Cartwright Consulting Co.

www.cartwright-consulting.com
pscartwright@msn.com

United States Office
8324 16th Avenue South
Minneapolis, MN 55425-1742
Phone: (952) 854-4911
Fax: (952) 854-6964

European Office
President Kennedylaan 94
2343 GT Oegstgeest
The Netherlands
Phone: 31-71-5154417
Fax: 31-71-5156636

THE ROLE OF MEMBRANE TECHNOLOGIES IN WATER REUSE APPLICATIONS

by

Peter S. Cartwright, PE

Membranes in Drinking & Industrial Water Production
Leeuwarden, The Netherlands

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Outline

Introduction

Water Reuse

Membrane Technologies

Device Configurations

System Design

Testing

Conclusions

Water Reuse Growth in the U.S.

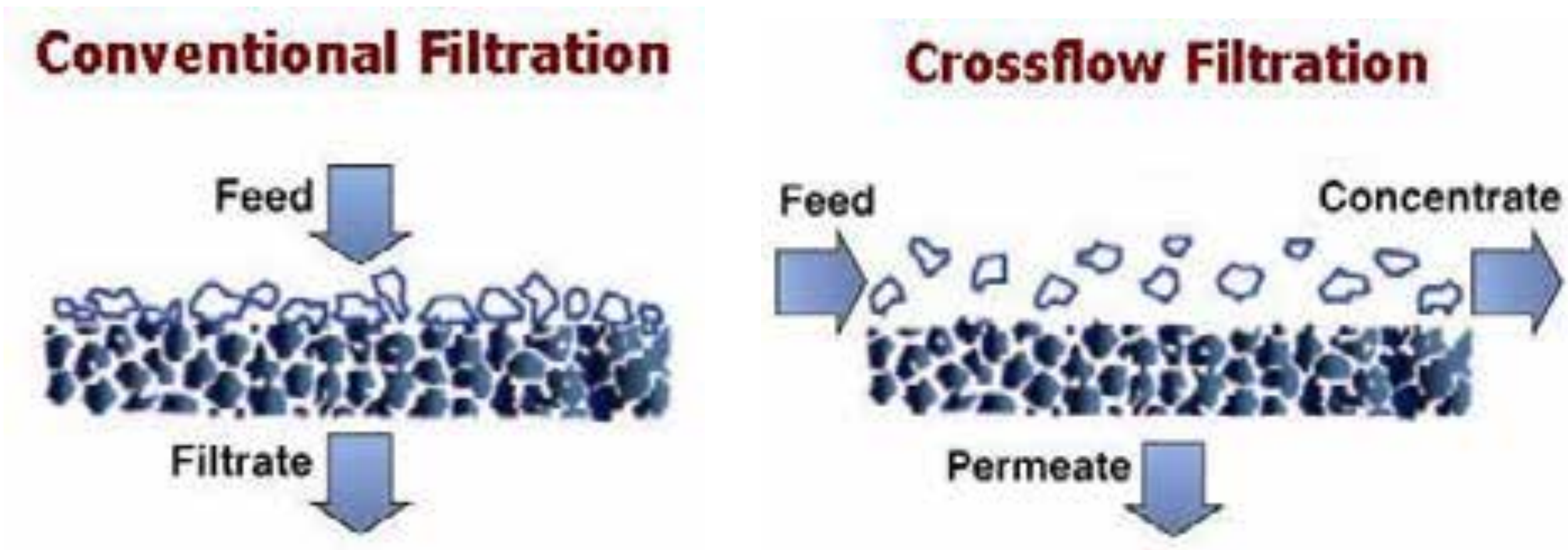
Overall: 11% per year

Industrial: 14% per year

Membrane Technologies

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

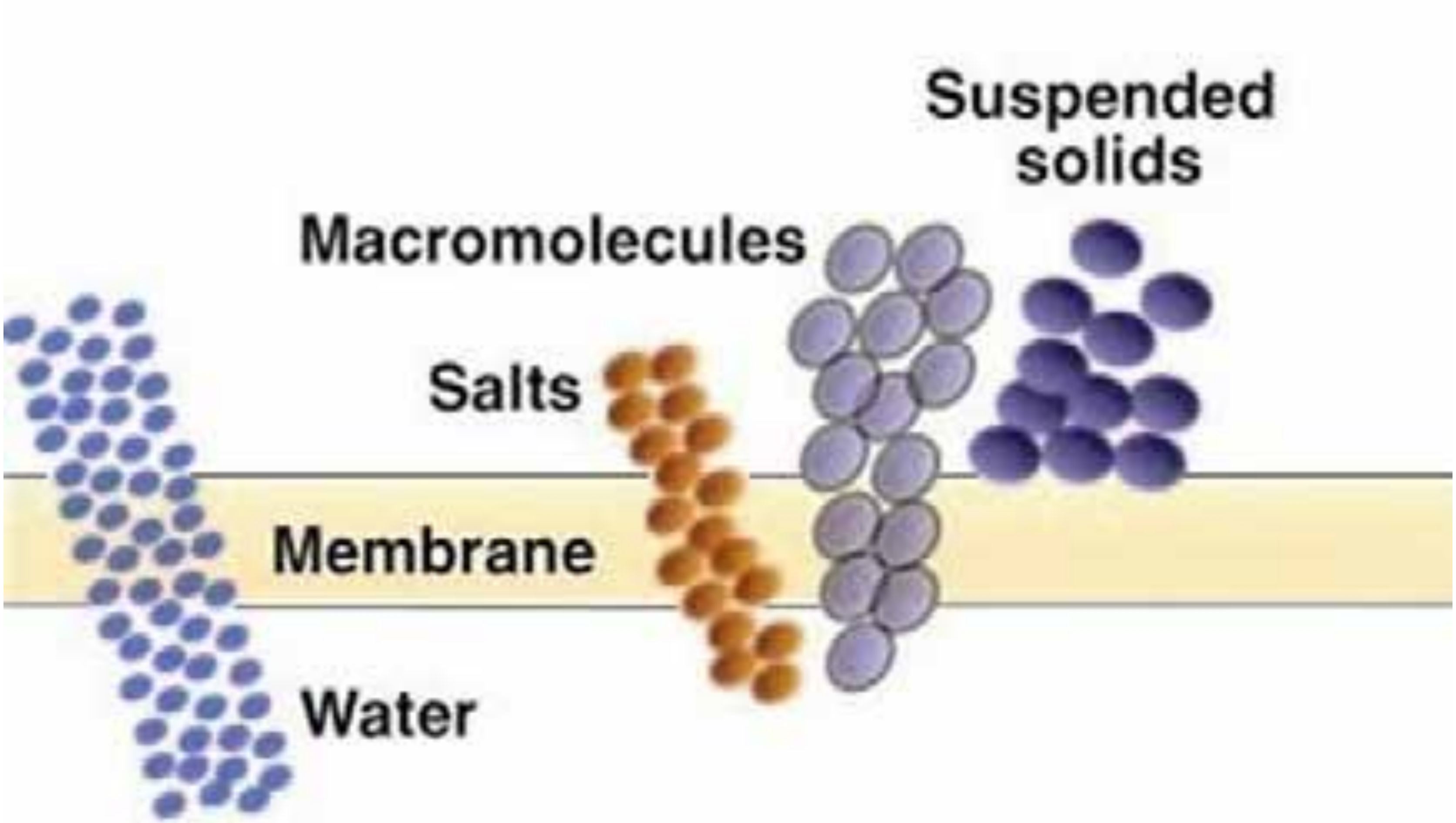
Conventional vs. Crossflow Filtration



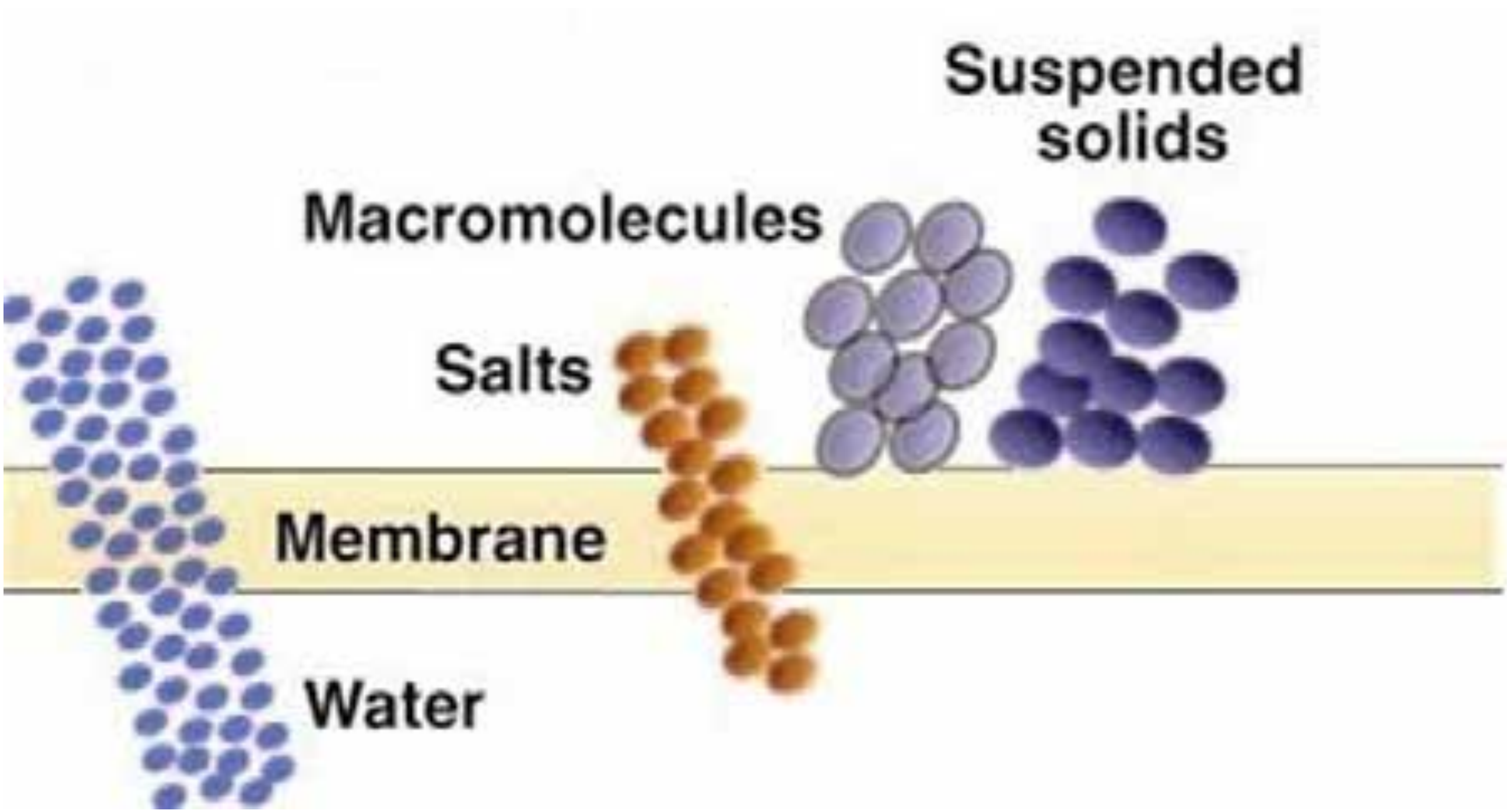
Membrane Technologies Advantages

- ✓ 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.

