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MEMBRANE TECHNOLOGIES FOR WATER RECLAMATION

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, sulfates
Microorganisms	Bacteria, viruses, protozoan cysts, fungi, algae, molds, yeast cells
Gases	Hydrogen sulfide, methane, radon, carbon dioxide

Treatment Technologies

Treatment Technologies	Suspended Solids Removal	Dissolved Organic Removal	Dissolved Salts Removal	Microorganism Removal
BIOLOGICAL PROCESSES				
MBR (Membrane Bioreactor)	X	—	—	X
Activated sludge	X	X	—	X
Anaerobic digestion	X	X	—	—
Bio-filters	—	X	—	—
EXTENDED AERATION				
Bio-denitrification	—	L	—	—
Bio-nitrification	X	X	—	—
Pasveer oxidation ditch	X	X	—	X
CHEMICAL PROCESSES				
CHEMICAL OXIDATION				
Catalytic oxidation	X	X	—	X
Chlorination	X	X	—	X
Ozonation	—	L	—	X
Wet air oxidation	X	X	—	X
CHEMICAL PRECIPITATION	—	—	X	—
CHEMICAL REDUCTION	—	—	X	—
Ion exchange	—	—	X	—
Liquid-liquid (solvent)	—	—	X	—
COAGULATION				
Inorganic chemicals	X	X	—	X
Polyelectrolytes	X	X	—	X

L = under certain conditions there will be limited effectiveness

Treatment Technologies (con't)

Treatment Technologies	Suspended Solids Removal	Dissolved Organic Removal	Dissolved Salts Removal	Microorganism Removal
ELECTOLYTIC PROCESSES				
Electrodialysis	—	—	X	L
Electrodeionization	—	—	X	—
Electrolysis	—	—	X	—
Ultraviolet irradiation	—	—	—	X
EXTRACTIONS				
INCINERATION				
Fluidized-bed	X	X	—	X
PHYSICAL PROCESSES				
CARBON ADSORPTION				
Granular activated	X	X	—	—
Powdered	X	X	—	X
SPECIALTY RESINS	—	L	L	—
FILTRATION				
Diatomaceous-earth filtration	X	—	—	X
Multi-media filtration	X	—	—	X
Micro-screening	X	—	—	X
Sand filtration	X	—	—	X
Flocculation-sedimentation	X	—	—	X
DAF (Dissolved air flotation)	X	X	—	—
Foam separation	X	—	X	—

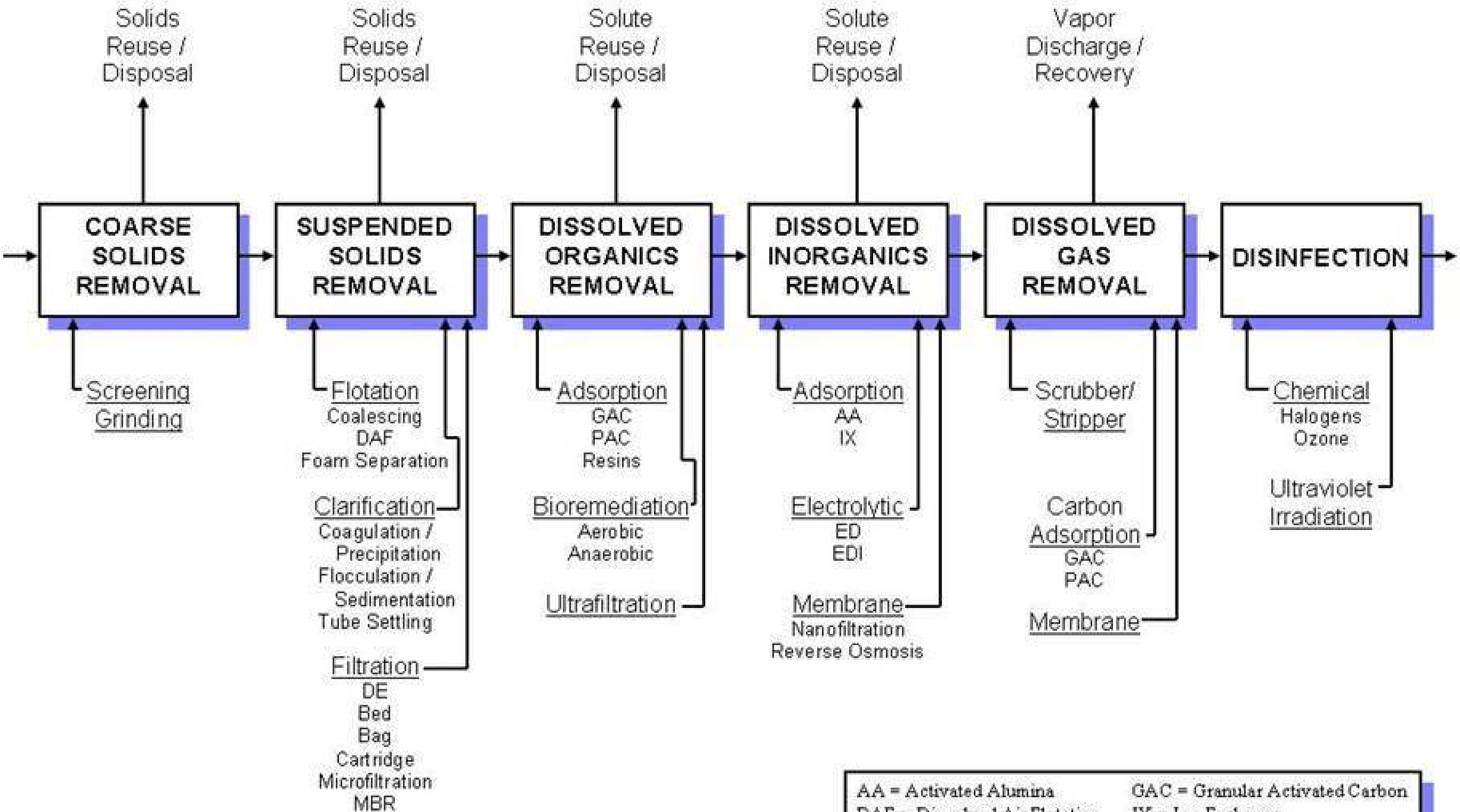
L = under certain conditions there will be limited effectiveness

Treatment Technologies (con't)

Treatment Technologies	Suspended Solids Removal	Dissolved Organic Removal	Dissolved Salts Removal	Microorganism Removal
MEMBRANE PROCESSES				
Microfiltration	X	—	—	X
Ultrafiltration	X	X	—	X
Nanofiltation	X	X	L	X
Reverse osmosis	X	X	X	X
Stripping (air or steam)	X	X	—	—
THERMAL PROCESSES				
Distillation	X	X	X	X
Freezing	—	X	X	—

L = under certain conditions there will be limited effectiveness

INDUSTRIAL WASTEWATER TREATMENT

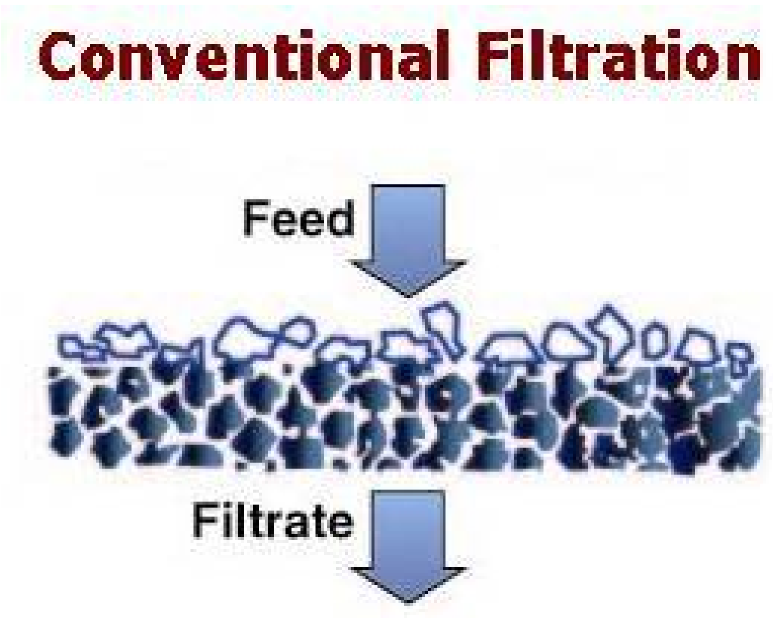


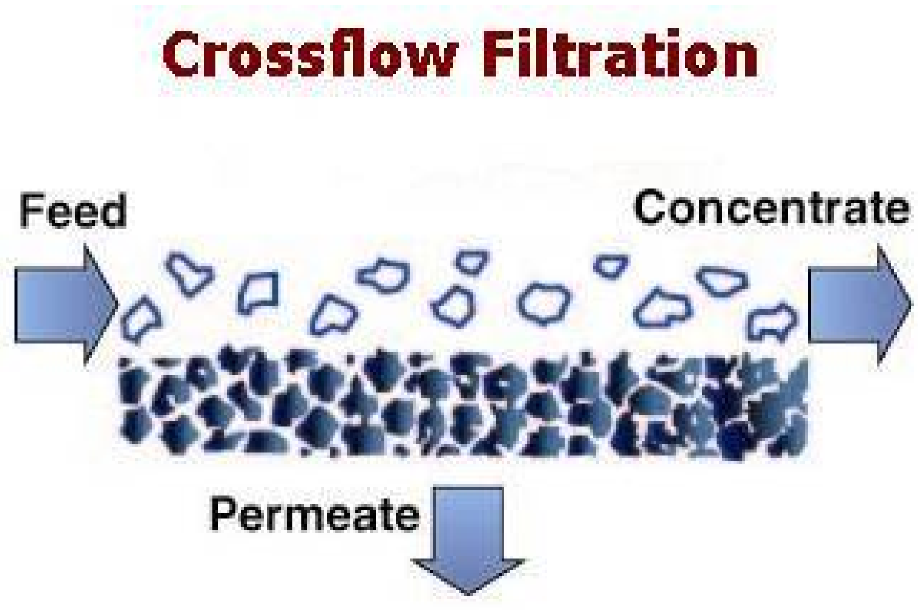
AA = Activated Alumina
DAF = Dissolved Air Flotation
DE = Diatomaceous Earth
ED = Electrodialysis
EDI = Electrodeionization
GAC = Granular Activated Carbon
IX = Ion Exchange
MBR = Membrane Bioreactor
PAC = Powdered Activated Carbon

Membrane Technologies

- Microfiltration (MF)
- Ultrafiltration (UF)
- Nanofiltration (NF)
- Reverse Osmosis (RO)

