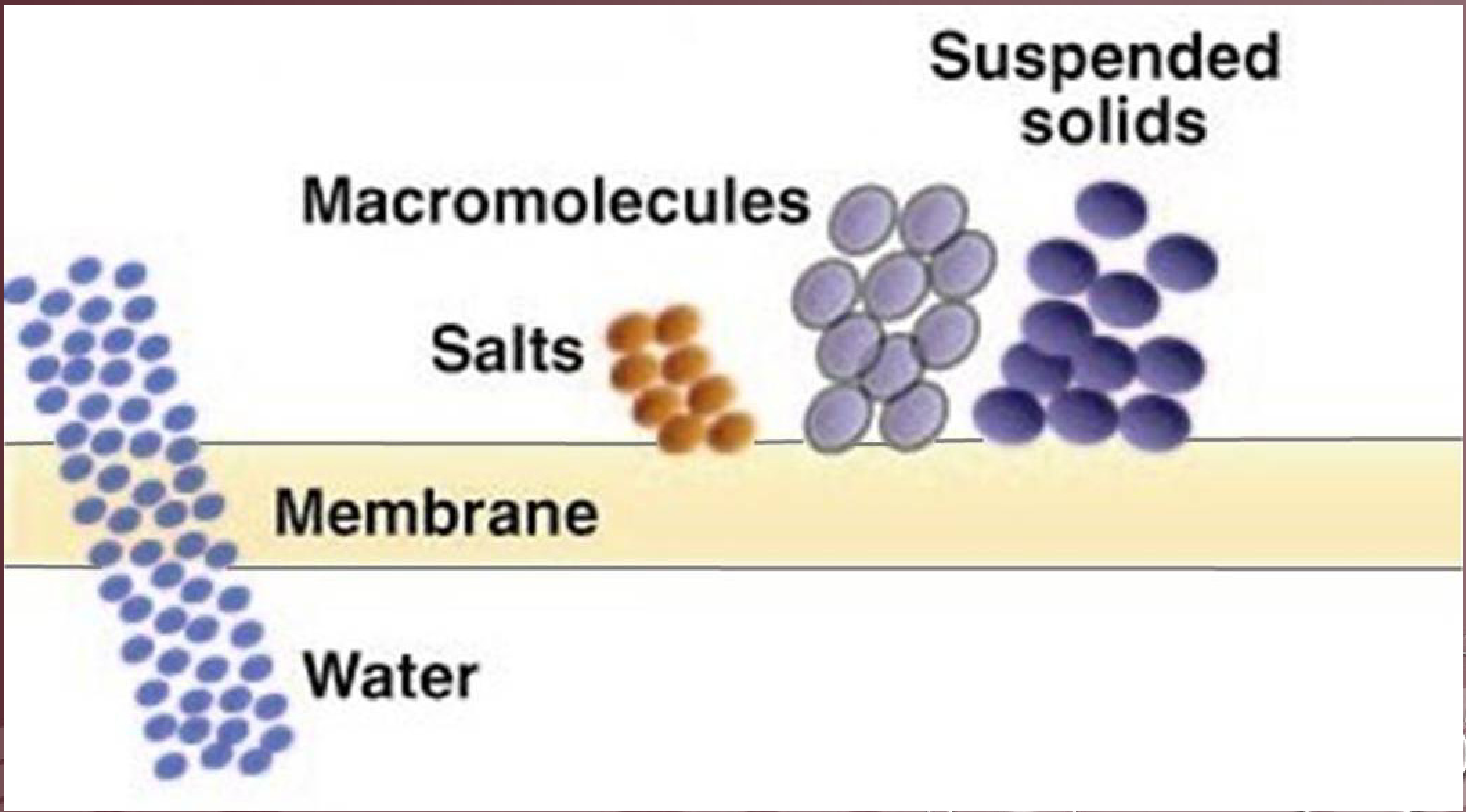


Level rises
Difference in level is Osmotic Pressure
Water Flow

Reverse Osmosis Applied



Reverse Osmosis



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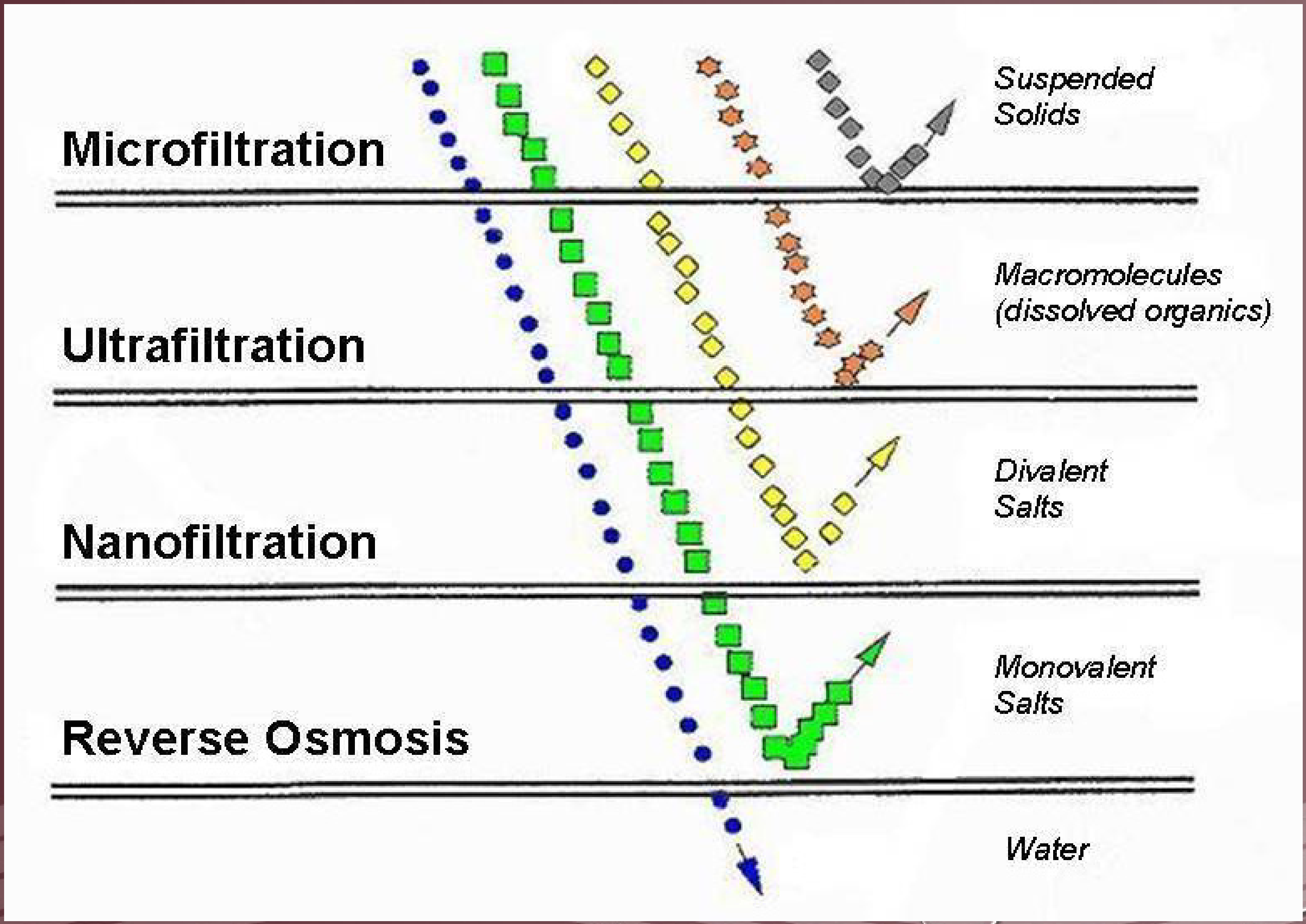
Membrane Technologies



Membrane Technologies Compared

Feature	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Materials of Construction	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 (micrometers)	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	<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+%