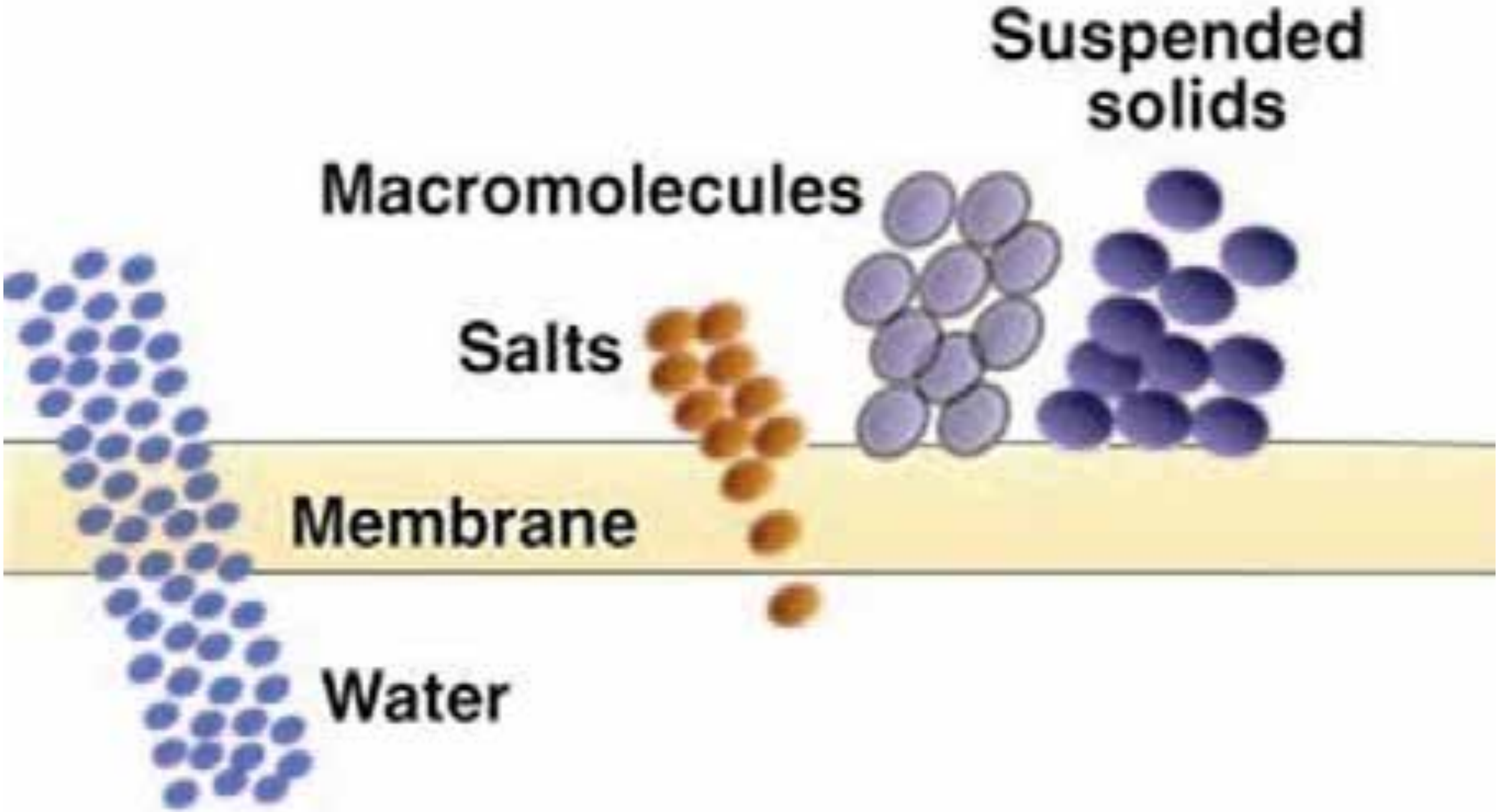
Microfiltration



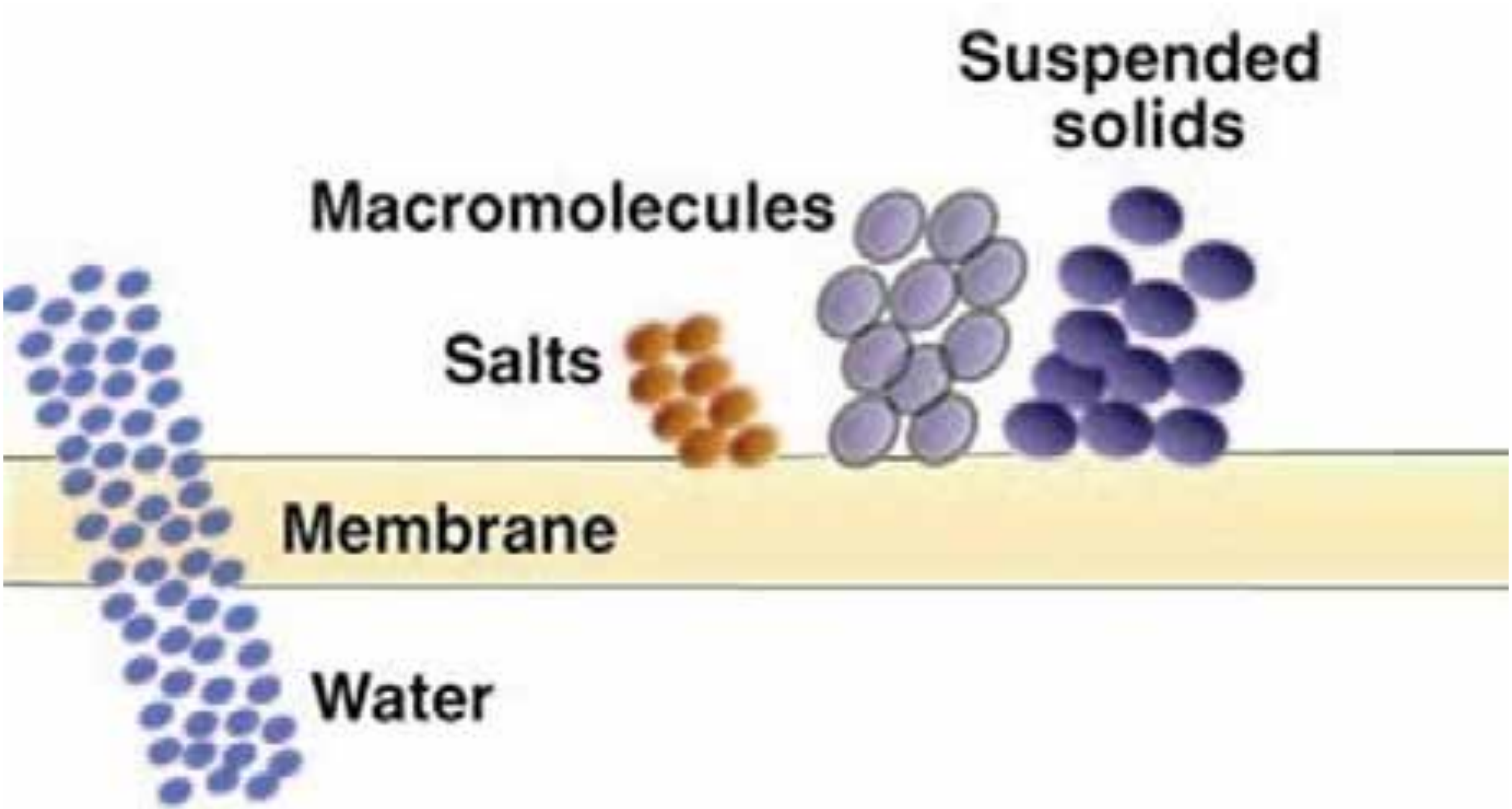
Ultrafiltration



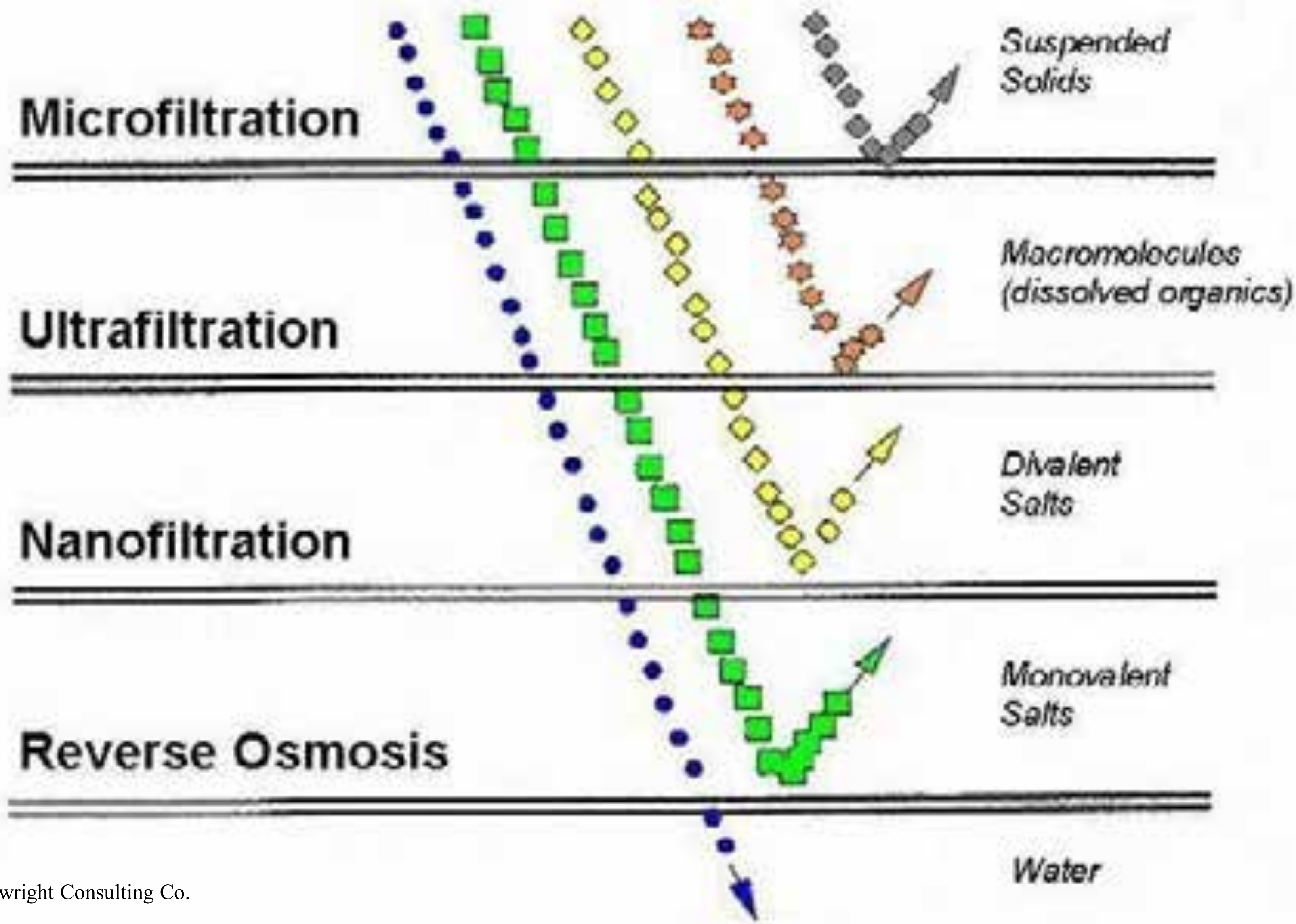
Nanofiltration



Reverse Osmosis



Membrane Technologies



Membrane Technologies Compared

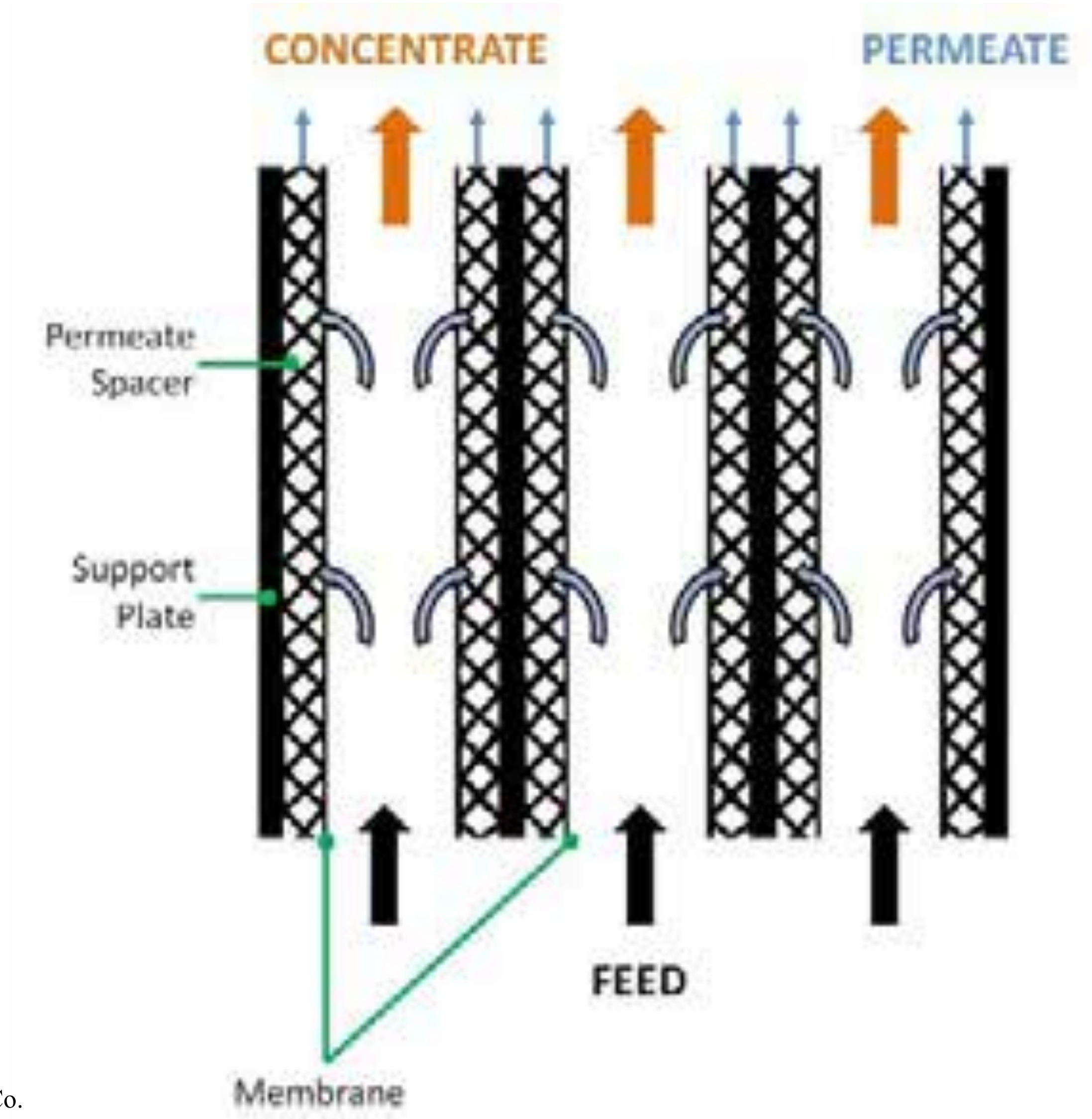
Feature	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Materials of Construction	Ceramics, Sintered metals, Polypropylene, Polysulfone, Polyethersulfone, Polyvinylidene fluoride, Polytetrafluoroethylene	Ceramics, Sintered metals, Polypropylene, Polysulfone, Polyethersulfone, Polyvinylidene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