Conventional vs. Crossflow Filtration

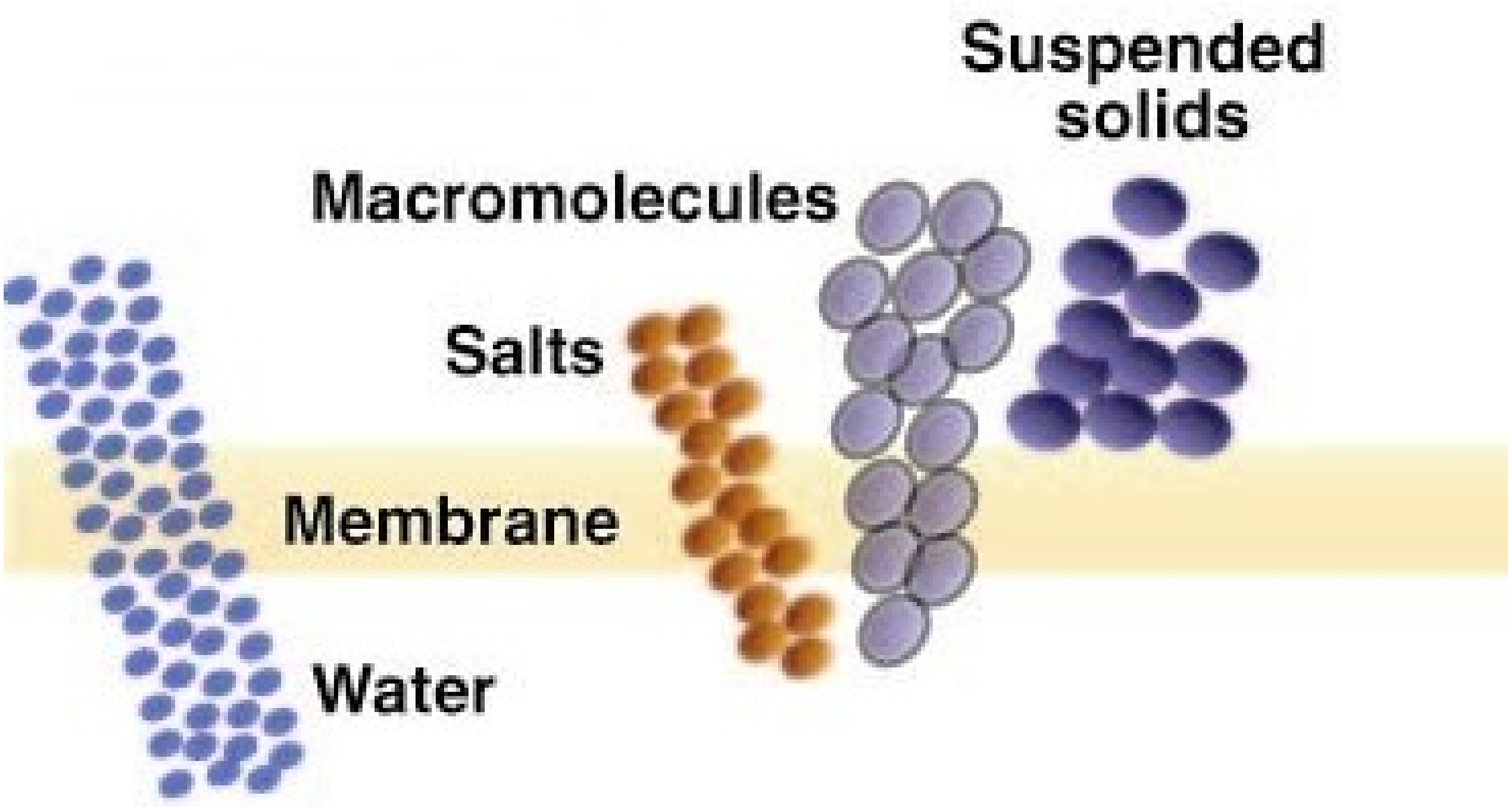




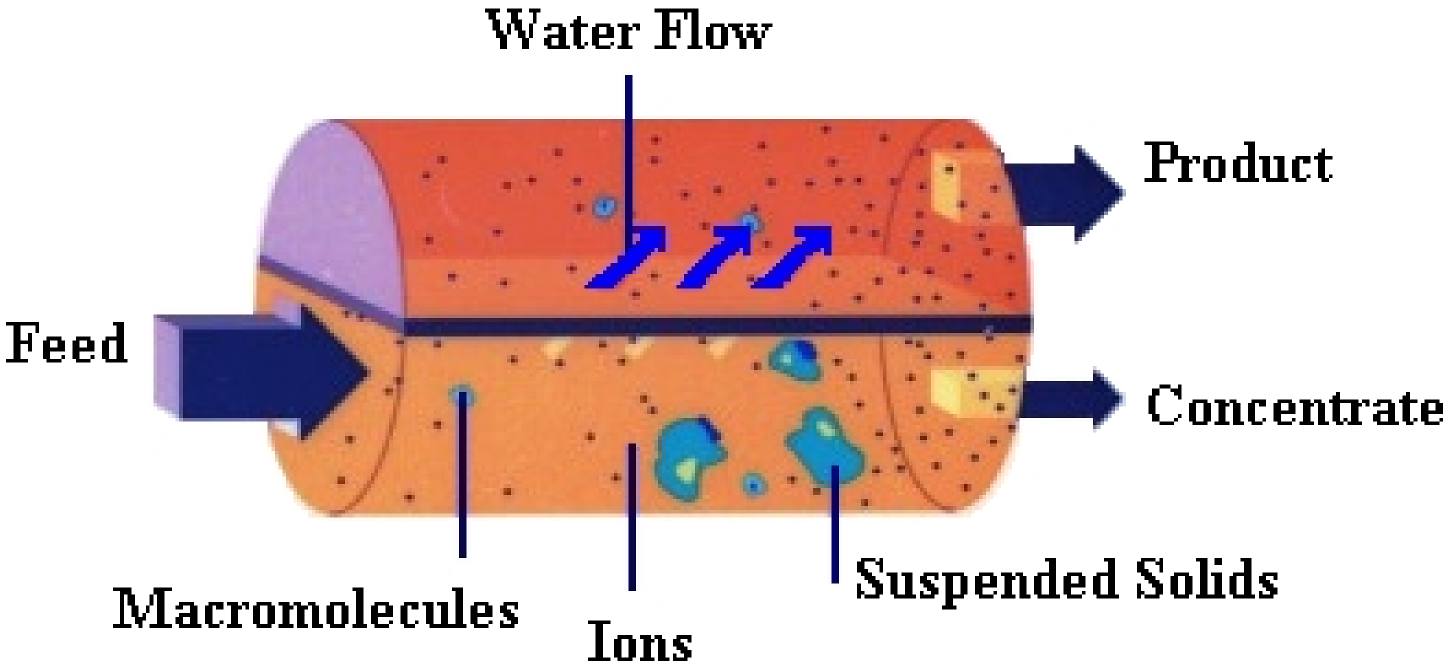
Membrane Technologies Advantages

- ✓ Continuous and automatic operation.
- ✓ Capable of removing contaminants down into the submicron size range.
- ✓ Usually requires no chemical addition.
- ✓ Backwashing capabilities.
- ✓ Generally can operate in turbulent flow conditions.
- ✓ Systems have a very small footprint.