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

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Membrane Technologies Compared

Feature	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Materials of Construction	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
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.*

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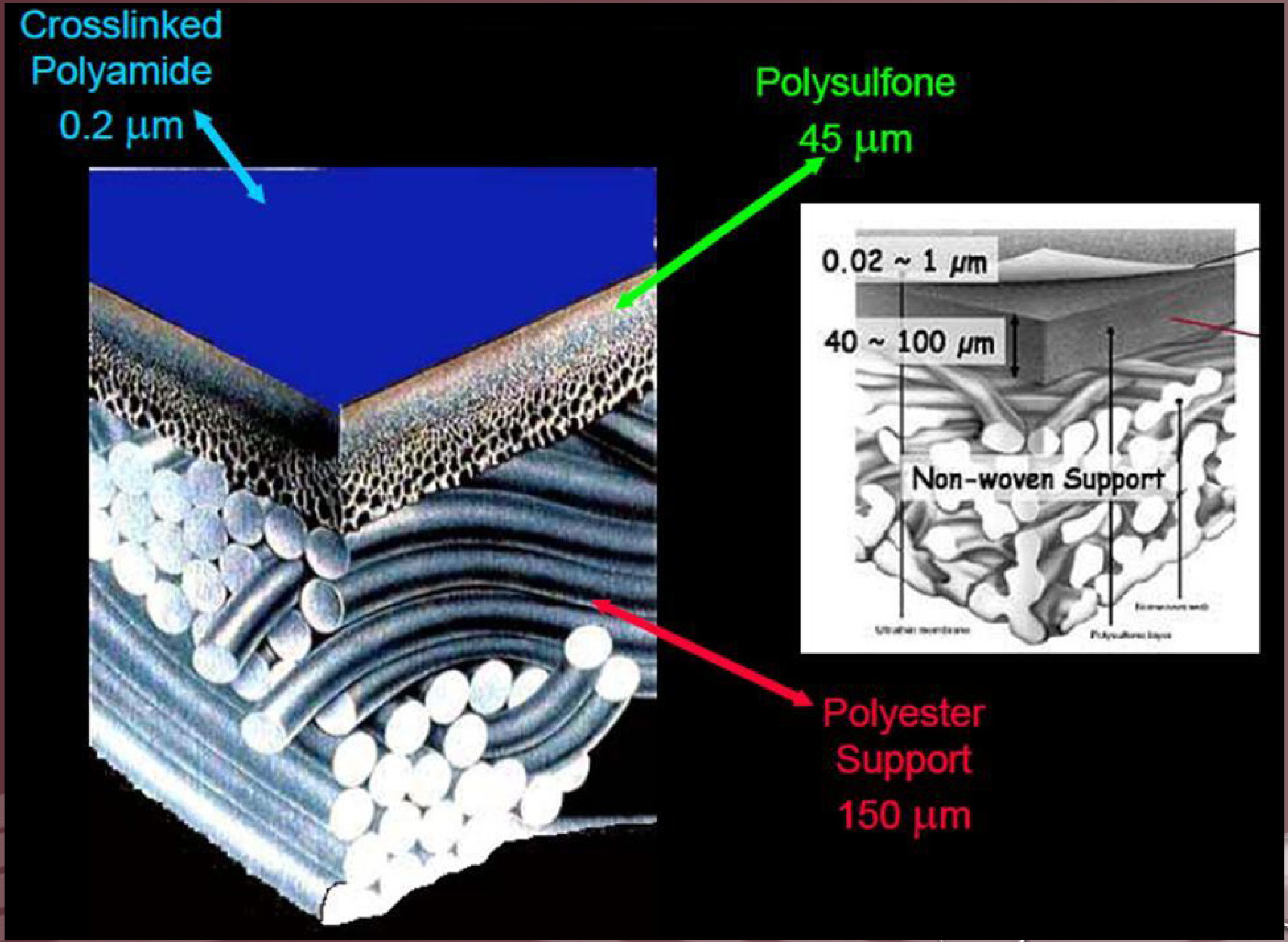
Membrane – Cross Section

