Seawater and Brackish Water Reverse Osmosis Design and Operation

Presented by

Sawaeng Gerdpratoom
Namsai Thai Co;Ltd.

Introduction

Water and Membranes Properties

Presented by

Sawaeng Gerdpratoom

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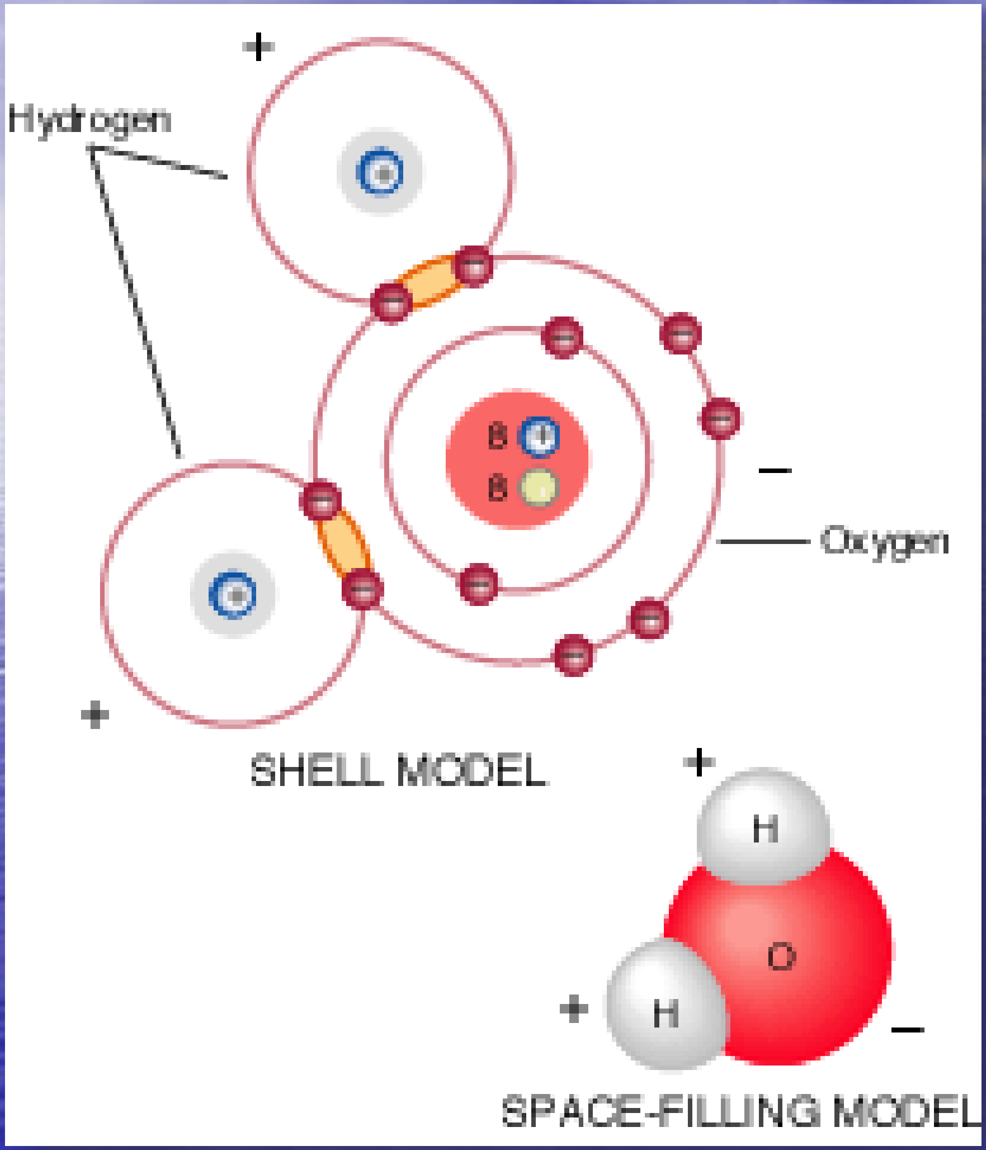
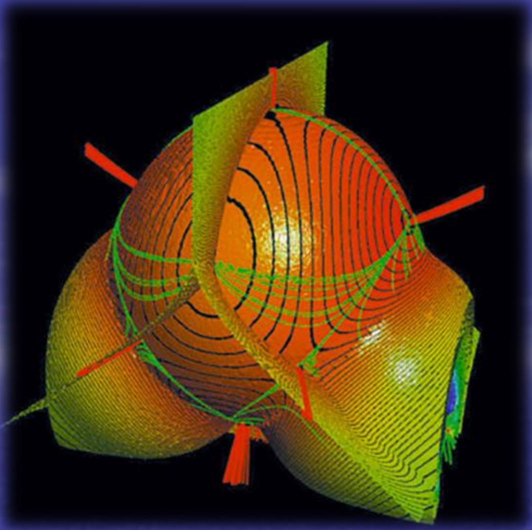
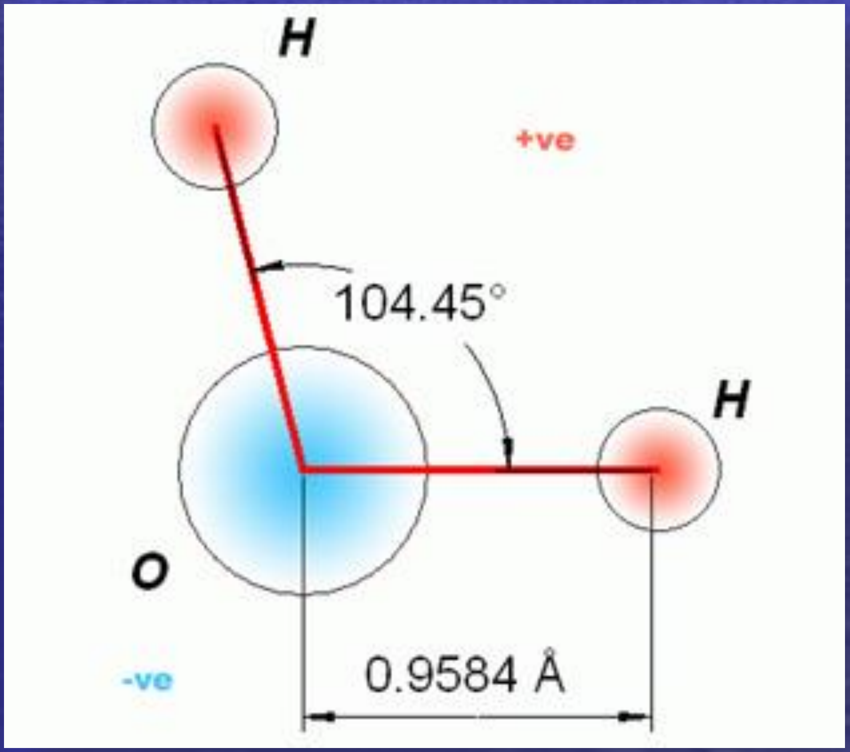
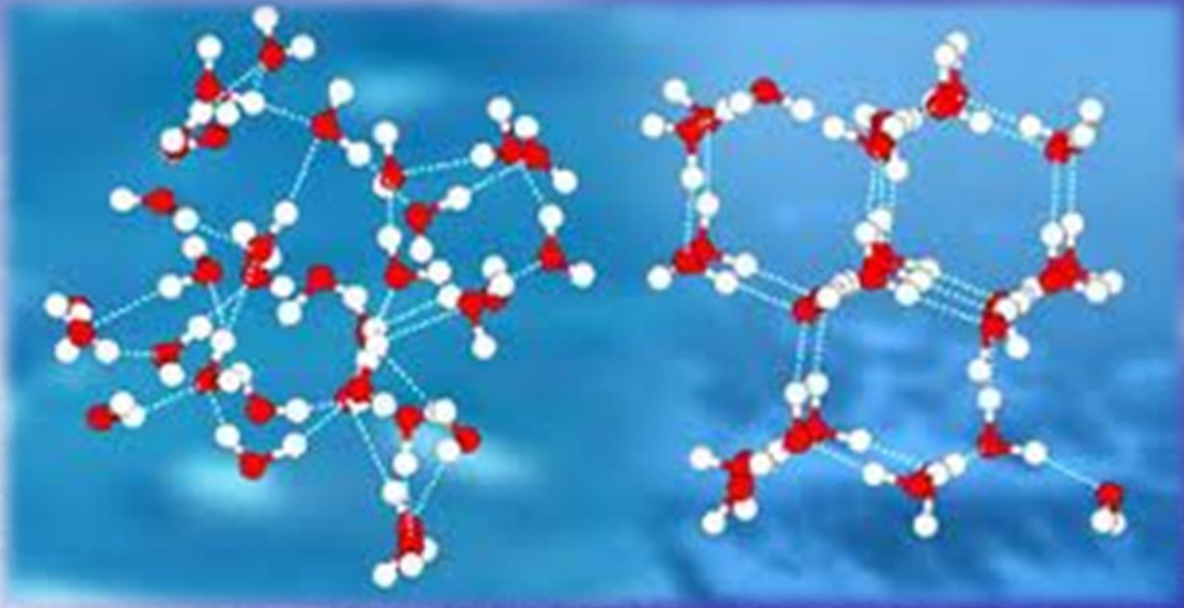
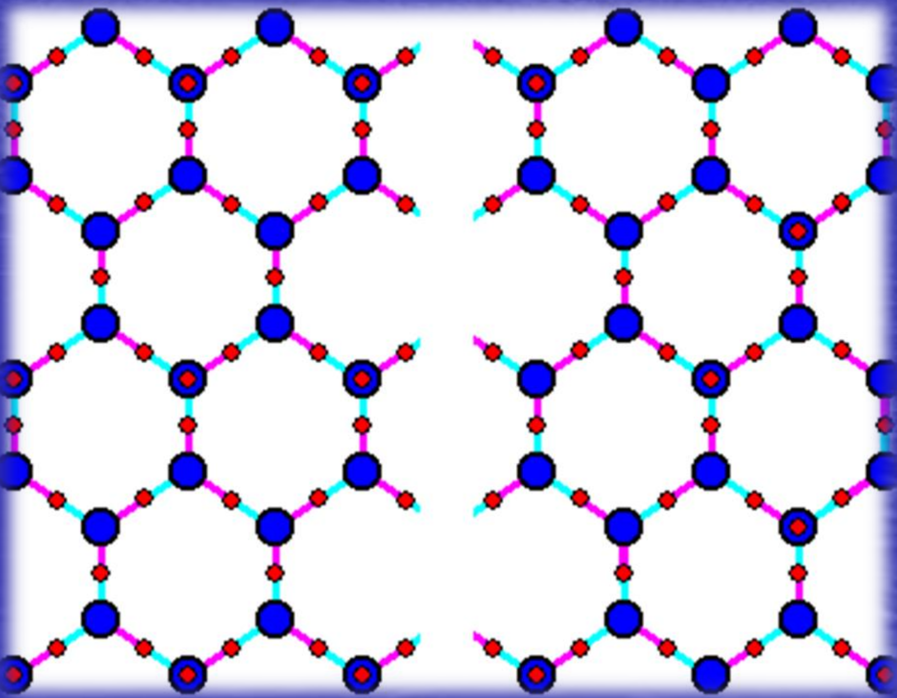
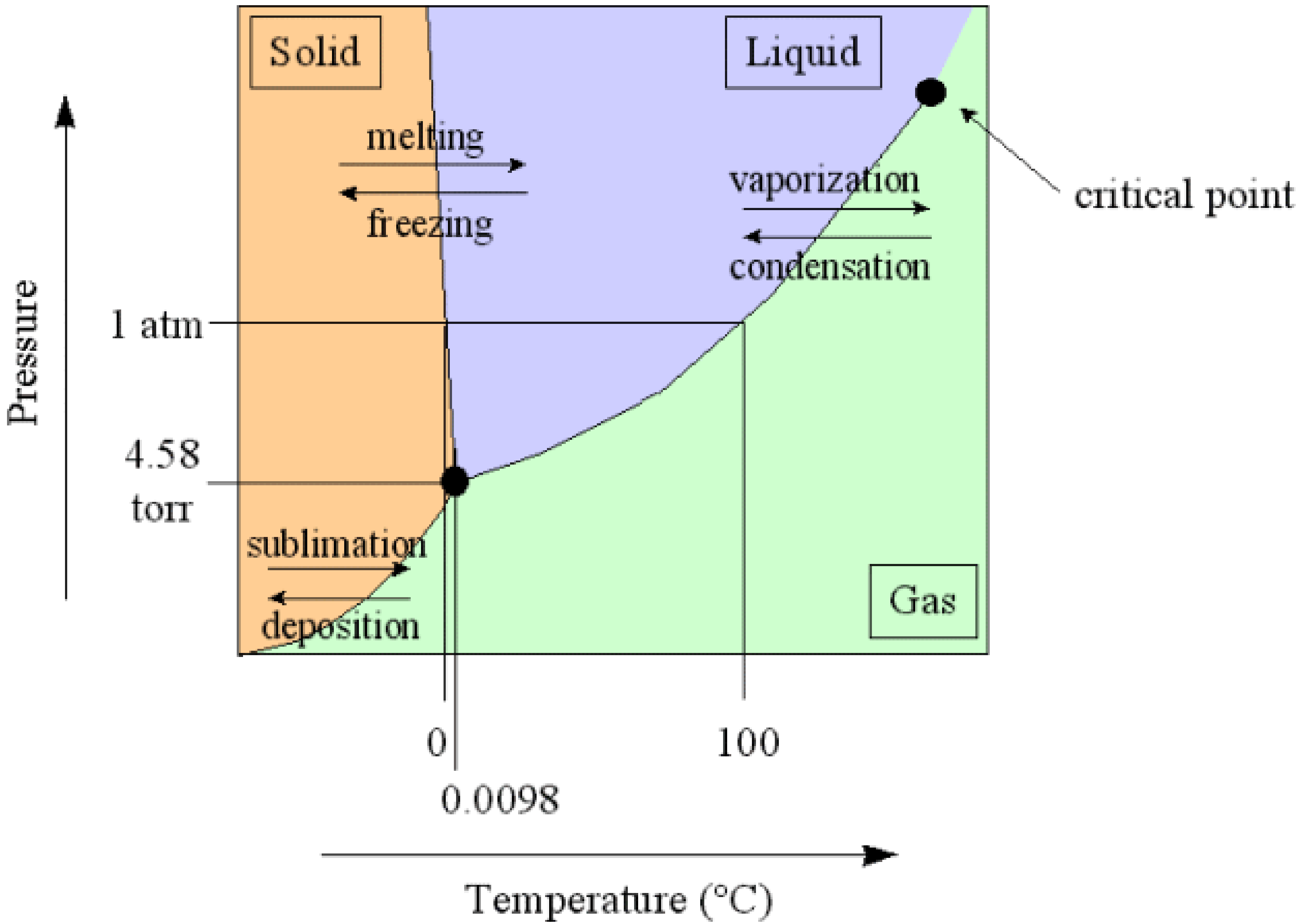

Hydrogen
Oxygen
SHELL MODEL
H
O
SPACE-FILLING MODEL

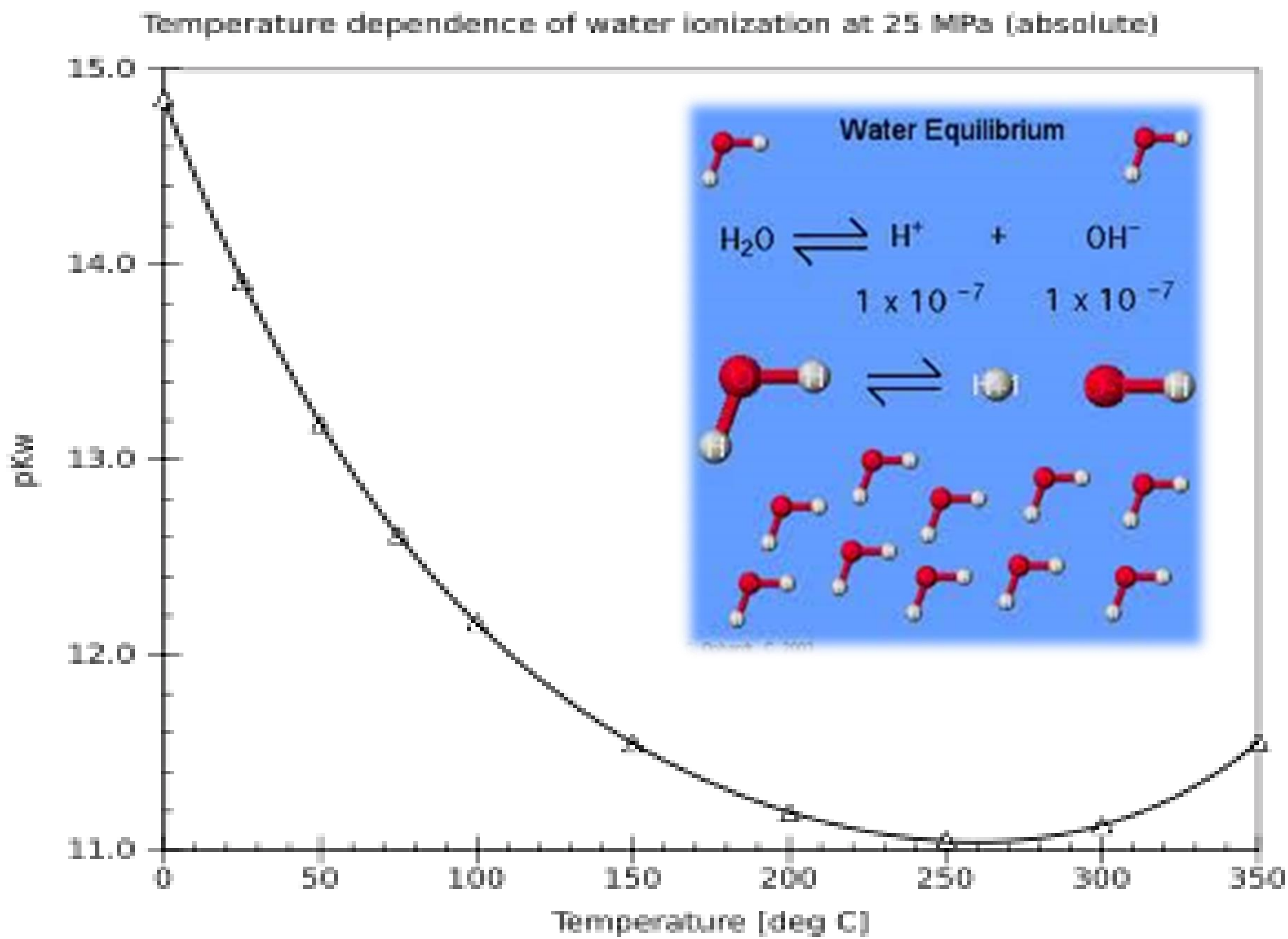



H
+ve
104.45°
H
O
-ve
0.9584 Å

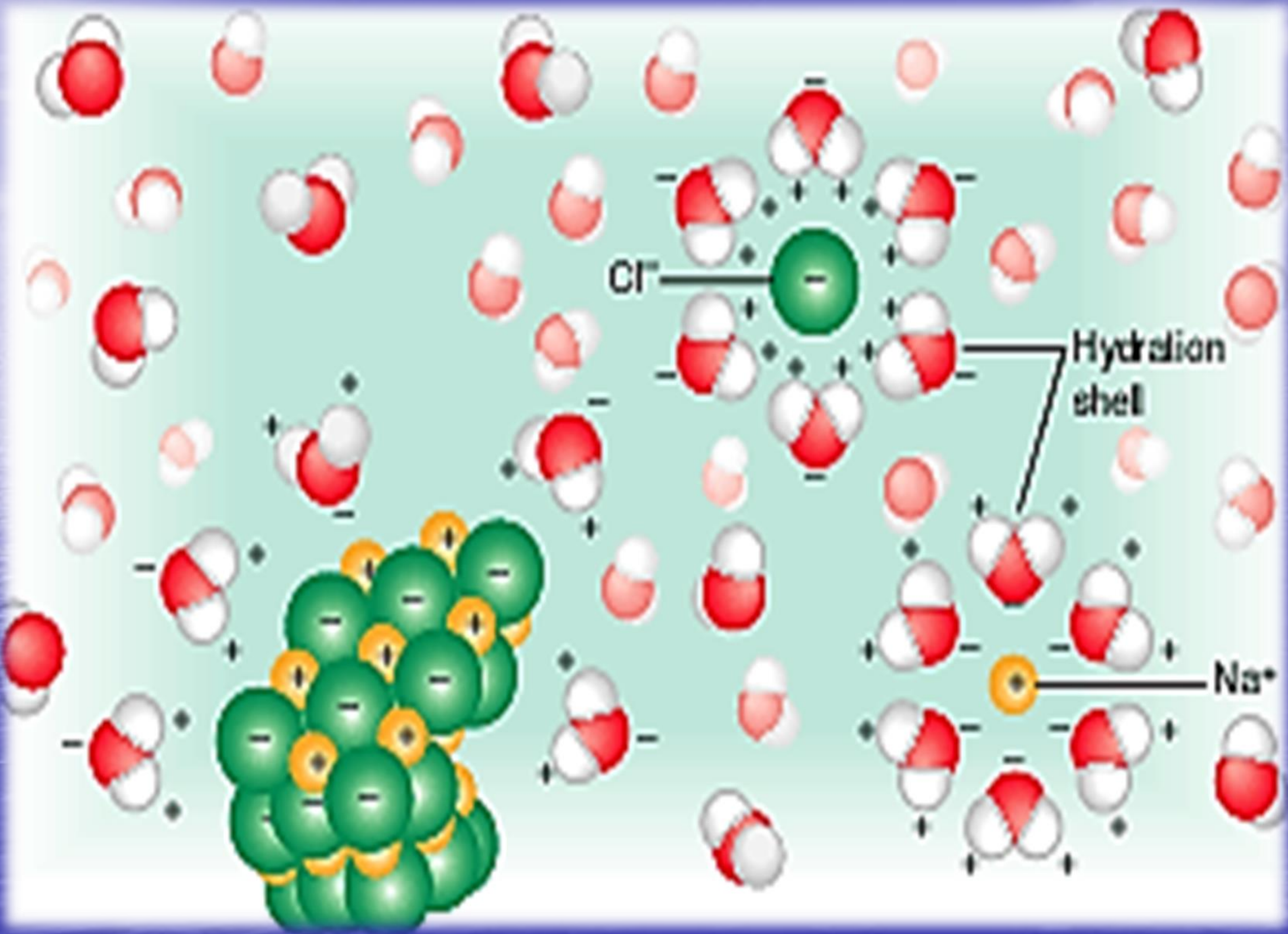





Solid
Liquid
Gas
melting
freezing
vaporization
condensation
sublimation
deposition
critical point
Pressure
1 atm
4.58
torr
0
0.0098
100
Temperature (°C)



Temperature dependence of water ionization at 25 MPa (absolute)
15.0
14.0
13.0
12.0
11.0
pKw
0
50
100
150
200
250
300
350
Temperature [deg C]
Water Equilibrium
$H_2O \rightleftharpoons H^+ + OH^-$
1×10^{-7}
1×10^{-7}



Cl⁻
Hydration shell
Na+

- หน่วยของความเข้มข้น
  - Parts per million (PPM)
  - Milligrams per liter (mg/l)
  - Grams per cubic meter (g/m^3)
  - เปอร์เซนของน้ำหนักไอออนที่ละลายอยู่ในน้ำ
    - 10,000 ppm ~ 1% weight concentratio
  - Milliequivalents per liter (meq/l)

Ex

$[Ca^{2+}]$ = 1000 ppm

$= \frac{1000}{40/2} = 50\ meq/l$

$$meq/l = \frac{[ppm]}{\text{equivalent weight}} \quad ; \quad equivalent\ weight = \frac{\text{น้ำหนักอิออน}}{\text{จำนวนอิเล็กตรอน}}$$

- การวัดปริมาณของ ของแข็งที่ละลายอยู่ในน้ำ (TDS)
  - วิธีวัดโดยตรง (วิธีนี้ค่อนข้างยุ่งยาก)
    - วัดโดยการระเหยสารที่ต้องการทราบค่า TDS หลังจากระเหยจนแห้งแล้วจึงนำตะกอนที่ได้จากการระเหลเอาน้ำออกแล้วไปชั่ง

– วิธีทั่วไปที่นิยมใช้

- โดยคำนวณจาก ปริมาณอิออนทั้งหมดที่ละลายอยู่ในน้ำ
  - วัดความสามารถในการนำไฟฟ้าของน้ำ และหาTDS โดย สมการ

$$TDS = K \bullet EC$$

; TDS ความเข้มข้น (ppm)

; K = conversion factor

; EC = ความสามารถในการนำไฟฟ้า(µS/cm)

» การเปลี่ยนแปลงของ ค่าความสามารถในการนำไฟฟ้า (EC) ขึ้นกับ

- อุณหภูมิ
  - ความนำไฟฟ้าเปลี่ยนแปลง ~ 2 % ทุกๆ 1°C ที่เปลี่ยนไป
  - อุณหภูมิมาตรฐานที่ใช้กัน และมีการบันทึกค่าไว้เพื่อใช้คำนวณ คือ 25 °C
- ส่วนประกอบ/อิออน ที่อยู่ในน้ำ
  - อิออนต่างชนิดกันจะมีค่าความสามารถในการนำไฟฟ้าต่างกัน

โดยปกติ แหล่งน้ำตามธรรมชาติจะมี อิออน ดังนี้

- น้ำตามบ่อน้ำ/ผิวน้ำที่มีความเค็มต่ำ

  ~200 ppm – 300 ppm
- น้ำทะเล

  ~35,000 -45,000 ppm

» Conversion factor (K)

- น้ำกรองที่ได้จาก RO เมมเบรน
  - K = 0.55
- น้ำทะเล
  - K = 0.75

Introduction to Membrane Technology

Presented by

Sawaeng Gerdpratoom
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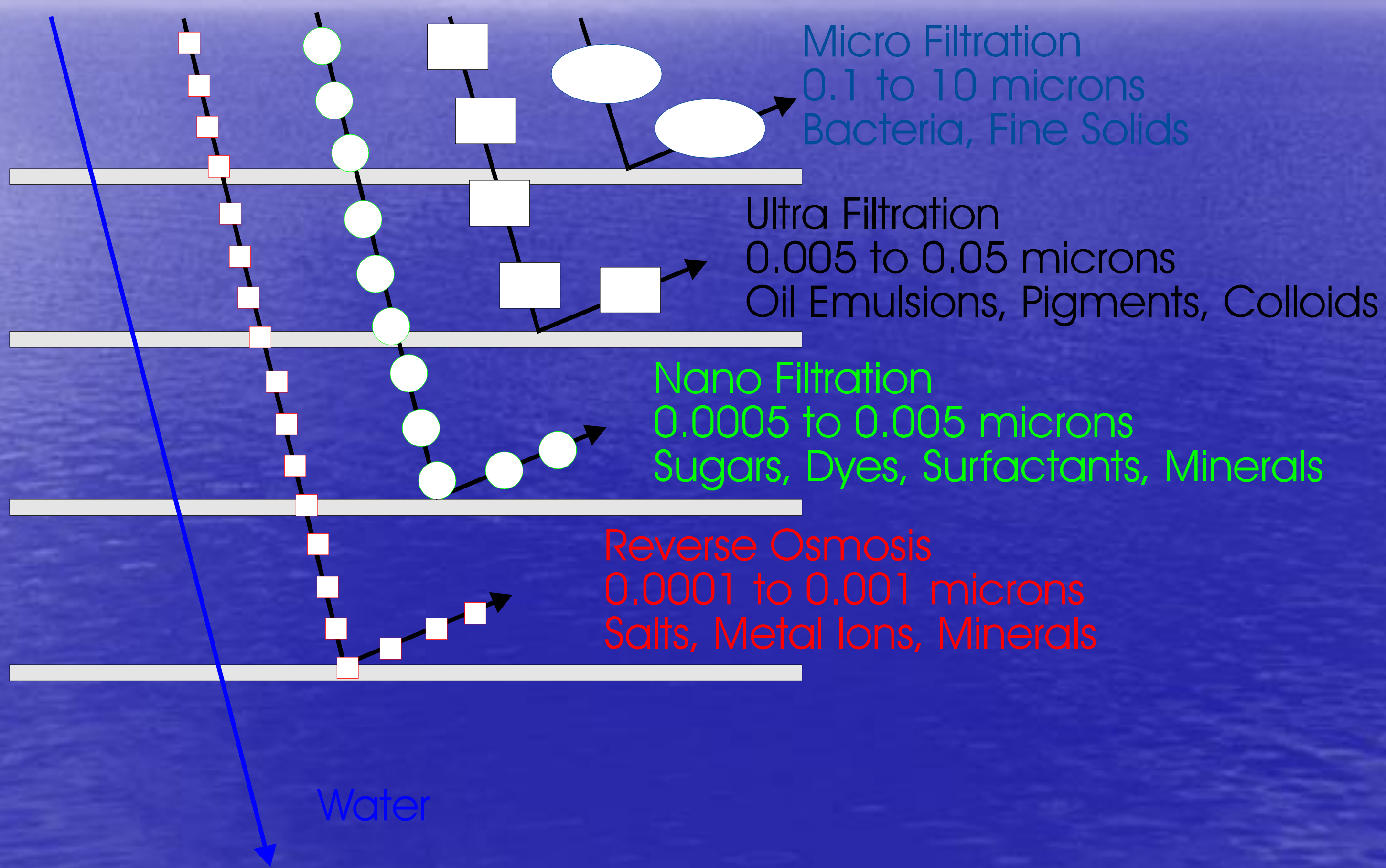
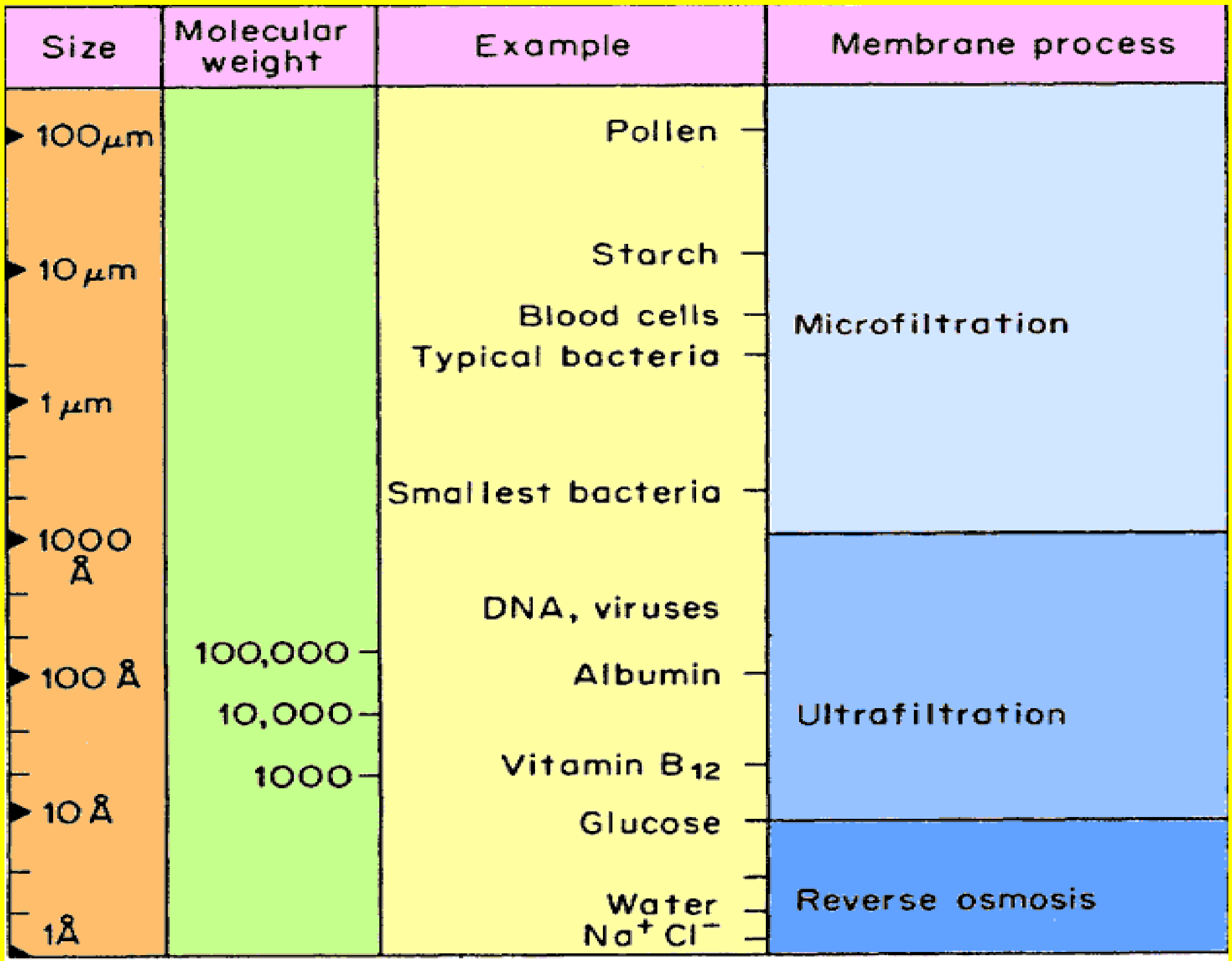
Membrane Types

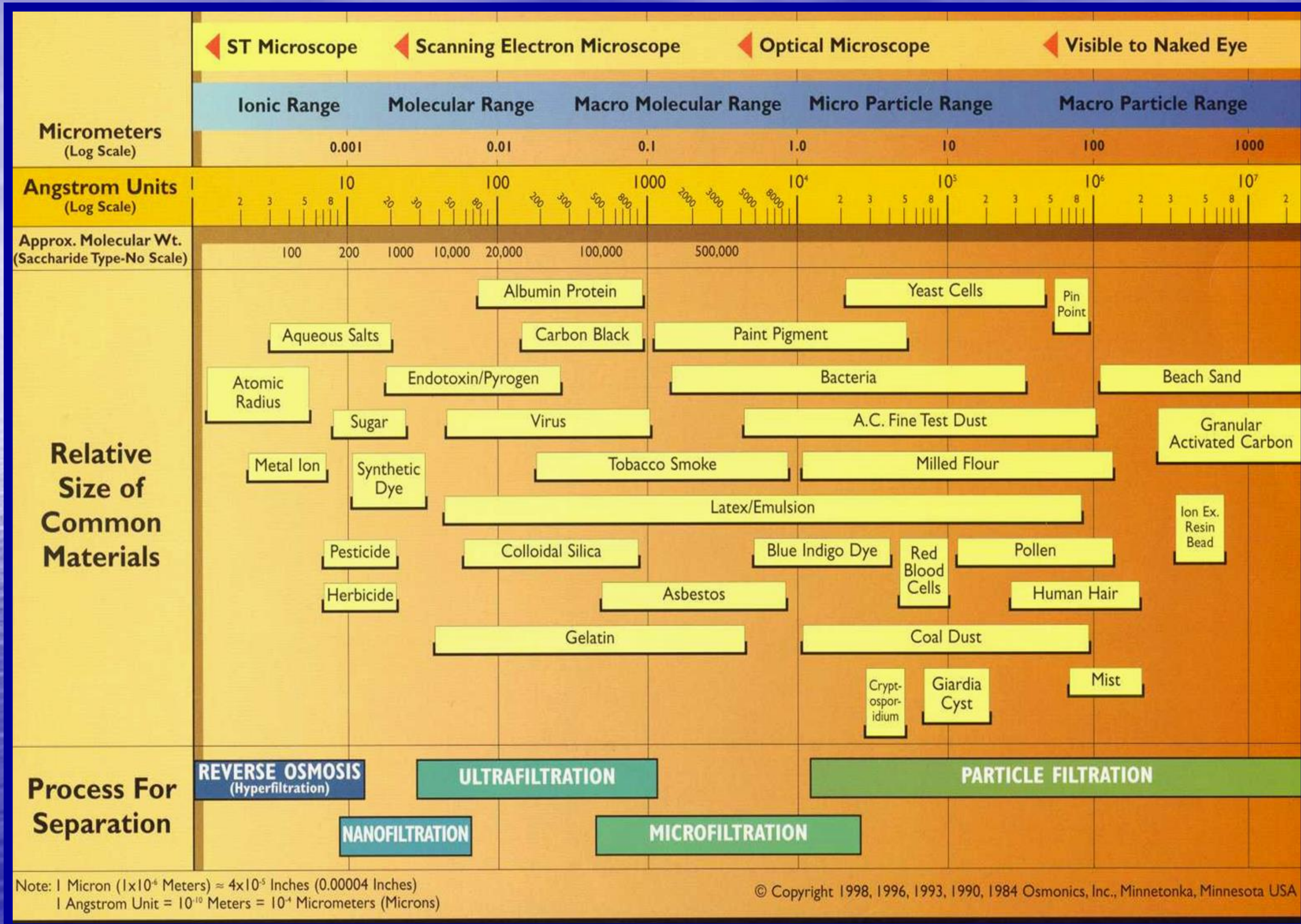
- Hyperfiltration (RO)
- Nanofiltration (NF)
- Ultrafiltration (UF)
- Microfiltration (MF)
- Prevaporation
- Gas Separation

Membrane Types





Typical species retained by MF, UF and RO membranes.