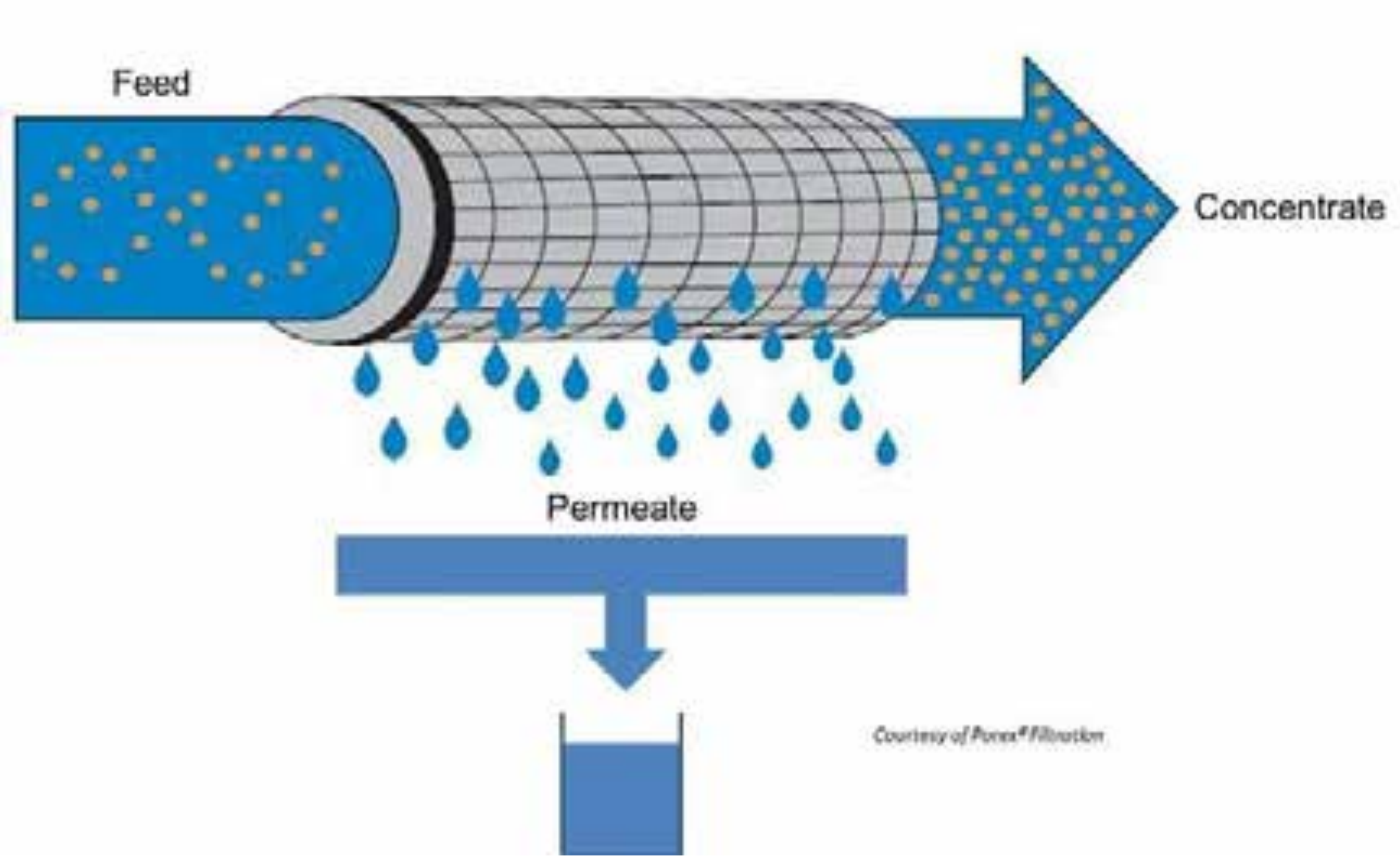
Device Configurations

- Plate & Frame
- Tubular
- Hollow (Capillary) Fiber
- Spiral Wound

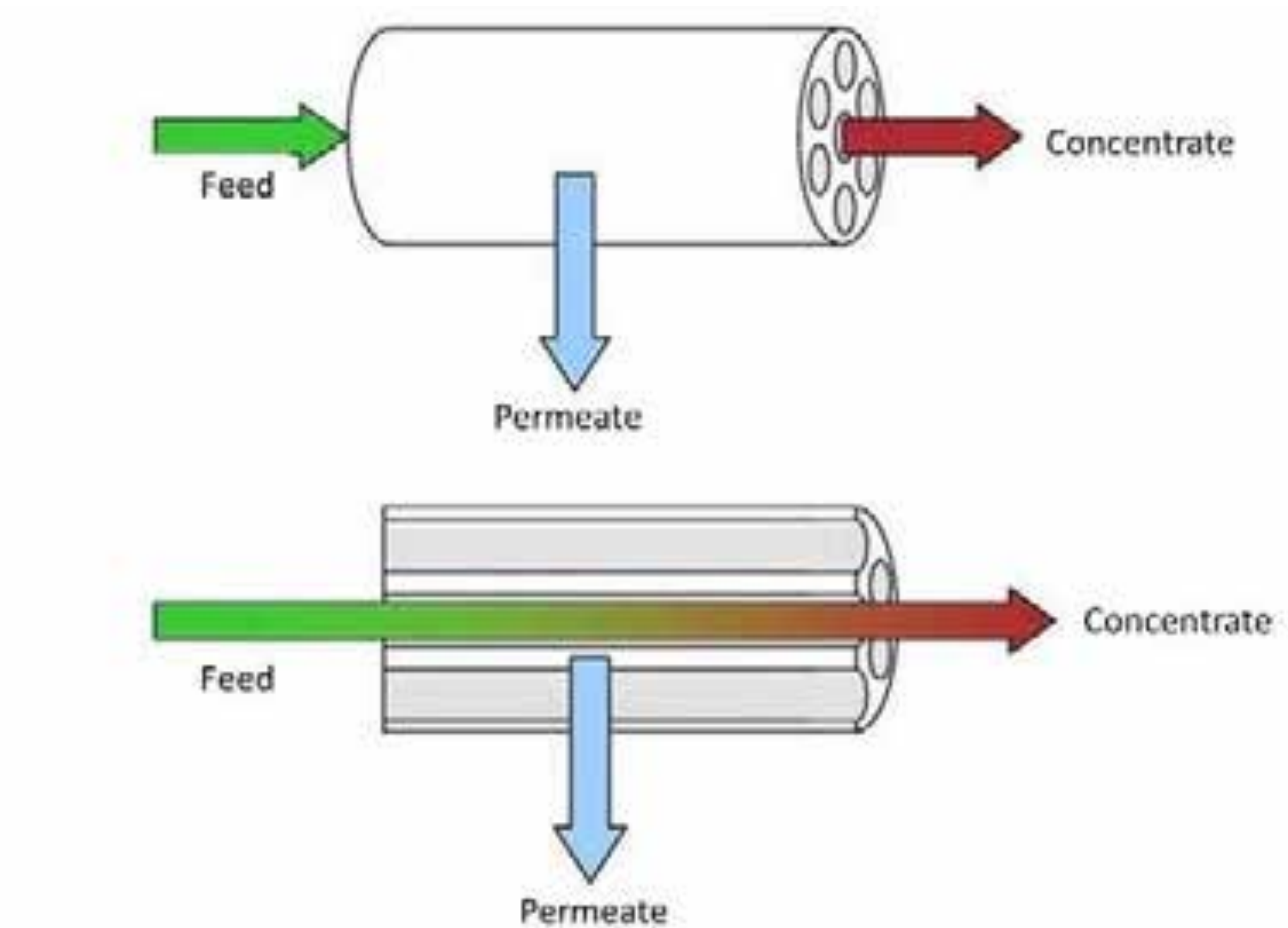
Plate & Frame


CONCENTRATE
PERMEATE
Permeate
Spacer
Support
Plate
FEED
Membrane

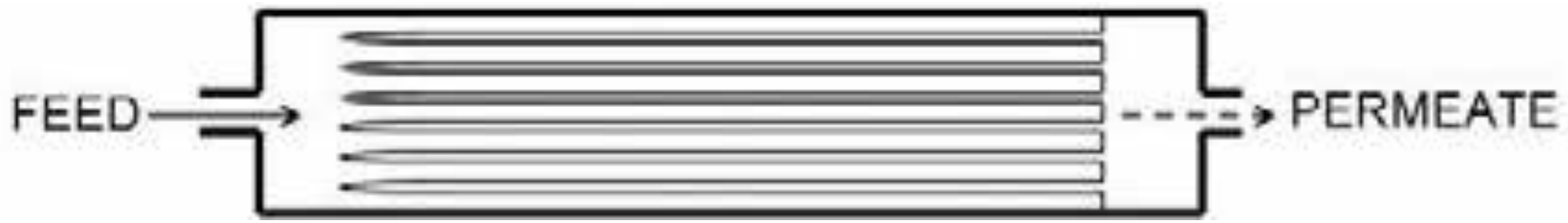
Tubular



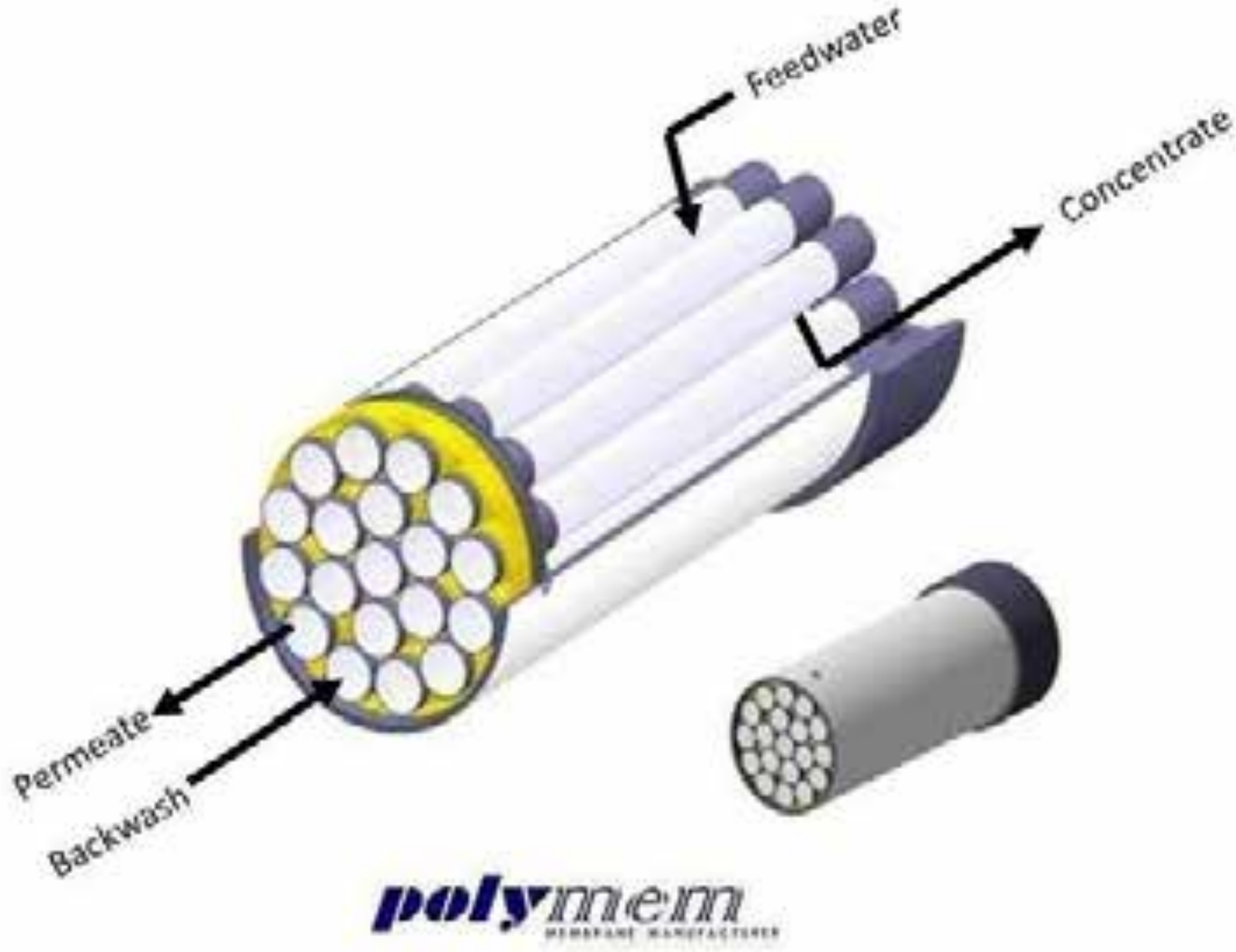
Tubular



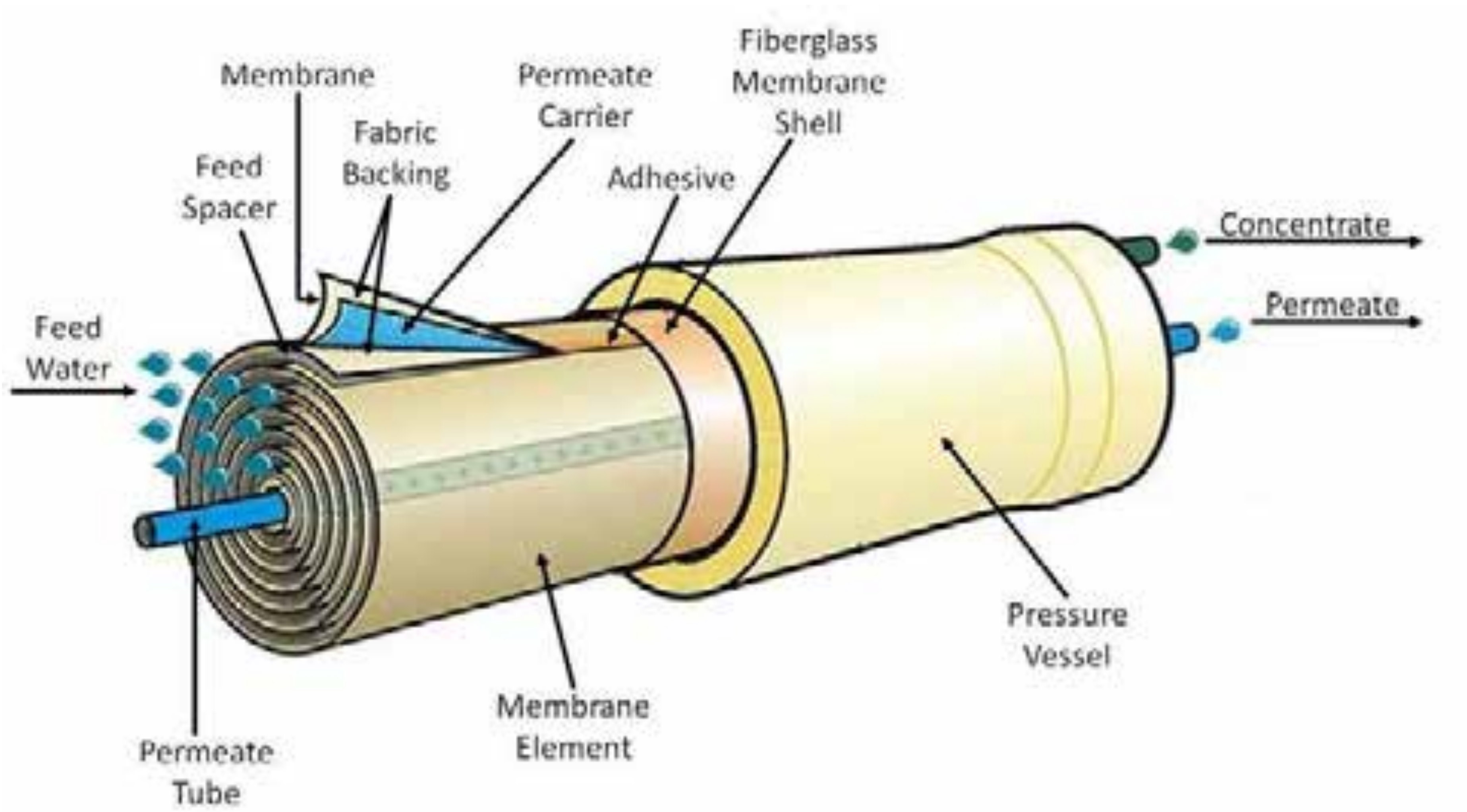