Typical RO Membrane



Thin Film

Vast majority of RO membranes are Thin Film Composite:

- High Rejection
- Excellent Thermal Stability
- Bacteria Resistant
- pH Stable

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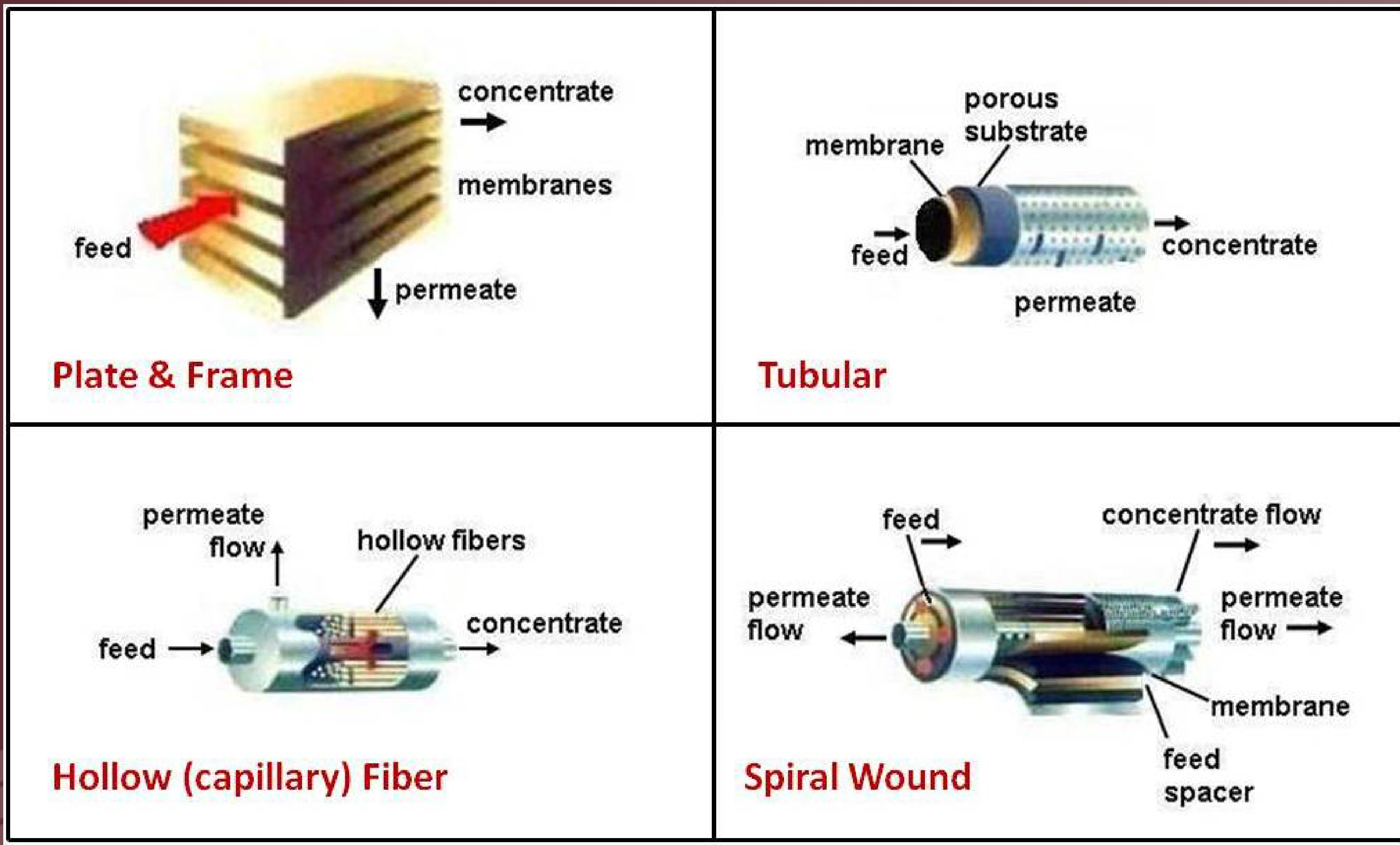
HOWEVER – They are chemically attacked by oxidizing agents:

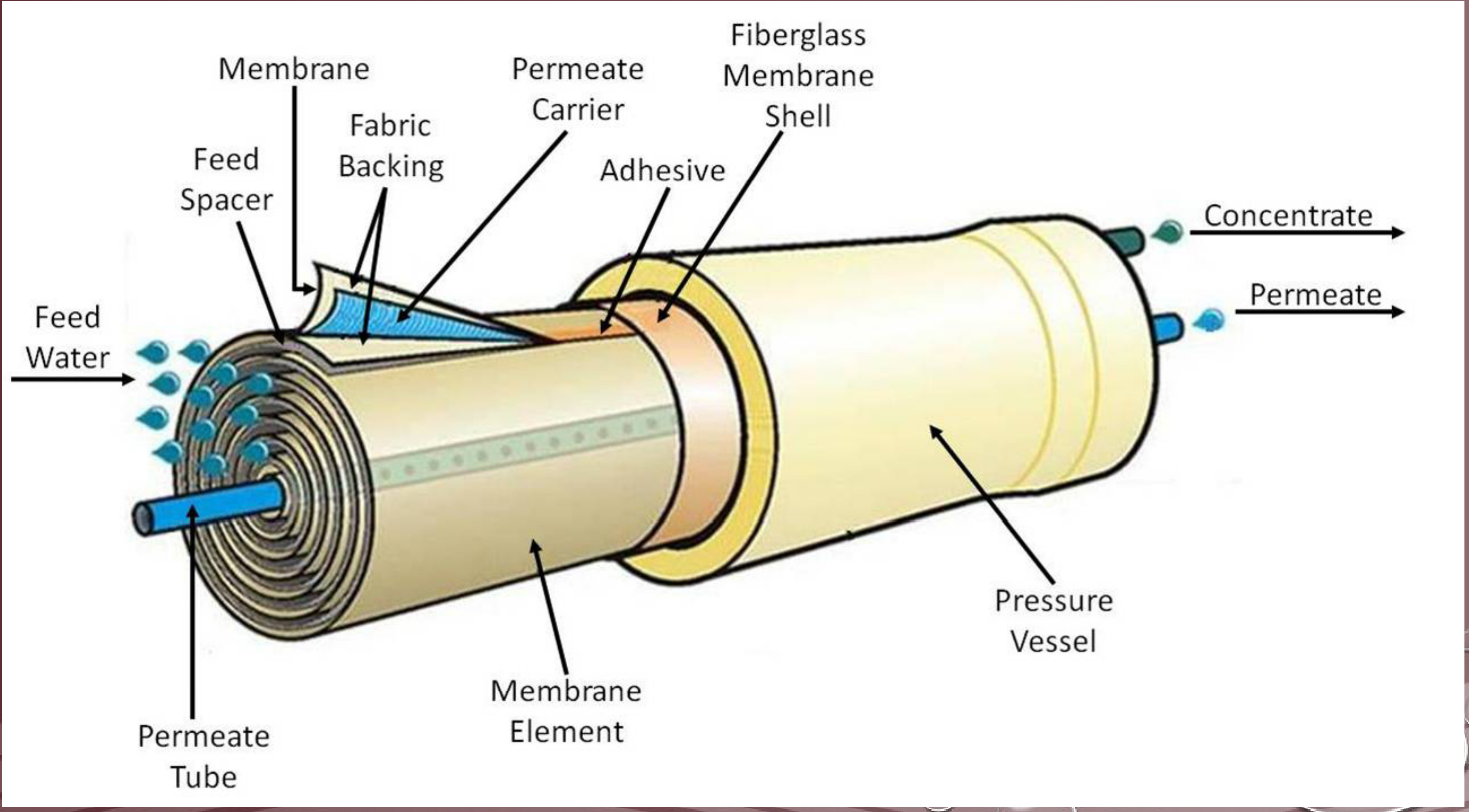
- Chlorine compounds
- Hydrogen peroxide
- Potassium permanganate
- Others