ST Microscope
Scanning Electron Microscope
Optical Microscope
Visible to Naked Eye
Ionic Range
Molecular Range
Macro Molecular Range
Micro Particle Range
Macro Particle Range
Micrometers (Log Scale)
0.001
0.01
0.1
1.0
10
100
1000
Angstrom Units (Log Scale)
10
100
1000
10^4
10^5
10^6
10^7
Approx. Molecular Wt. (Saccharide Type-No Scale)
100
200
1000
10,000
20,000
100,000
500,000
Relative Size of Common Materials
Albumin Protein
Yeast Cells
Pin Point
Aqueous Salts
Carbon Black
Paint Pigment
Atomic Radius
Endotoxin/Pyrogen
Bacteria
Beach Sand
Sugar
Virus
A.C. Fine Test Dust
Granular Activated Carbon
Metal Ion
Synthetic Dye
Tobacco Smoke
Milled Flour
Latex/Emulsion
Ion Ex. Resin Bead
Pesticide
Colloidal Silica
Blue Indigo Dye
Red Blood Cells
Pollen
Herbicide
Asbestos
Human Hair
Gelatin
Coal Dust
Crypt-ospor-idium
Giardia Cyst
Mist
Process For Separation
REVERSE OSMOSIS (Hyperfiltration)
ULTRAFILTRATION
PARTICLE FILTRATION
NANOFILTRATION
MICROFILTRATION
Note: 1 Micron (1×10^{-6} Meters) ≈ 4×10^{-5} Inches (0.00004 Inches)
1 Angstrom Unit = 10^{-10} Meters = 10^{-4} Micrometers (Microns)
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MEMBRANE FILTRATION SPECTRUM

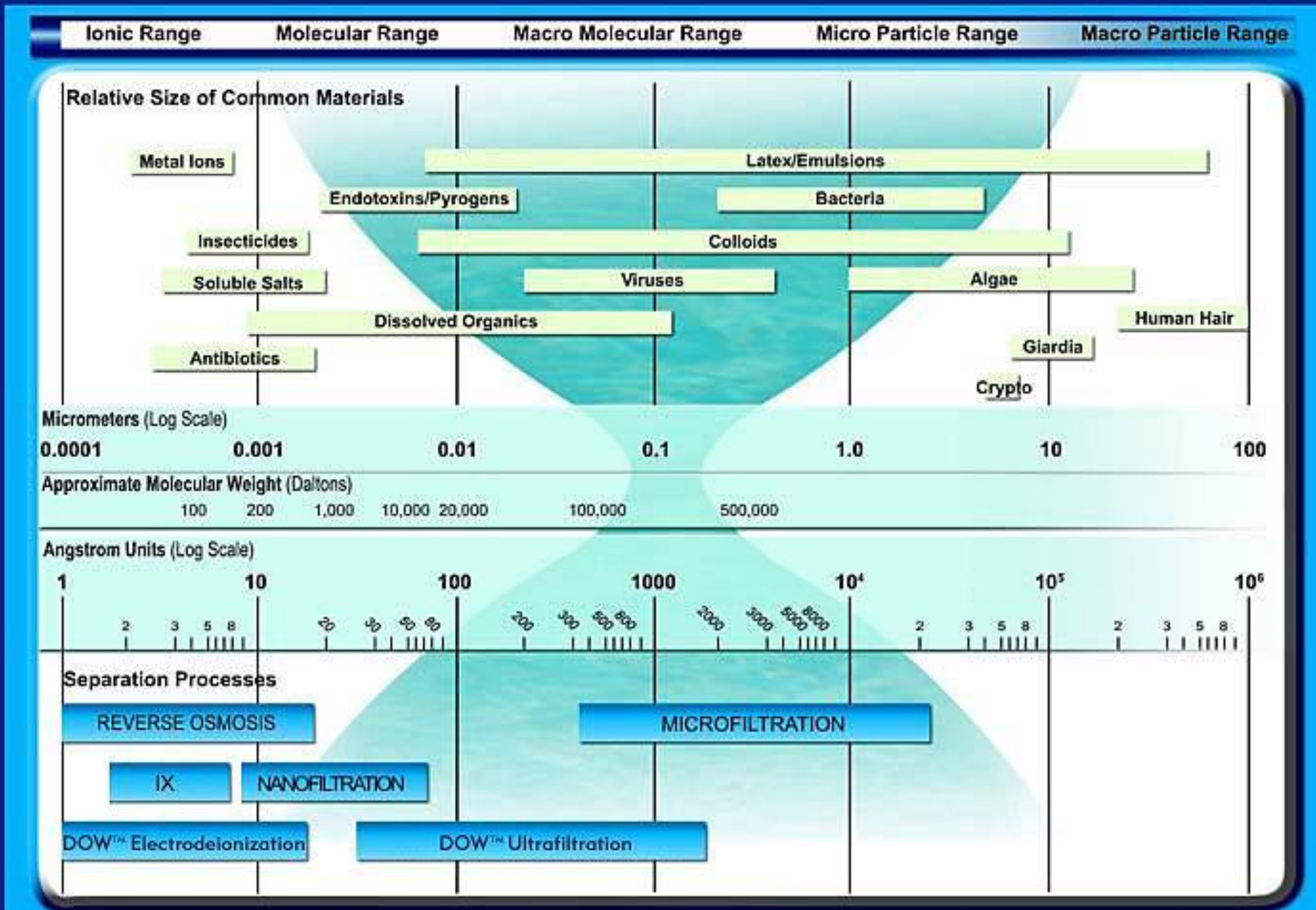


Table 2. Comparing Four Membrane Processes

	Reverse Osmosis	Nanofiltration	Ultrafiltration	Micro filtration
Membrane	Asymmetrical	Asymmetrical	Asymmetrical	Symmetrical Asymmetrical
Thickness Thin film	150 μm 1 μm	150 μm 1 μm	150 - 250 μm 1 μm	10-150 μm
Pore size	<0.002 μm	<0.002 μm	0.2 - 0.02 μm	4 - 0.02 μm
Rejection of	HMWC, LMWC sodium chloride glucose amino acids	HMWC mono-, di- and oligosaccharides polyvalent neg. ions,	Macro molecules, proteins, polysaccharides vira	Particles, clay bacteria
Membrane material(s)	CA Thin film	CA Thin film	Ceramic PSO, PVDF, CA Thin film	Ceramic PP, PSO, PVDF
Membrane Module	Tubular, spiral wound, plate-and-frame	Tubular, spiral wound, plate-and-frame	Tubular, hollow fiber, spiral wound, plate-and-frame	Tubular, hollow fiber
Operating pressure	15-150 bar	5-35 bar	1-10 bar	<2 bar

ตาราง 2 แสดงการเปรียบเทียบสมรรถนะในการขัดกรองสารของเทคโนโลยีเมมเบรนแบบต่าง ๆ

คุณสมบัติ	MF	UF	NF	RO	ED/EDR
การกำจัดสารแขวนลอย	ดี	ดี	ดี	ดี	ไม่ได้
การกำจัดเชื้อโรคแบคทีเรีย	ปานกลาง	ดี	ดี	ดี	ไม่ได้
ความสามารถในการกำจัดสารอินทรีย์	ไม่ได้	ปานกลาง 1	ได้ดี	ได้ดี	ไม่ได้
ความสามารถในการกำจัดสารอนินทรีย์ในรูปไอออน	ไม่ได้	ไม่ได้	ปานกลาง 2	ได้ดี	ได้
ระดับความบริสุทธิ์ของน้ำที่ผ่านการกรอง	ปานกลาง	สูง	สูง	สูง	ปานกลาง
พลังงานที่ใช้	ต่ำ	ต่ำ	ปานกลาง	สูง	ปานกลาง
ความทนแรงดันของเมมเบรน	สูง	สูง	ปานกลาง	ปานกลาง	สูง

หมายเหตุ : 1. จะกำจัดสารอินทรีย์ที่มีน้ำหนักโมเลกุลมากกว่า 1,000 ขึ้นไป

2. กำจัดไอออนที่มีประจุบวก 2 หรือ ลบ 2 ขึ้นไปได้ดี ส่วนไอออนที่มีประจุบวก 1 จะกำจัดได้ปานกลาง

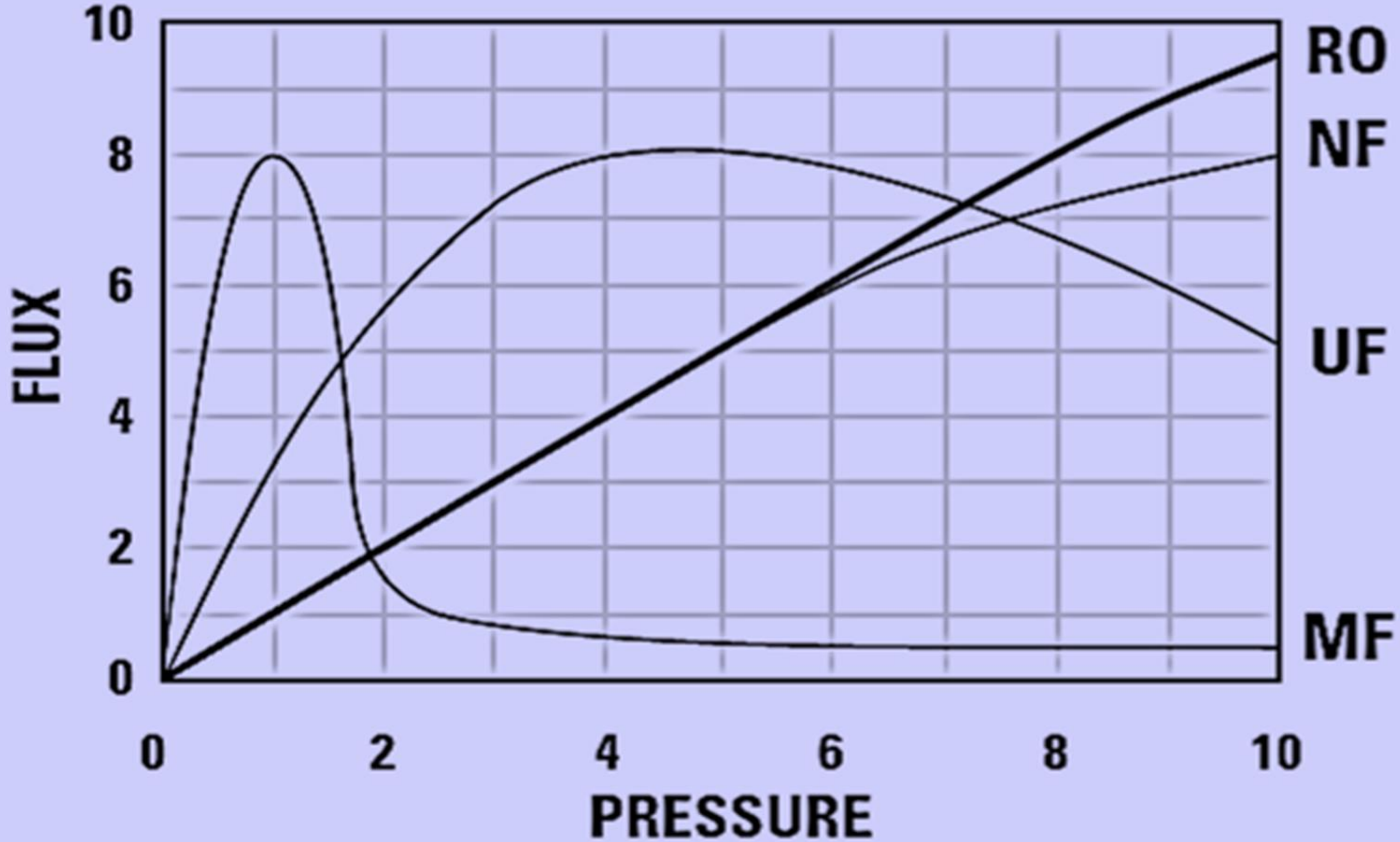
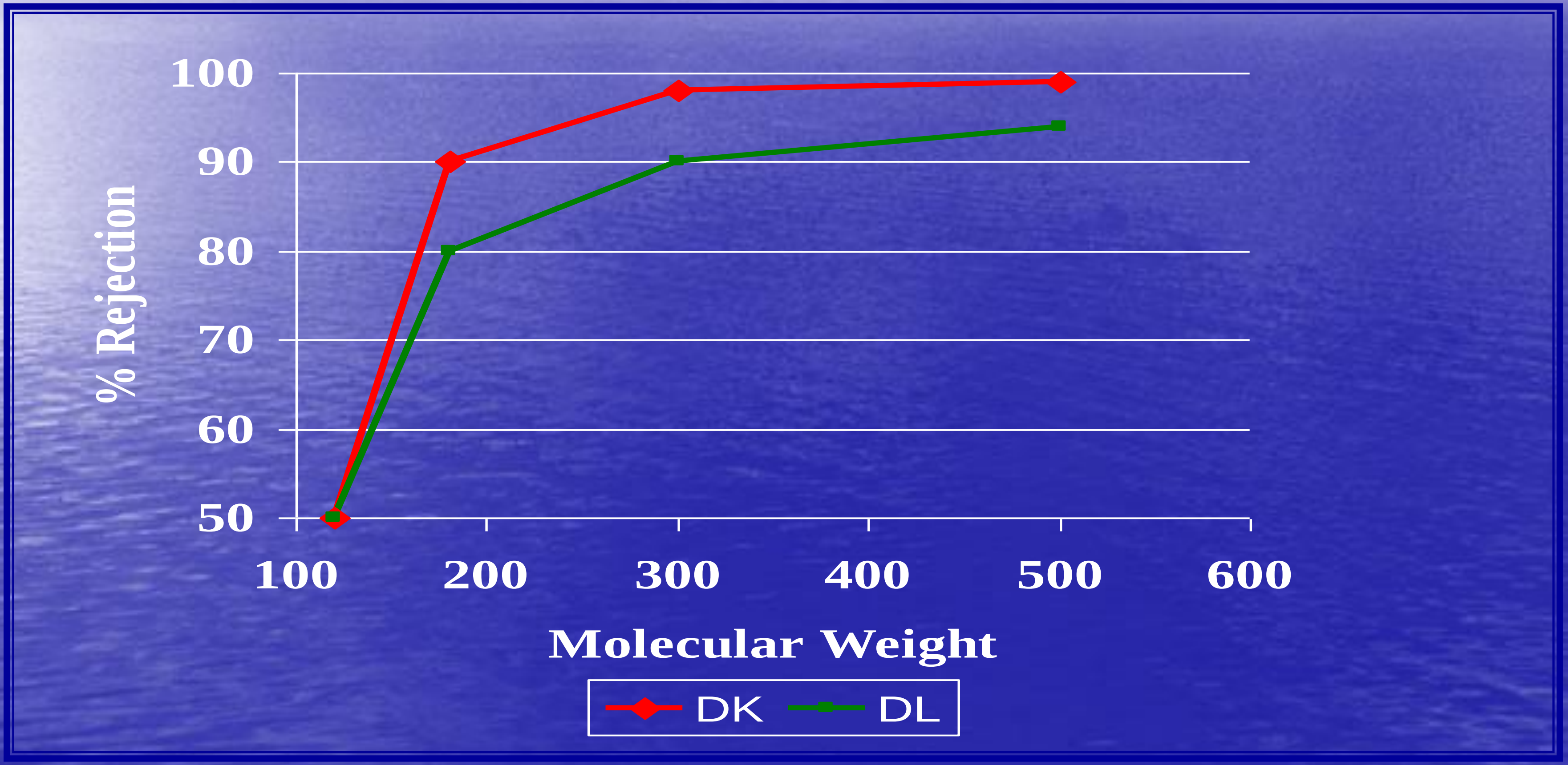
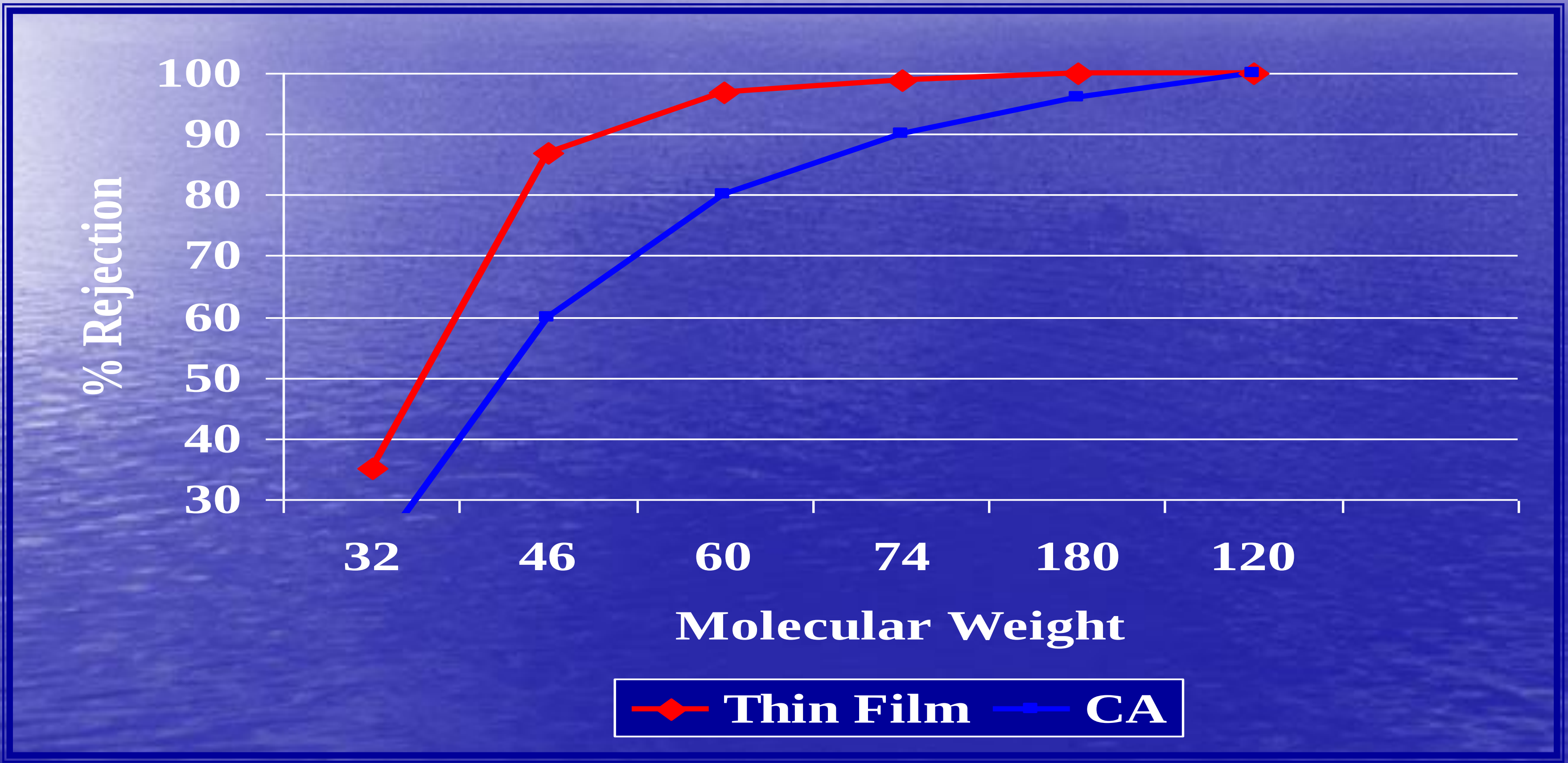