Hollow (Capillary) Fiber



Hollow (Capillary) Fiber



Spiral Wound



Membrane Element Configuration Comparison

MEMBRANE ELEMENT CONFIGURATION COMPARISON

Element Configuration	Packing Density *	Fouling Resistance **
Plate & Frame	Low	High
Tubular	Low	Very High
Hollow (Capillary) Fiber	High	Medium
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
Polymeric				
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	–	–	–
Non-Polymeric				
Coated 316LSS	–	X	–	None
α- 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
<u>Polymeric</u>				
PS*	–	X	X	X
PES*	–	X	X	X
CA	–	X	X	X
TF	–	X	X	X
<u>Non-Polymeric</u>				
None				

** Base polymer below TF polymer*

PS = Polysulfone

PES = Polyethersulfone

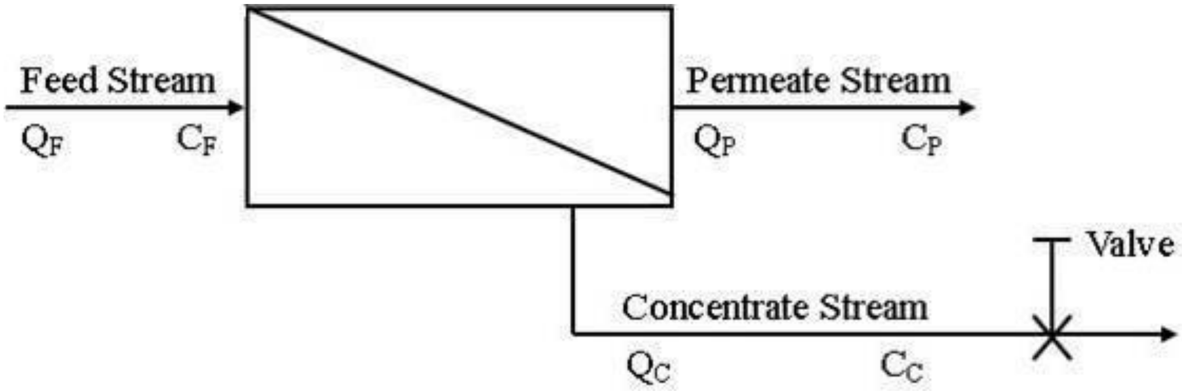
CA = Cellulose Acetate

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)