Membrane Devices

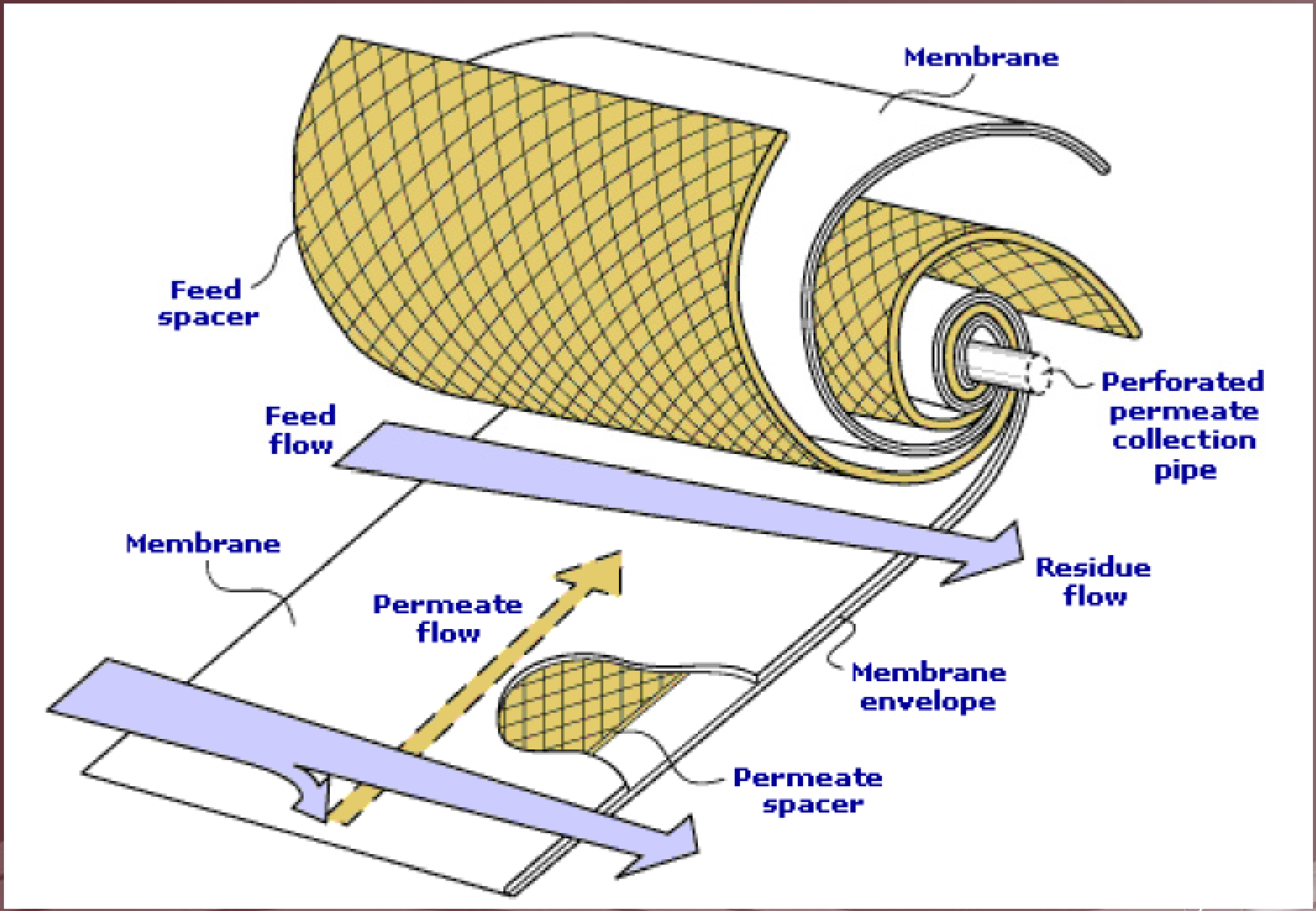


Spiral Wound Element

Spiral Wound



Spiral Wound



Courtesy of Mike Grigus

Spiral Element Sizes

(2”∅, 4”∅, 8”∅, 16”∅)

Terminology

Feed = Influent
Concentrate = Brine = Reject
Permeate = Product   Dilute = Filtrate
Bank = Array

- RO always rejects a **percentage** of salts (up to 99.8%).
- Therefore, permeate quality a function of feedwater quality.

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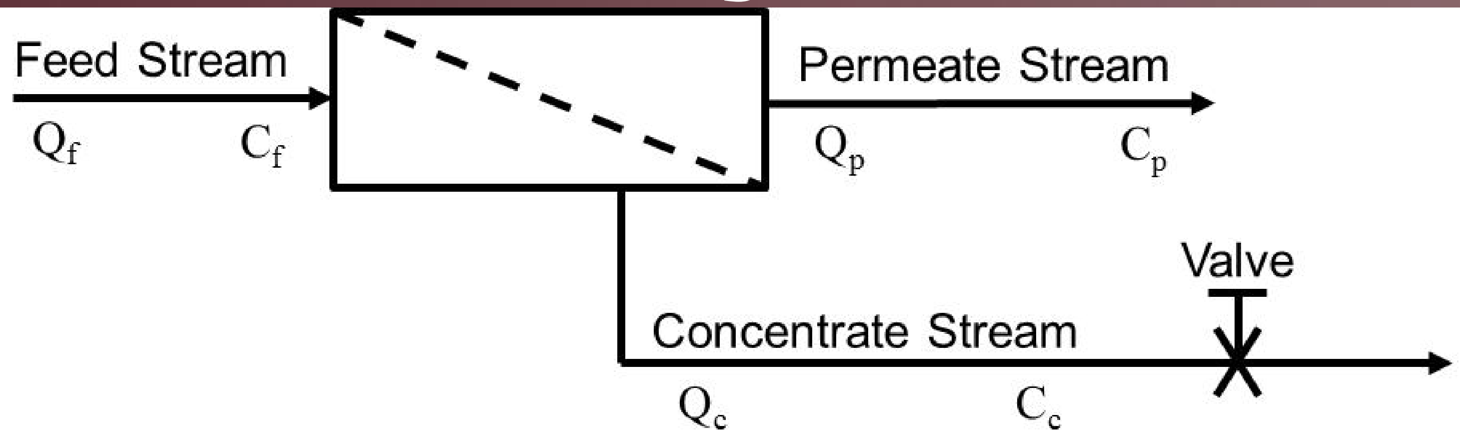
RO Removes dissolved organic contaminants by a process of SIZE EXCLUSION:

- What's too big to go through the membrane is held back.
- Function of both the size and shape of the organic molecule.
- Down to ~ 100 molecular weight (Daltons).

Membrane Element System



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)

Definition of Recovery

% Recovery: The percentage of feedwater that passes through the membrane as product water (i.e. how efficiently water is converted into product water).

$$\text{Recovery (\%)} = \frac{\text{Permeate Rate}}{\text{Feed Rate}} \times 100$$

Part of system design

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

High Recovery Advantages

- Lower flow rate
  (smaller diameter piping, etc.)

- Smaller high pressure pump

High Recovery Hazards

- Precipitation – Fouling
- For RO/NF – High π (osmotic pressure)
- For RO/NF – As Recovery ⬆ Permeate TDS ⬆
- Discharge Issues

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If feedwater TDS ↑, Permeate TDS ↑

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Feedwater temperature will affect RO permeate rate:

As temperature ↓,
Permeate rate ↓

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Colder water has a higher viscosity than warm water, so more pressure is required to force it through the membrane.