Figure 23. Flux as a Function of Pressure

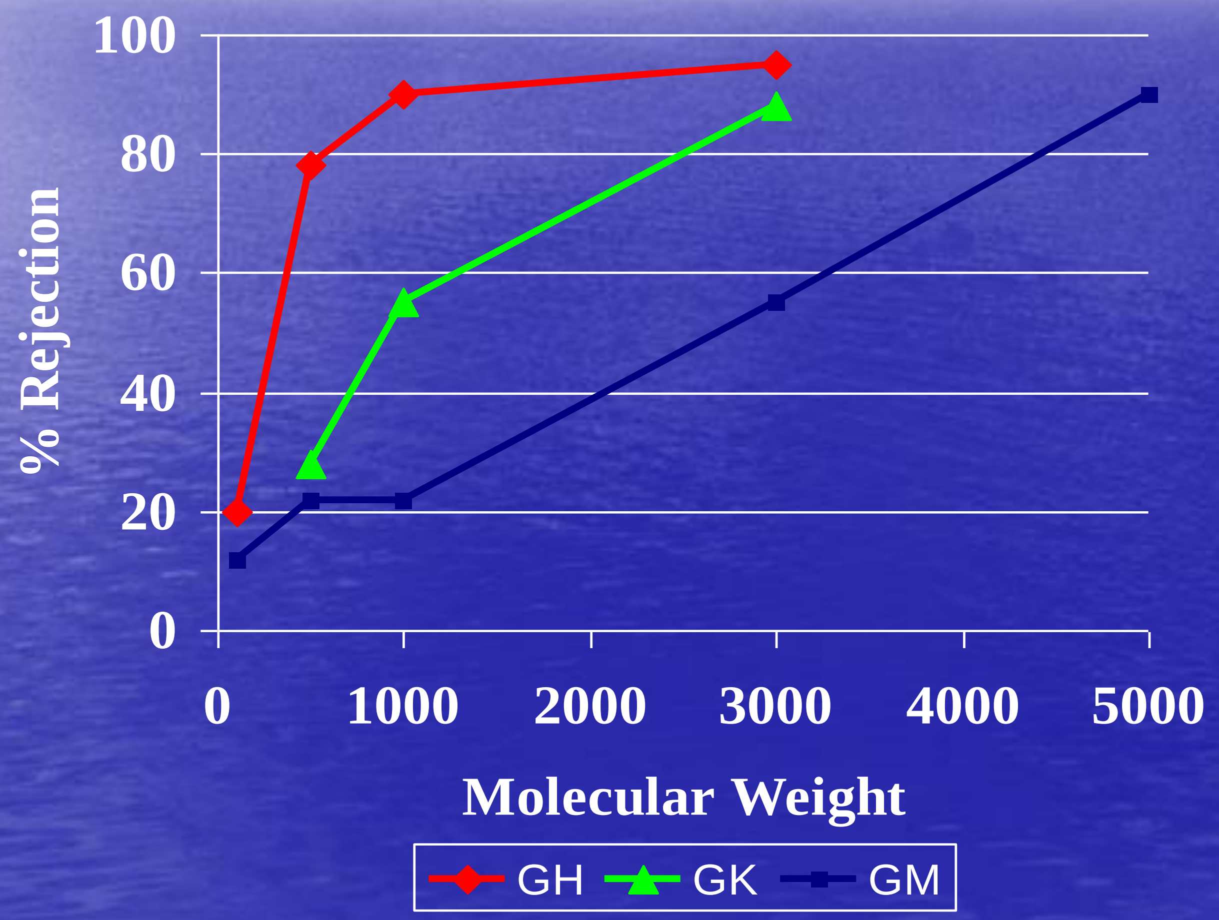
Nanofiltration NF



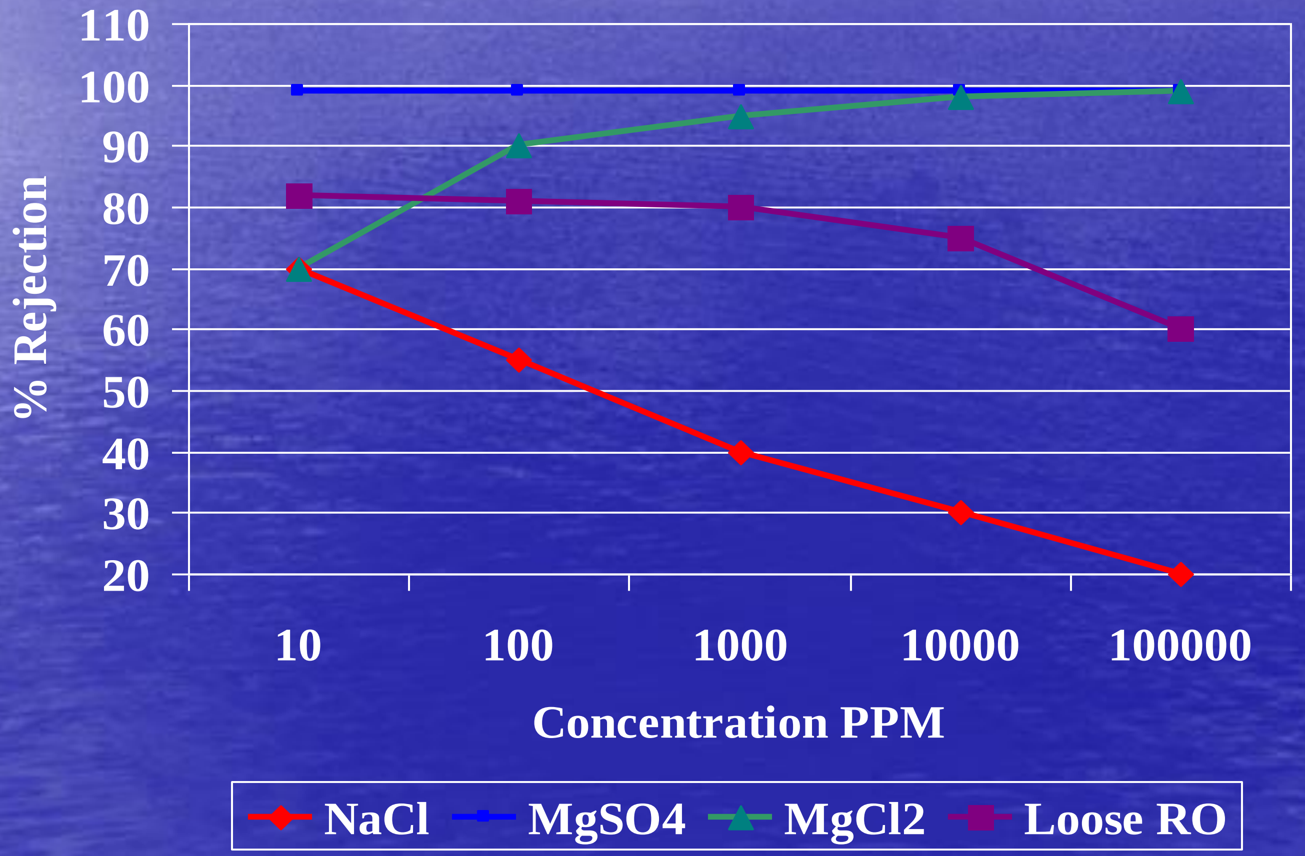
Hyperfiltration Reverse osmosis



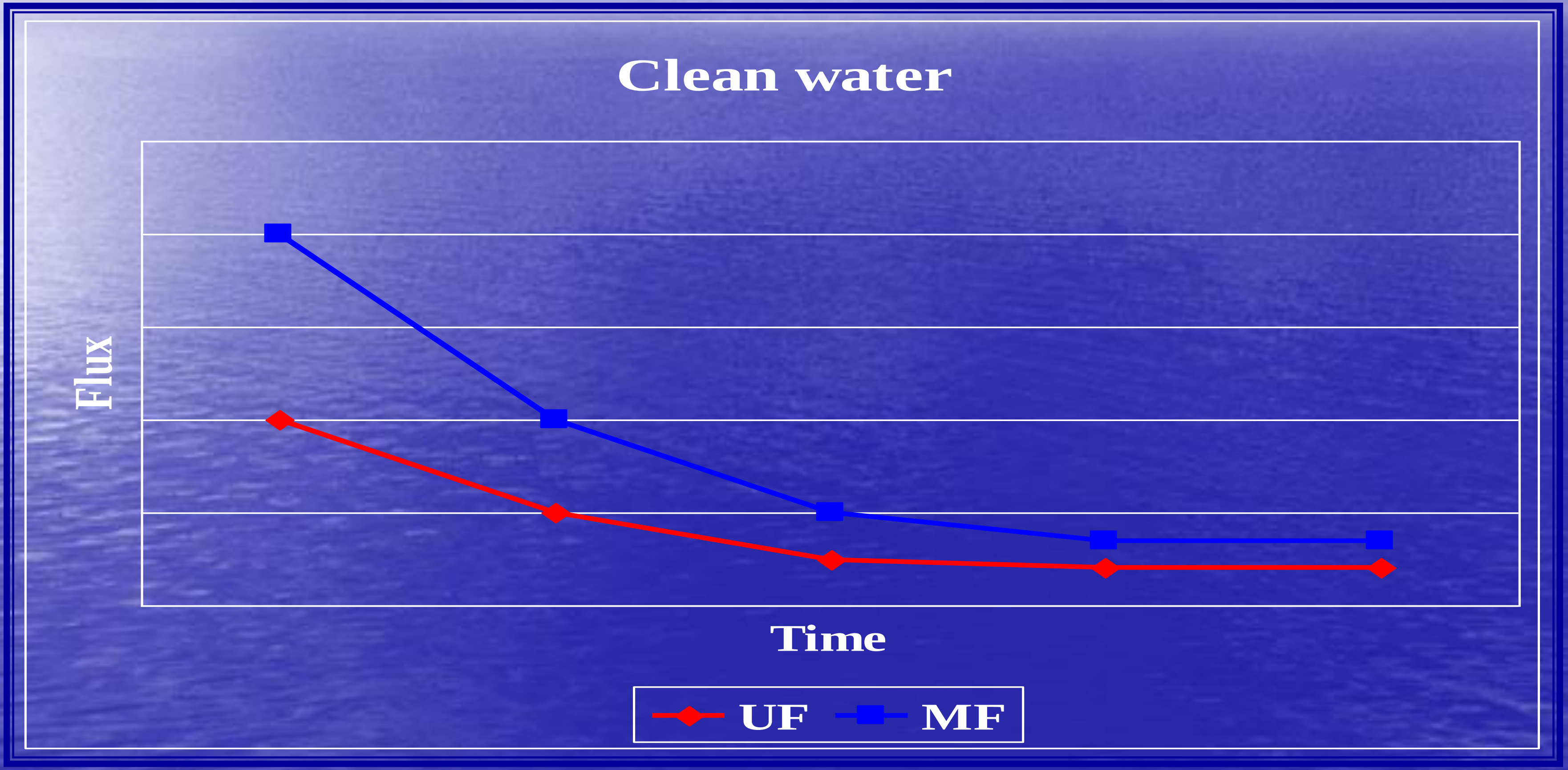
Ultrafiltration UF



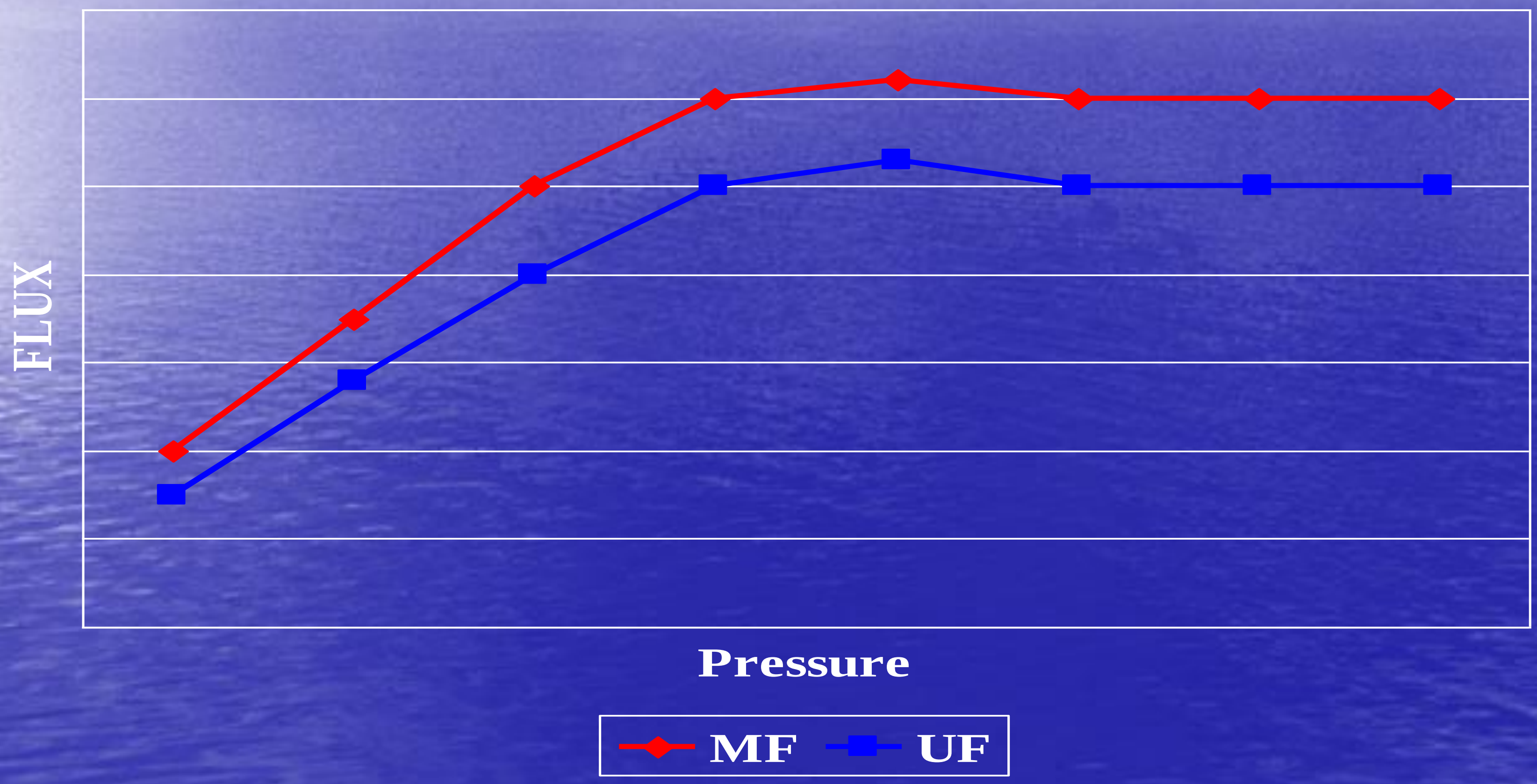
Nanofiltration NF



Ultrafiltration-4



Microfiltration-3



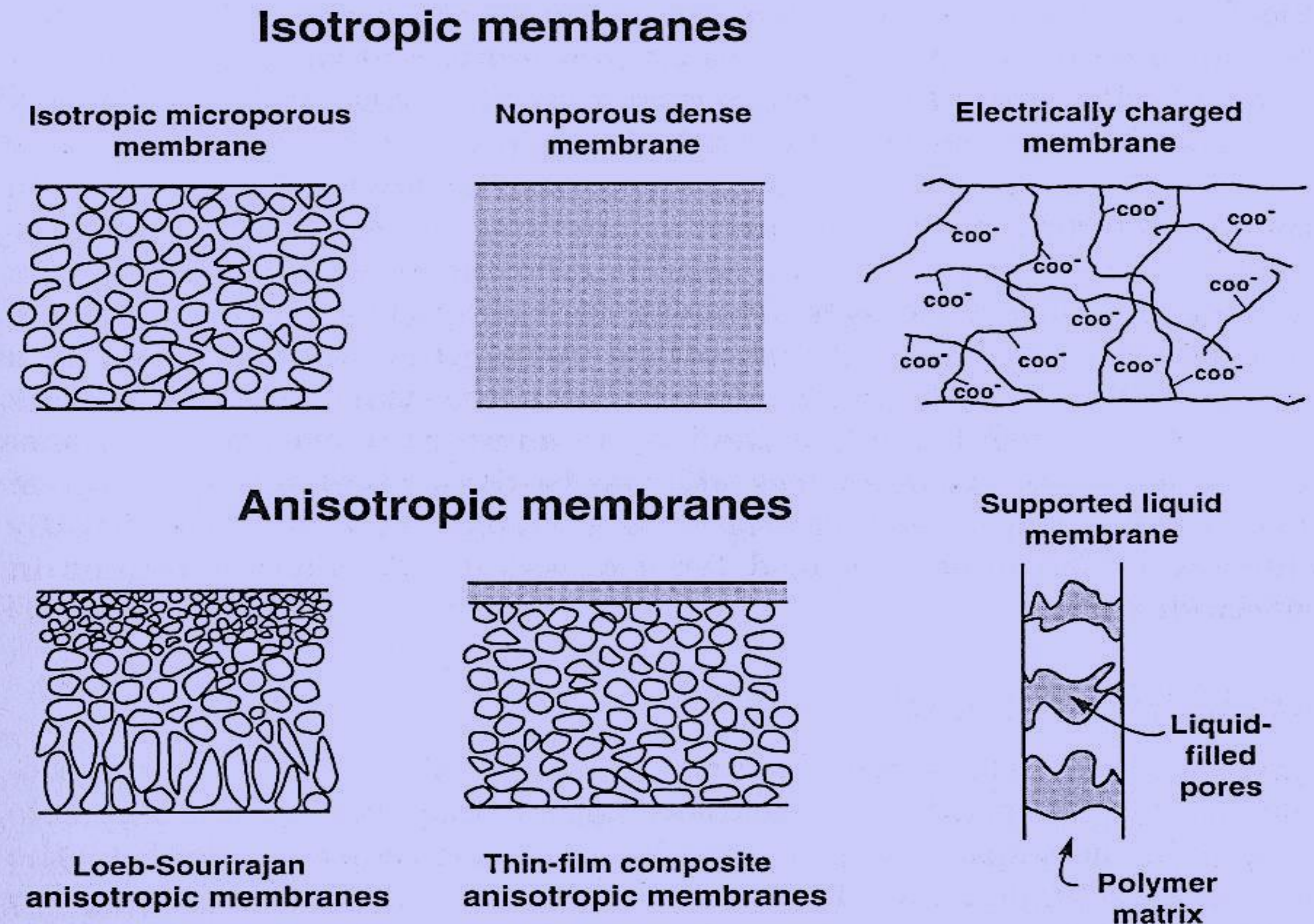
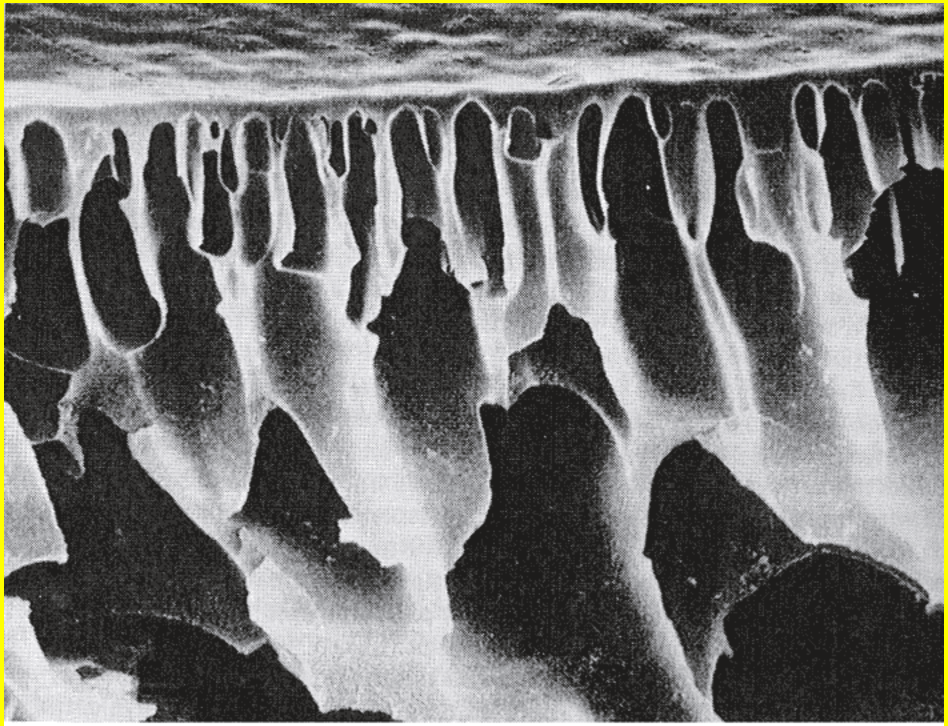
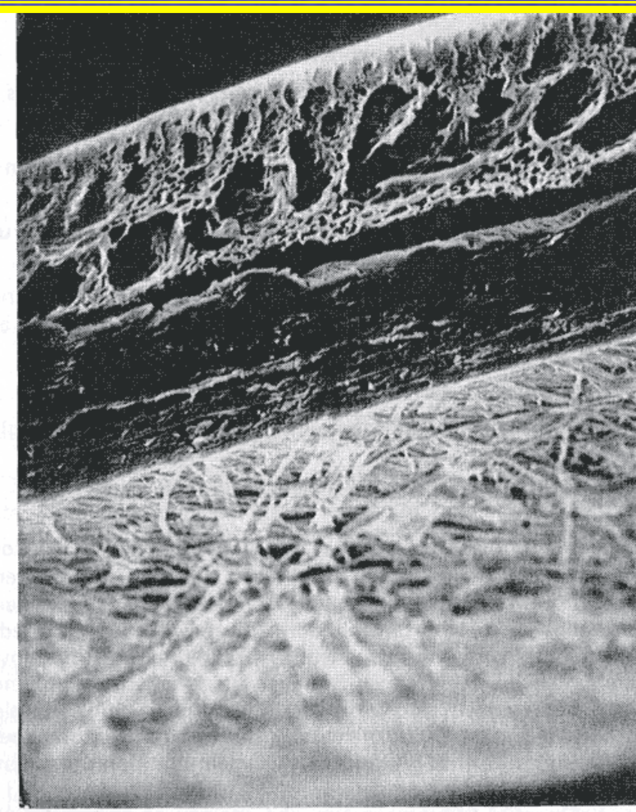


Figure 1.1 Schematic diagrams of the principal types of membranes.

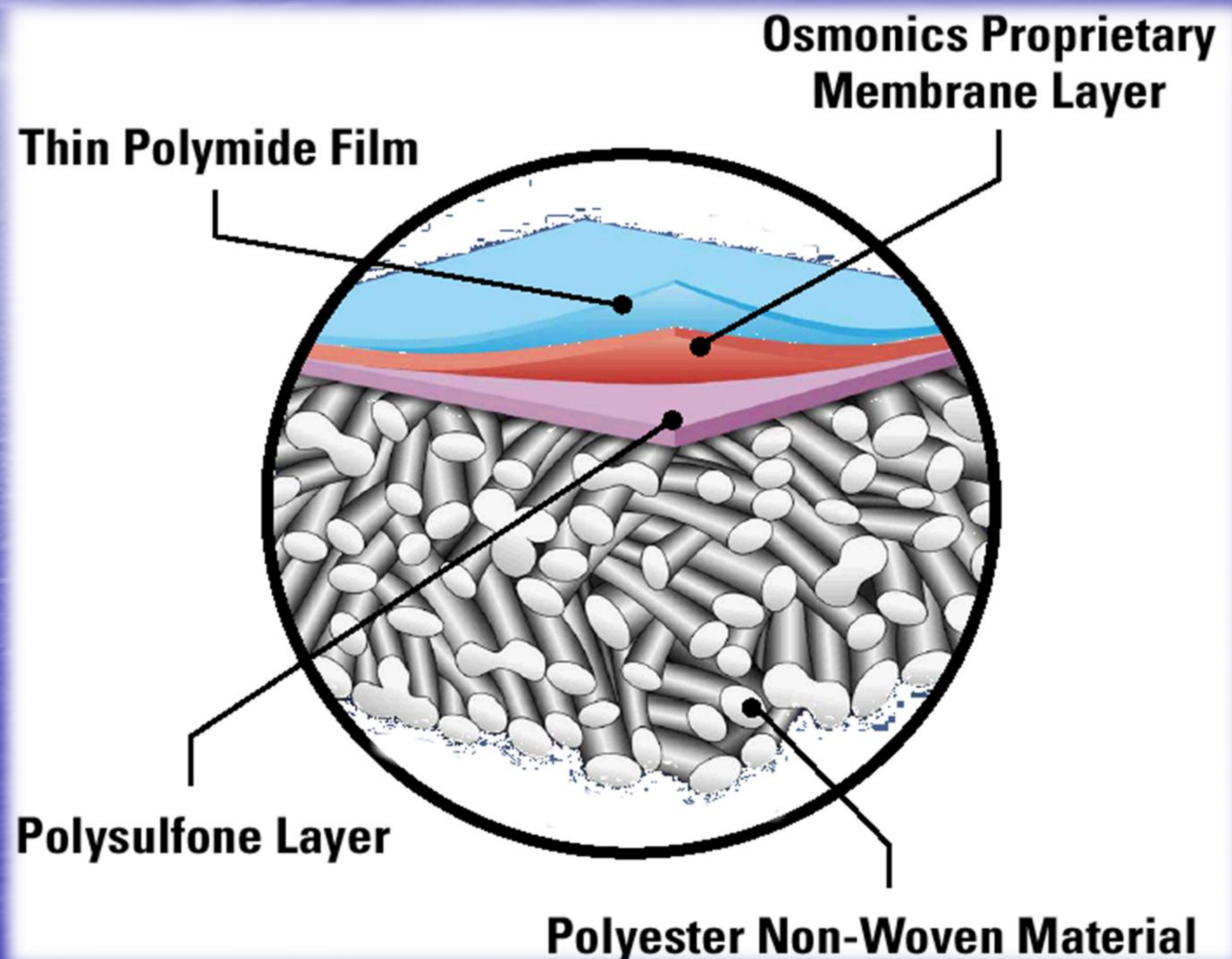


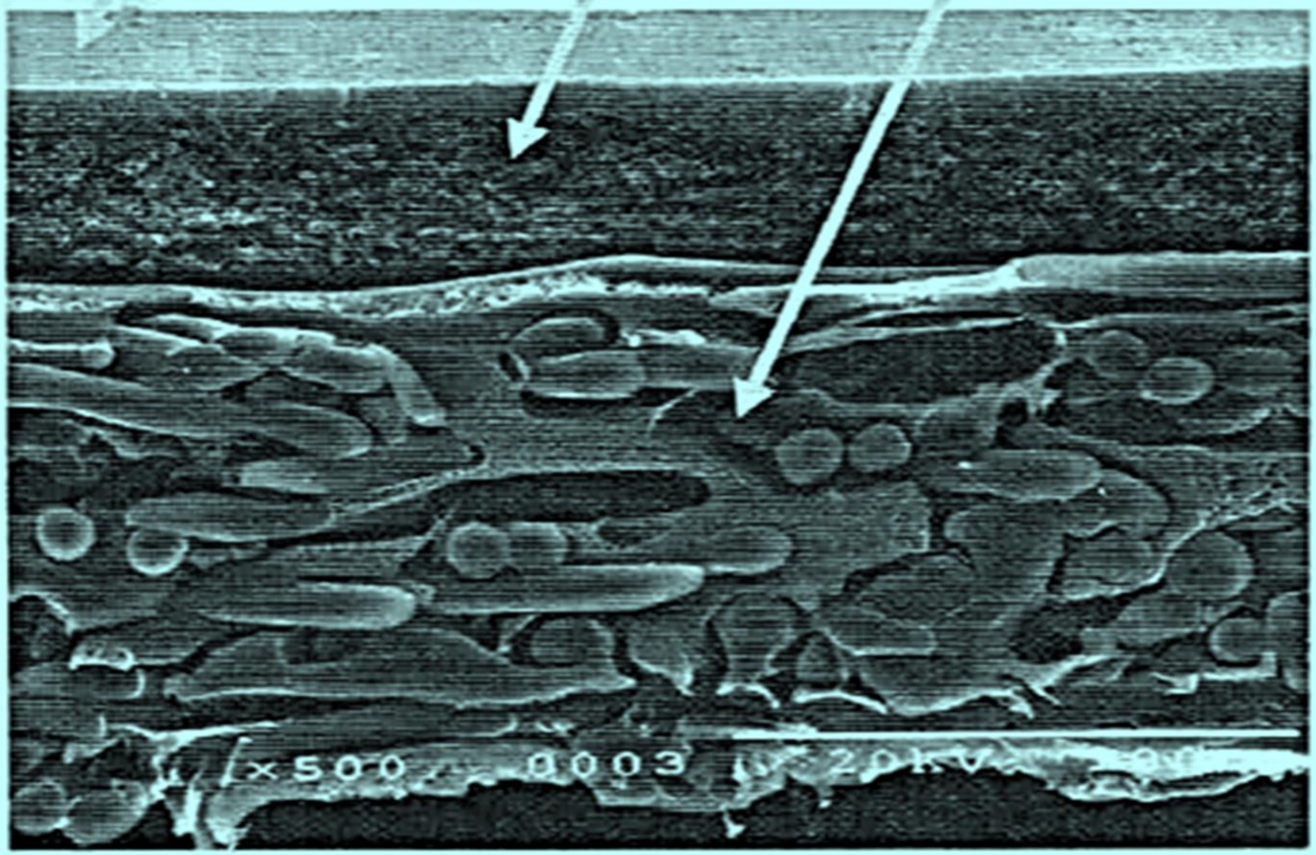
Cross-section photomicrograph of asymmetric UF membrane.



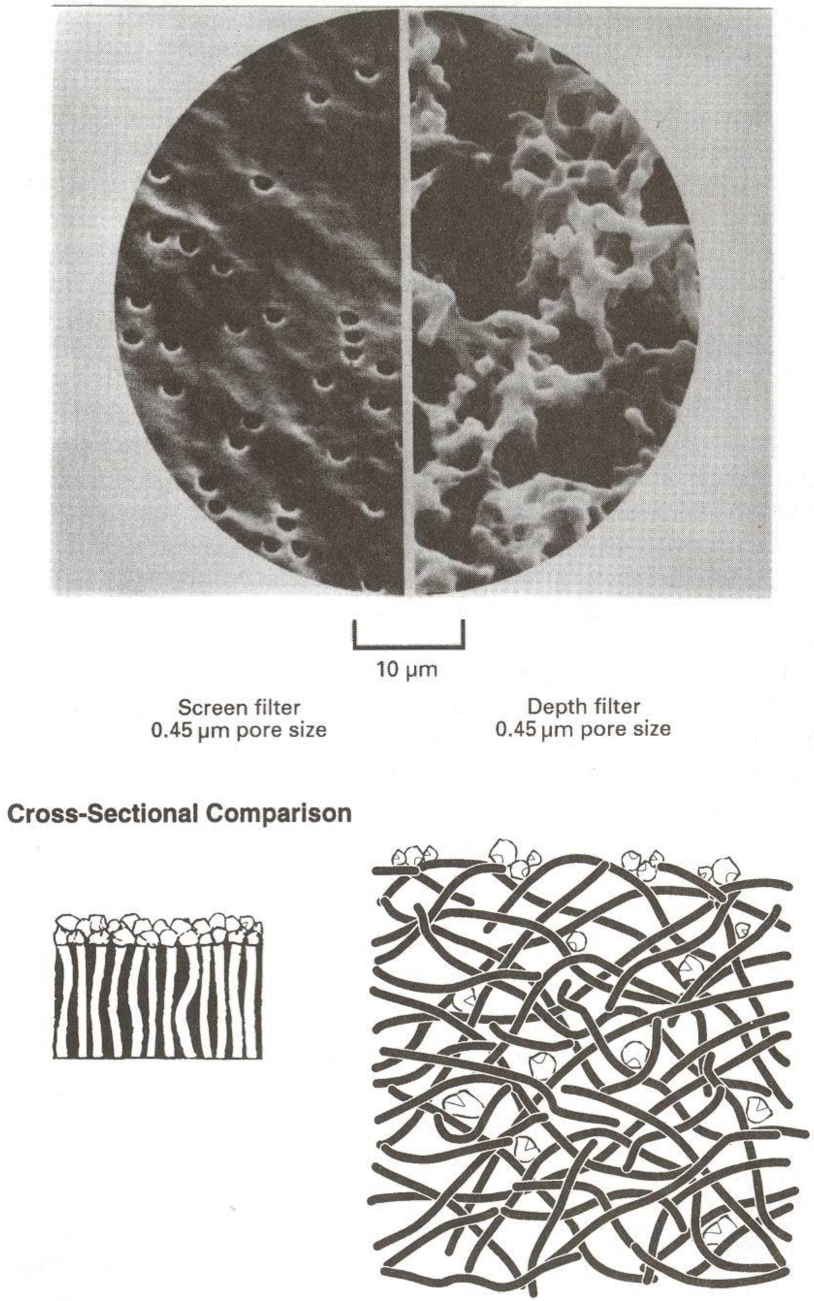
Cross-section of UF membrane cast on spun-bonded polyethylene backing.

Membrane Morphology





SEM picture of cross section of cross section of commercial flat sheet composite RO membrane.



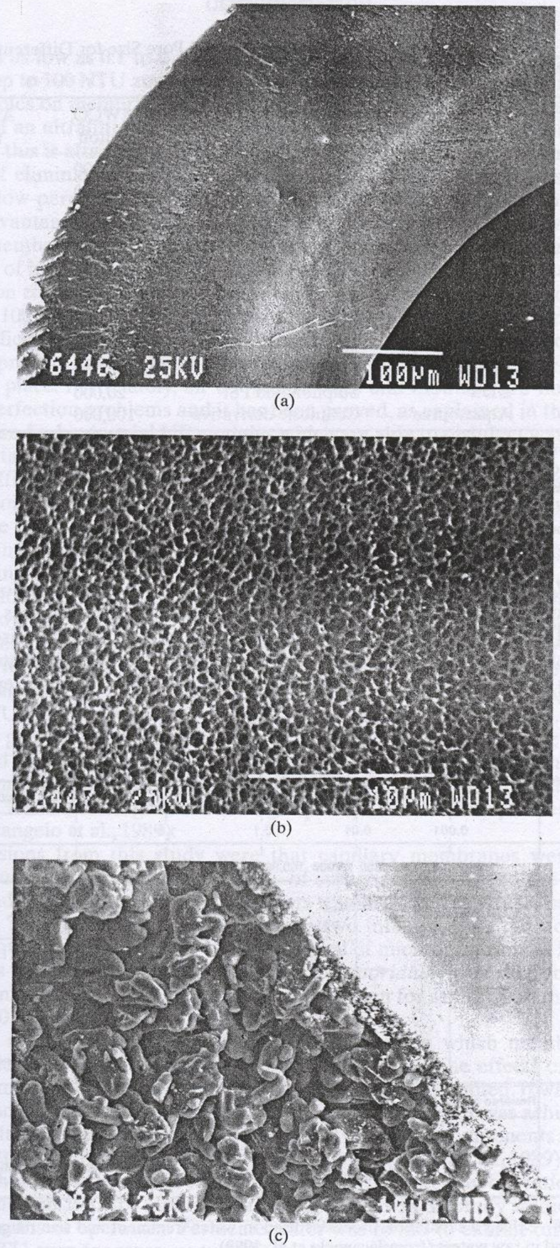
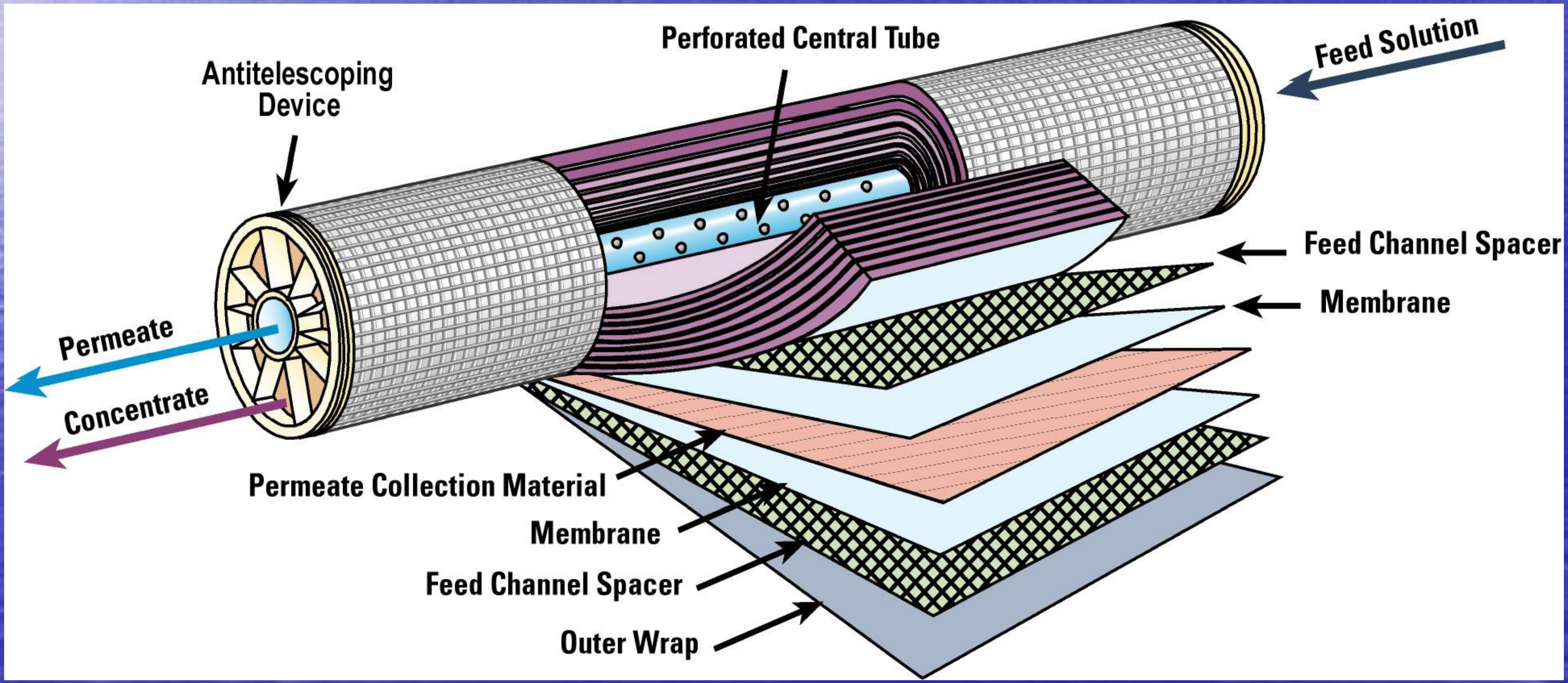


FIGURE 10.5 Modular structure of a UF polymeric: (*a*) and (*b*) Aquasource; and a ceramic membrane (*c*) Techsep.

Spiral Wound Module



MEMBRANE MATERIALS

DIACETATE MEMBRANES

COMPACTION, DETERIORATION IN PRESENCE OF MICRO-ORGANISMS GOOD FLUX (15 GFD)

TRIACETATE

HIGHER SALT REJECTION, MORE STABLE
LOW FLUX (3 GFD)

BLEND

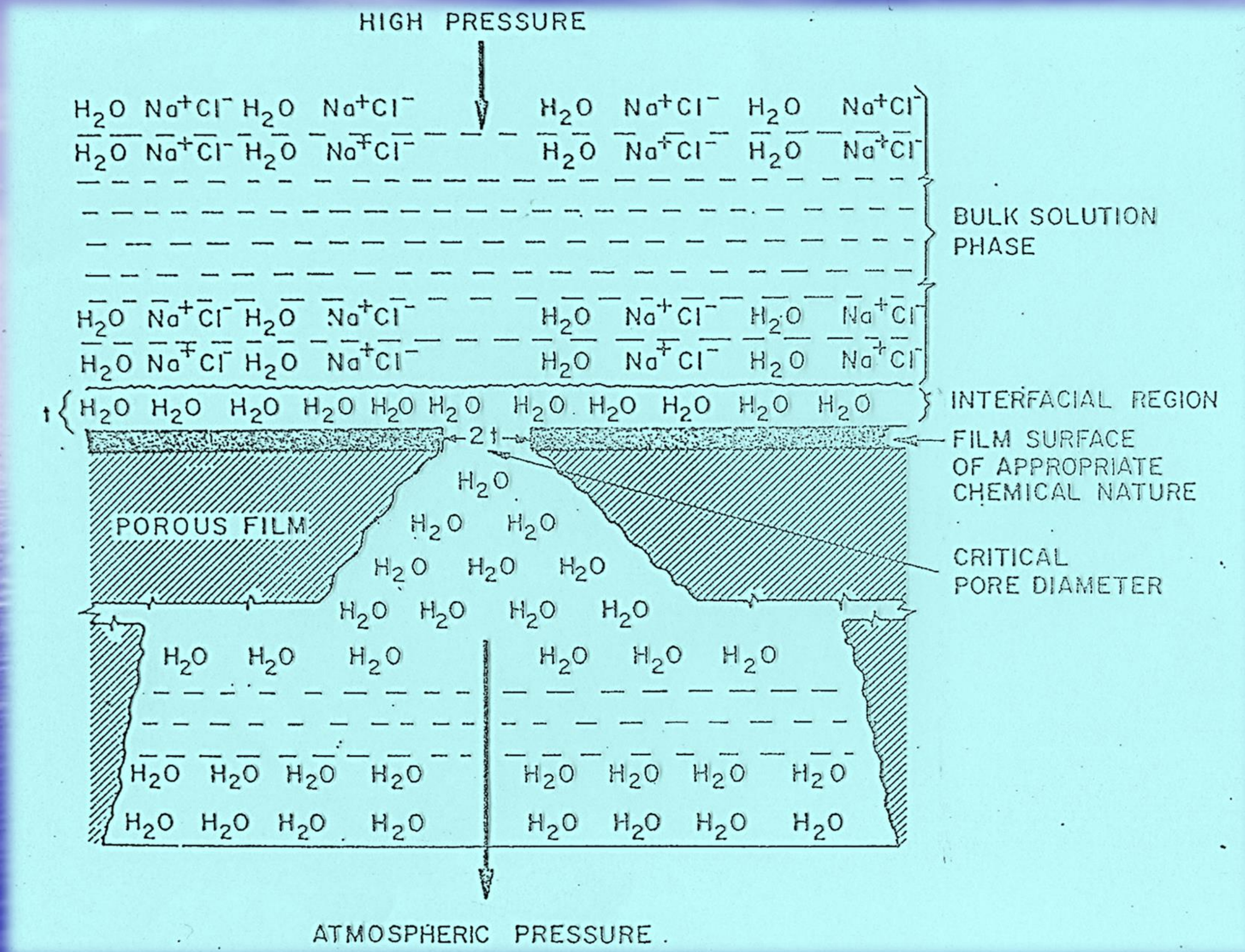
OPTIMIZES DI- AND TRI- ACETATE PROPERTIES

POLYAMIDE (HOLLOW FIBER)

INERT, WIDE pH AND TEMPERATURE RANGE

THIN FILM COMPOSITE (TFC)

SOLUTION DEPOSITION OR IN-SITU INTERFACIAL POLYMERIZATION
HIGH REJECTION, EXCELLENT FLUX, STABLE


HIGH PRESSURE
BULK SOLUTION PHASE
INTERFACIAL REGION
FILM SURFACE OF APPROPRIATE CHEMICAL NATURE
POROUS FILM
CRITICAL PORE DIAMETER
ATMOSPHERIC PRESSURE .