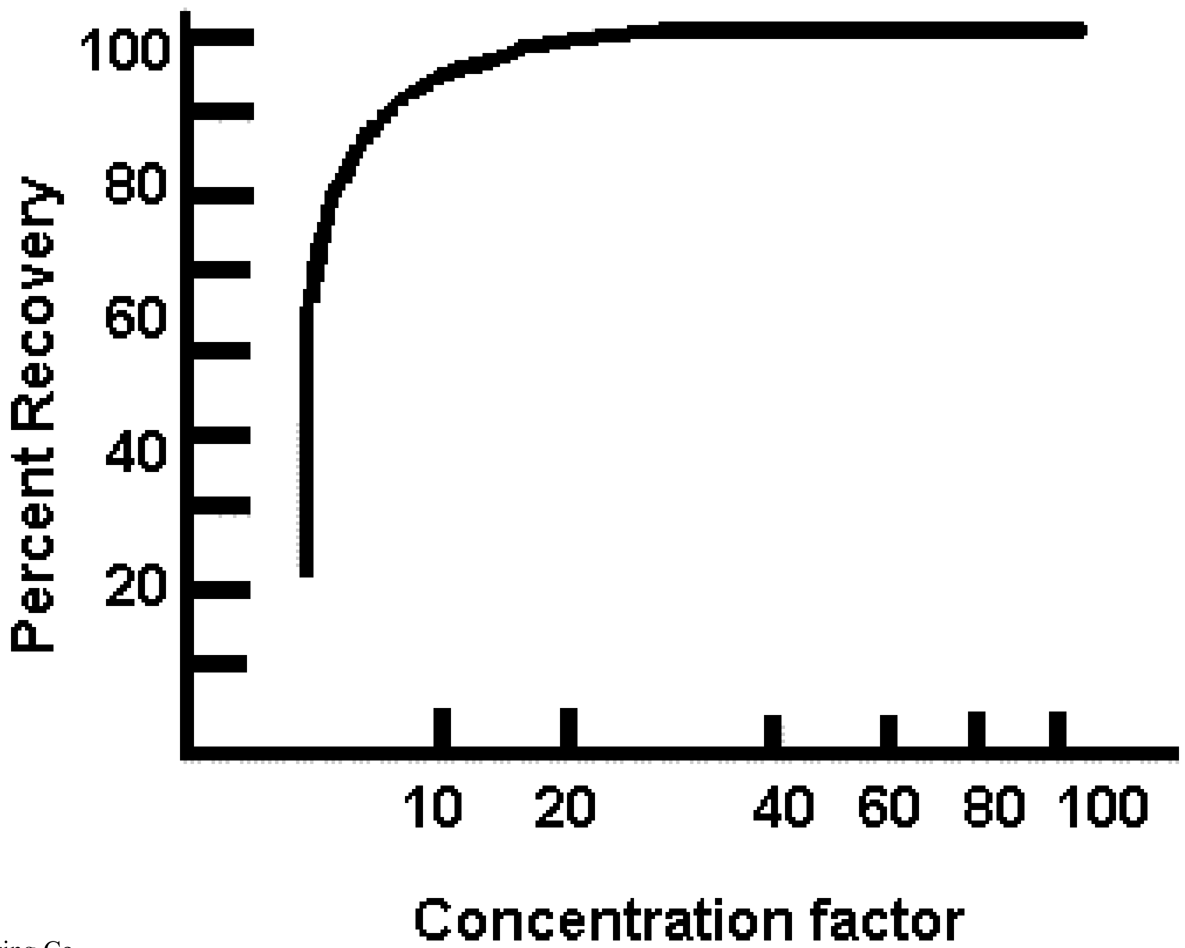
Effect of Recovery on Concentration

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

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

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

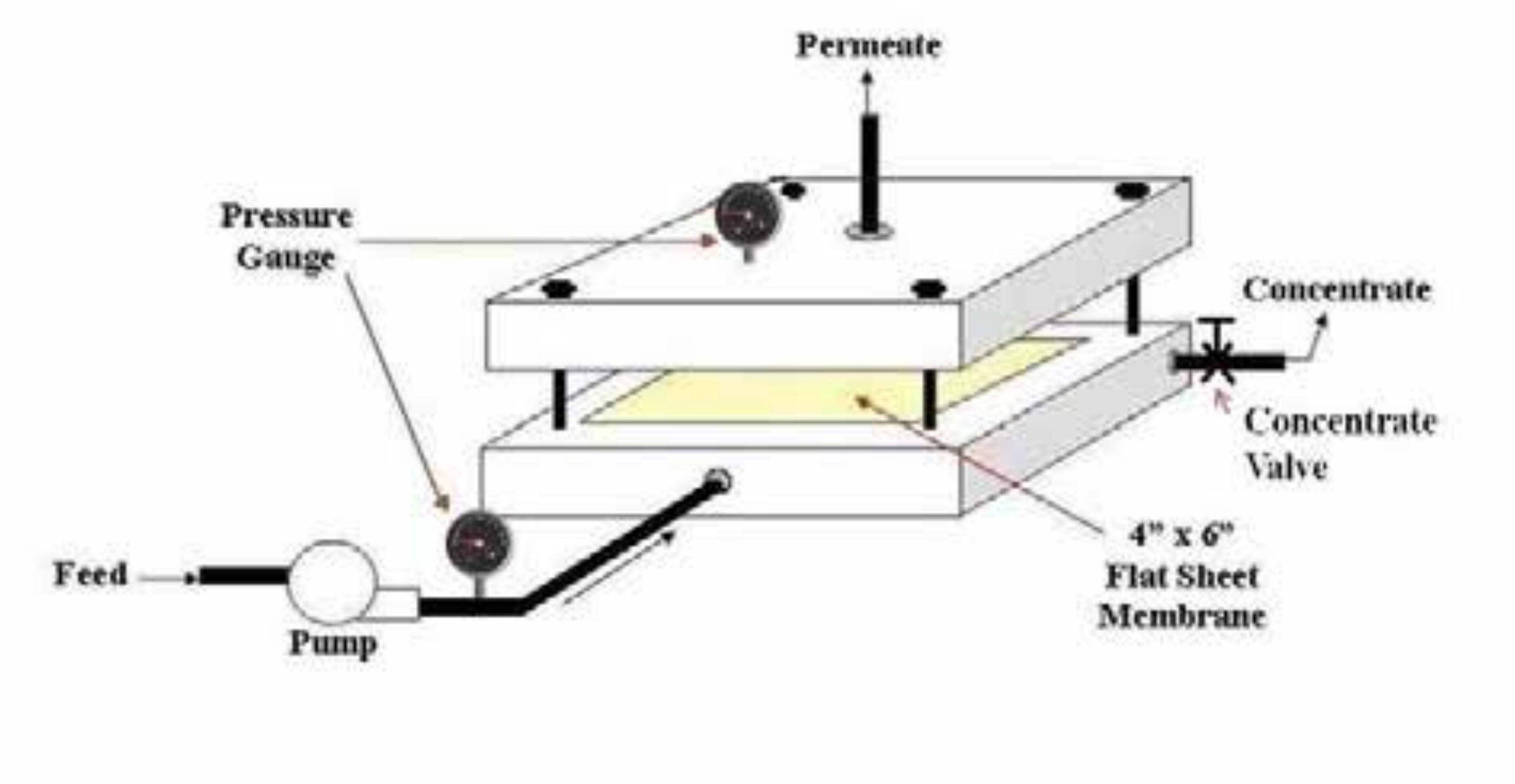