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Temperature Correction

Temperature Correction Chart

(Typical)

Temperature (t)		T_{cor}	Temperature (t)		T_{cor}	Temperature (t)		T_{cor}
°C	°F		°C	°F		°C	°F	
1	33.8	0.460	19	66.2	0.830	37	98.6	1.403
2	35.6	0.482	20	68.0	0.861	38	100.4	1.440
3	37.4	0.499	21	69.8	0.888	39	102.0	1.479
4	39.2	0.510	22	71.6	0.915	40	104.0	1.520
5	41.0	0.534	23	73.4	0.943	41	105.8	1.56
6	42.8	0.552	24	75.2	0.971	42	107.6	1.603
7	44.6	0.571	25	77.0	1.000	43	109.4	1.645
8	46.4	0.590	26	78.8	1.030	44	111.2	1.686
9	48.2	0.609	27	80.6	1.060	45	113.0	1.730
10	50.0	0.630	28	82.4	1.091	46	114.8	1.776
11	51.8	0.651	29	84.2	1.122	47	116.6	1.821
12	53.6	0.672	30	86.0	1.155	48	118.4	1.869
13	55.4	0.693	31	87.8	1.188	49	120.2	1.916
14	57.2	0.716	32	89.6	1.221	50	122.0	1.965
15	59.0	0.739	33	91.4	1.256			
16	60.8	0.760	34	93.2	1.292			
17	62.6	0.786	35	95.0	1.328			
18	64.4	0.810	36	96.8	1.364			

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RO pump pressure directly affects permeate rate.

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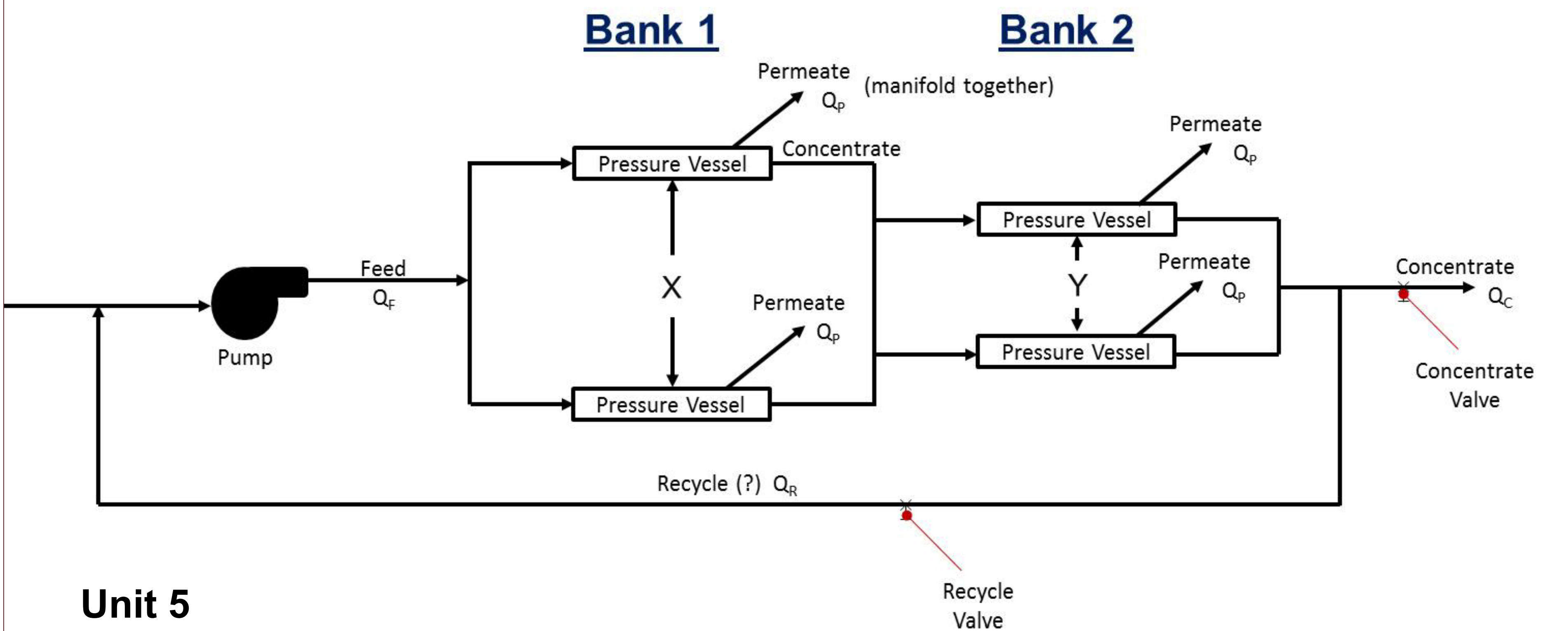
As pump pressure ↑, Permeate rate ↑

Membrane Element Array



Unit 5

RO Limitations

On a practical basis, RO only CANNOT produce 18 MΩ-cm quality water.