ADVANTAGES AND DISADVANTAGES OF DIFFERENT MEMBRANES

Asymmetric Cellulose Acetate

Inexpensive	Hydrolyzed easily (pH limits: 4-8)
Easily processed	Biodegradable
Resistant to chlorine	Temperature-sensitive (max. 35°C)
Well characterized	Difficult to clean

Asymmetric Aromatic Polyamide

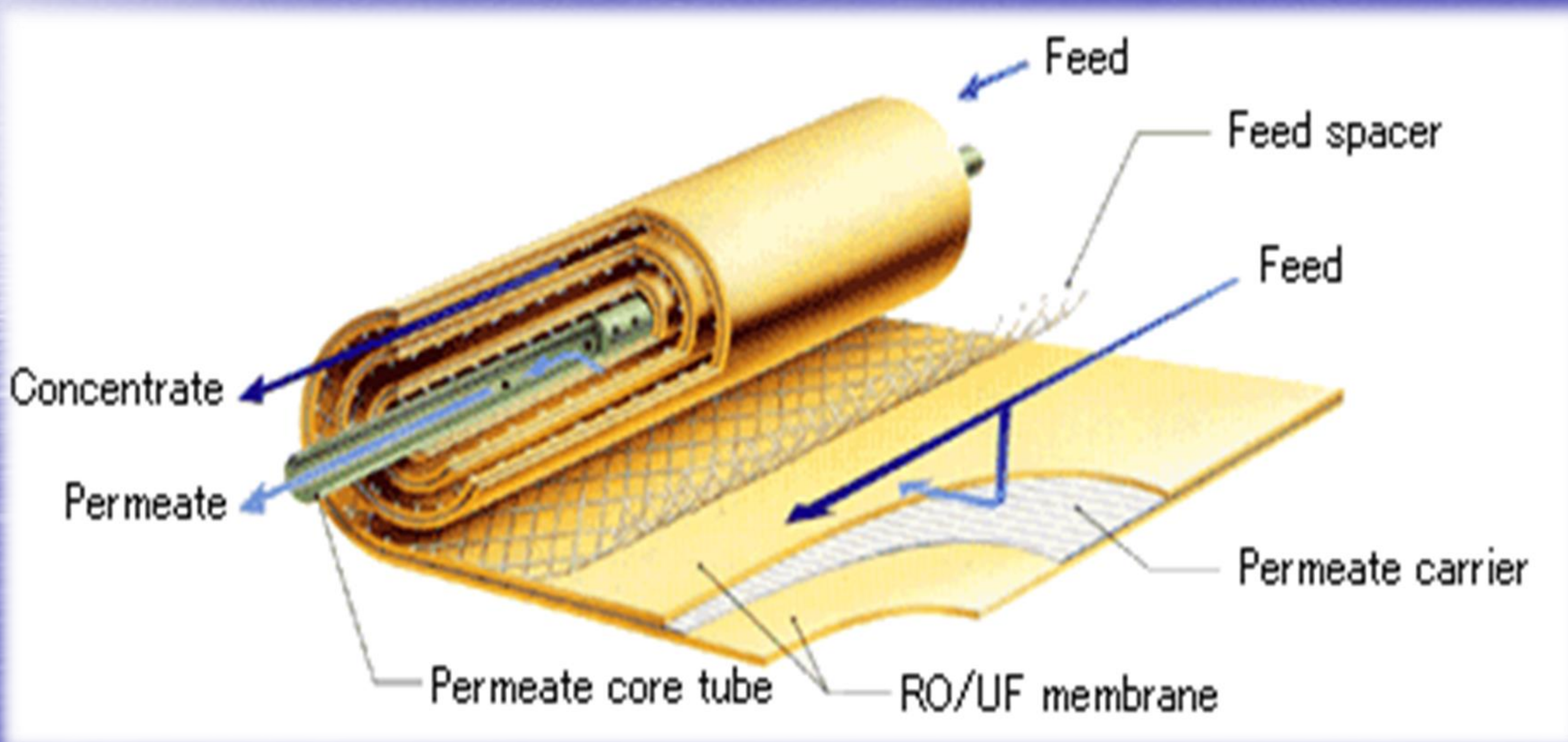
Resistant to pH extremes	Damaged by chlorine
Nonbiodegradable	Temperature-sensitive (max. 35°C)
Relatively easily processed	
Well characterized	
Higher rejections	

Thin Film Composite Aromatic Polyamide: FT-30

Resistant to pH extremes	Damaged by chloride (some Cl_2 tolerance)
Non biodegradable	More difficult to manufacture
Very high fluxes	
Better temperature resistance (max. 45-80°C)	
Higher rejections	

Thin Film Composite: PEC-1000

Nonbiodegradable	Unstable to chlorine and oxygen
Very high rejections	Low fluxes
Good pH resistance	More difficult to manufacture


Feed
Feed spacer
Feed
Concentrate
Permeate
Permeate carrier
Permeate core tube
RO/UF membrane

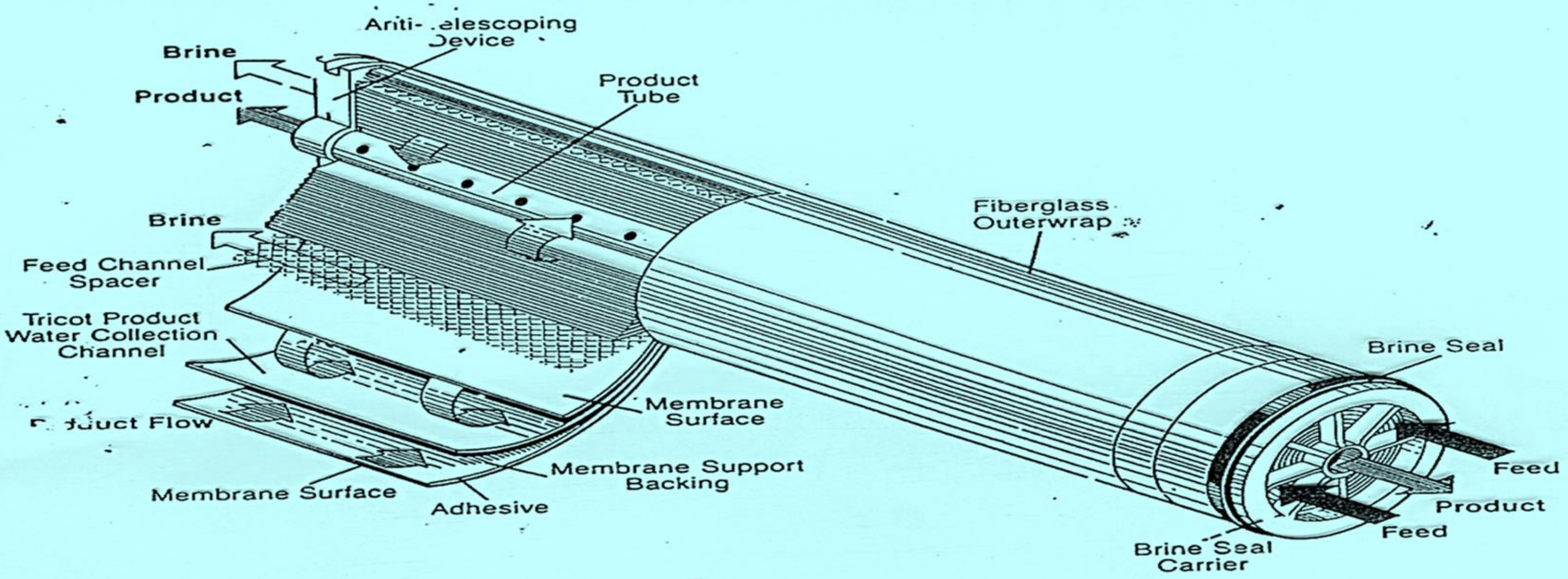
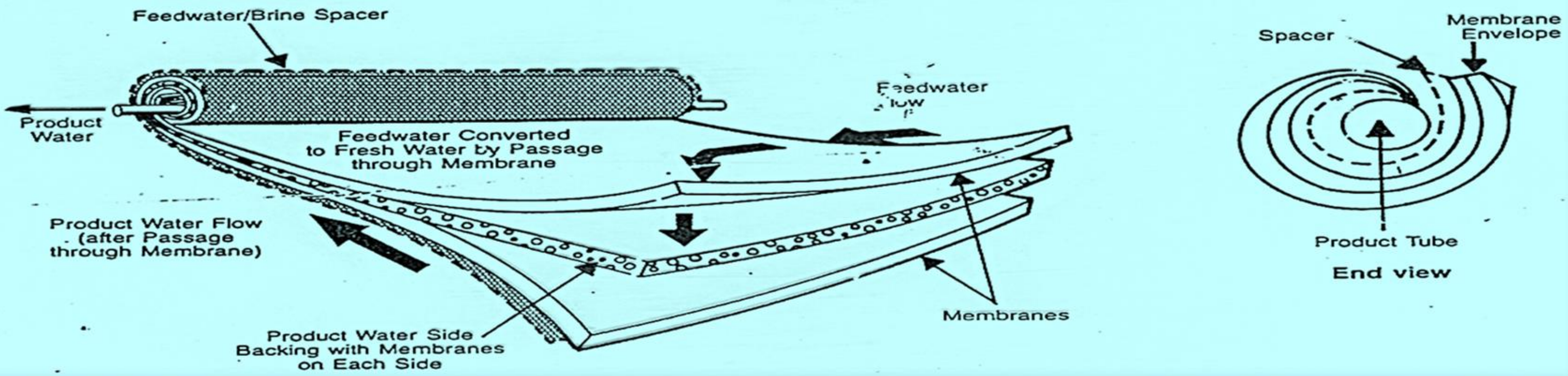
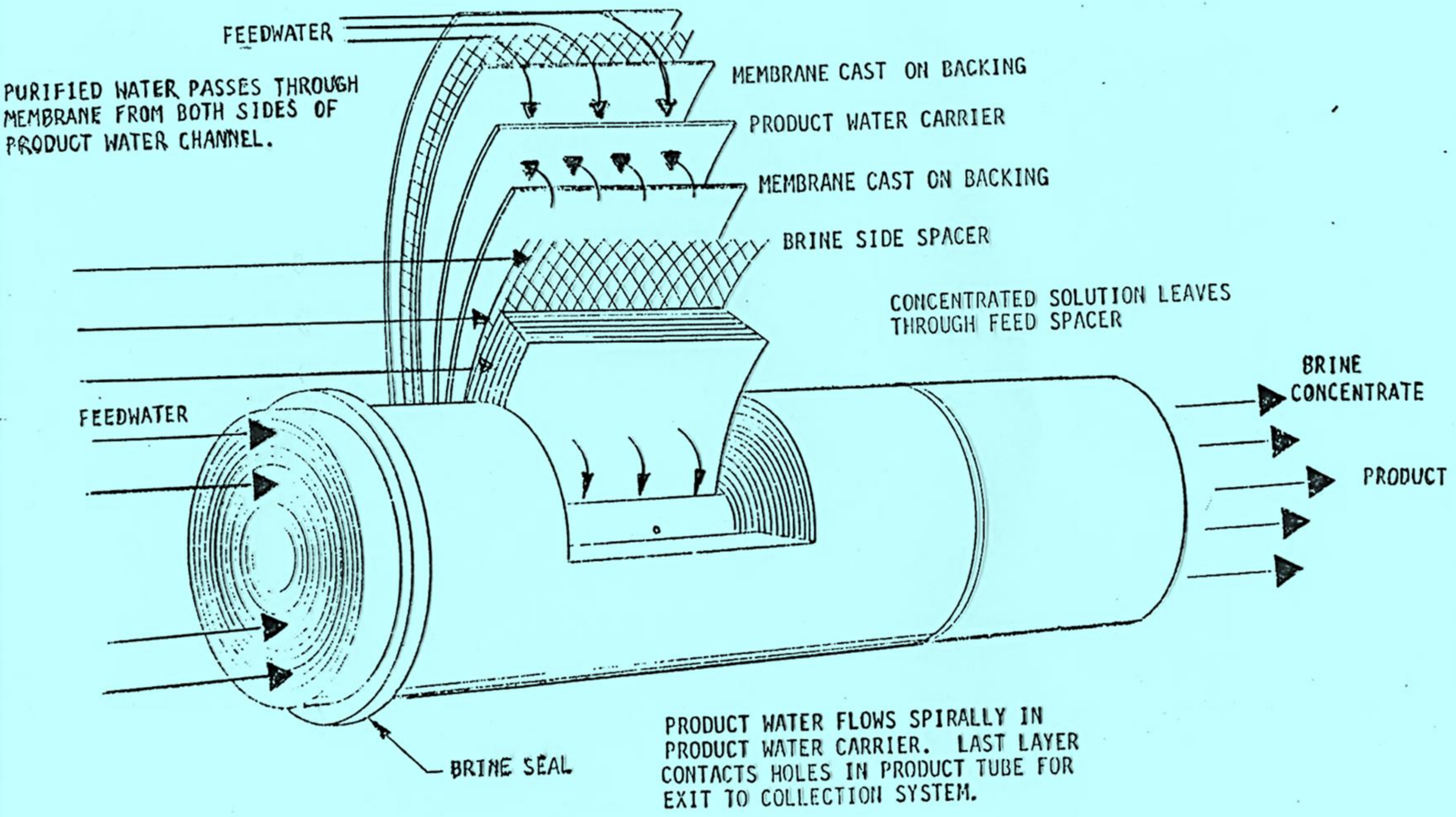


Figure 2. Spiral-wound Reverse Osmosis Cartridge Flow Pattern



SPIRAL-WOUND CARTRIDGE (FLOW PATTERN)




LP21-8040
LP11-4040
SW11-4040
ULP11-4021

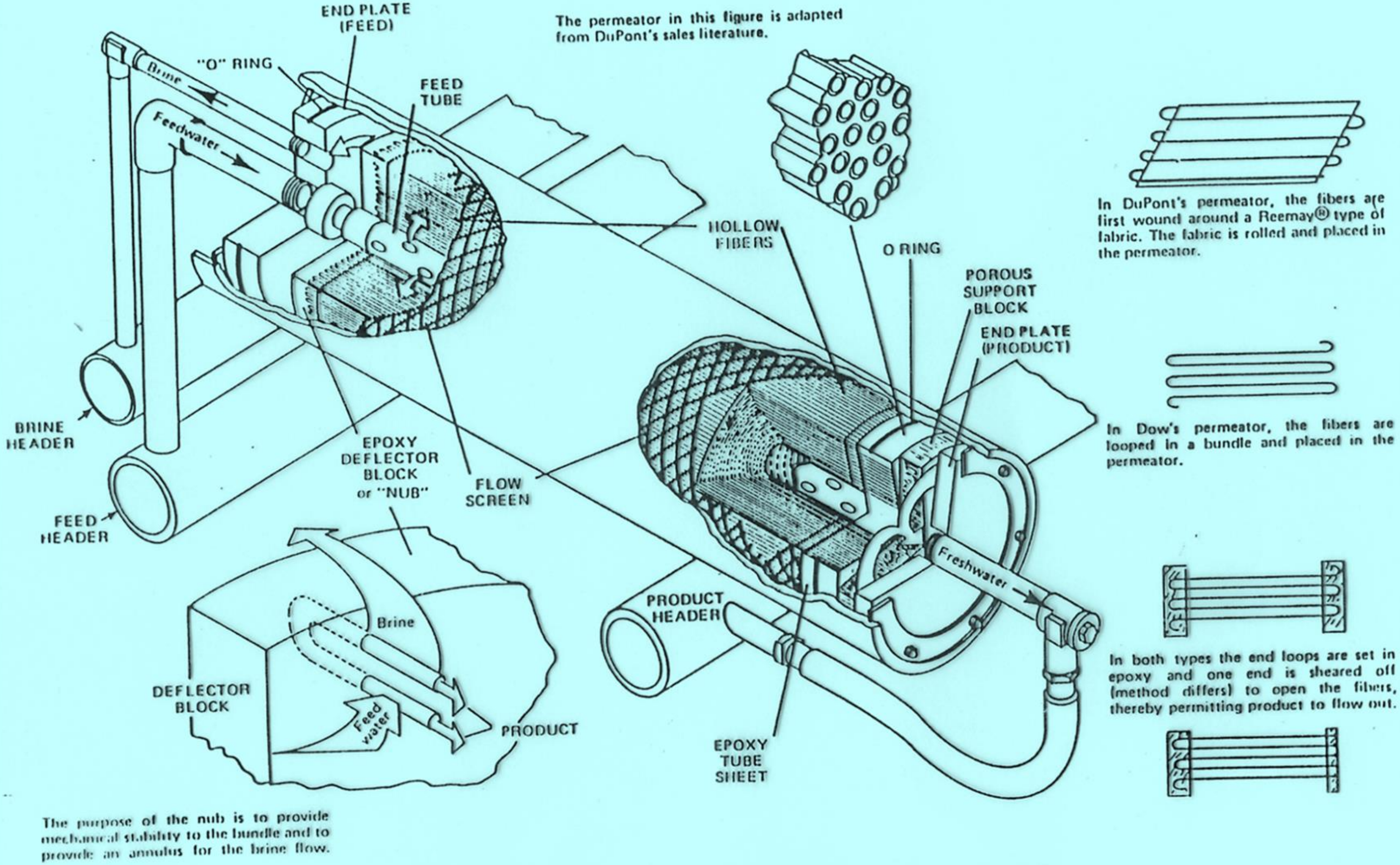


FIGURE 5-9. Permeator assembly for hollow fine fiber membranes.

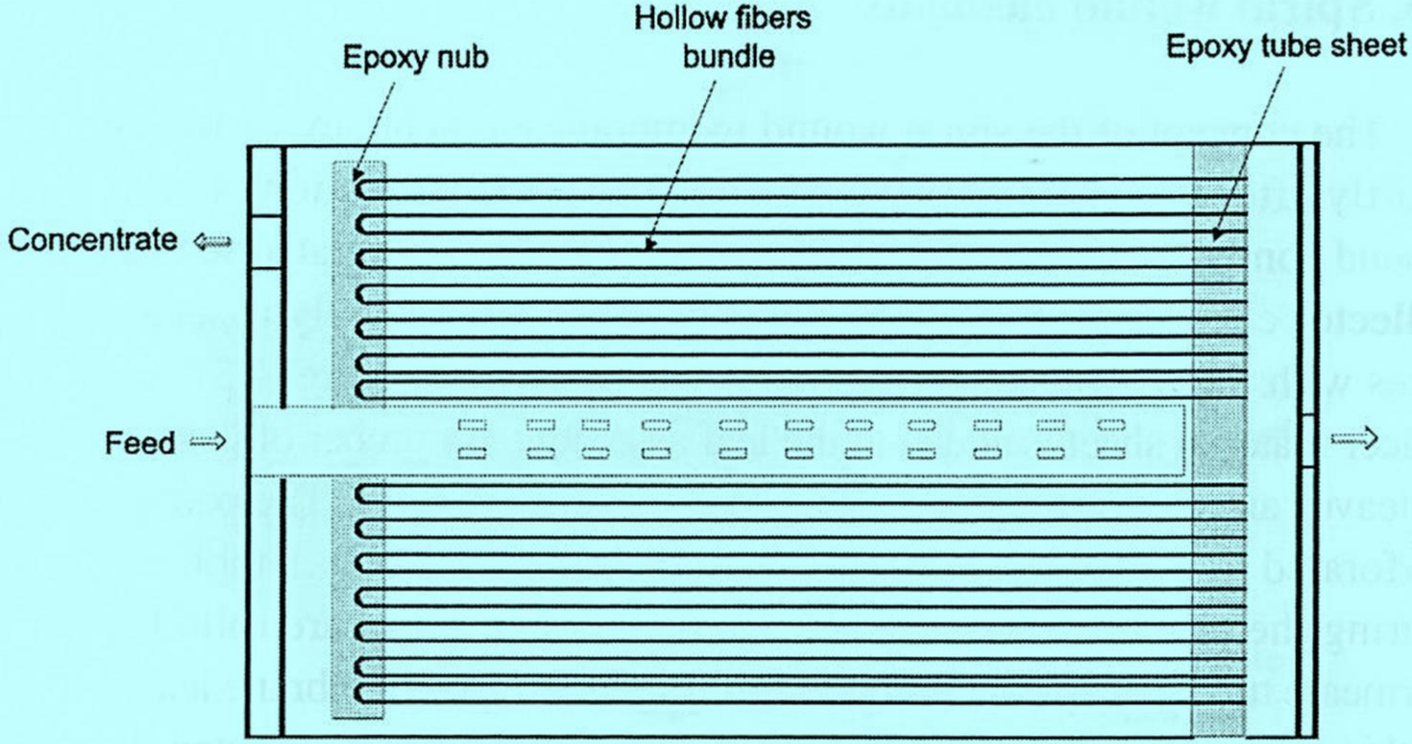


FIG. 4.2 Configuration of the hollow fiber membrane module.

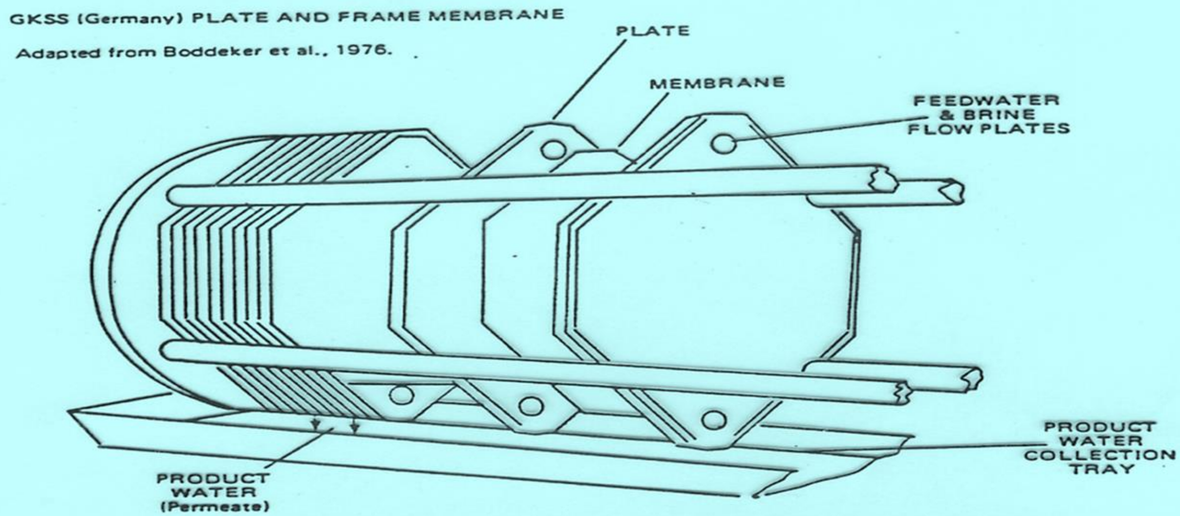



FIGURE 5-3. Construction of a plate and frame membrane.

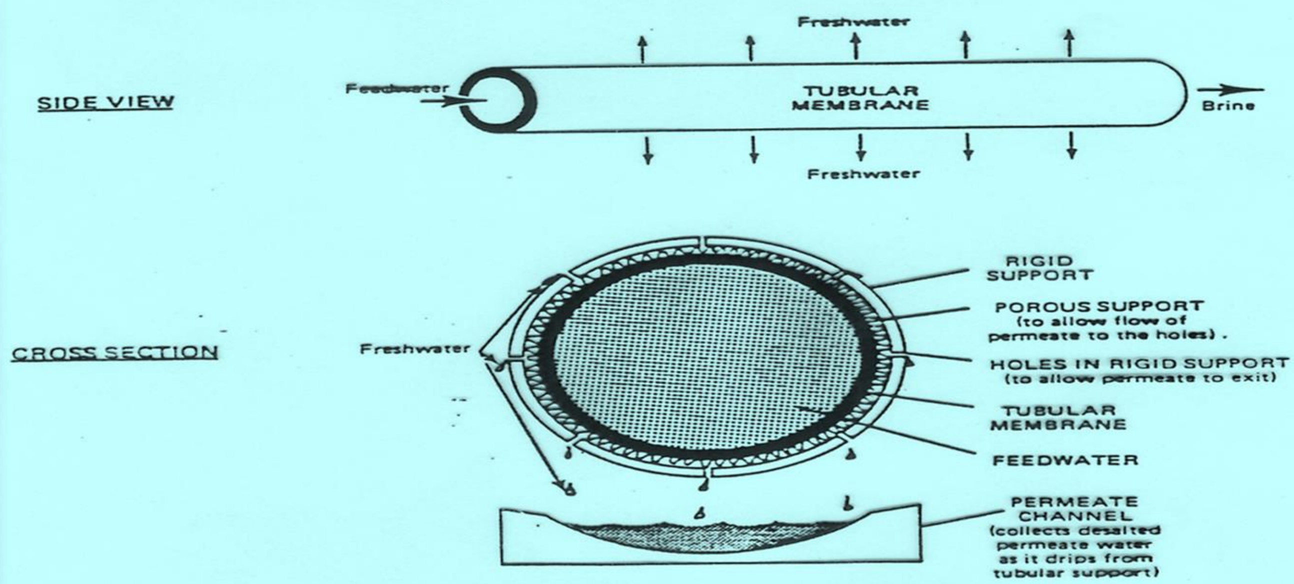


FIGURE 5-4. Construction of a tubular membrane.

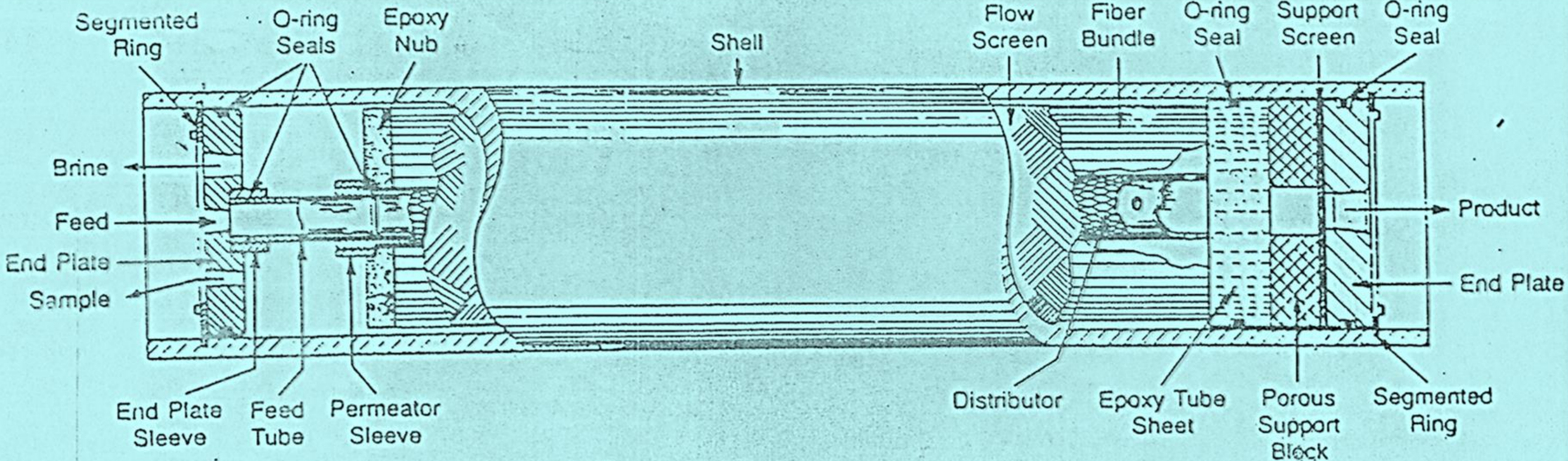
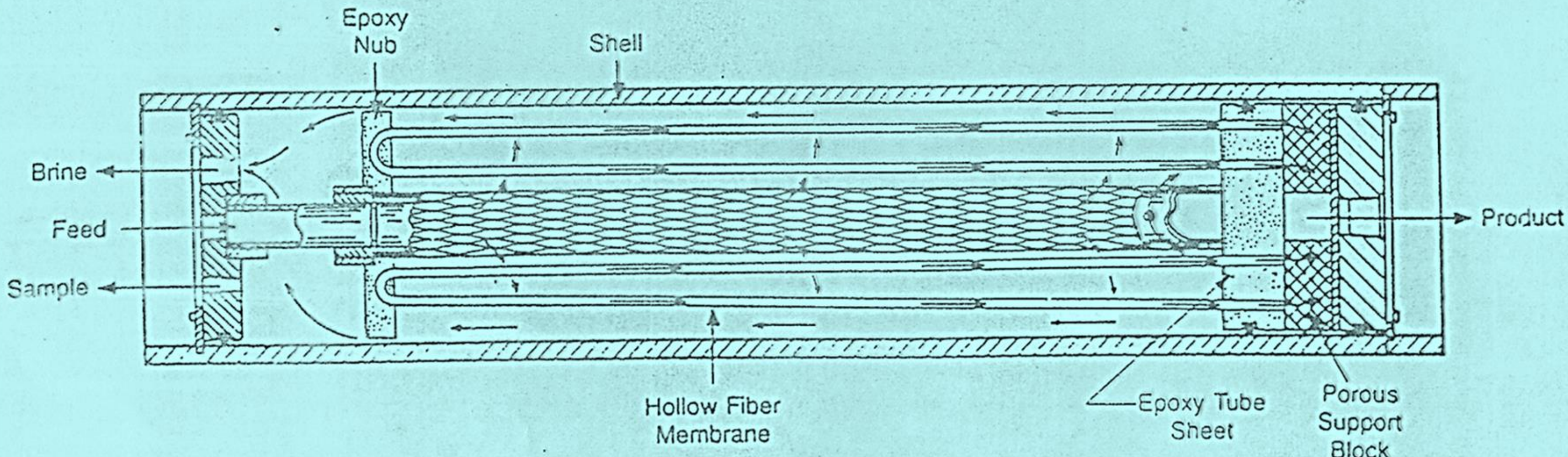