Design Factor Considerations

- 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

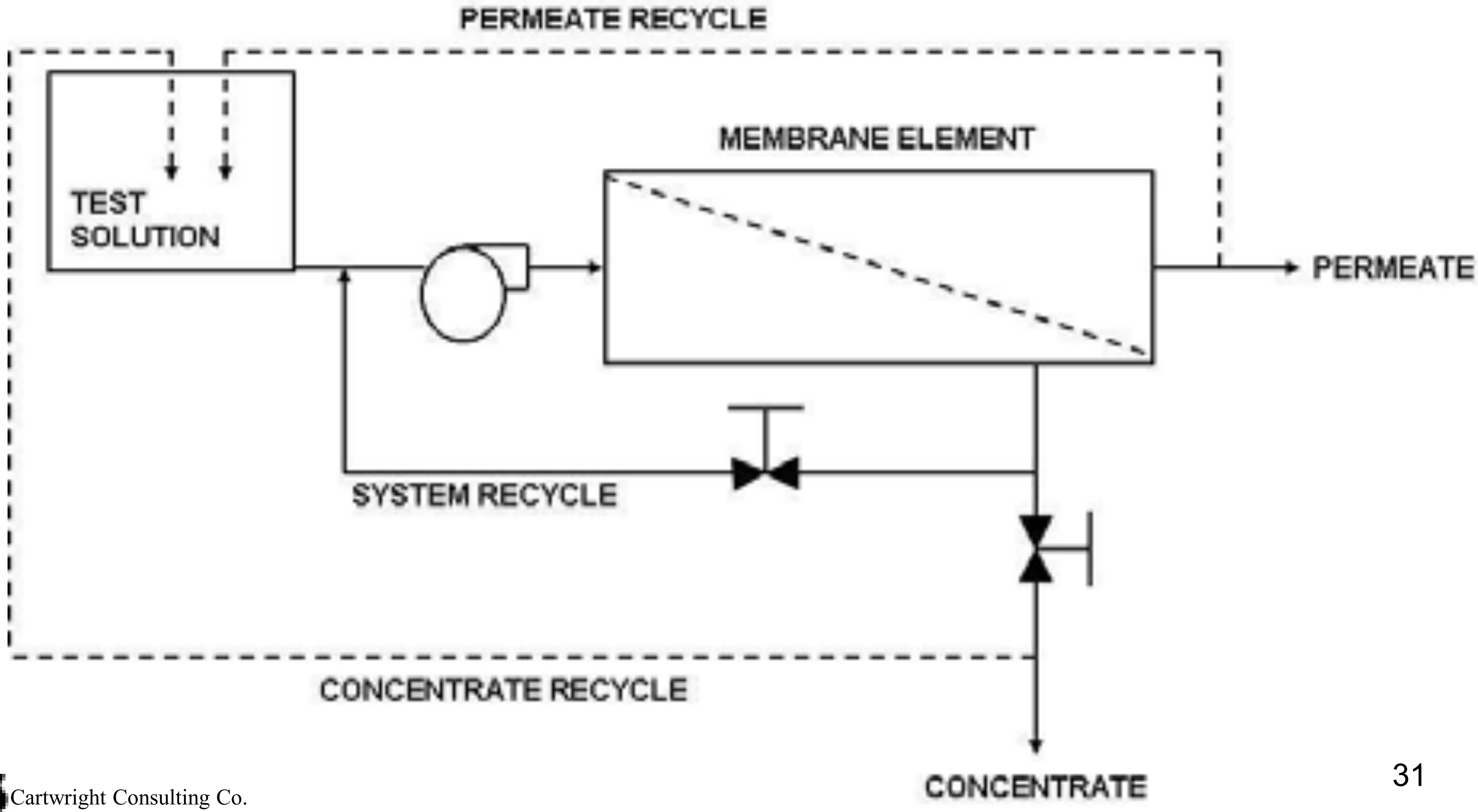
Advantages

- 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

Contact Information

Peter S. Cartwright, PE

pscartwright@msn.com

www.cartwright-consulting.com

1/952-854-4911