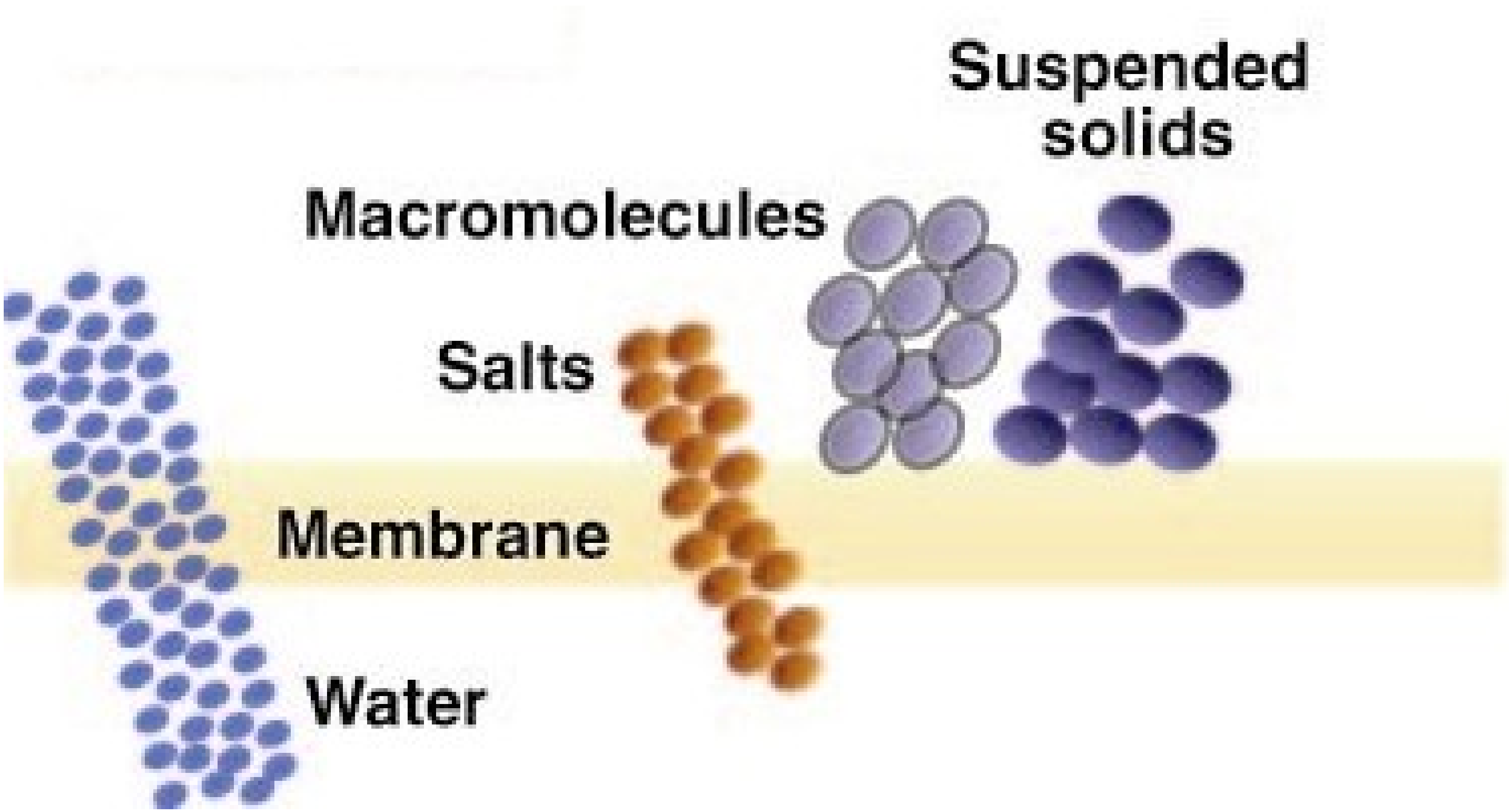
Microfiltration



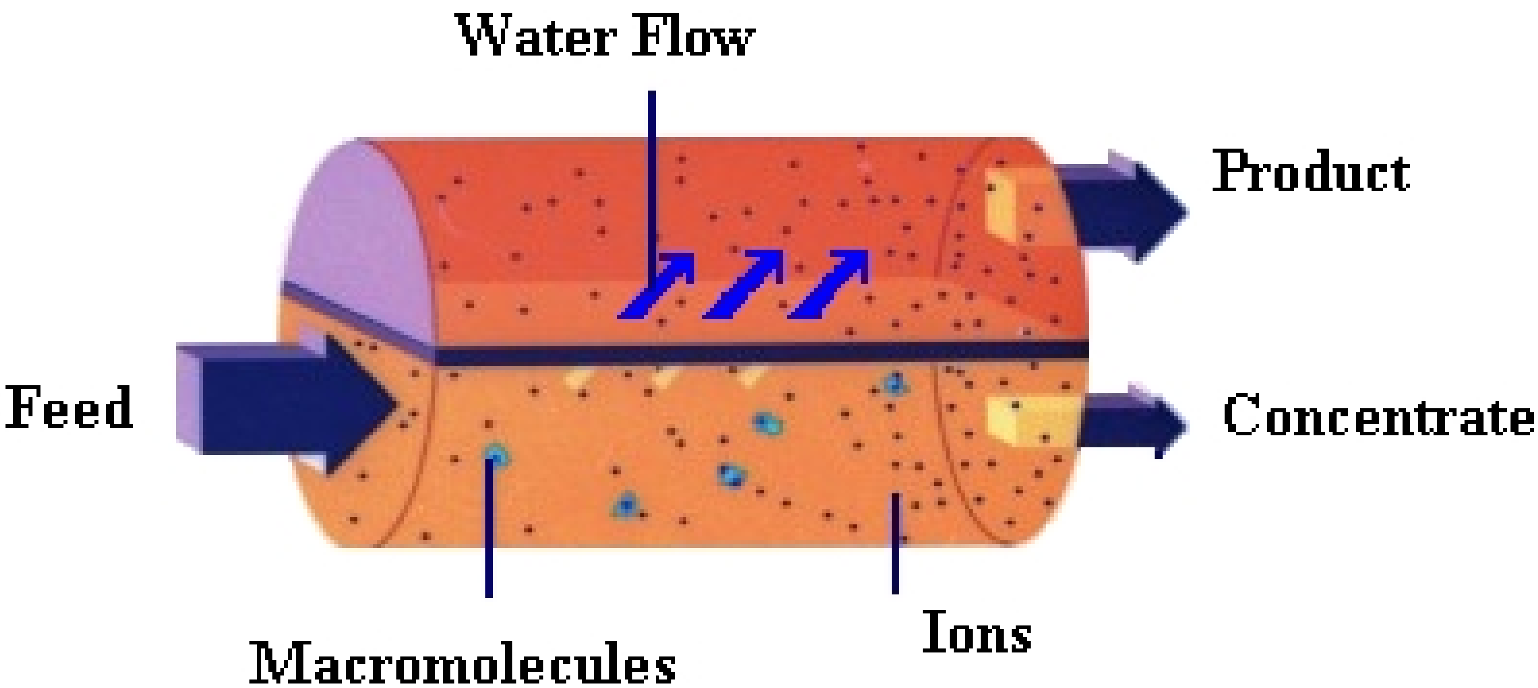
Microfiltration



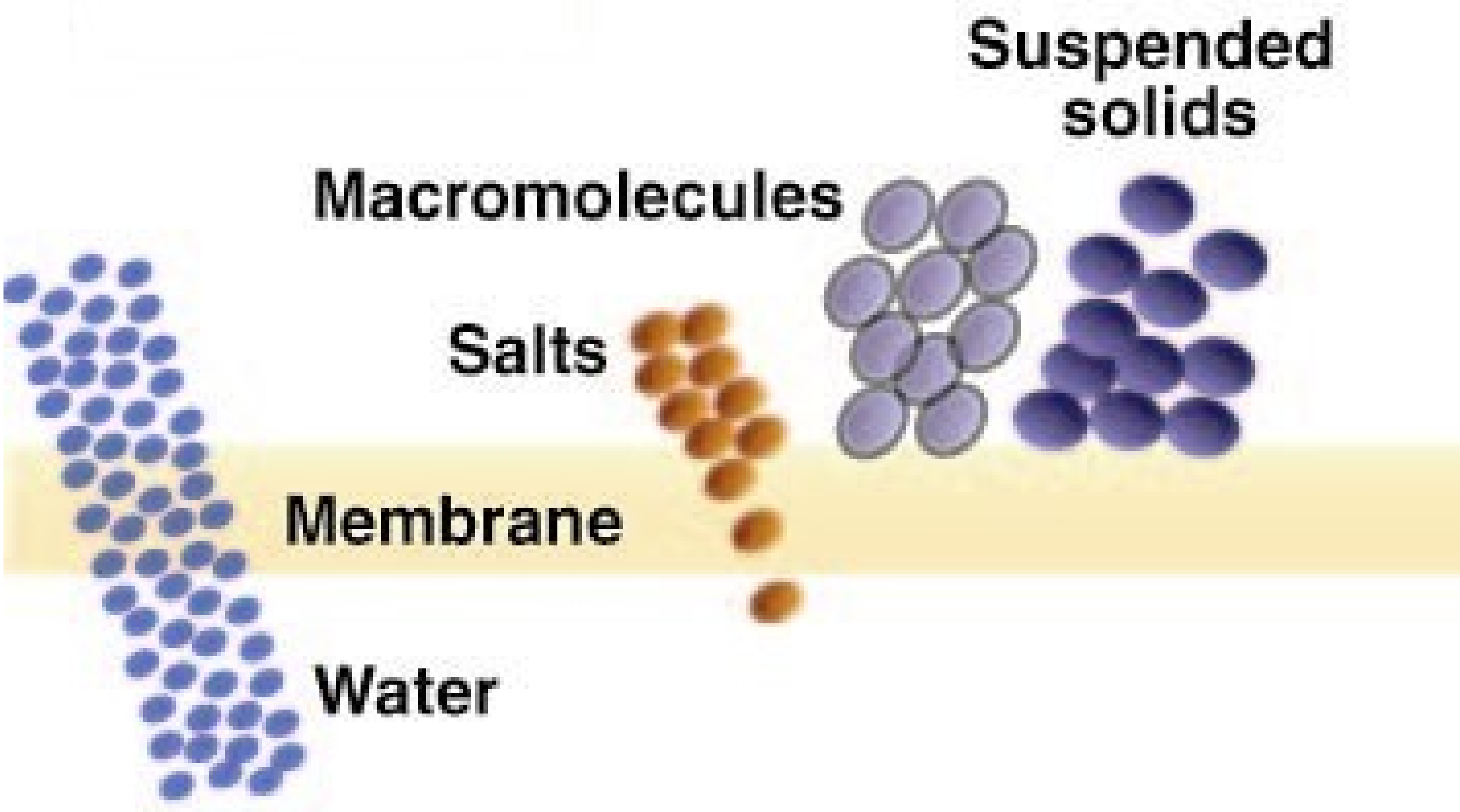
Ultrafiltration



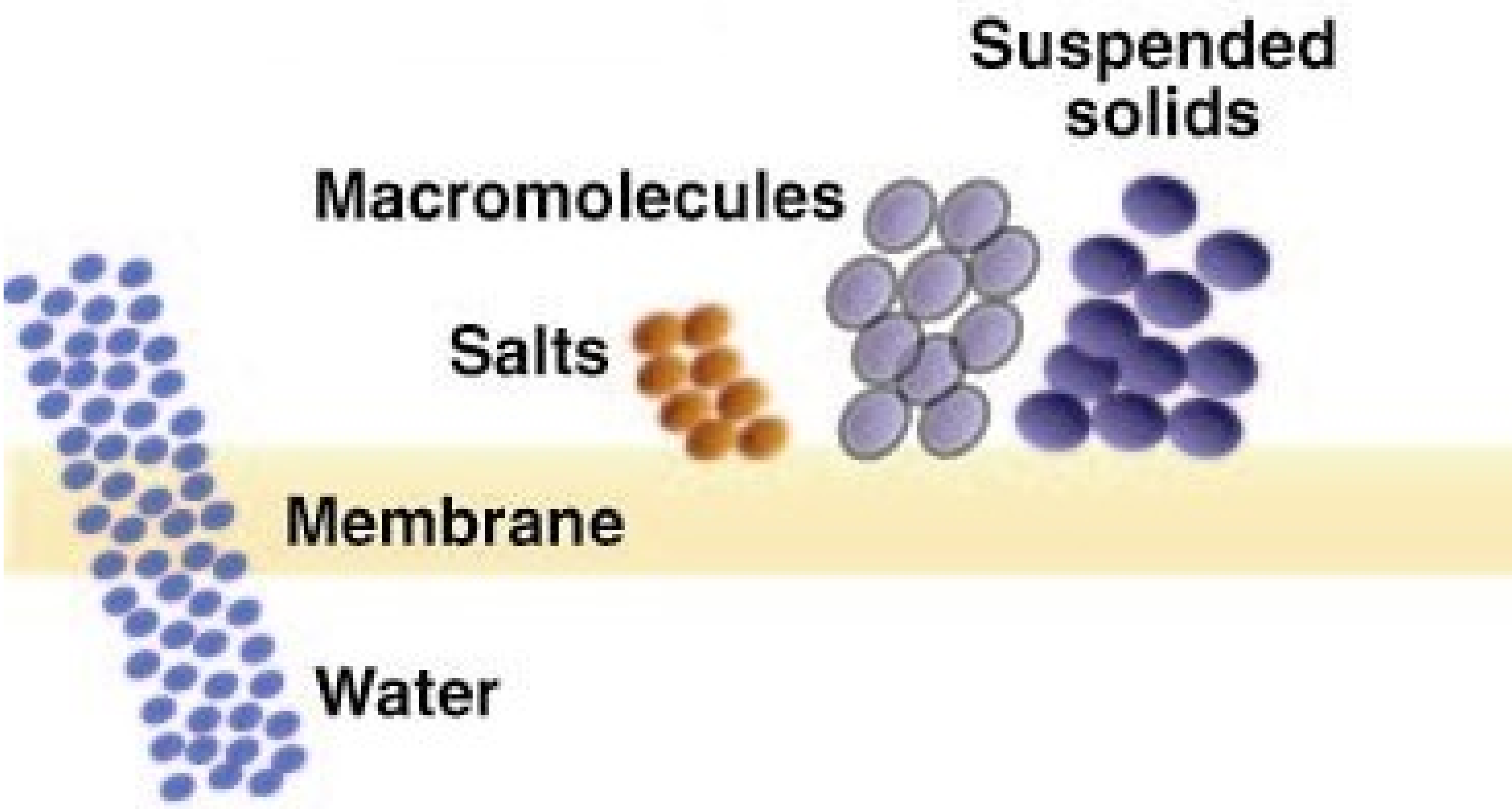
Ultrafiltration



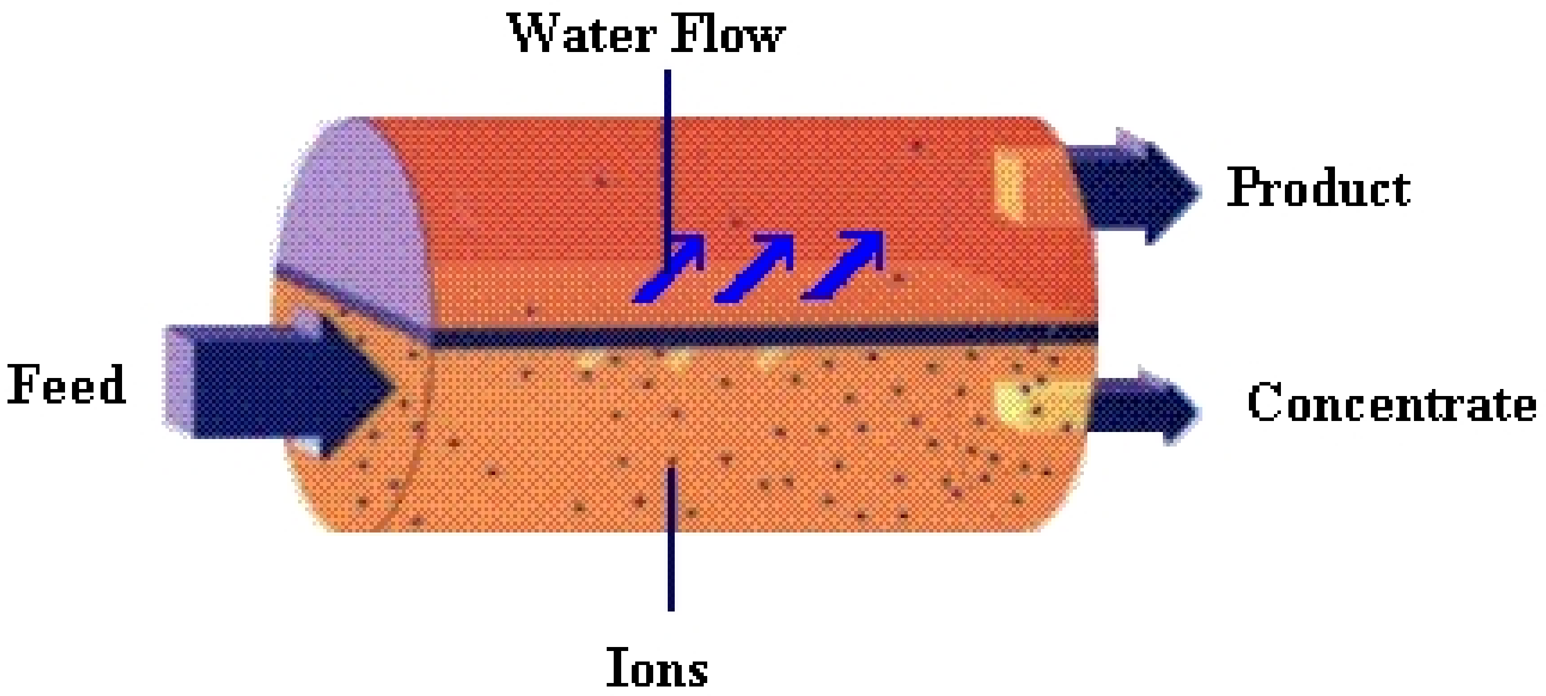
Nanofiltration

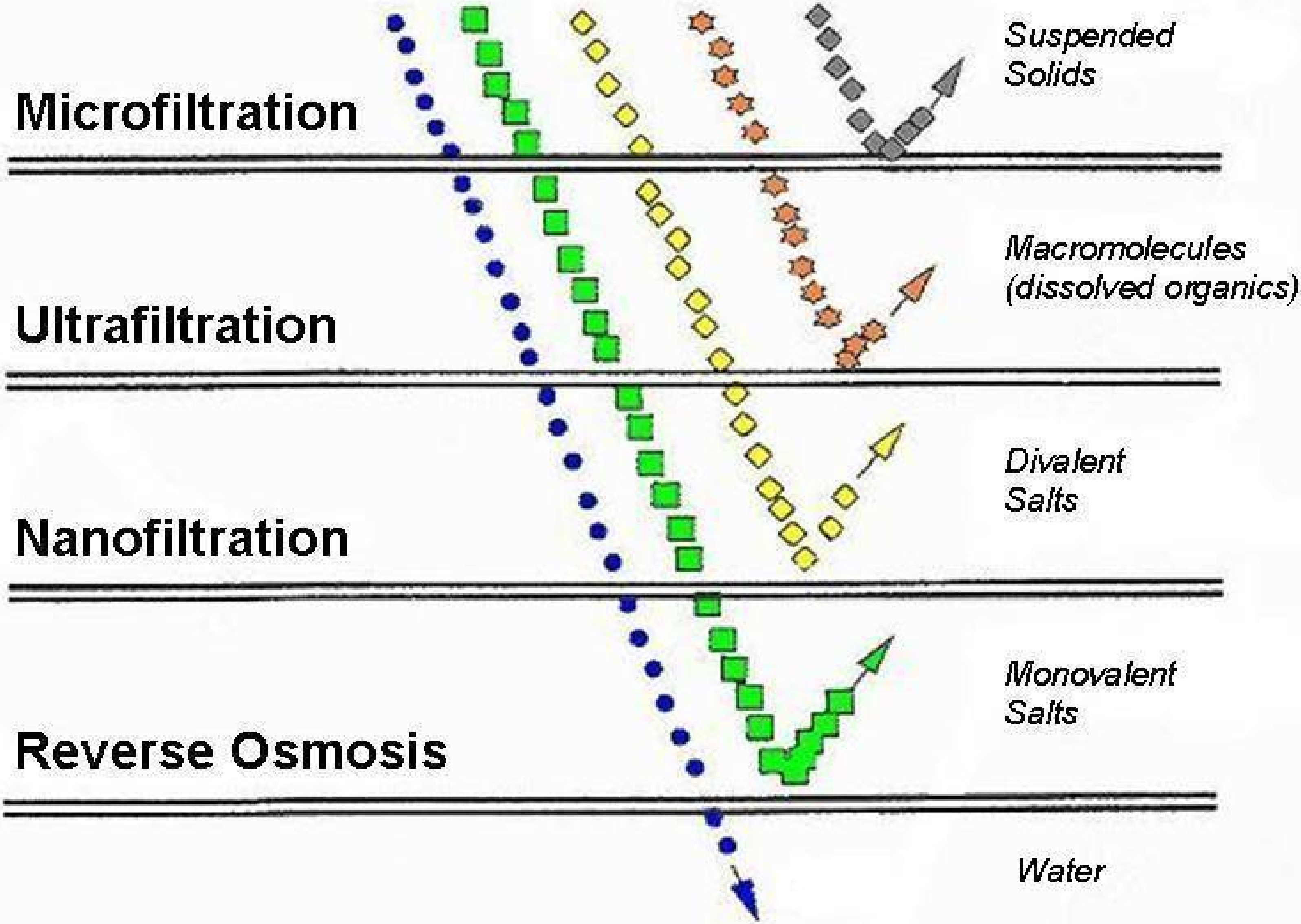


Reverse Osmosis



Reverse Osmosis




Microfiltration
Ultrafiltration
Nanofiltration
Reverse Osmosis
Suspended Solids
Macromolecules (dissolved organics)
Divalent Salts
Monovalent Salts
Water

Membrane Technologies Compared

Feature	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Materials of Construction	Ceramics, Sintered metals, Polypropylene, Polysulfone, Polyethersulfone, Polyvinylidene fluoride, Polytetrafluoroethylene	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+%
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.*