Illustration of Hollow Fiber RO Process



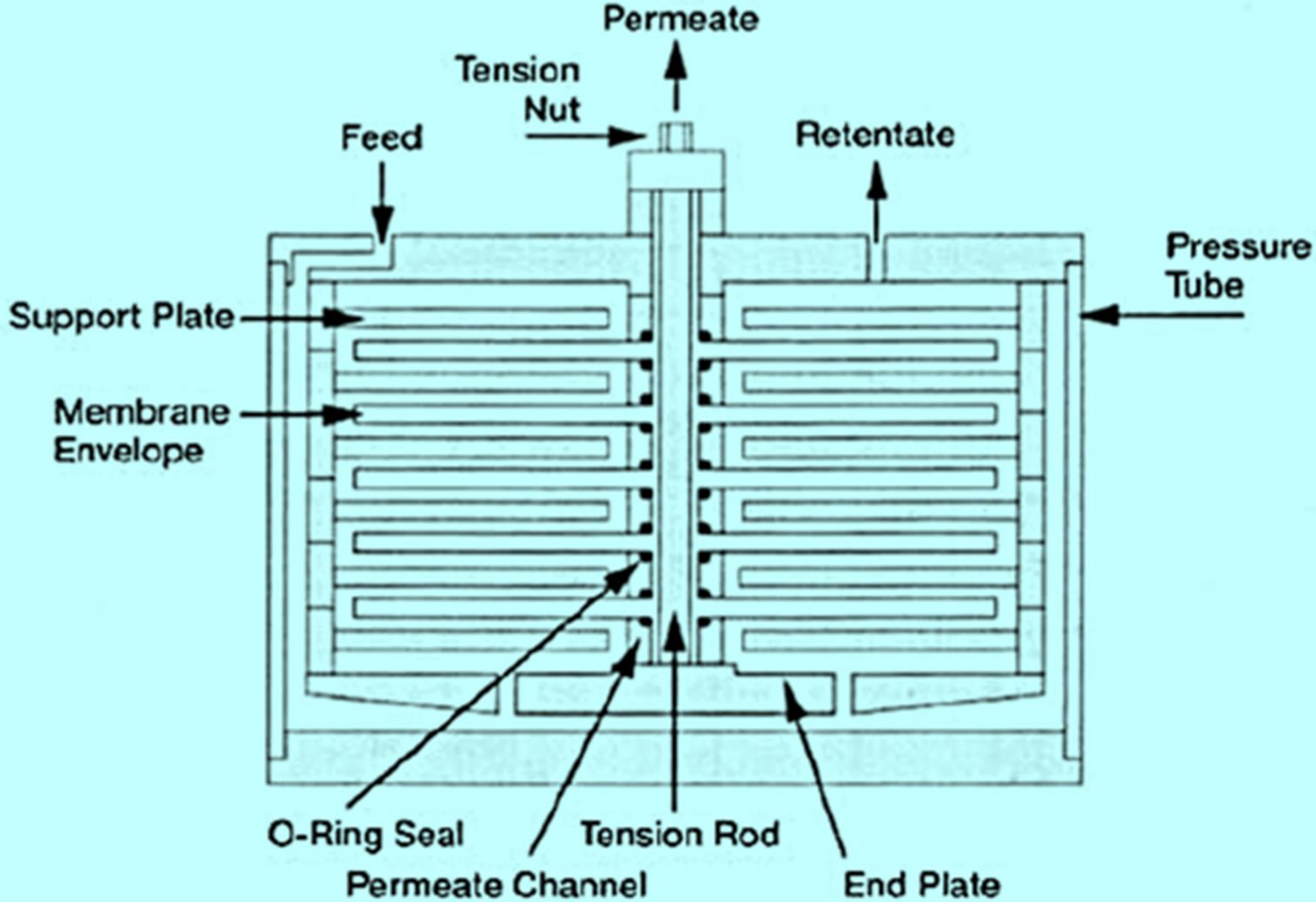
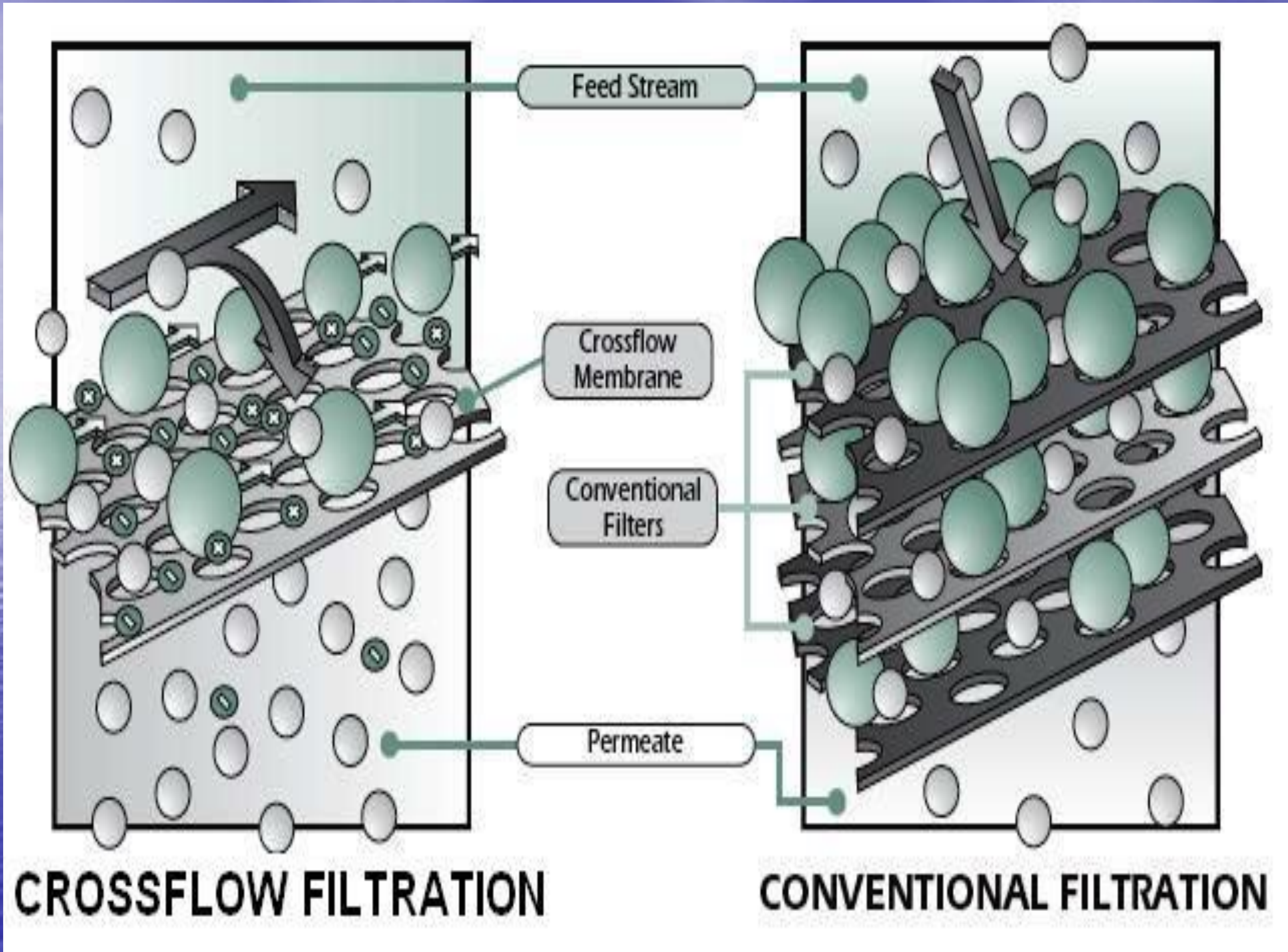
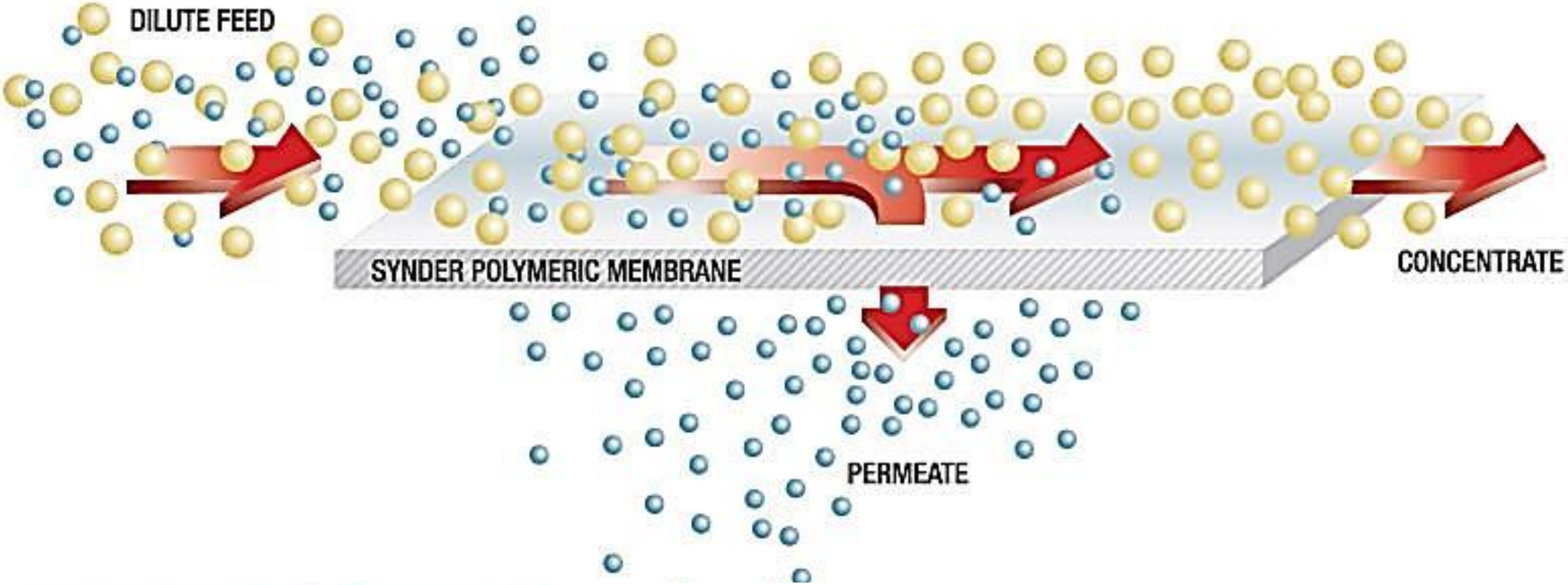


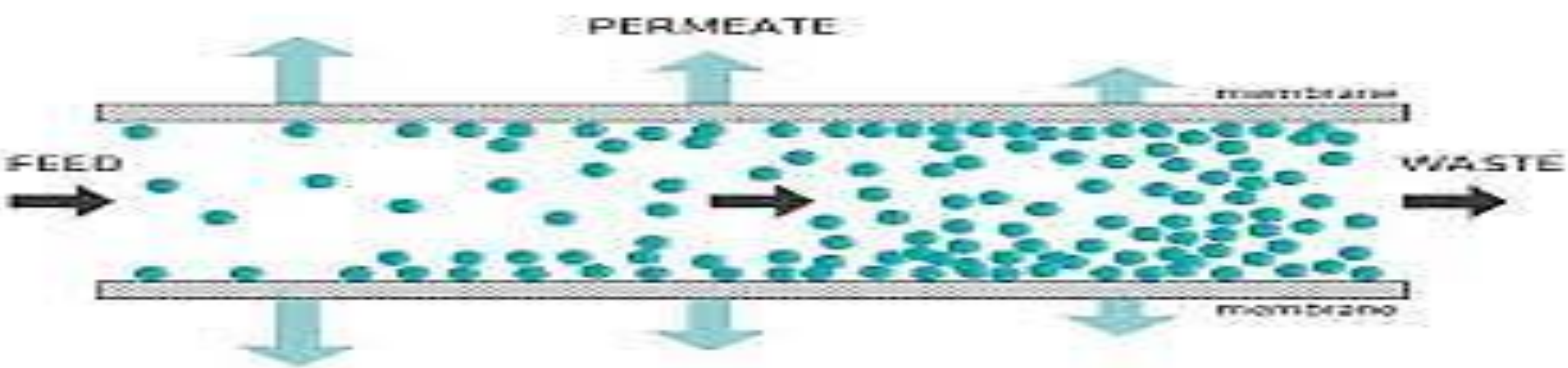
Figure 4.12 Plate-and-frame membrane module. *Courtesy of Elsevier.*


Feed Stream
Crossflow Membrane
Conventional Filters
Permeate
CROSSFLOW FILTRATION
CONVENTIONAL FILTRATION

CROSS FLOW PROCESS



Cross-flow filtration



Filtering

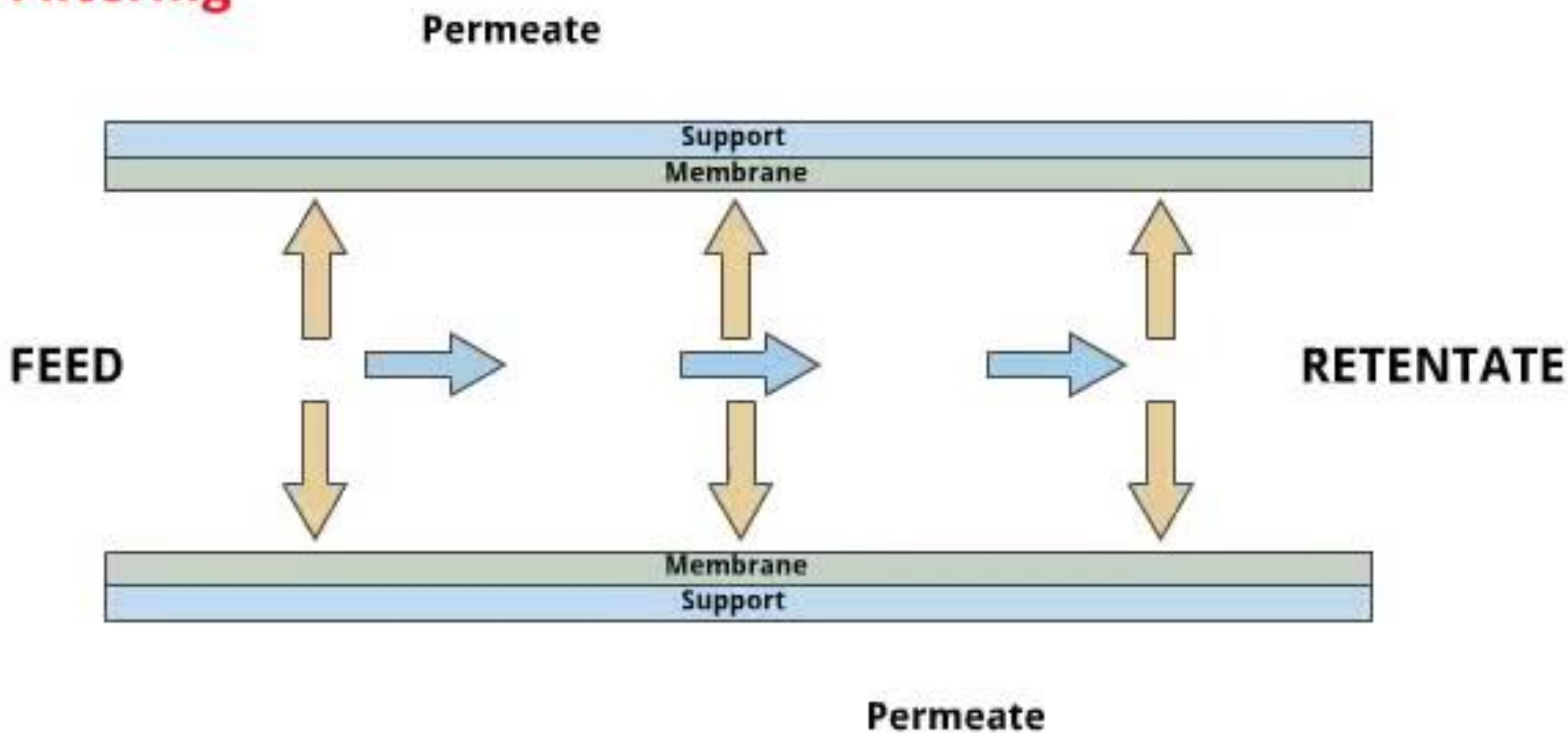
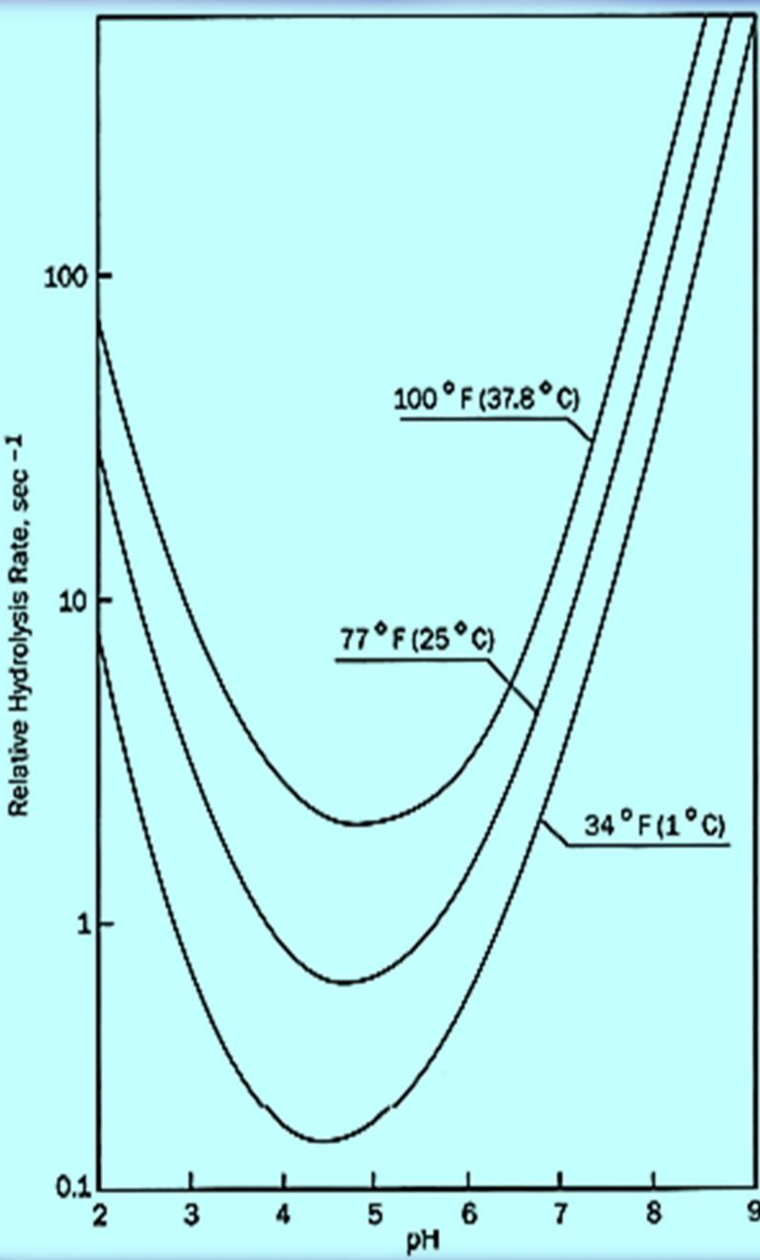

Permeate
Support
Membrane
FEED
RETENTATE
Membrane
Support
Permeate

Table 4.3 Brief comparison of four basic RO membrane module configurations.[22]

Property	Plate-and-Frame	Tubular	Spiral Wound	Hollow Fine Fiber
Packing Density, ft^2/ft^3	45–150	6–120	150–380	150–1,500
Potential for Fouling	Moderate	Low	High	Very High
Ease of Cleaning	Good	Excellent	Poor	Poor
Relative Manufacturing Cost	High	High	Moderate	Low

Table 4.1 Characteristics of cellulose acetate RO membranes.

Property	Value for CA Membranes
Membrane Type	Homogenous asymmetric
Salt Rejection (%)	~95
Silica Rejection (%)	~85
pH Range	4–6
Feed Pressure (brackish membrane)	220–440 psi
Temperature Tolerence	Up to 30ºC
Surface Charge	Neutral
Chlorine Tolerance	Up to 1 ppm continuously
Biological growth	Metabolized membrane
Fouling Tolerance	Good
Surface Roughness	Smooth



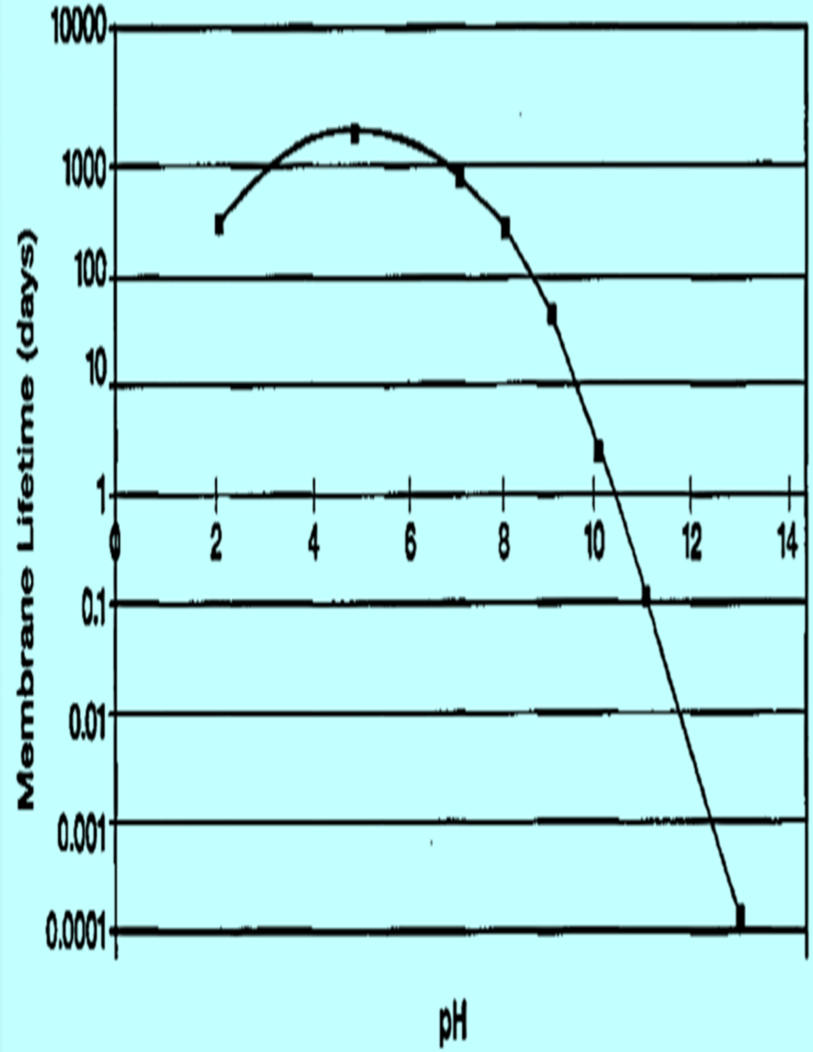


Figure 4.6 Lifetime of a CA membrane as a function of pH.

Table 4.2 Characteristics of polyamide composite RO membranes.

Property	Value for PA Membranes
Membrane Type	Homogenous asymmetric, thin-film composite
Salt Rejection (%)	~98+
Silica Rejection (%)	~96+
pH Range	2–12*
Feed Pressure (brackish membrane)	145 – 400 psi
Temperature Tolerence	Up to 45°C**
Surface Charge	Negative (anionic)
Chlorine Tolerance	< 0.02 ppm
Biological growth	Causes membrane fouling
Fouling Tolerance	Fair
Surface Roughness	Rough

* Broader range possible for cleaning. Check with membrane manufacturer.

** Higher temperature possible for "heat sanitisable" membranes. Check with manufacturer.

TABLE 1.6 SWRO Products Lineup Released from Toray[a]

Type of Membrane	Standard Use	High Permeability	High Pressure	Ultrahigh Pressure
Name of membrane element	TM820-370	TM820L-370	TM820H-370	SU820BCM
Salt rejection, %	99.75	99.70	99.75	99.83
Product flow rate, m^3/day (gpd)	23 (6000)	34 (9000)	21 (5600)	23 (6000)
Boron rejection, %	91–93	88–90	91–93	91–93
Membrane area, m^2 (ft^2)	34 (370)	34 (370)	34 (370)	29 (320)
Max. operating pressure, MPa (psi)	6.9 (1000)	6.9 (1000)	8.3 (1200)	10.0 (1450)

[a]Testing conditions were: applied pressure, 800 psi (5.52 MPa) for others; recovery ratio, 8%; feed solution: 32,000 ppm, NaCl with 5.0 mg/L boron for others; pH = 8; temperature, 25°C.

TABLE 1.6 SWRO Products Lineup Released from Toray[a]

Type of Membrane	Standard Use	High Permeability	High Pressure	Ultrahigh Pressure
Name of membrane element	TM820-370	TM820L-370	TM820H-370	SU820BCM
Salt rejection, %	99.75	99.70	99.75	99.83
Product flow rate, m^3/day (gpd)	23 (6000)	34 (9000)	21 (5600)	23 (6000)
Boron rejection, %	91–93	88–90	91–93	91–93
Membrane area, m^2 (ft^2)	34 (370)	34 (370)	34 (370)	29 (320)
Max. operating pressure, MPa (psi)	6.9 (1000)	6.9 (1000)	8.3 (1200)	10.0 (1450)

[a]Testing conditions were: applied pressure, 800 psi (5.52 MPa) for others; recovery ratio, 8%; feed solution: 32,000 ppm, NaCl with 5.0 mg/L boron for others; pH = 8; temperature, 25°C.

TABLE 1.8 Permeate Boron Concentration by a Single-Stage SWRO Operation (Calculated)[a]

Seawater (Temp., TDS conc., Boron conc.)	Permeate Boron Concentration (mg/L) — Boron Rejection Performance of Used Membrane Element: 90%	95% (TM820A)	97%	99%
Japan (25°C, 3.5%, 5 mg/L)	1.5	0.9	0.4	0.2
Southeast Asia (32°C, 3.5%, 5 mg/L)	1.6	1.0	0.5	0.2
Middle East (38°C, 4.5%, 7 mg/L)	3.0	2.0	1.1	0.4

[a]Assumed conditions: Plant: 7 elements/vessel, 14 lmh; operation: 25°C, pH 8.0, 800 psi, 3.5 L/min, recovery ratio 40%, after 3 years. Japanese law grade: <1.0 mg/L, WHO guideline grade: <0.5 mg/L.

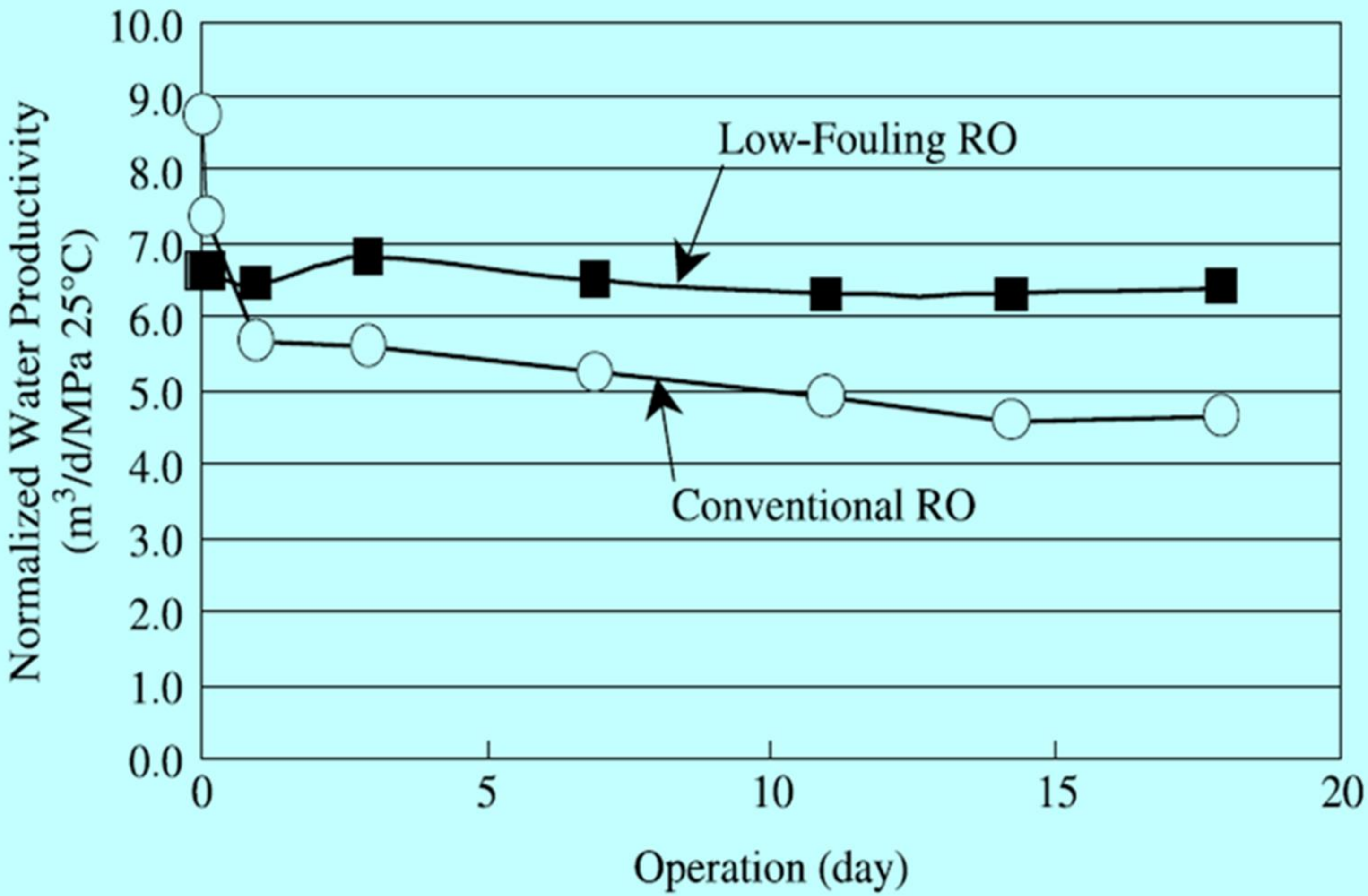


Figure 1.9 Water productivity of low-fouling RO compared with conventional RO.

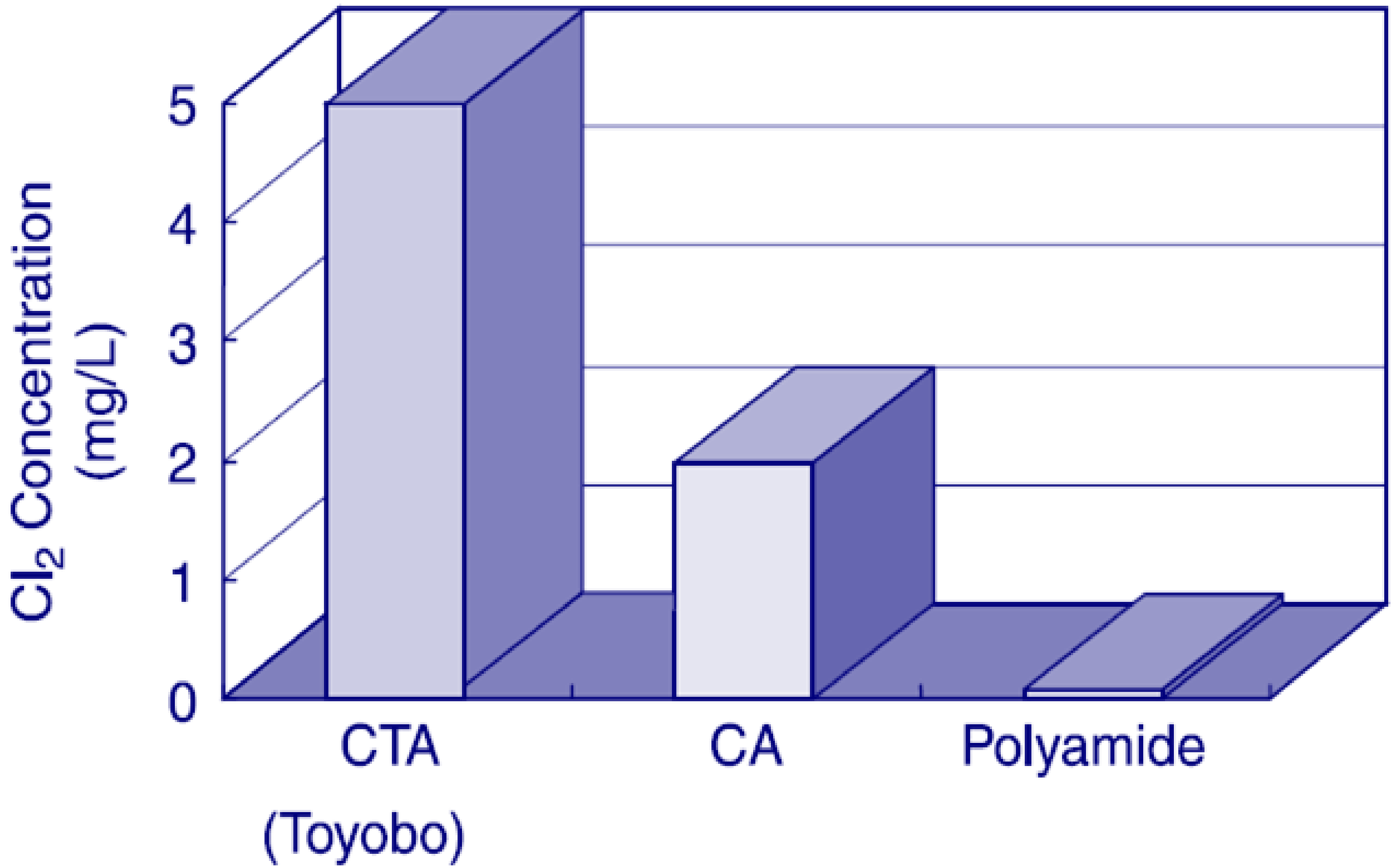
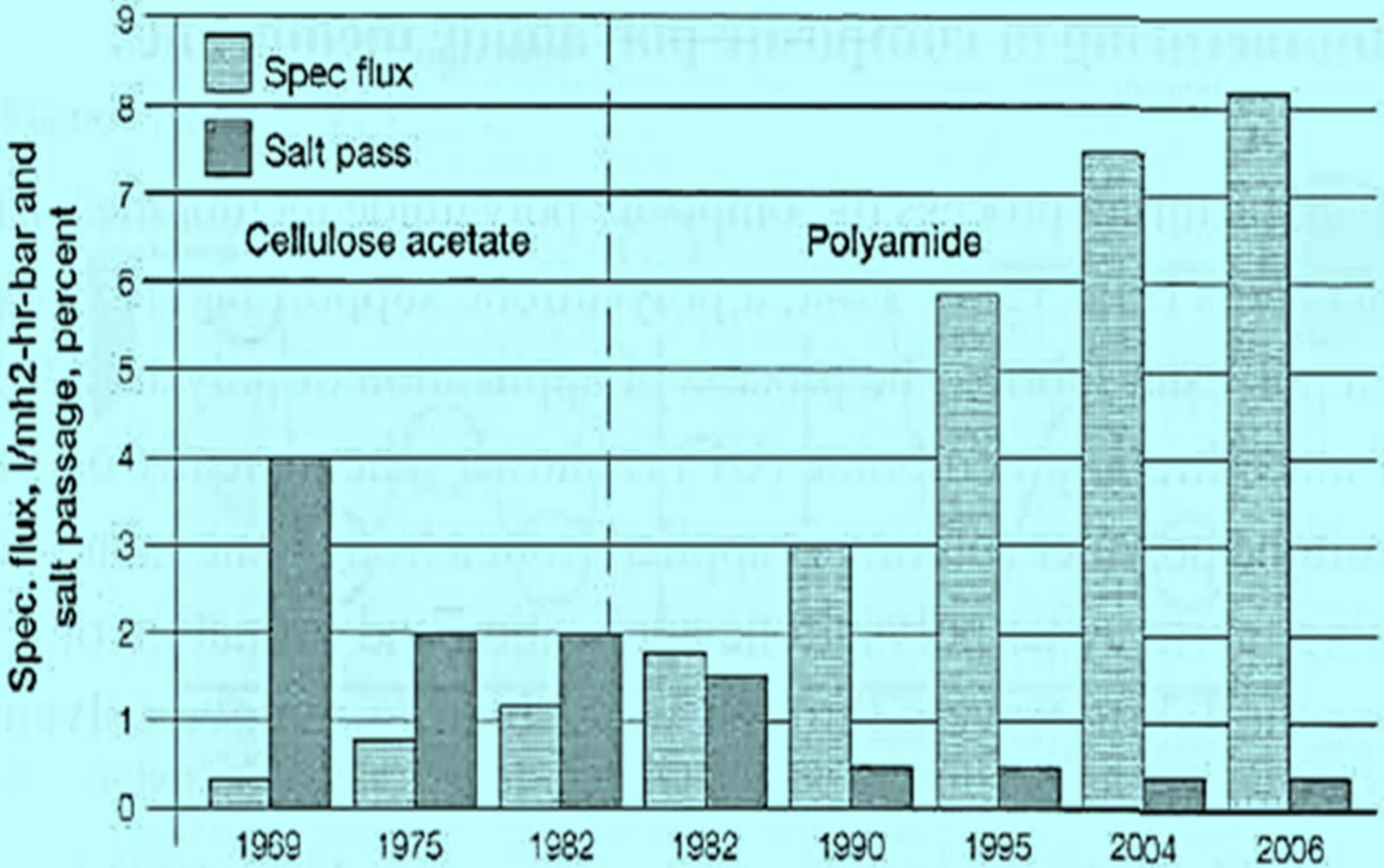


Figure 2.3 Comparison of chlorine resistance.