RO Limitations

To produce 18 MΩ-cm quality water, the best approach is RO followed by either mixed bed IX or EDI

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Fouling – The bane of all membrane systems

Fouling

- **Plugging** - Particulate materials (suspended solids)
- **Scaling** - Precipitated materials
- **Organic Fouling** - Coating and plugging by organics
- **Microorganisms** - Bacterial biofilm

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Relative Solubilities

Solubility

(In distilled water)

Compound	Cold	Hot
$MgCO_3(S)$	0.176 g/L	0.375 g/L
$CaCO_3(S)$	0.0014 g/L	0.0018 g/L
NaCl(s)	35.7 g/L	39.12 g/L

Results in scaling

Fouling Summary

Foulant	Primary Mechanism	Examples
Suspended Solids (plugging)	Filtration	Dirt, clay, silt, dust, hydrous metal oxides, *e.g.* $Fe(OH)_3$
Inorganic Salts (scaling)	Concentration effects, Adsorption	$CaCO_3$, $MgCO_3$, $BaSO_4$, $CaSO_4$, SiO_2, and other salts
Organics (plugging)	Adsorption, Film Formation	Oils, grease, surfactants, coagulants, antiscalants, humic and fulvic acids
Microorganisms (Biofouling)	Adhesion, Adsorption, Biofilm Formation	Bacteria