Device Configurations

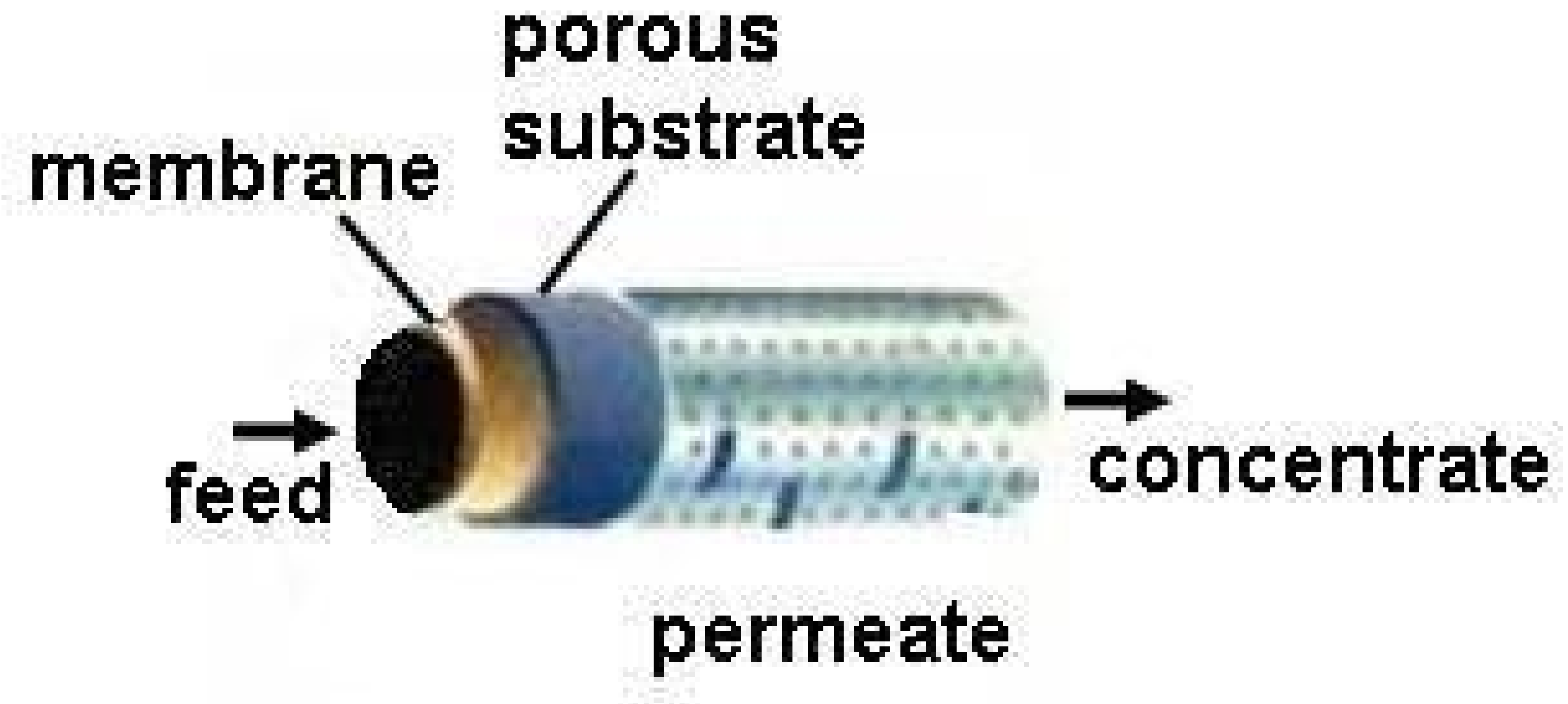
Tubular

Hollow (Capillary) Fiber

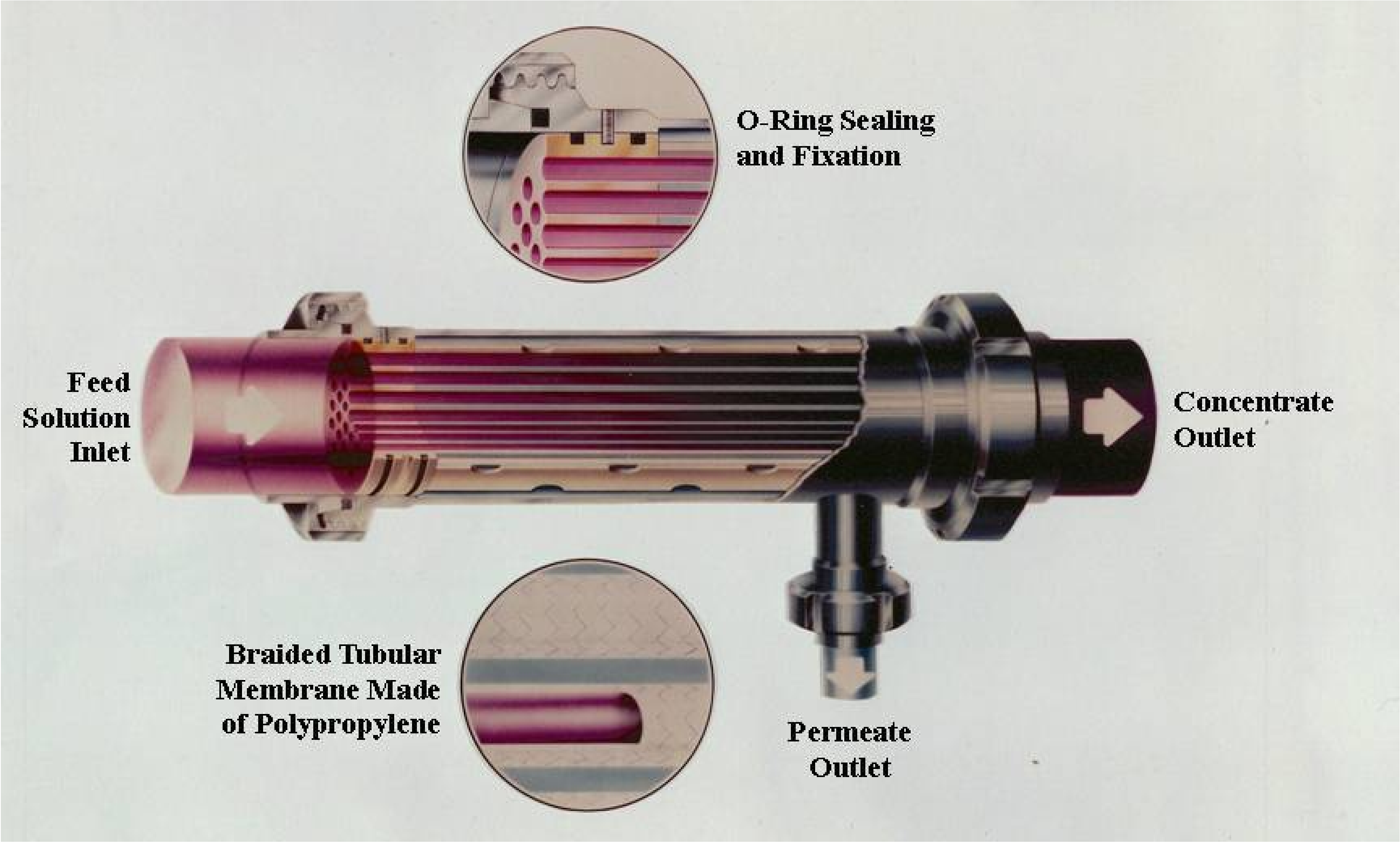
Spiral Wound

Plate & Frame

Tubular

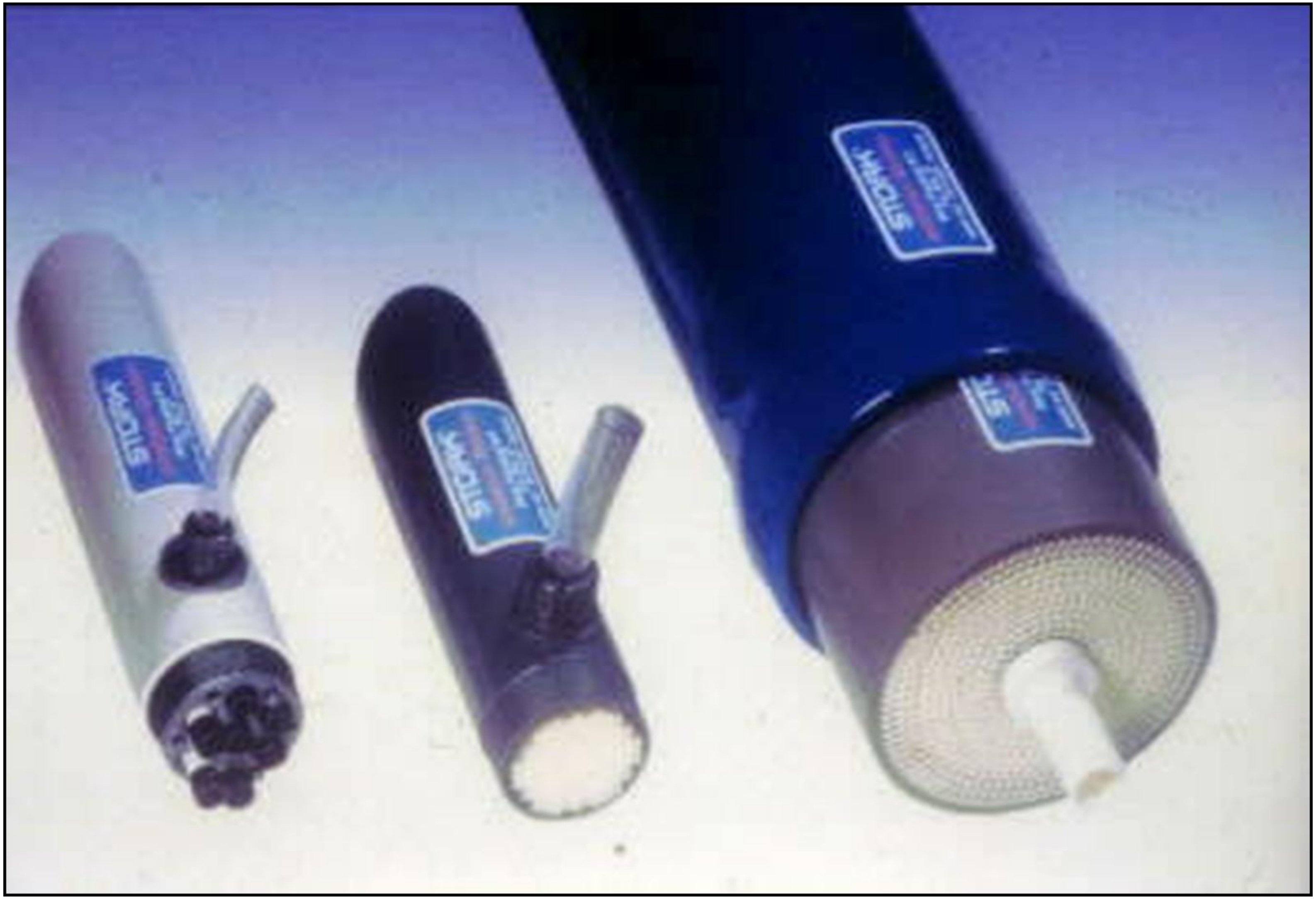


Tubular



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

Tubular



Hollow (Capillary) Fiber

Spiral Wound

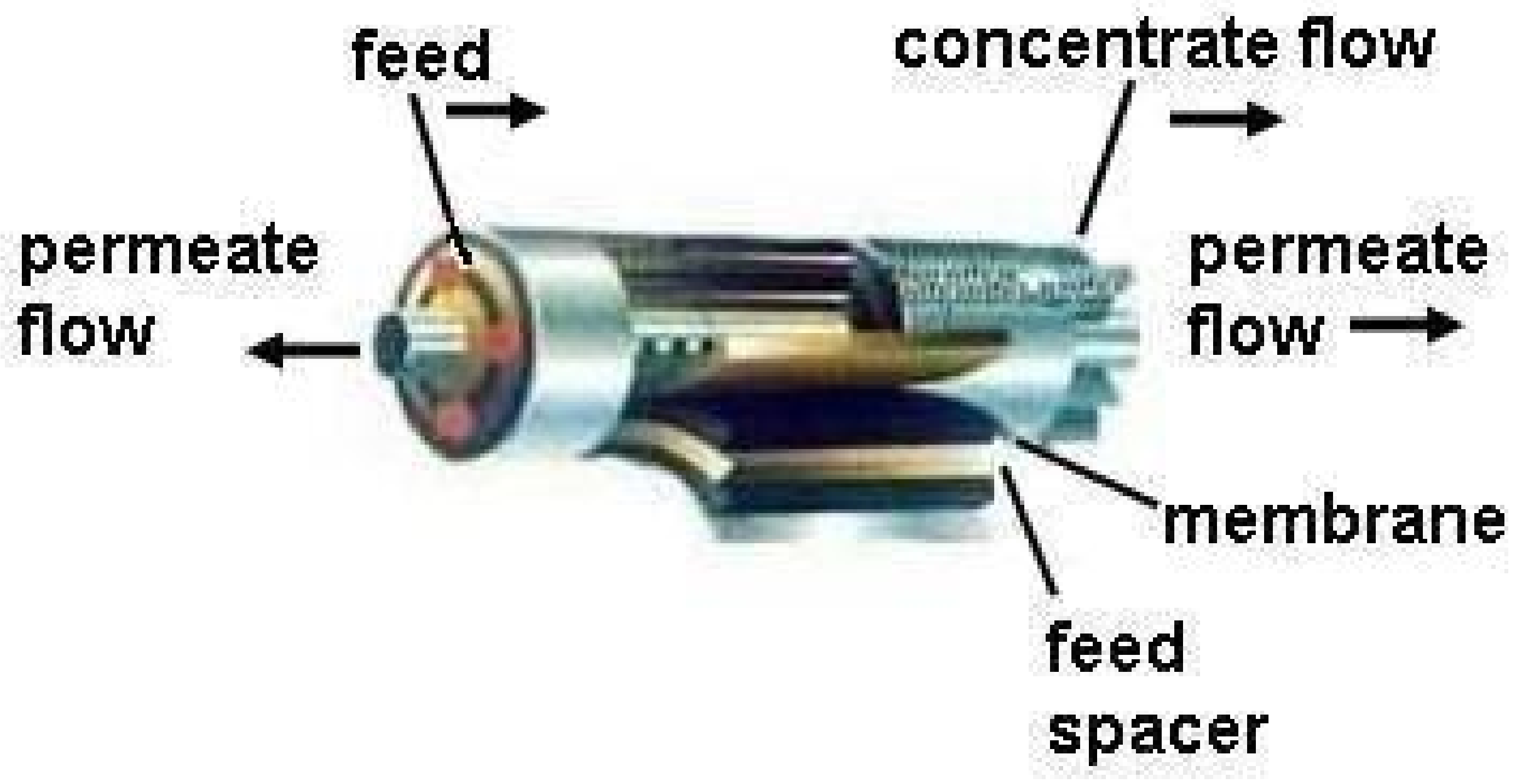


Plate & Frame

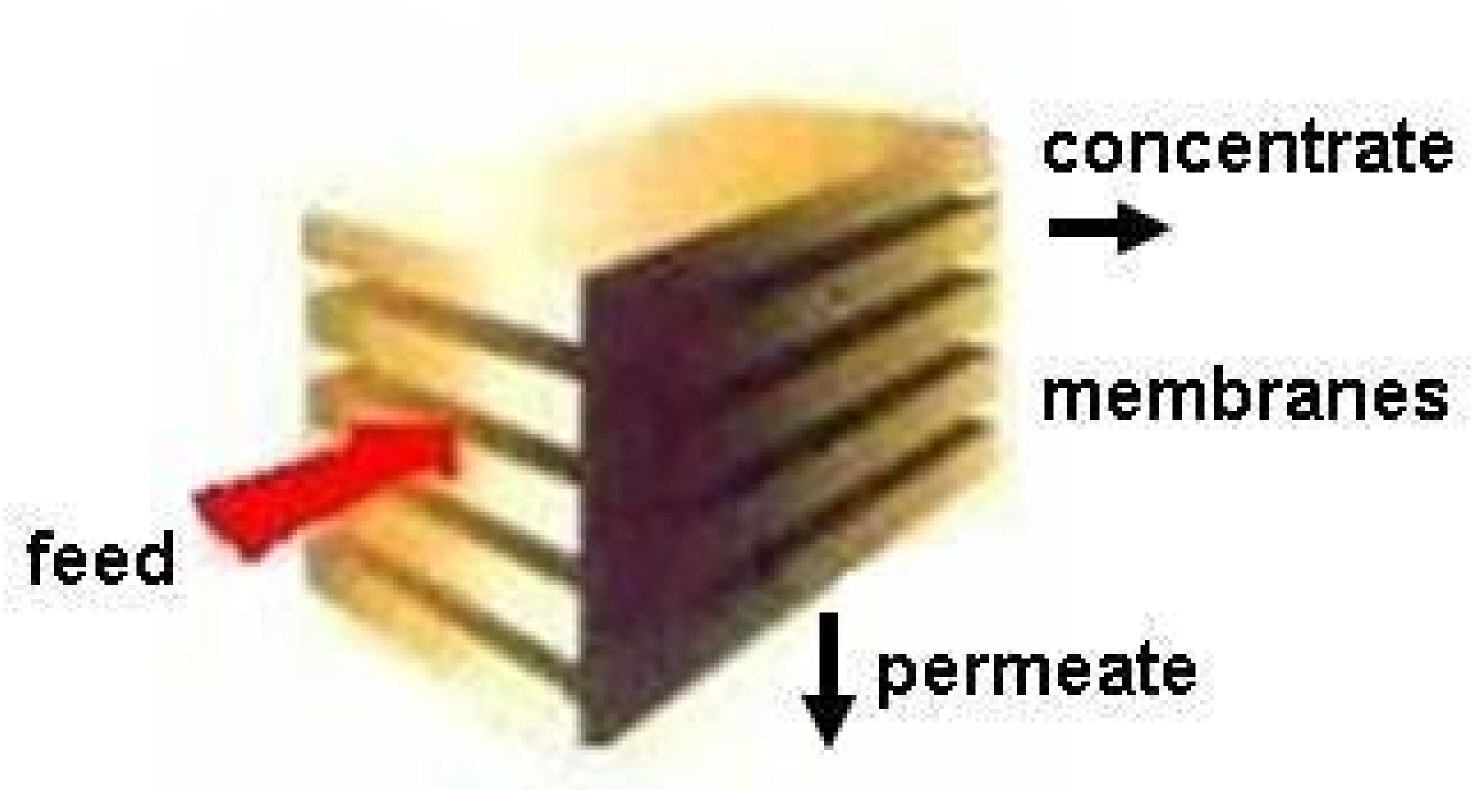
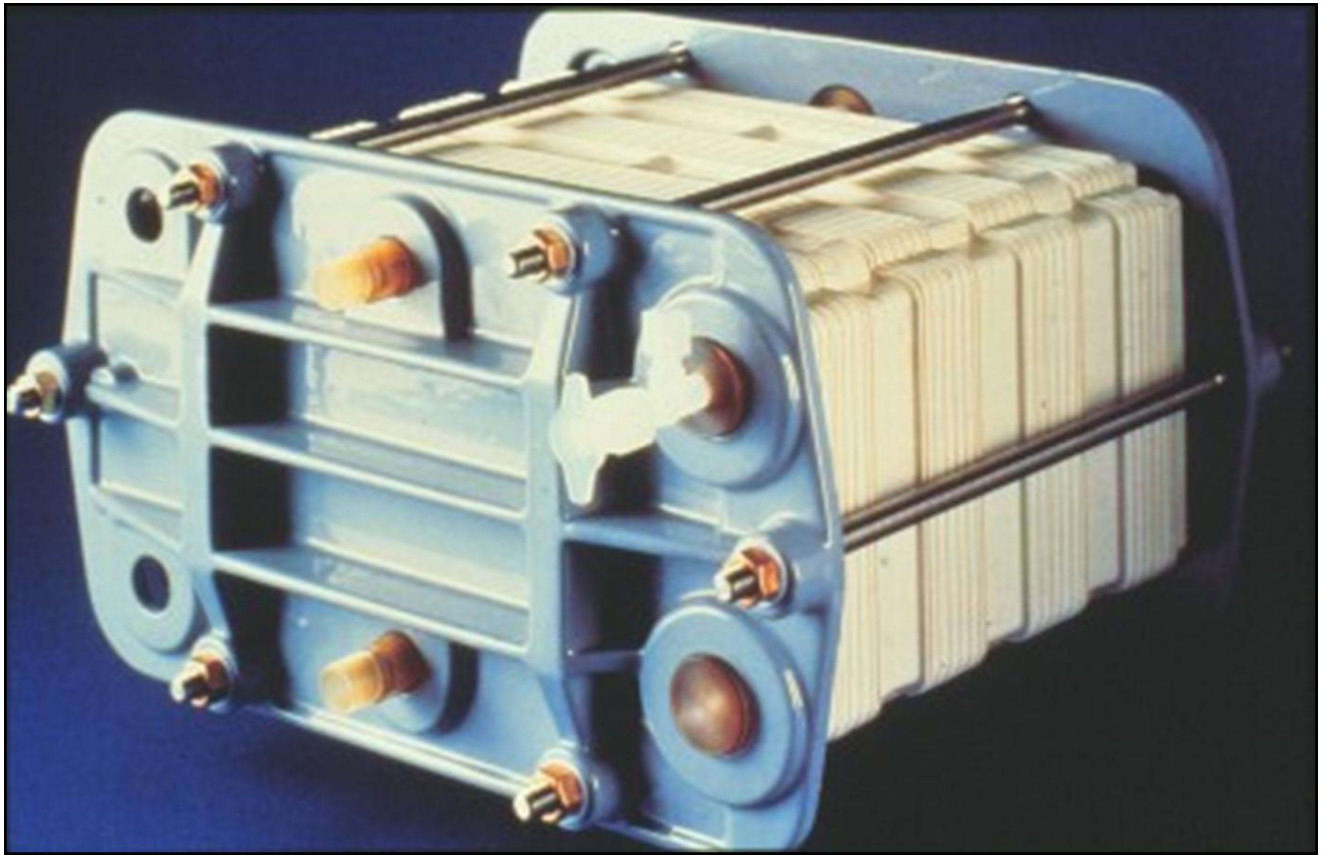


Plate & Frame



Membrane Element Configuration Comparison

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

** Membrane area per unit volume*

*** Tolerance to suspended solids*

Microfiltration (MF) & Ultrafiltration (UF)

Materials of Construction	Device Configuration			