12.3 Evolution of water permeability and salt passage of commercial brackish RO membranes.

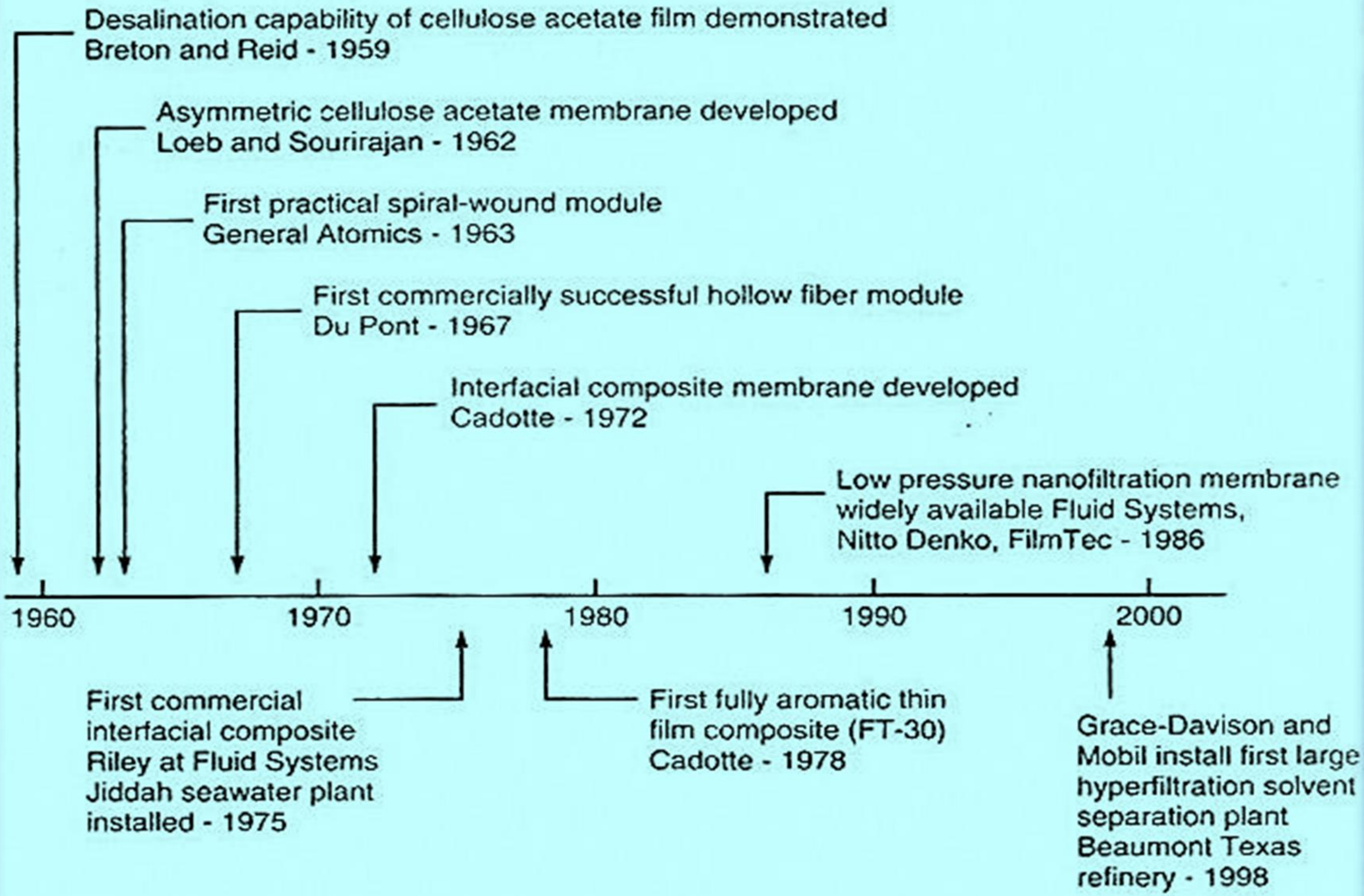


Figure 5.1 Milestones in the development of reverse osmosis

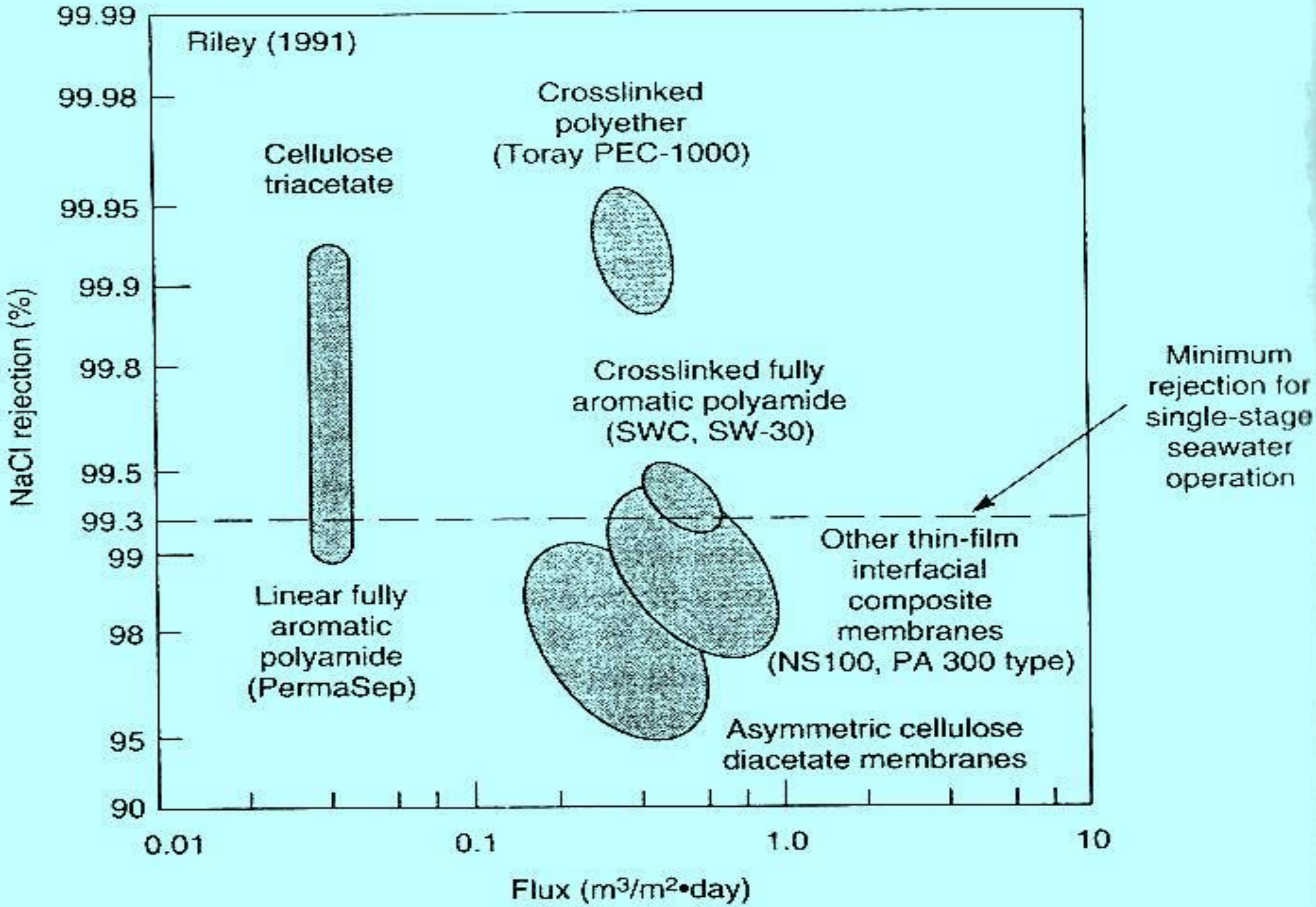


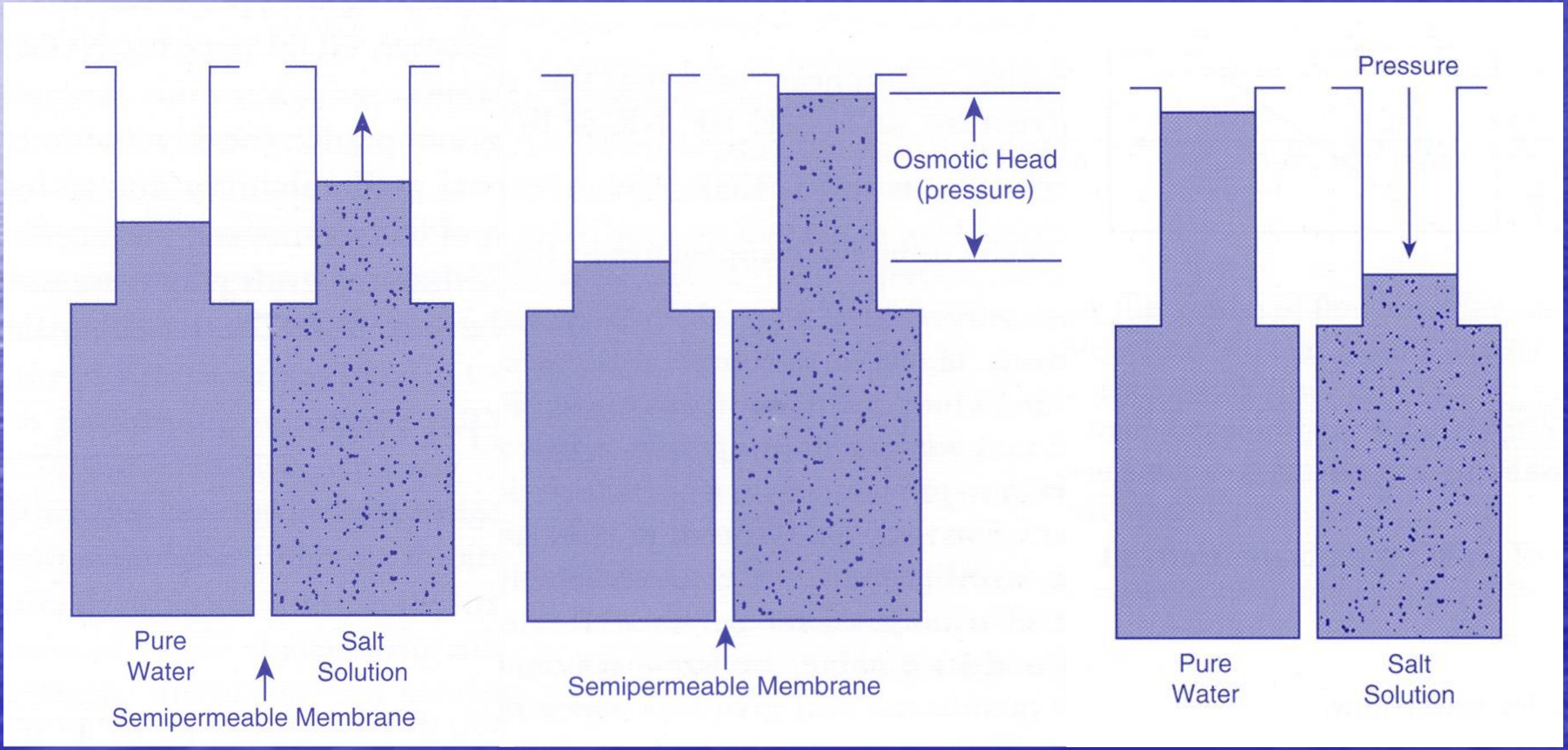
Figure 5.12 Performance characteristics of membranes operating on seawater at 56 kg/cm^2 (840 psi) and 25 °C [13]

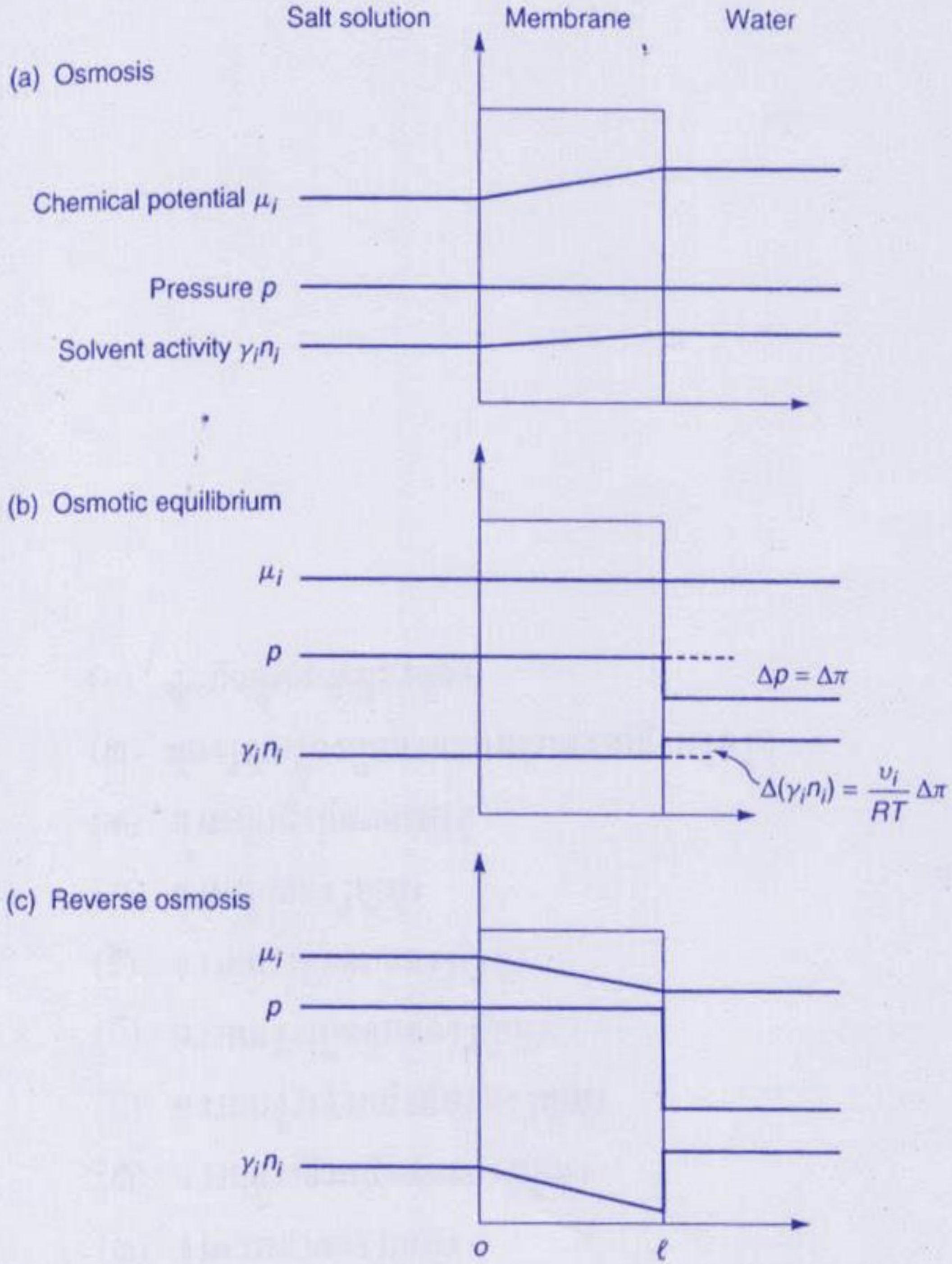
Introduction to Reverse Osmosis

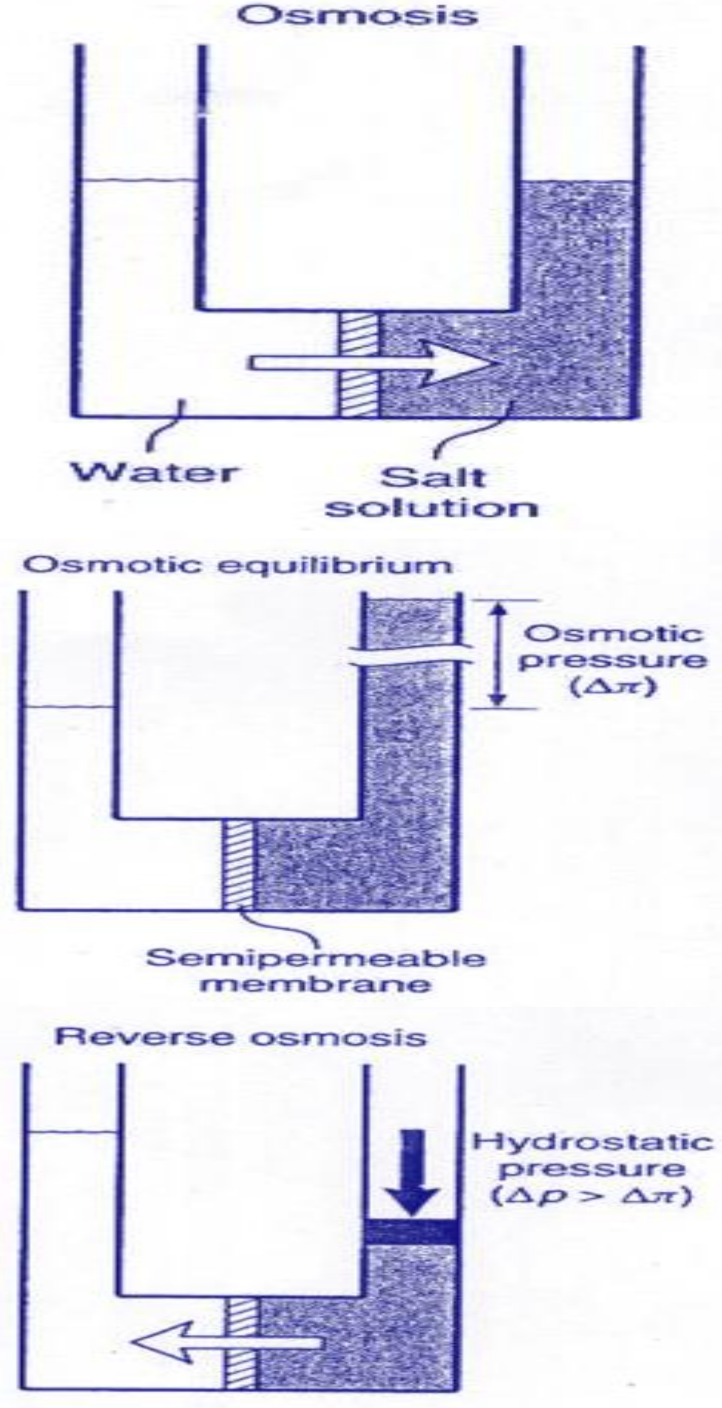
Basic Terms

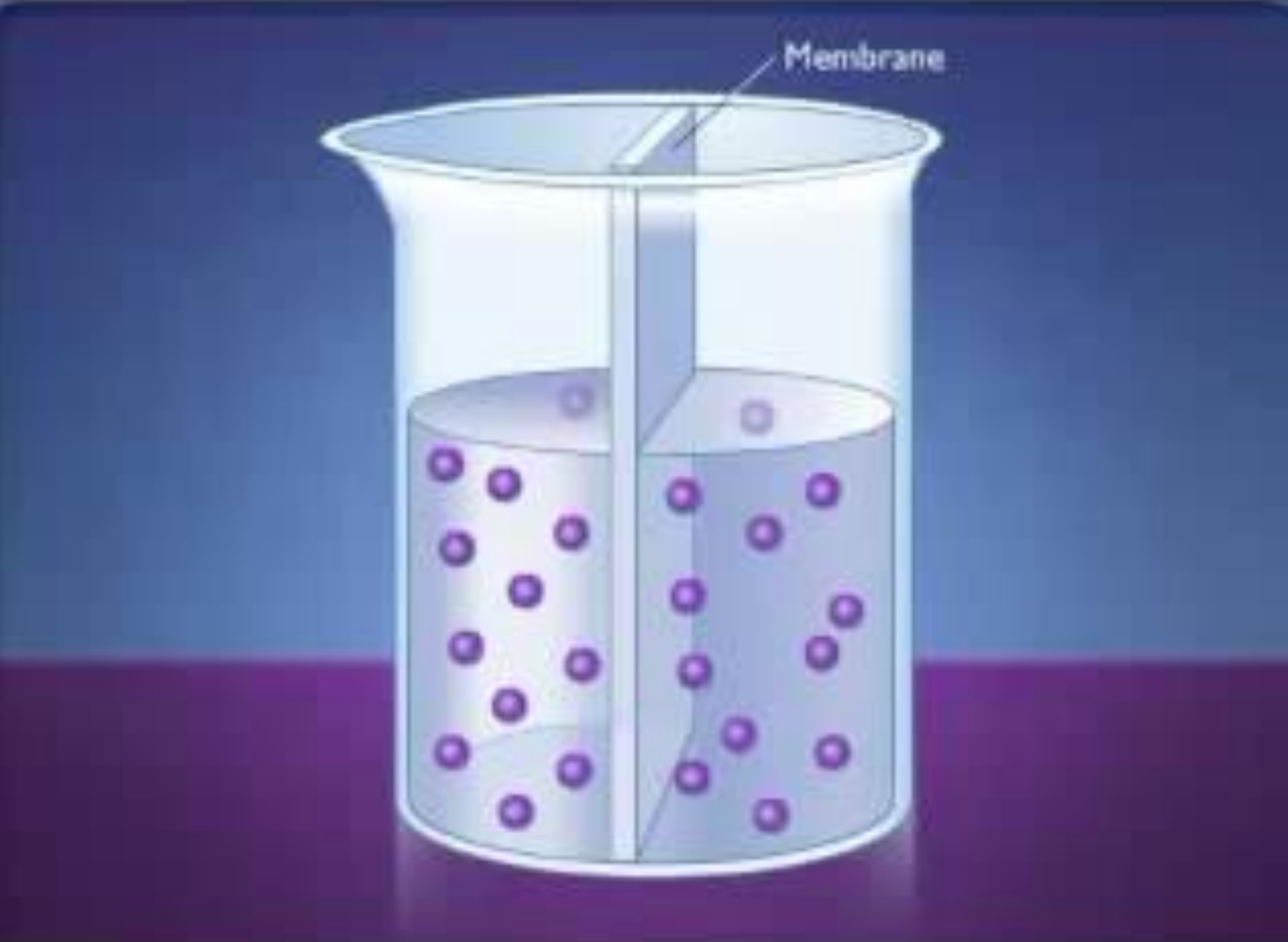
Presented by

Sawaeng Gerdpratoom
Numsai Thai Co;Ltd


Pure
Water
Salt
Solution
Semipermeable Membrane
Osmotic Head
(pressure)
Semipermeable Membrane
Pressure
Pure
Water
Salt
Solution


Salt solution
Membrane
Water
(a) Osmosis
Chemical potential μ_i
Pressure p
Solvent activity $\gamma_i n_i$
(b) Osmotic equilibrium
μ_i
p
$\Delta p = \Delta\pi$
$\gamma_i n_i$
$\Delta(\gamma_i n_i) = \frac{\upsilon_i}{RT}\Delta\pi$
(c) Reverse osmosis
μ_i
p
$\gamma_i n_i$
o
ℓ


Osmosis
Water
Salt solution
Osmotic equilibrium
Osmotic pressure ($\Delta\pi$)
Semipermeable membrane
Reverse osmosis
Hydrostatic pressure ($\Delta p > \Delta\pi$)


Membrane

- การคำนวณค่า Osmotic Pressure (P_{os} หรือ π)
  - $P_{os} = R(T+273) \bullet \Sigma(m_i)$; สมการนี้ใช้ได้กับสารที่มีความเข้มข้นต่ำเท่านั้น

    ; P_{os} = Osmotic Pressure (bar)

    ; R = ค่าคงที่ของก๊าซ = 0.082 L atm $mol^{-1}K^{-1}$

    ; T = อุณหภูมิ (°C)

    ; $\Sigma(m_i)$ = โมลความเข้มข้นทั้งหมดของส่วนประกอบทั้งหมดที่อยู่ในสารละลาย
  - P_{os} หรือ π สามารถประมาณค่าได้จาก ค่าTDS โดย 1000 ppm = 0.77 bar (11psi) :

$$\pi \approx \frac{TDS \times 11}{1000}$$

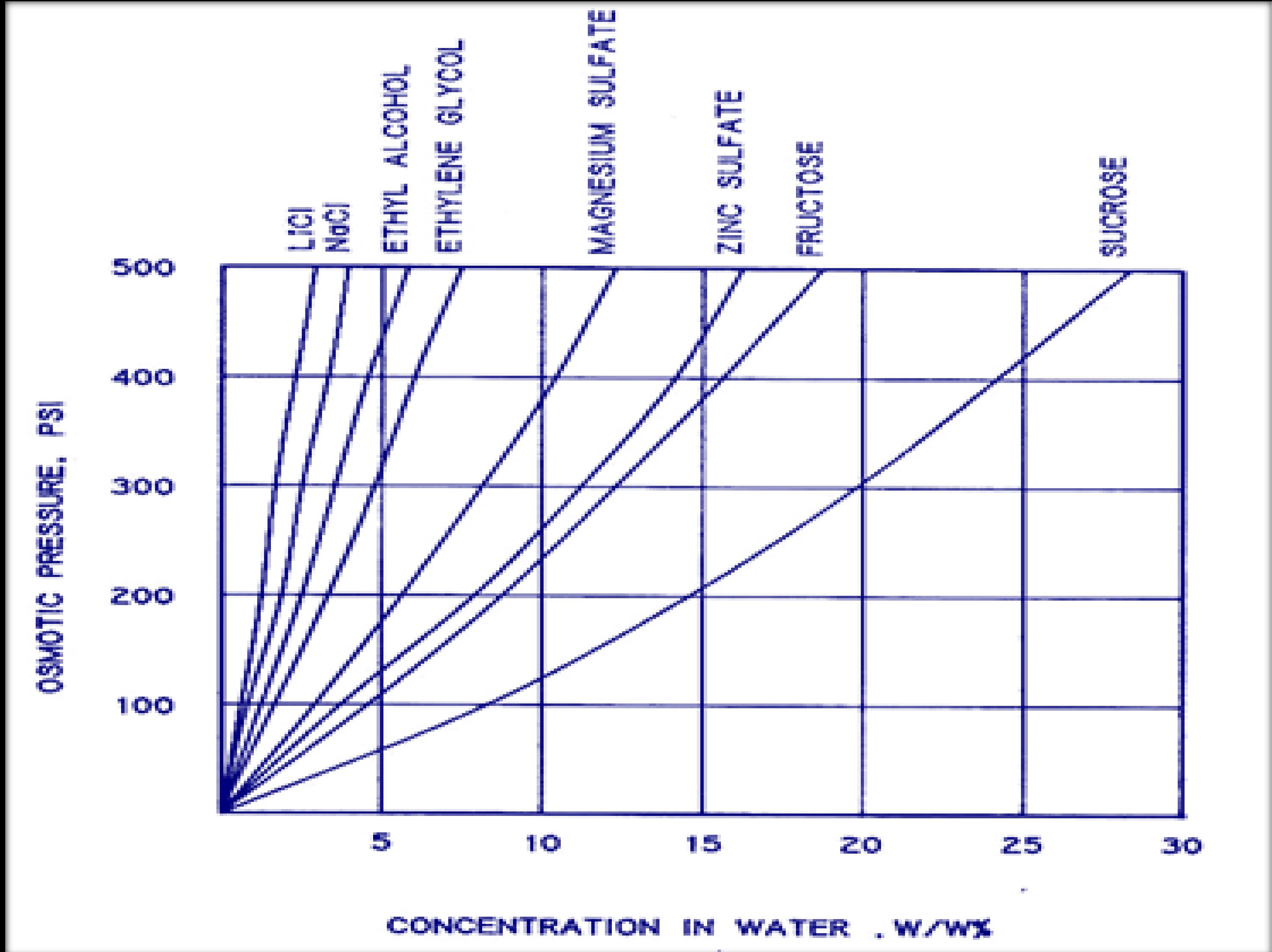
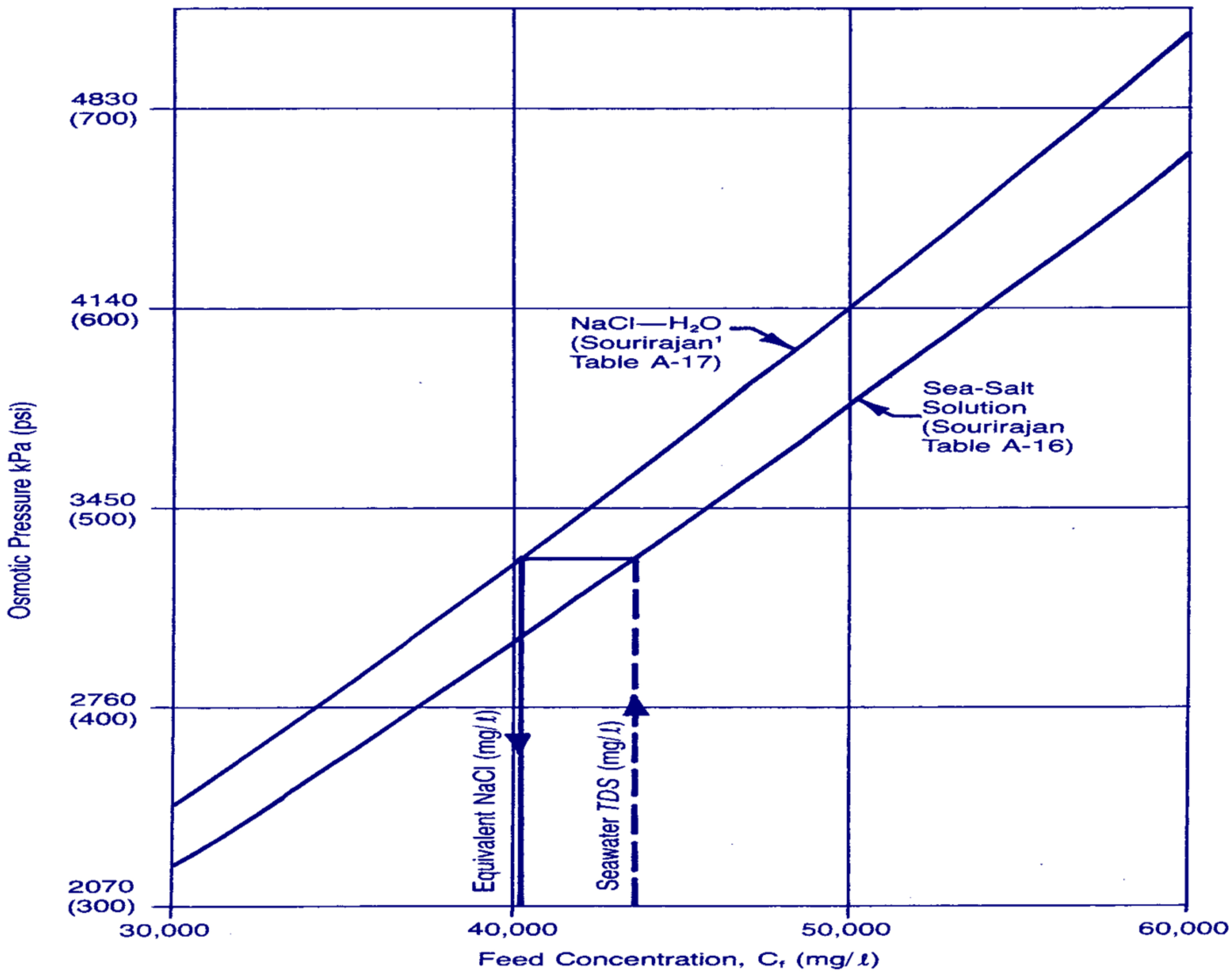
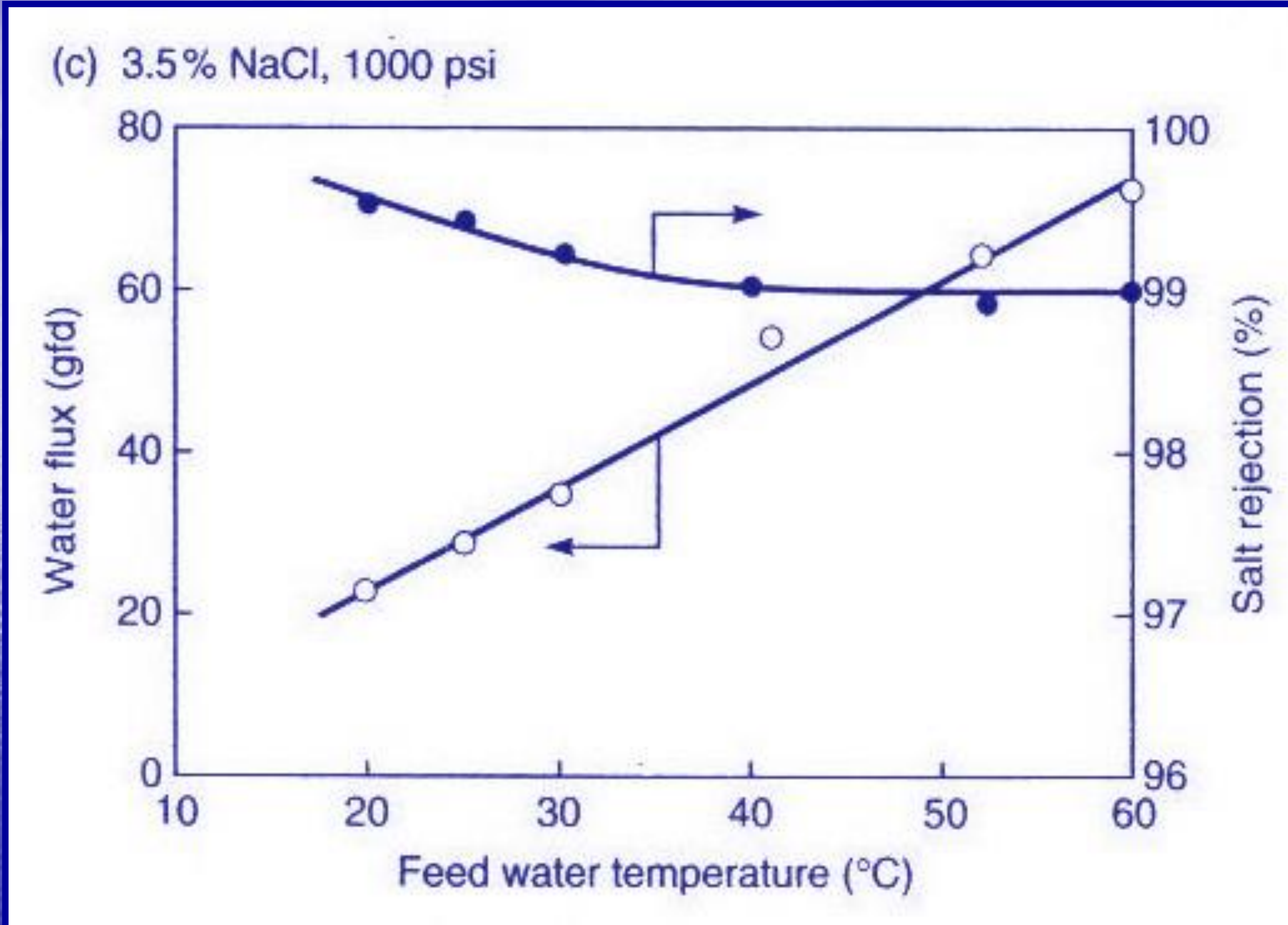
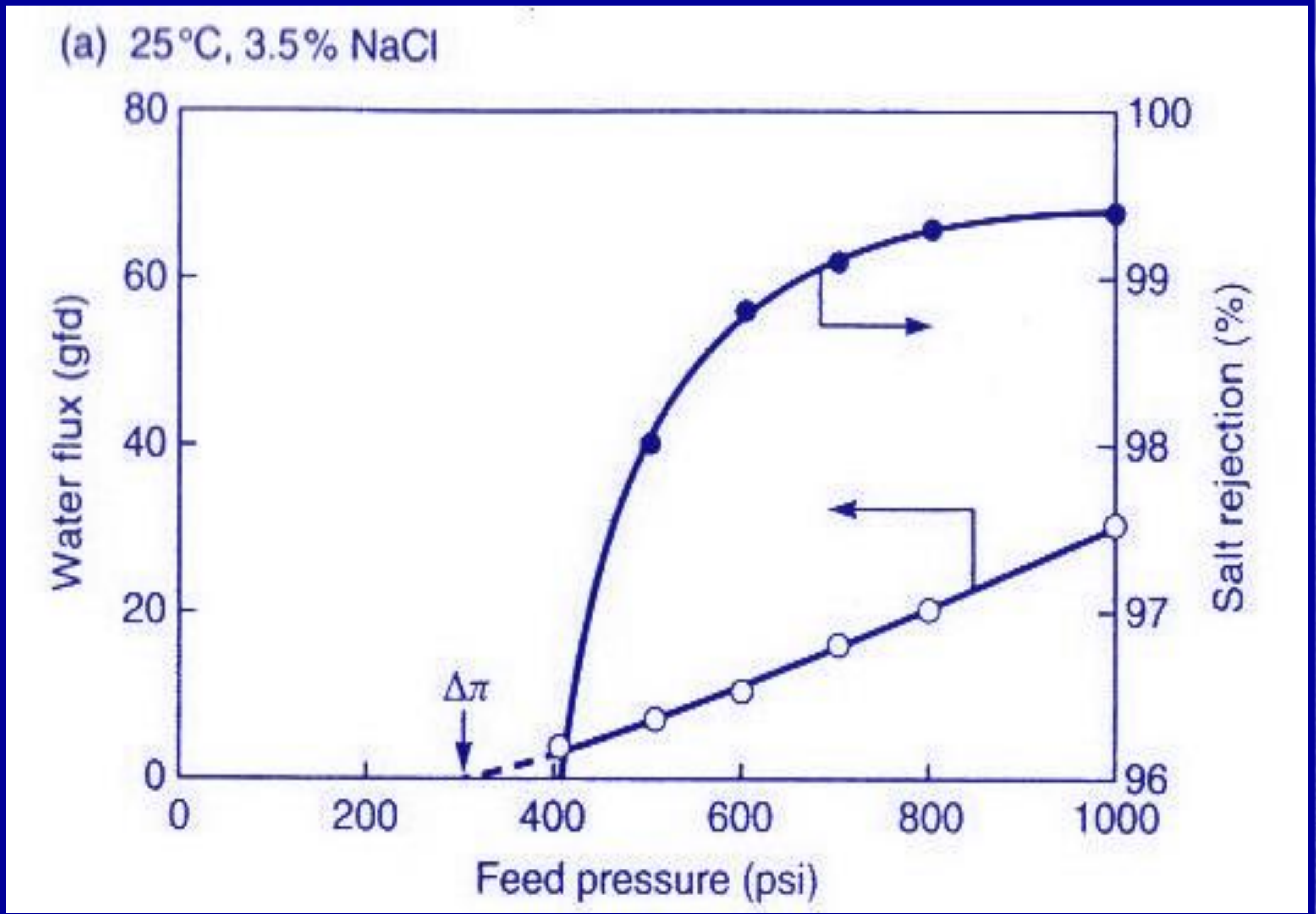