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Treatment Locations

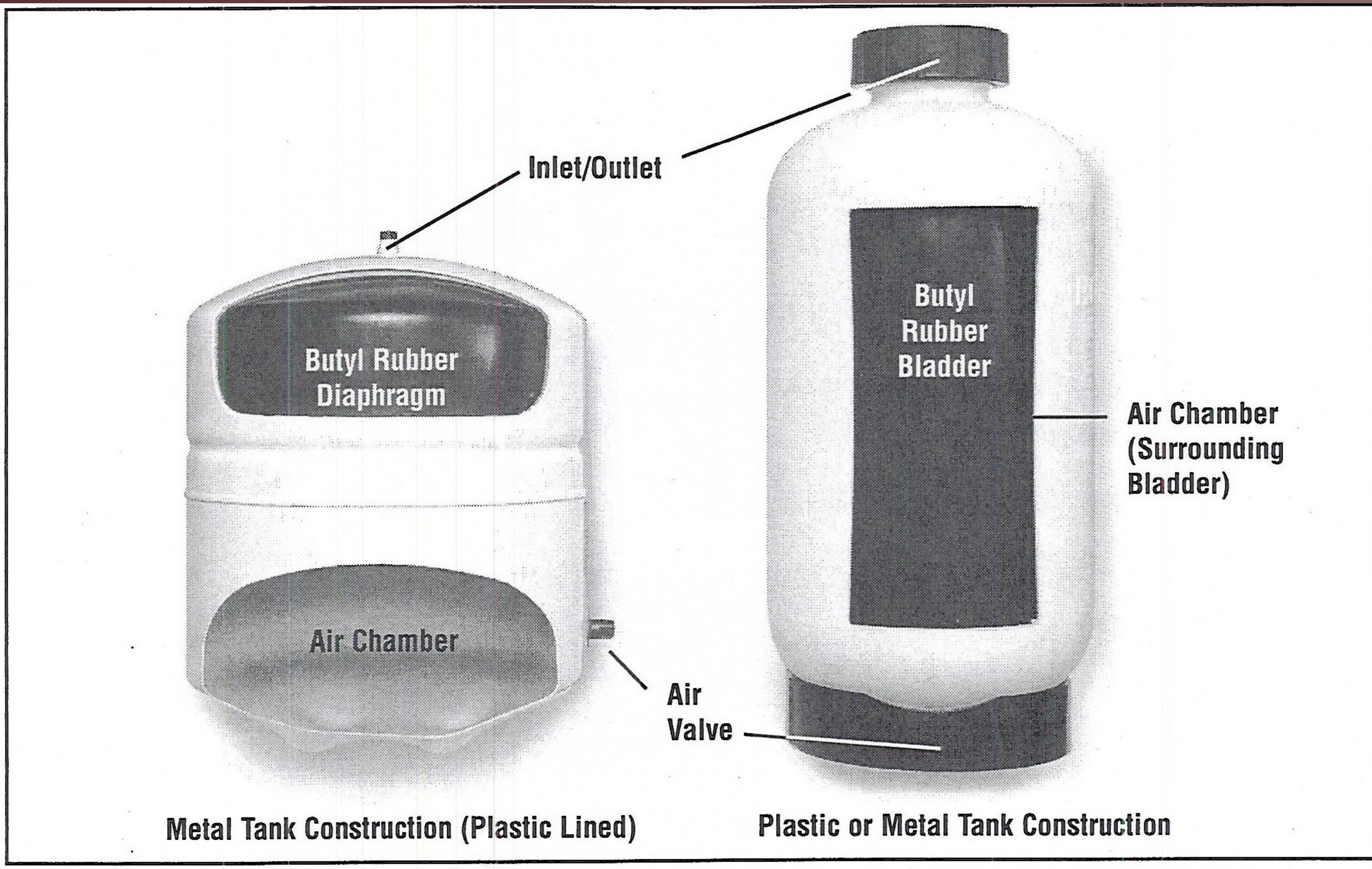
POE – Point of Entry

POU – Point of Use

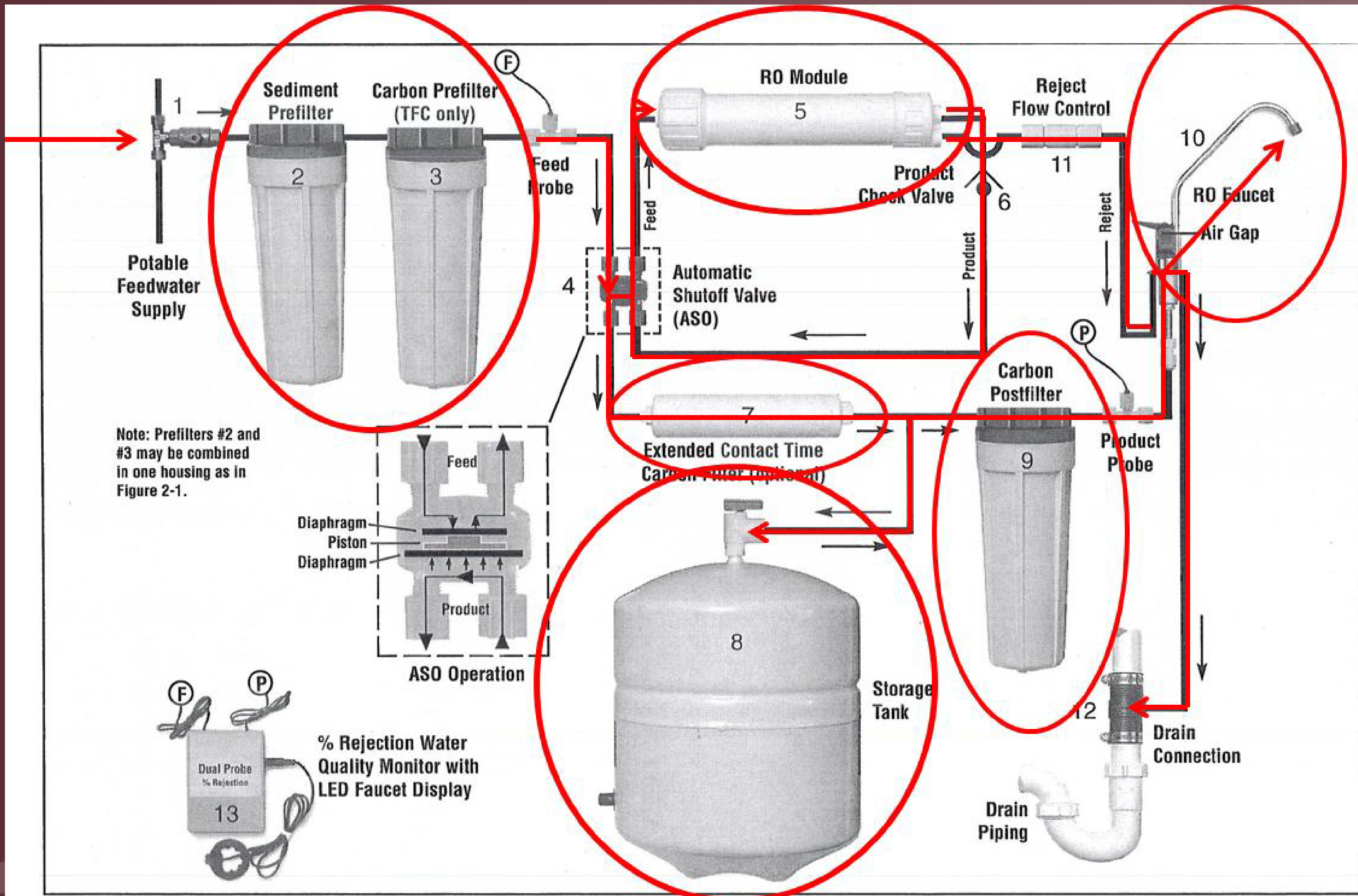
Normal POU RO System

- Filtration (sediment)
- Softening (harness)
- GAC (chlorine) for TFC membranes

POU RO System



POU RO System



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For more information visit us on the web at www.ngwa.org/foundation or write us at the address below.

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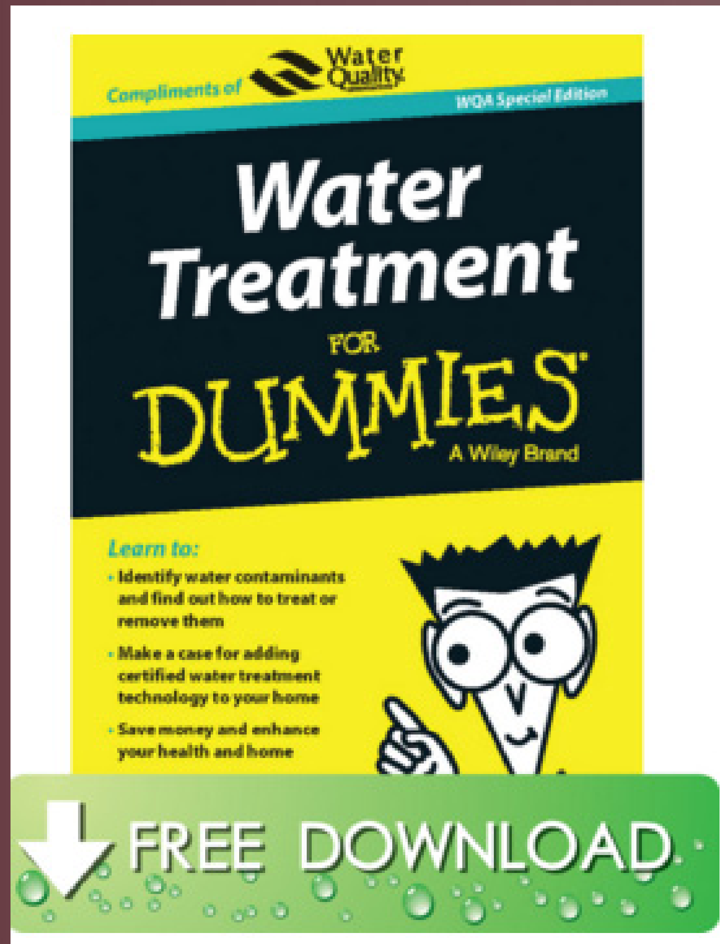

www.wqa.org/dummies