	Hollow Fiber	Tubular	Plate & Frame	Spiral Wound
<u>Polymeric</u>				
PS	X	X	X	X
PES	X	X	X	X
PAN	X	X	X	X
PE	–	X	–	–
PP	X	X	X	–
PVC	–	X	–	–
PVDF	X	X	–	–
PTFE	X	–	X	–
PVP	X	X	–	–
CA	X	–	–	–
<u>Non-Polymeric</u>				
Coated 316LSS	–	X	–	None
a- Alumina	–	X	X	None
Titanium Dioxide	–	X	–	None
Silicon Dioxide	–	X	–	None

PS = Polysulfone

PES = Polyethersulfone

PE = Polyethylene

PP = Polypropylene

PAN = Polyacrylonitrile

PVDF = Polyvinylidene Fluoride

PTFE = Polytetrafluoroethylene

CA = Cellulose Acetate

PVP = Polyvinylpyrrolidone

TF = Thin Film Composite

Nanofiltration (NF) & Reverse Osmosis (RO)

Materials of Construction	Device Configuration			
	Hollow Fiber	Tubular	Plate & Frame	Spiral Wound
Polymeric				
PS*	–	X	X	X
PES*	–	X	X	X
CA	–	X	X	X
TF	–	X	X	X
Non-Polymeric				
None				