LiCl
NaCl
ETHYL ALCOHOL
ETHYLENE GLYCOL
MAGNESIUM SULFATE
ZINC SULFATE
FRUCTOSE
SUCROSE
OSMOTIC PRESSURE, PSI
500
400
300
200
100
5
10
15
20
25
30
CONCENTRATION IN WATER , W/W%

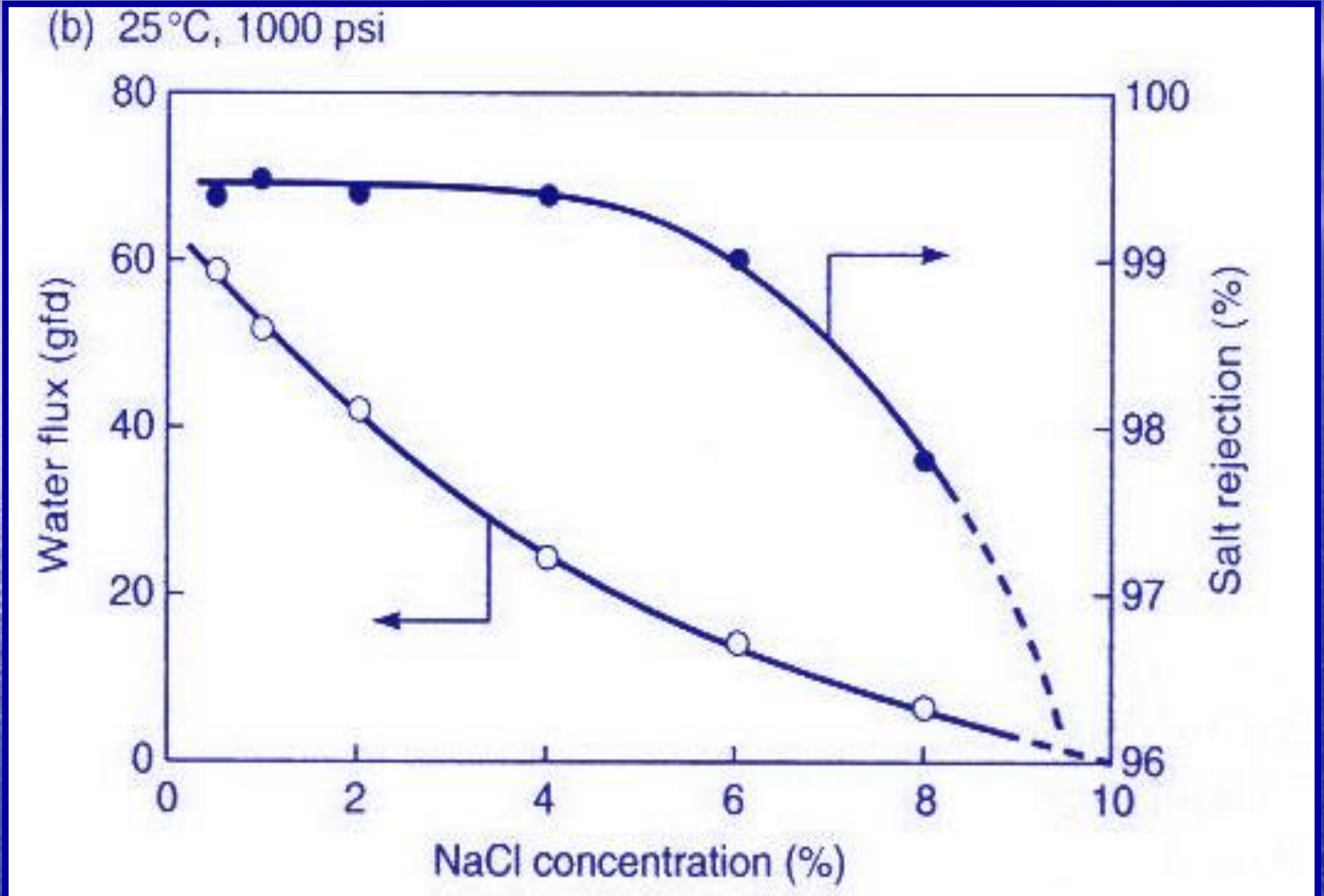
Figure 5. Conversion of Seawater *TDS* (mg/ℓ) to Equivalent NaCl (mg/ℓ)





(c) 3.5% NaCl, 1000 psi
80
60
40
20
0
100
99
98
97
96
10
20
30
40
50
60
Water flux (gfd)
Salt rejection (%)
Feed water temperature (°C)


(a) 25°C, 3.5% NaCl
Water flux (gfd)
Salt rejection (%)
Feed pressure (psi)
Δπ
0
20
40
60
80
0
200
400
600
800
1000
96
97
98
99
100



(b) 25°C, 1000 psi
80
60
40
20
0
0
2
4
6
8
10
100
99
98
97
96
Water flux (gfd)
Salt rejection (%)
NaCl concentration (%)

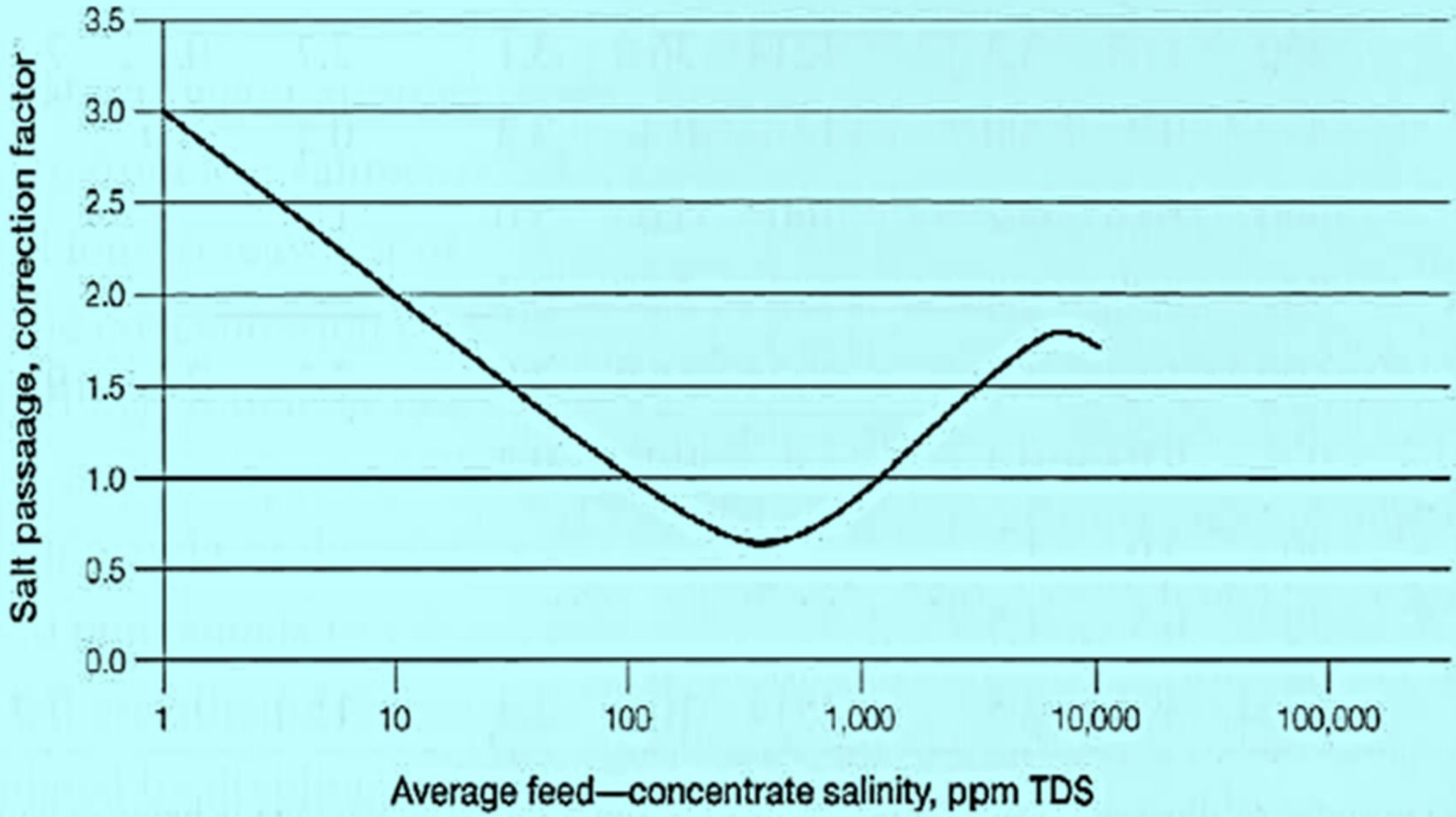


FIG. 11.1 Effect of feed salinity on salt passage using polyamide membrane.

TABLE I

B-9 SEPARATION PERFORMANCE[a] ON NICKEL PLATING RECOVERY

Ion	Concentration in Feed (mg/ℓ as ion)	Concentration in Product (mg/ℓ as ion)	% Rejection
Ni^{++}	4,610	230	95.0
$SO_4^{=}$	3,924	53	98.6
Cl^{-}	2,580	270	89.5

[a]Feed pressure = 2,760 kPa (400 psig); feed temperature = 12°C; conversion = 75%.

TABLE II

SEPARATION OF ORGANIC ACIDS AND THEIR SALTS BY B-9 PERMEATORS[a]

Compounds	Molecular Weight	Dissociation Constant	Feed Concentration (mg/ℓ)	Feed pH	Percent Rejection
Formic Acid $HCOOH$	46	1.77×10^{-4}	500	3.2	50
Sodium Formate	68	—	740	6.9	94
Acetic Acid CH_3COOH	60	1.75×10^{-5}	500	3.7	40
Sodium Acetate	82	—	680	8.1	98
n-Butyric Acid $CH_3CH_2CH_2COOH$	88	1.51×10^{-5}	500–2,000	2.8–4.2	70
Sodium Butyrate	110	—	2,500	7.0	98
Phenol C_6H_5OH	94	1.28×10^{-10}	500–2,000	7.0–9.0	55
Sodium Phenolate	116	—	2,500	10.7	95
Pivalic Acid $(CH_3)_3C—COOH$	102	8.91×10^{-6}	500–2,000	4.0	98
Sodium Pivalate	124	—	2,400	8.1	99
n-Caproic Acid $CH_3(CH_2)_4COOH$	116	1.32×10^{-5}	500	4.2	87
Sodium Caproate	138	—	600	7.8	99
Benzoic Acid C_6H_5COOH	122	6.32×10^{-5}	500	3.7	83
Sodium Benzoate	144	—	590	8.1	99
Oxalic Acid $HOOC—COOH$	90	K_1 6.5×10^{-2} K_2 6.1×10^{-5}	500–2,000	2.2	94
Di-Sodium Oxalate	134	—	2,980	6.7	98
Adipic Acid $HOOC(CH_2)_4COOH$	146	K_1 3.7×10^{-5} K_2 3.87×10^{-5}	500–2,000	2.7–4.3	95
Di-Sodium Adipate	190	—	2,600	5.6–10	99

[a]Test conditions used were: Feed pressure = 2,760 kPa (400 psig); feed temperature = 20°C; conversion = 75%.

Figure 1. Effect of pH on Rejection of Organic Acids

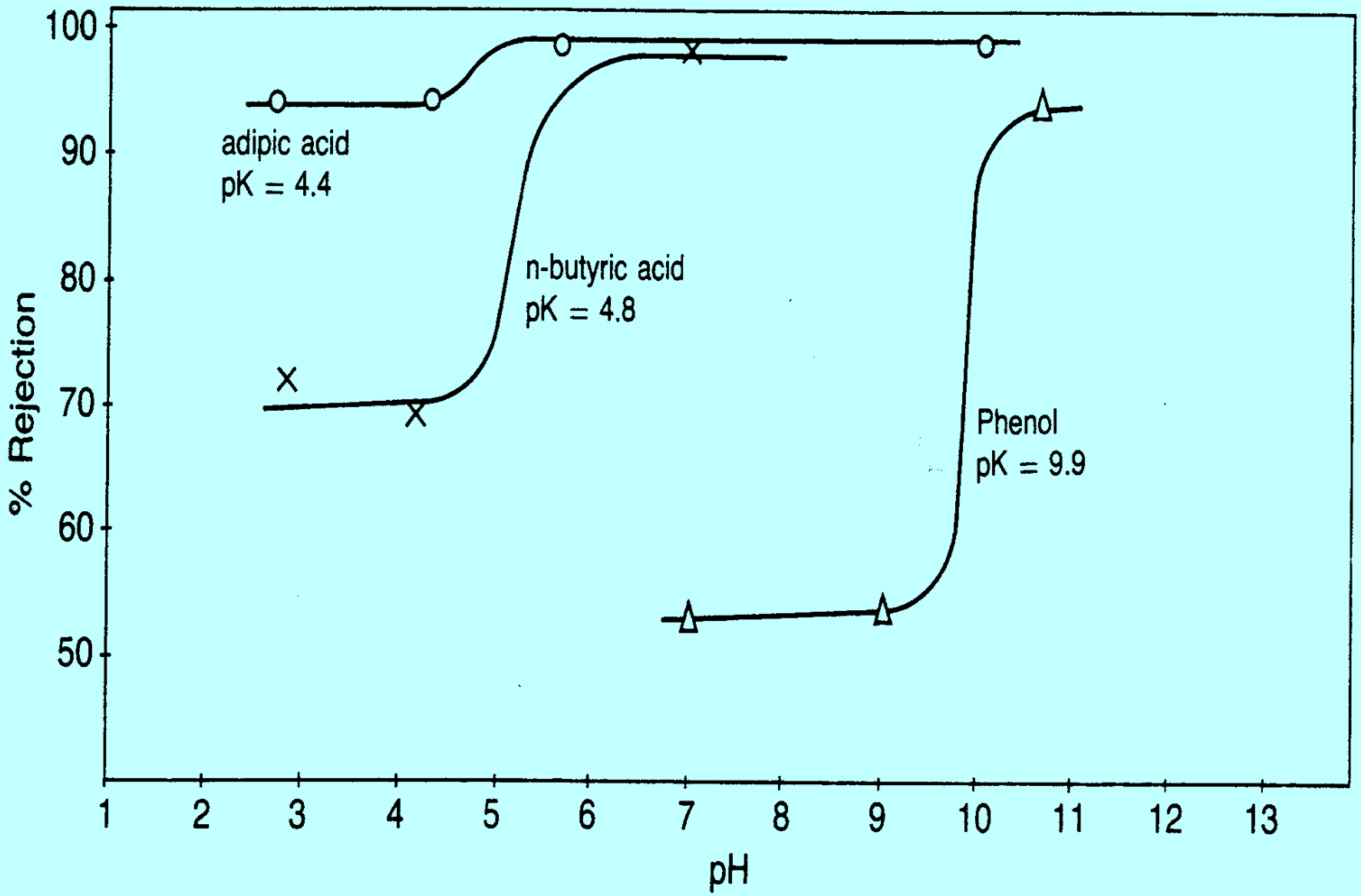
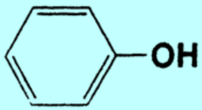
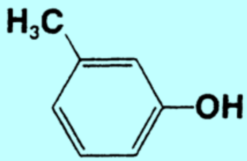
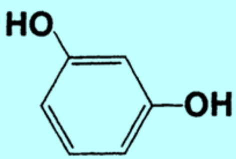
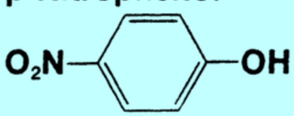
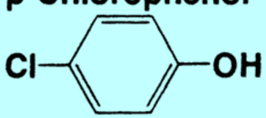
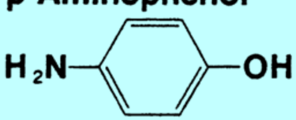


TABLE VI
REJECTION OF SUBSTITUTED PHENOLS[a,b]

Phenols	Molecular Weight	Dissociation Constant	Feed pH	Percent Rejection
Phenol 	94	1.28×10^{-10}	7–9 11	55 95
m-Cresol 	108	9.8×10^{-11}	7 11	74 94
Resorcinol 	110	1.55×10^{-10}	4–7 10	63 85
p-Nitrophenol 	139	6.5×10^{-8}	6	56
p-Chlorophenol 	128	7.0×10^{-10}	7	51
p-Aminophenol 	109	—	7	84

[a]Test conditions used were: Feed pressure = 2,760 kPa (400 psig); feed temperature = 20°C; conversion = 75%.
[b]All feed concentrations were 2,000 mg/ℓ.

Figure 2. Effect of Molecular Weight on Rejection of Organic Acids

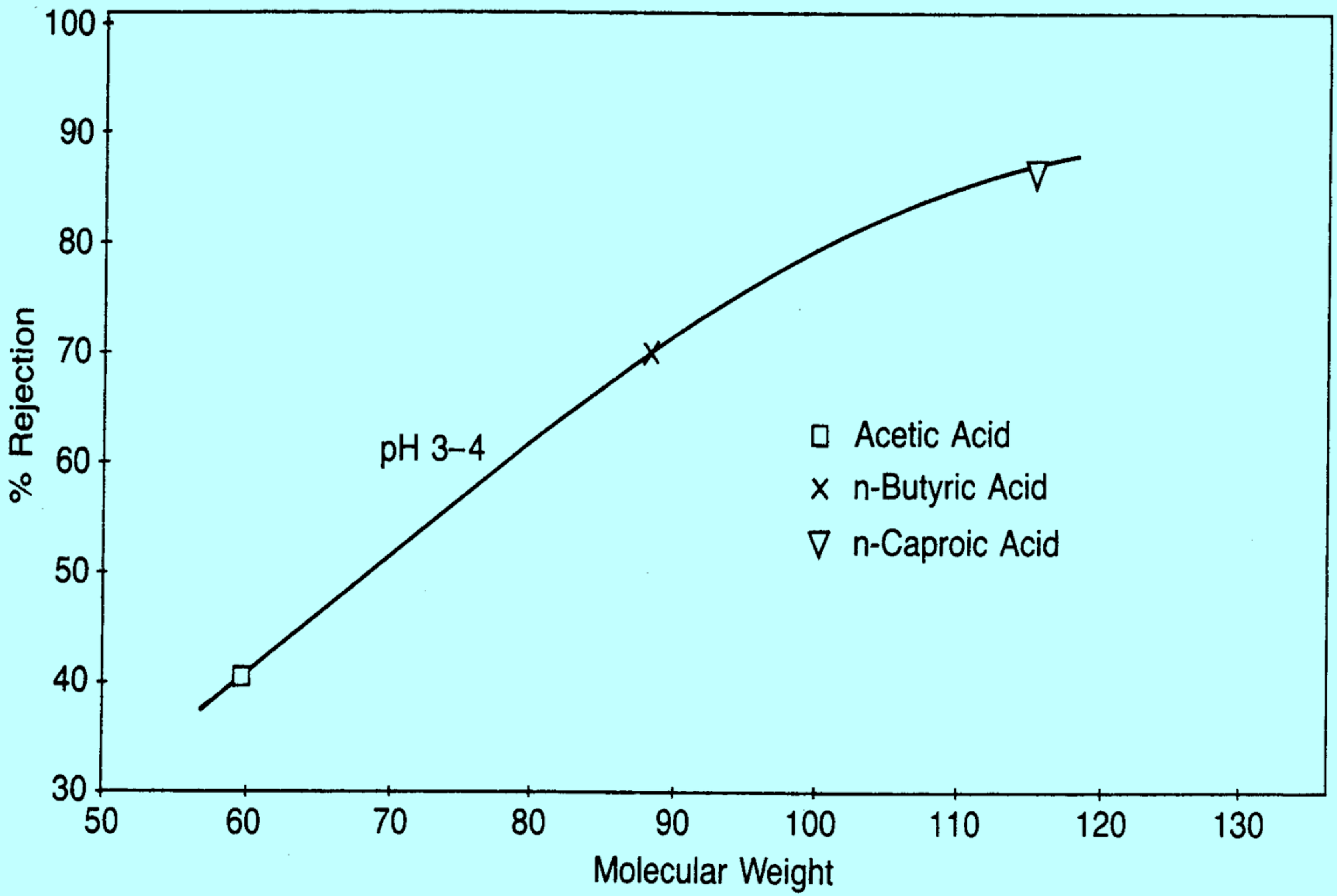


TABLE III
SEPARATION OF CARBOHYDRATES AND GLYCOLS BY B-9 PERMEATORS[a]

Compound	Molecular Weight	Feed Concentration (mg/ℓ)	Percent Rejection[b]
Raffinose $C_{18}H_{32}O_{16}$ Trisaccharide	504	2,000	99.4
Sucrose $C_{12}H_{22}O_{11}$ Disaccharide	342	500–2,000	99.8
Sorbitol $C_6H_{14}O_6$ 6-c polyol	182	2,000	99.6
Glucose $C_6H_{12}O_6$ Monosaccharide	180	500–2,000	99.0
Arabinose $C_5H_{10}O_5$ 5-c sugar	150	2,000	98.9
Glycerol $CH_2OH\text{-}CHOH\text{-}CH_2OH$ 3-c polyol	92	500–2,000	90.0
Ethylene Glycol $CH_2OH\text{-}CH_2OH$ 2-c polyol	62	2,000	28.0

[a]Test conditions used were: Feed pressure = 2,760 kPa (400 psig); feed temperature = 20°C; conversion = 75%.
[b]Rejection based on total organic carbon analyses.

Figure 3. Effect of Molecular Weight on Rejection for Carbohydrates and Glycols

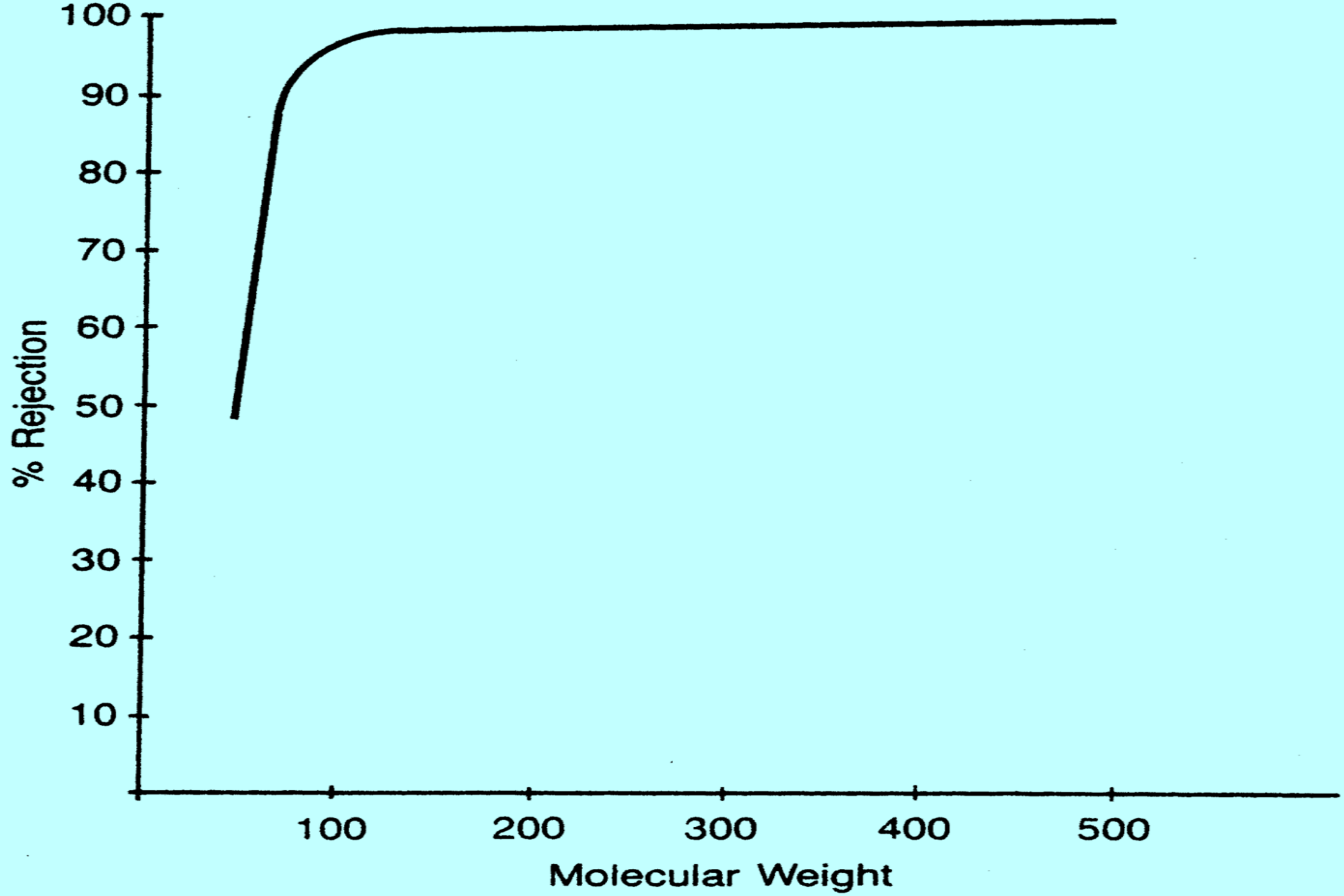


TABLE III

SEPARATION OF CARBOHYDRATES AND GLYCOLS BY B-9 PERMEATORS[a]

Compound	Molecular Weight	Feed Concentration (mg/ℓ)	Percent Rejection[b]
Raffinose $C_{18}H_{32}O_{16}$ Trisaccharide	504	2,000	99.4
Sucrose $C_{12}H_{22}O_{11}$ Disaccharide	342	500–2,000	99.8
Sorbitol $C_6H_{14}O_6$ 6-c polyol	182	2,000	99.6
Glucose $C_6H_{12}O_6$ Monosaccharide	180	500–2,000	99.0
Arabinose $C_5H_{10}O_5$ 5-c sugar	150	2,000	98.9
Glycerol $CH_2OH\text{-}CHOH\text{-}CH_2OH$ 3-c polyol	92	500–2,000	90.0
Ethylene Glycol $CH_2OH\text{-}CH_2OH$ 2-c polyol	62	2,000	28.0

[a]Test conditions used were: Feed pressure = 2,760 kPa (400 psig); feed temperature = 20°C; conversion = 75%.
[b]Rejection based on total organic carbon analyses.