** Base polymer below TF polymer*

PS = Polysulfone

PES = Polyethersulfone

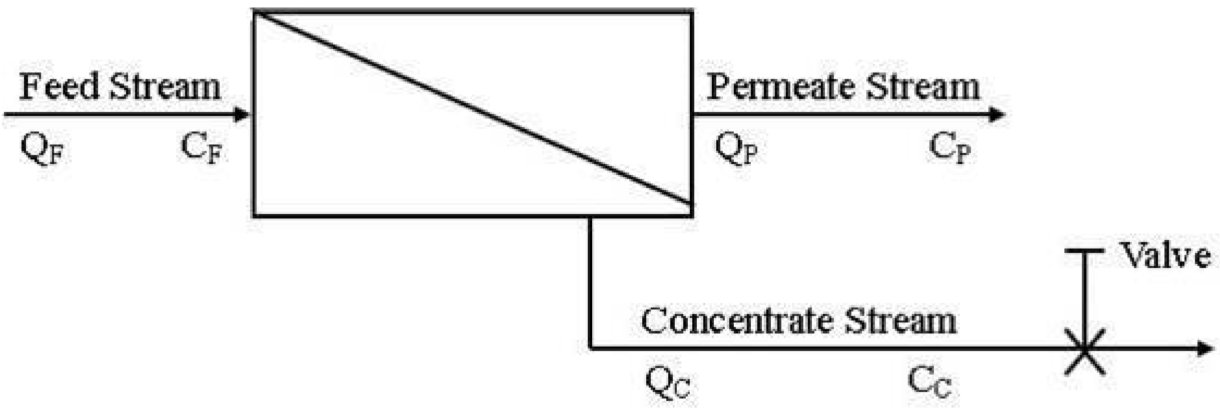
CA = Cellulose Acetate

TF = Thin Film Composite

Membrane Element Cleaning Capability

Element Configuration	Membrane Technology				Backwashable?
	MF	UF	NF	RO	
Plate & Frame	Yes	Yes	Yes	Yes	No (except for inorganic membrane)
Tubular	Yes	Yes	Yes	Yes	Yes
Hollow Fiber	Yes	Yes	Yes	No	Yes
Spiral Wound	Yes	Yes	Yes	Yes	No (NF, RO) Yes (MF, UF)

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)

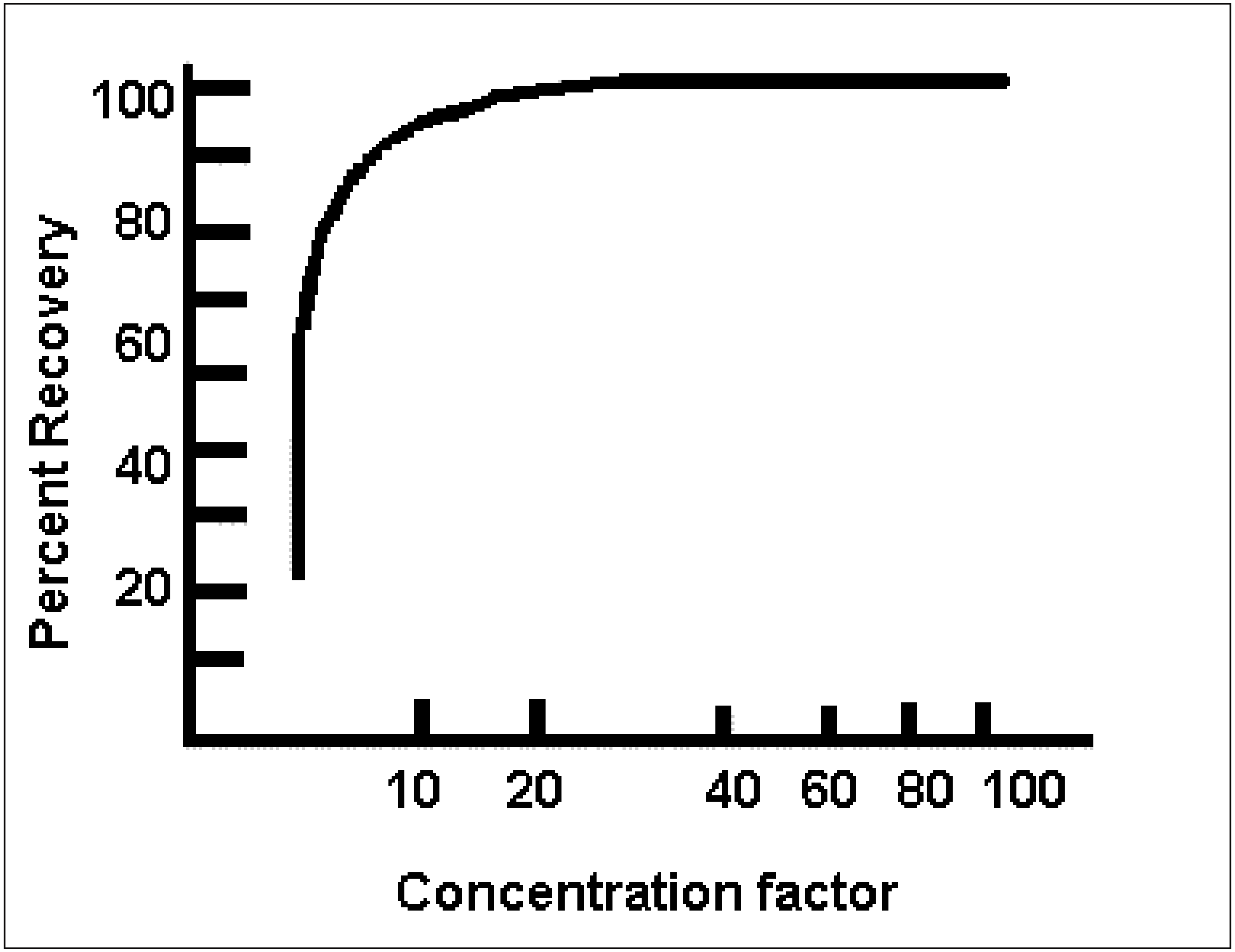
Effect of Recovery on Concentration

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

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

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

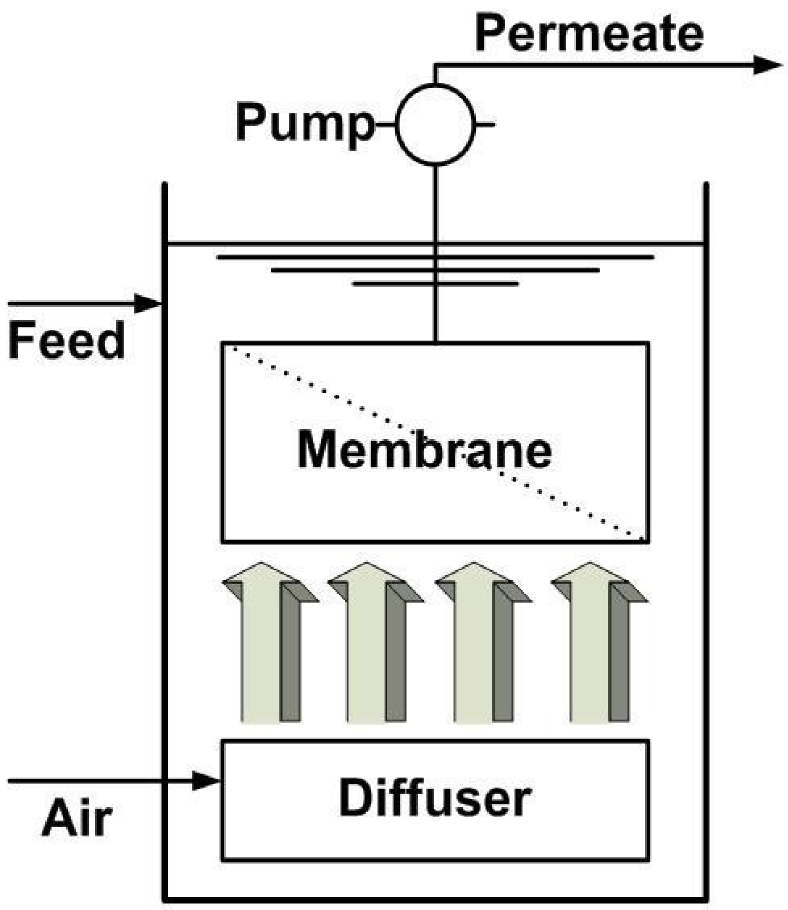
Effect of Recovery on Concentration Factor



MBR

- High-quality effluent, almost free of suspended solids.
- The ability to partially disinfect without the need for chemicals.
- Complete independent control of HRT (Hydraulic Retention Time) and SRT (Sludge Retention Time).
- Reduced sludge production.
- Process intensification through high biomass concentrations with MLSS (Mixed Liquor Suspended Solids) concentrations above 15,000 mg/L.
- Treatment of recalcitrant organic fractions and improved stability of processes such as nitrification.
- Ability to treat high strength wastes.

Aerobic MBR Applications



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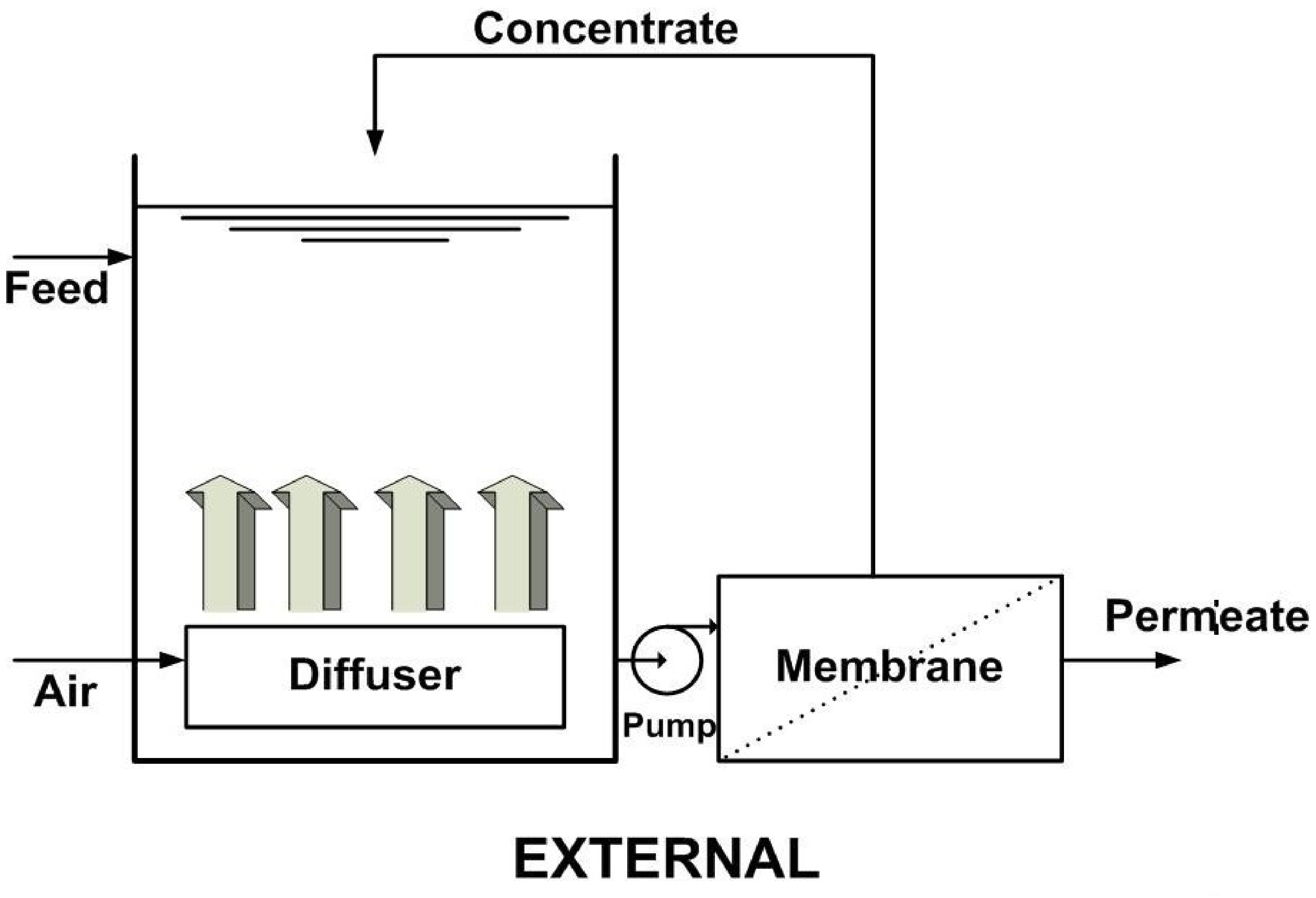
Aerobic MBR Applications

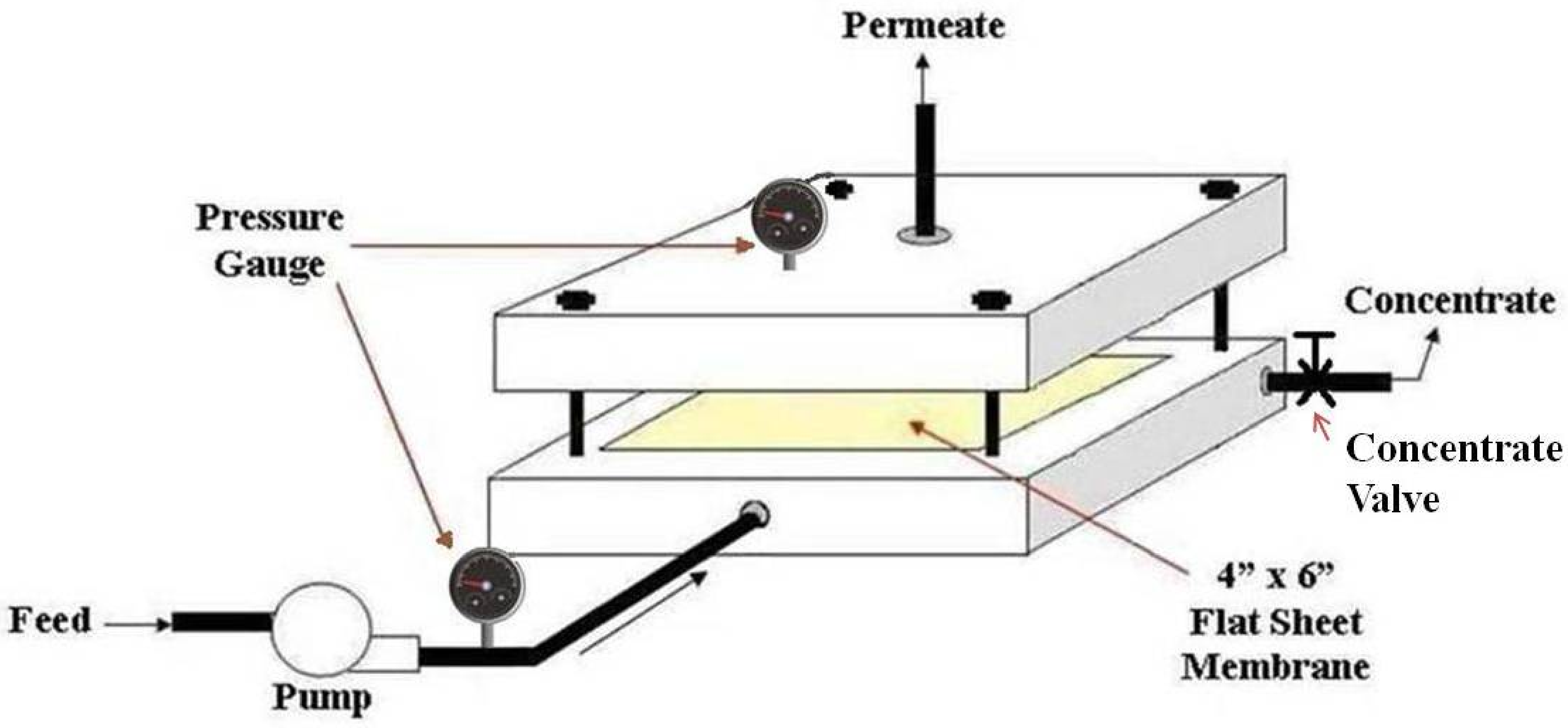


Design Factor Considerations

- Optimum membrane element configuration
- Total membrane area
- Specific membrane polymer
- Optimum pressure
- Maximum system recovery
- Flow conditions
- Membrane element array
- Pretreatment requirements

TESTING

Cell Test Unit



Cell Testing

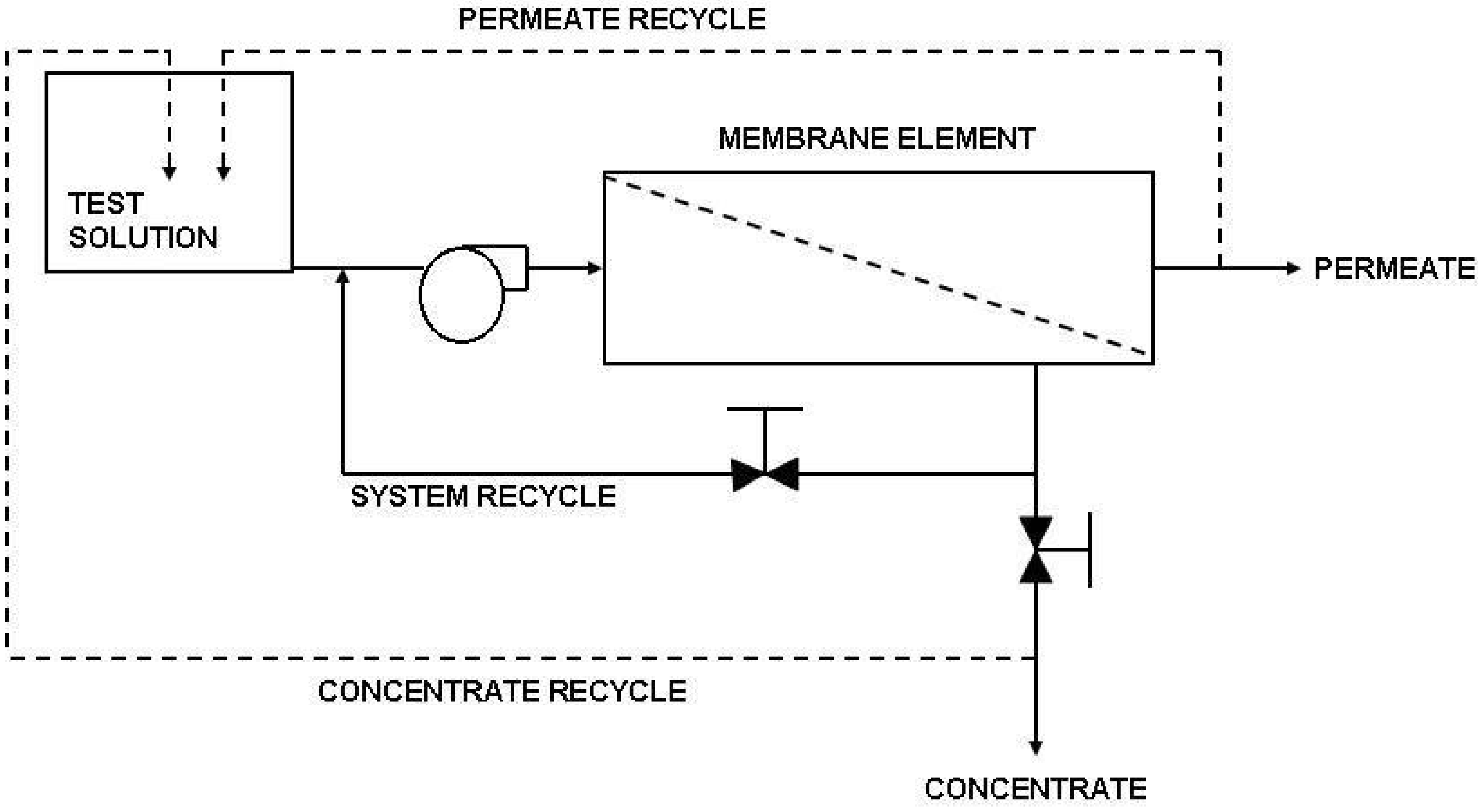
Advantages

- Only small areas of membranes are needed; excellent for screening various membranes
- Unit is simple to operate
- Can be run on small volumes of test stream
- Takes very little time

Disadvantages

- Cannot obtain engineering design data
- Cannot be used for long-term fouling studies
- Is only useful with membranes available as flat sheet

Applications
Test Schematic



Applications Testing

- Run control (tap water or water treated with RO or DI)

  Take data (see Membrane Application Test Data Sheet)

- Run feedwater starting at low recovery, and after stabilization (usually less than 5 minutes) take data (see Membrane Application Test Data Sheet)

The system recovery is then increased incrementally while adjusting the recycle valve to ensure that the correct crossflow velocity is maintained.

Applications Testing

Advantages

- Fast
- Provides scale-up data

  (Flux rate, osmotic pressure as a function of recovery, pressure requirements, etc.)
- Can provide an indication of membrane stability

Disadvantages

- Does not reveal long term chemical effects
- Does not provide data on long term fouling effects

Pilot Testing

Advantages

- Accomplishes all of the functions of the applications test plus provides long term membrane fouling and stability data.

Disadvantages

- Expensive in terms of monitoring and time requirements.

MEMBRANE APPLICATION TEST DATA

Date: ____________________ Client: ______________________________________

Membrane Element: ____________________ ______________________________________

____

		PRESSURE			FLOW			TEMP	CONDUCTIVITY		
	% Recovery	Prefilter ΔP	Primary	Final	Recycle	Permeate	Concentrate		Feed	Permeate	Concentrate
Start											
End											

Comments: ____

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Conclusions

WATER – CRITICAL TO LIFE

Conservation, **Collection & Conversion**

are practical, economical and essential

Water Recovery & Reuse

is an achievable goal