Figure 4. Effect of Molecular Weight on Rejection for Straight Chain Alcohols

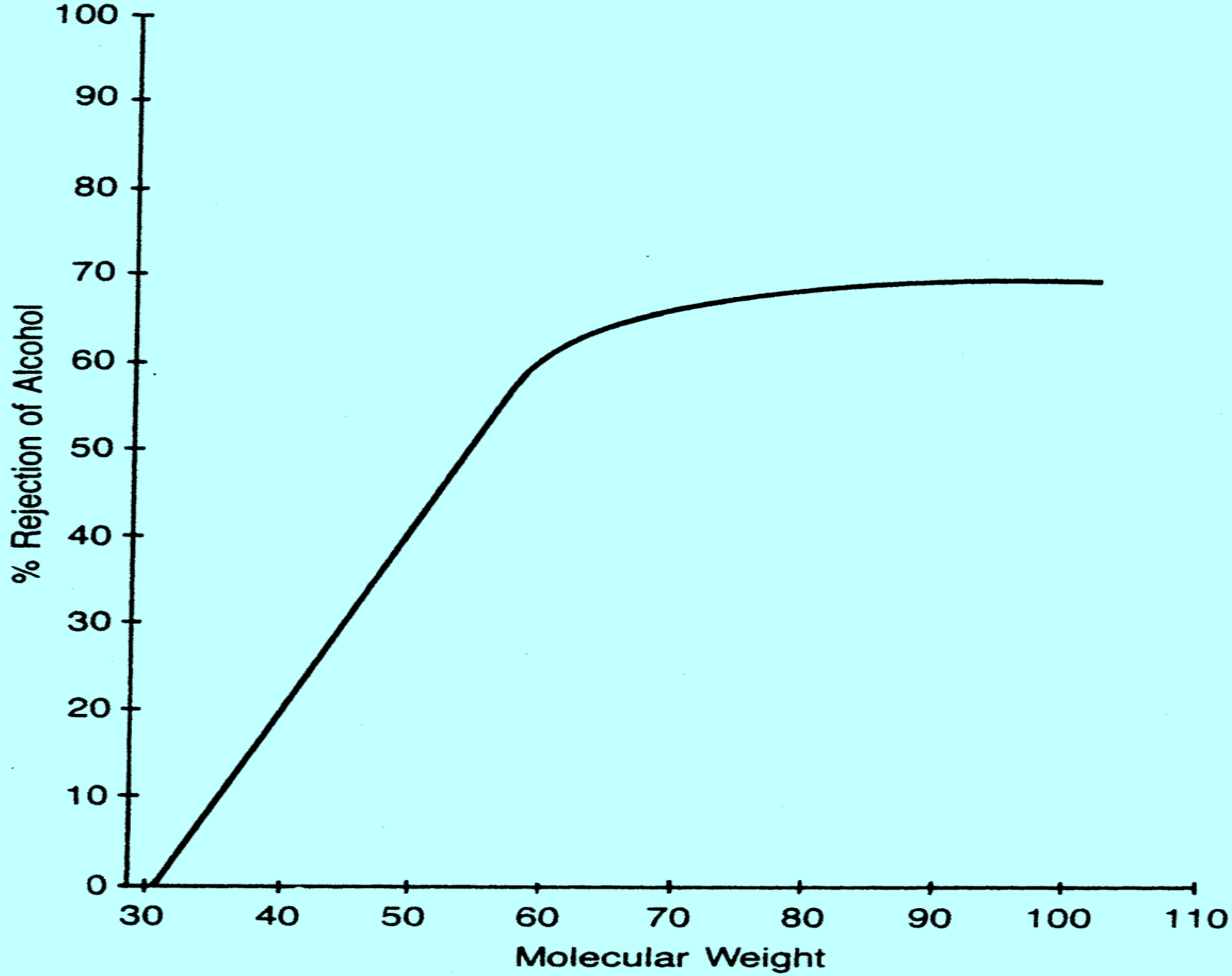
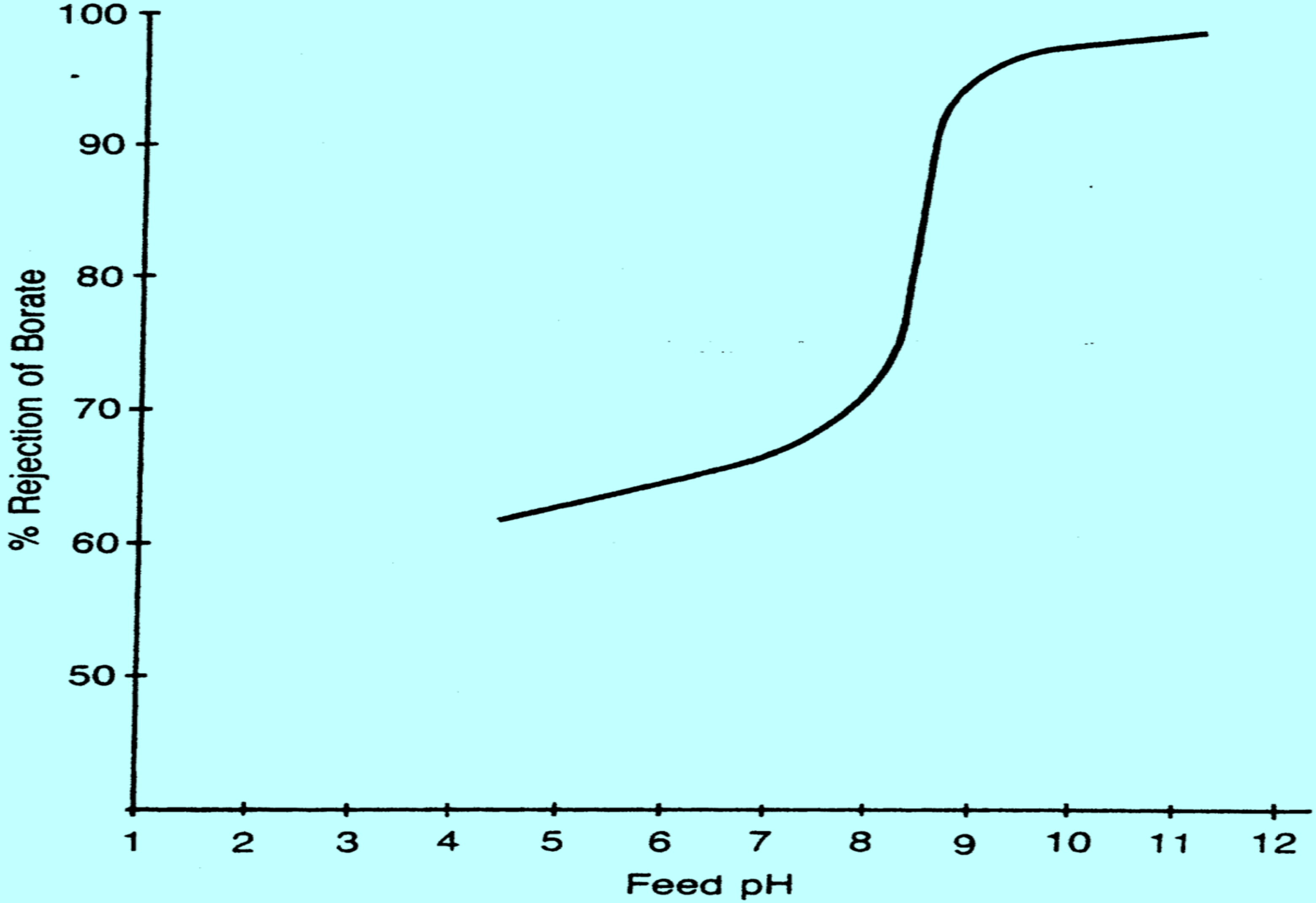


TABLE IV
SEPARATION OF ALCOHOLS BY B-9 PERMEATORS[a]

Alcohol	Molecular Weight	Feed Concentration (mg/ℓ)	Percent Rejection
Methyl CH_3OH	32	500–2,000	0
Ethyl CH_3CH_2OH	46	500–2,000	28
n-Propyl $CH_3CH_2CH_2OH$	60	500–2,000	62
n-Butyl $CH_3(CH_2)_2CH_2OH$	74	500–2,000	65
n-Amyl $CH_3(CH_2)_3CH_2OH$	88	500–2,000	68
n-Hexyl $CH_3(CH_2)_4CH_2OH$	102	500	68
Iso-Propyl	60	500–2,000	75
iso-Butyl $(CH_3)_2CHCH_2OH$	74	500–2,000	95
iso-Amyl $(CH_3)_2CHCH_2CH_2OH$	88	500	90
sec-Butyl $CH_3CH_2CHOHCH_3$	74	2,000	77
t-Butyl $(CH_3)_3COH$	74	500–2,000	96

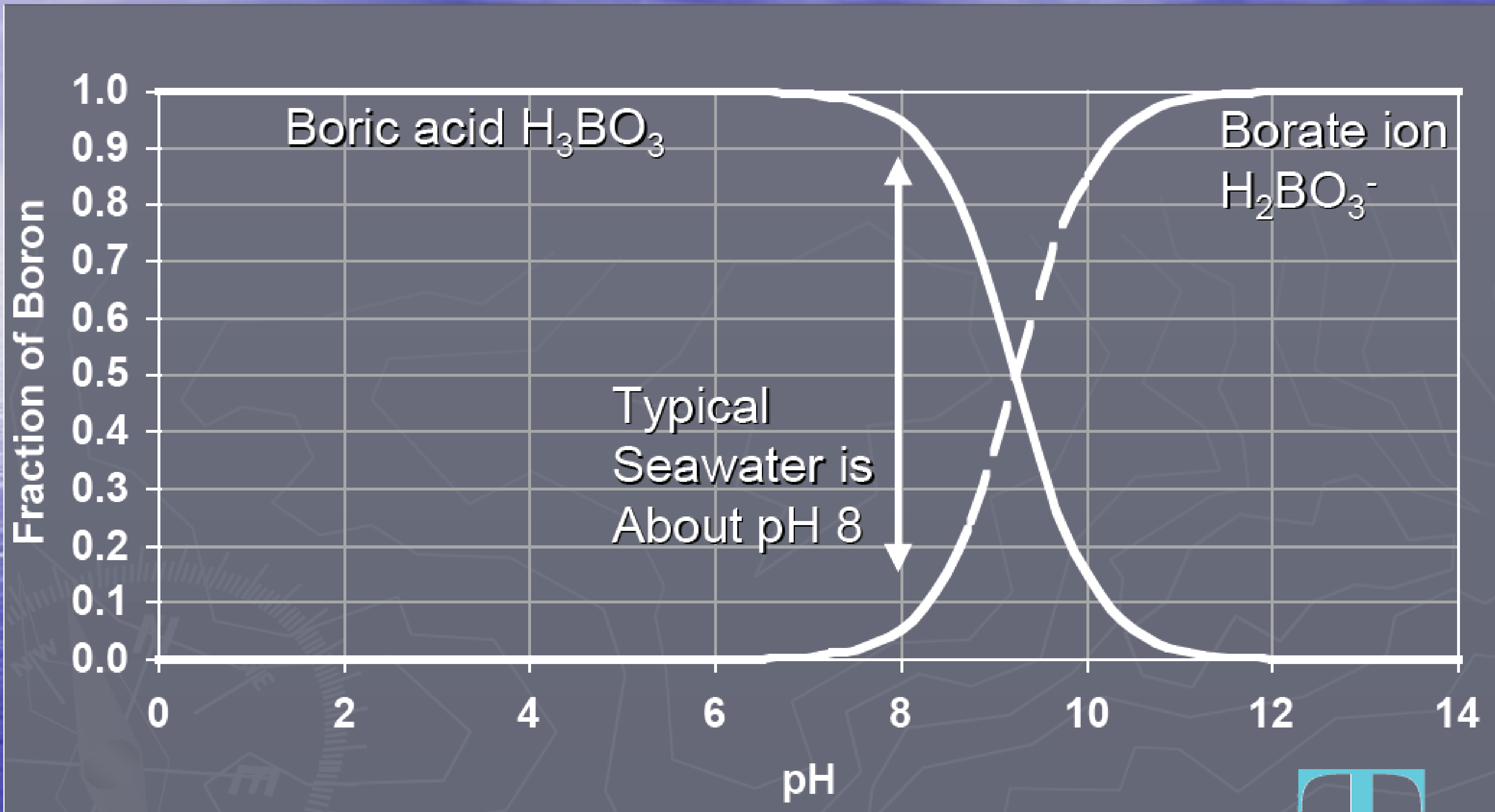
[a]Test conditions used were: Feed pressure = 2,760 kPa (400 psig); feed temperature = 20°C; conversion = 75%.

Figure 5. Borate Rejection by B-9 Permeators

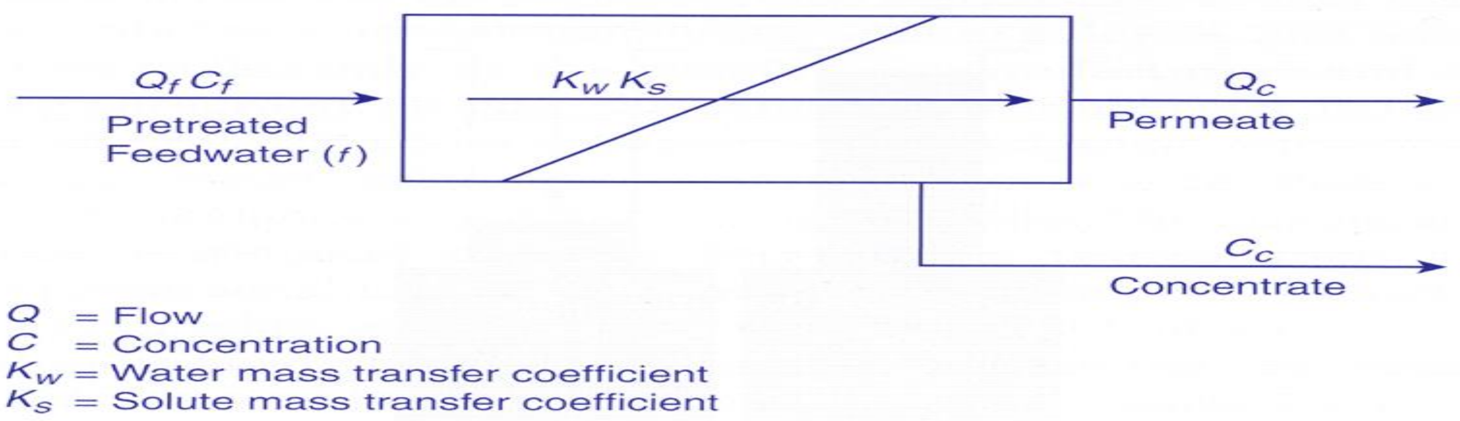


Test conditions used were: feed pressure = 2760 kPa (400 psig) feed temperature = 20°C and conversion = 75%.

Feed pH adjusted with NaOH.



Boric acid H_3BO_3
Borate ion $H_2BO_3^-$
Typical Seawater is About pH 8
Fraction of Boron
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
pH



Schematic diagram of an RO membrane element

Mass balance for water flow:

$$Q_f = Q_p + Q_c \qquad \text{(Eq 2-2)}$$

Where:

- Q_f = feedwater flow rate, units of volume per time, e.g., gpd
- Q_p = permeate flow rate, units of volume per time, e.g., gpd
- Q_c = concentrate flow rate, units of volume per time, e.g., gpd

Mass balance for solute flux:

$$Q_f C_f = Q_p C_p + Q_c C_c \qquad \text{(Eq 2-3)}$$

Where:

- C_f = feedwater solute concentration, units of mass per volume, e.g., mg/L
- C_p = permeate solute concentration, units of mass per volume, e.g., mg/L
- C_c = concentrate solute concentration, units of mass per volume, e.g., mg/L

$$R_p = 100\% \frac{Q_p}{Q_f} \quad \text{——(1)}$$

$$R_p = 100\% \frac{Q_p}{Q_p + Q_c} \quad \text{——(2)}$$

; R_p = product recovery rate (in %)

; Q_p = product water flow rate

; Q_f = feed water flow rate

; Q_c = concentrate flow rate

จาก (1) และ (2) ; เพราะฉะนั้นทราบว่า $Q_f = Q_p + Q_c$ ——(3)

Mass Balance (3) ; $Q_f C_f = Q_p C_p + Q_c C_c$; C_f = feed concentration

$Q_f C_f = Q_p C_p + (Q_f - Q_p) C_c$; C_f = permeate concentration

$Q_f C_f = Q_p C_p + Q_f C_c - Q_p C_c$; C_f = concentrate concentration

$$\frac{C_f - C_c}{C_p - C_c} = \frac{Q_p}{Q_f}$$

$$\boxed{\frac{C_c - C_f}{C_c - C_p} = \frac{Q_p}{Q_f} = R_p} \quad \text{——(4)}$$

Product recovery rate:

$$R = \frac{Q_p}{Q_f}$$

Where:
R = decimal fraction of product water recovered from feedwater

Water flux:

$$F_w = K_w(\Delta P - \Delta\pi) = \frac{Q_p}{A} \qquad \text{(Eq 2-5)}$$

Where:

- F_w = water flux, units of flow rate per unit area, e.g., gpd/ft^2
- K_w = water mass transfer coefficient (see Eq 2-5), units of flux per pressure, e.g., gpd/ft^2/psi
- ΔP = transmembrane pressure differential, units of pressure, e.g., psi
- $\Delta\pi$ = transmembrane osmotic pressure differential, units of pressure, e.g., psi
- A = effective membrane area

NOTE: $\Delta P - \Delta\pi$ = net applied pressure (NAP).

$$\boxed{Q_w = (\Delta P - \Delta P_{osm}) K_w \frac{S}{d}} \qquad (7.1)$$

; Q_w = อัตราการไหลของน้ำผ่านเมมเบรน

; ΔP = ความแตกต่างของ ความดันไฮดรอลิก บนผิวหน้าแต่ละด้านของเมมเบรน

; ΔP_{osm} = ความแตกต่างของ ความดันออสโมติก บนผิวหน้าแต่ละด้านของเมมเบรน

; K_w = ค่าคงที่การซึมของน้ำผ่านเมมเบรน

; S = พื้นที่ผิวของเมมเบรน

; d = ความหนาของเมมเบรน

หรือ

$$\boxed{Q_w = A \times S \times NDP} \qquad (7.2)$$

; A = water transport coefficient (g/cm^2/s <u>หรือ</u> gal/ft^2/d/psi)

; *NDP* = net driving pressure หรือ net driving force ของ mass transfer ของน้ำที่ผ่านเมมเบรน

- NDP คือ ความสามมารถในการเคลื่อนย้ายน้ำผ่านเยื่อกึ่งเลือดผ่าน (semipermeable membrane) โดย :

ในทางปฏิบัติ ค่านี้จะถูกละไป

$$\boxed{NDP = P_f - P_{os} - P_p - 0.5P_d\ (+ P_{osp})} \quad \text{——(6)}$$

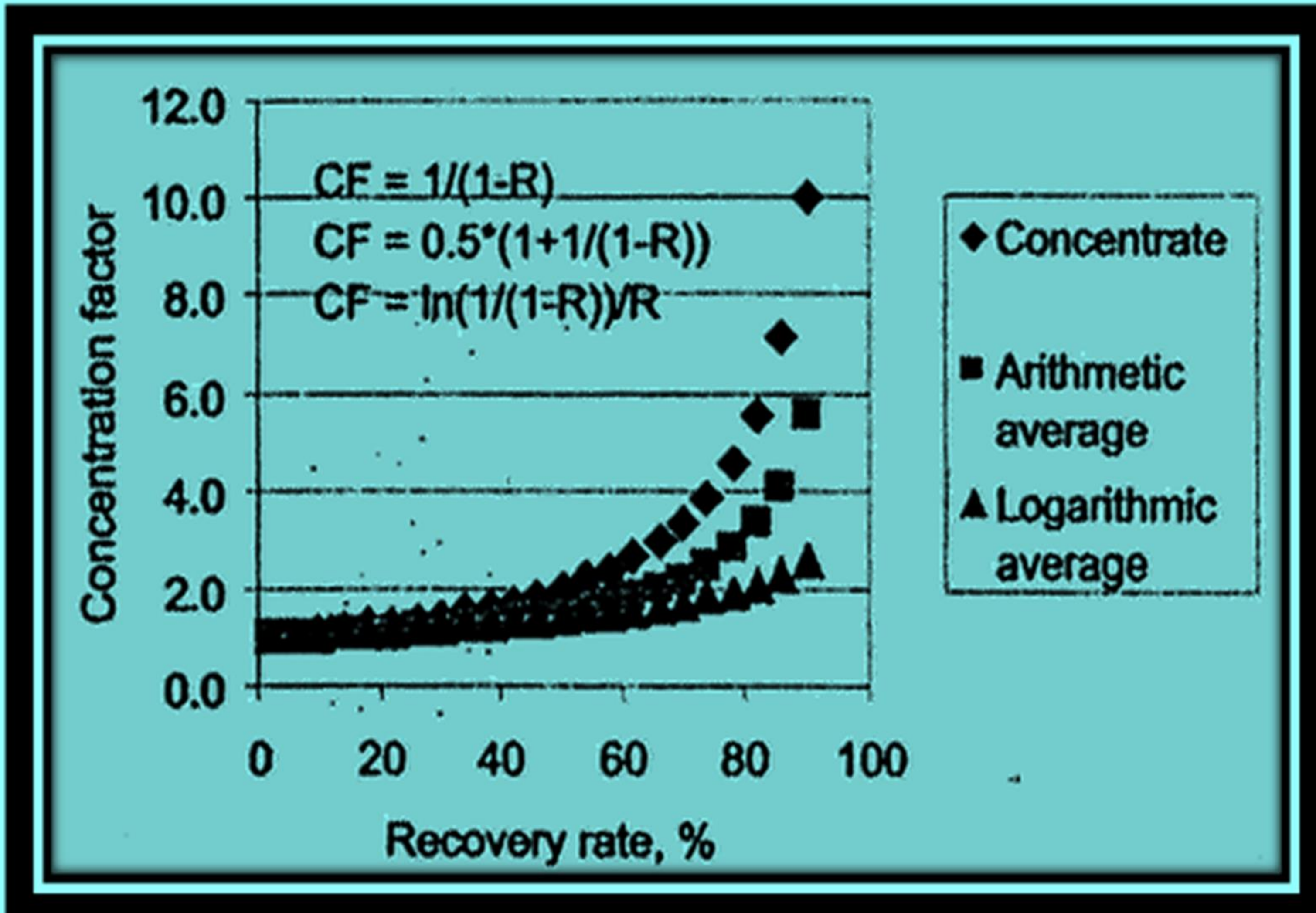
; P_f = feed pressure

; P_{os} = average feed osmotic pressure

; P_p = permeate pressure

; P_d = pressure drop across RO elements

; P_{osp} = osmotic pressure of permeate.



รูปที่1 : กราฟแสดงค่า *concentration factor* ของค่าเฉลี่ยความเค็มชนิดต่างๆ *VS percent recovery*

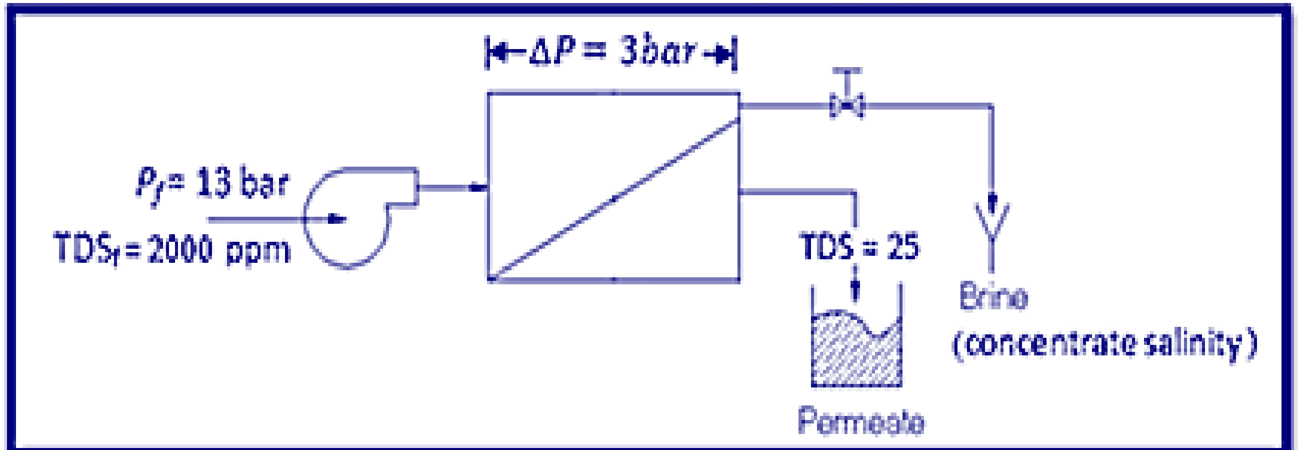
- **ตัวอย่างการคำนวณ**

โจทย์ : กรองน้ำกร่อยด้วยระบบรีเวิร์สออสโมซิสที่มี %Recovery Rate = 85% = 0.85

Feed Salinity = 2000 ppm TDS, Feed pressure = 13 bar (188.5 psi)

Permeate Salinity = 25 ppm TDS

Pressure drop across the system = 3.0 bar (45 psi)



จากสมการ $AFS = 0.5\ C_f(1+1/(1-R))$

จะได้ $AFS = 0.5\ (2000)(1+1/(1-0.85)) = \underline{7666.67\ ppm}$

จากสมการ $\pi = \frac{TDS \times 0.77}{1000}$

จะได้ ความดันออสโมซิสเฉลี่ย = $\frac{AFS \times 0.77}{1000} = \frac{7666.67 \times 0.77}{1000} = 5.9\ bar$

ฉะนั้น Average net driving pressure: $NDP = P_f - P_{os} - P_p - 0.5P_d$

$= 13-5.9-1.0-(0.5x3.0) = 5.9\ bar$

Dissolved solute flux:

$$F_s = K_s(C_m - C_p)$$

$$= K_s\left[\left(\frac{C_f + C_c}{2}\right) - C_p\right] = \frac{Q_p C_p}{A} \qquad \text{(Eq 2-6)}$$

Where:

F_s = solute flux, units of mass per time per area, e.g., lb/ft^2/d

K_s = solute mass transfer coefficient (see Eq 2-6), units of length per time, e.g., ft/d

C_m = concentration at the membrane surface

NOTE: The use of average feed-side solute concentration disregards concentration polarization and film theory effects.

Water mass transfer coefficient:

$$K_w = \frac{Q_p}{A(\Delta P - \Delta\pi)} = \frac{Q_p}{A(NAP)} \qquad \text{(Eq 2-7)}$$

Solute mass transfer coefficient:

$$K_s = \frac{Q_p C_p}{A \Delta C} \qquad \text{(Eq 2-8)}$$

Concentration differential:

$$\Delta C = (C_m - C_p) = \left(\frac{C_f + C_c}{2}\right) - C_p \qquad \text{(Eq 2-9)}$$

Equation 2-10 describes the effects of each of the five independent variables (K, C_r, K_w, ΔP, and R) on the permeate concentration:

Permeate concentration:

$$C_p = \frac{K_s C_f}{K_w \Delta P + \Delta\pi\left(\frac{2 - 2R}{2R}\right) + K_s} \qquad \text{(Eq 2-10)}$$

$$Q_s = K_s \frac{A}{\tau} \Delta C\,TM \qquad (12)$$

Where

K_s	=	membrane permeability coefficient for salt
A	=	membrane area
τ	=	membrane thickness
ΔC	=	salt concentration differential across membrane
T	=	temperature effect
M	=	membrane flux decline effect

$$Q_s = \Delta C \times K_s \frac{S}{d} \qquad (8.1)$$

; Q_s = อัตราการไหลของเกลือผ่านเมมเบรน

; ΔC = ความแตกต่างของ ความเข้มข้นบนผิวหน้าแต่ละด้านของเมมเบรน

; K_s = ค่าคงที่การซึมของเกลือผ่านเมมเบรน (cm/s หรือ ft/s)

; S = พื้นที่ผิวของเมมเบรน

; d = ความหนาของเมมเบรน

หรือ

$$Q_w = B \times S \times \Delta C \qquad (8.2)$$

; B = Salt transport coefficient

$$Q_s = \Delta C \times K_s \frac{S}{d} \qquad (8.1)$$

; Q_s = อัตราการไหลของเกลือผ่านเมมเบรน

; ΔC = ความแตกต่างของ ความเข้มข้นบนผิวหน้าแต่ละด้านของเมมเบรน

; K_s = ค่าคงที่การซึมของเกลือผ่านเมมเบรน (cm/s <u>หรือ</u> ft/s)

; S = พื้นที่ผิวของเมมเบรน

; d = ความหนาของเมมเบรน

หรือ

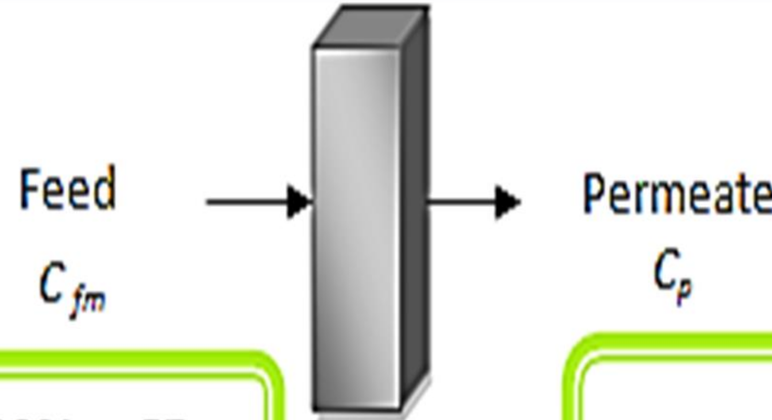
$$Q_w = B \times S \times \Delta C \qquad (8.2)$$

; B = Salt transport coefficient

- <u>ความเค็มของน้ำที่กรองได้ (C_p)</u>

$$C_p = \frac{Q_s}{Q_w} \qquad (8.3)$$

- *<u>Note</u>*: การเดินทางของเกลือผ่านเยื่อเมมเบรน มีความสำพันธ์กับ การเดินทางของน้ำผ่านเยื่อเมมเบรน
  - อัตราการแพร่(Q) ของเกลือและน้ำ ทำให้เกิด ปรากฏการณ์ "การแยกออกจากกันของเกลือและน้ำ"



(9.2) $$\boxed{SR = 100\% - SP}$$

$$\boxed{SP = 100\% \frac{C_p}{C_{fm}}}$$ (9.1)

; Salt passage (*SP*) = ปริมาณเกลือที่ผ่านเมมเบรนได้ หรือ ปริมาณเกลือในน้ำสายที่กรองได้

; Salinity of the permeate (C_p) = ความเข้มข้นของเกลือในน้ำที่กรองได้

; Mean salt concentration in feed stream (C_{fm}) = ความเข้มข้นของเกลือโดยเฉลี่ยในสายน้ำขาเข้า

; Salt rejection (*SR*) = ปริมาณเกลือที่ถูกเมมเบรนดักไว้

- ***Note:*** ค่า SP และ SR สามารถใช้ในการหา ค่าคงที่ของอัตราการส่งผ่านน้ำ ซึ่งค่าคงที่นี้ขึ้นกับอุณหภูมิ

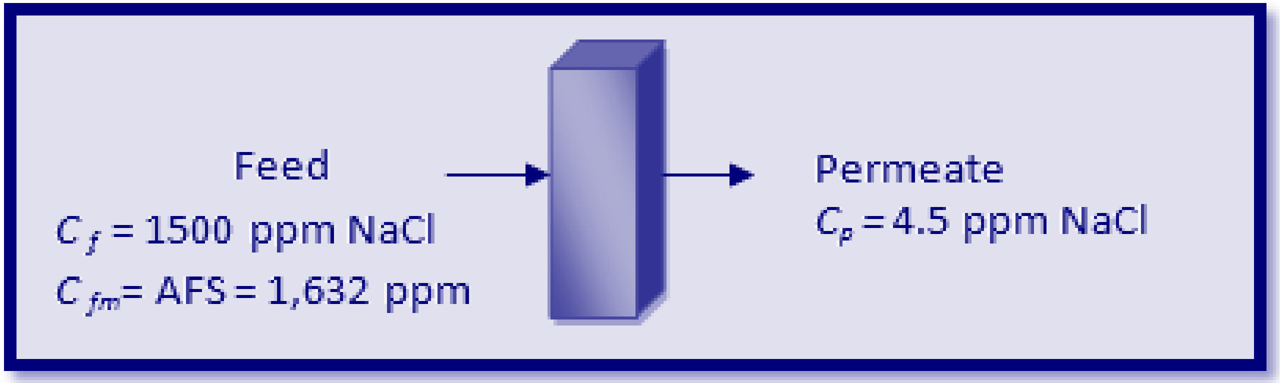
โจทย์ : จงคำนวณหาค่า*SP* และค่า*SR* ของROเมมเบรน โดยกำหนดตัวแปรต่างๆให้ ดังนี้

-Recovery rate =15%

-ความเข้มข้นของเกลือขาเข้า (feed salinity) = 1500 ppm NaCl

-ความเข้มข้นของเกลือที่กรองได้ (permeate salinity) = 4.5 ppm NaCl

วิธีทำ



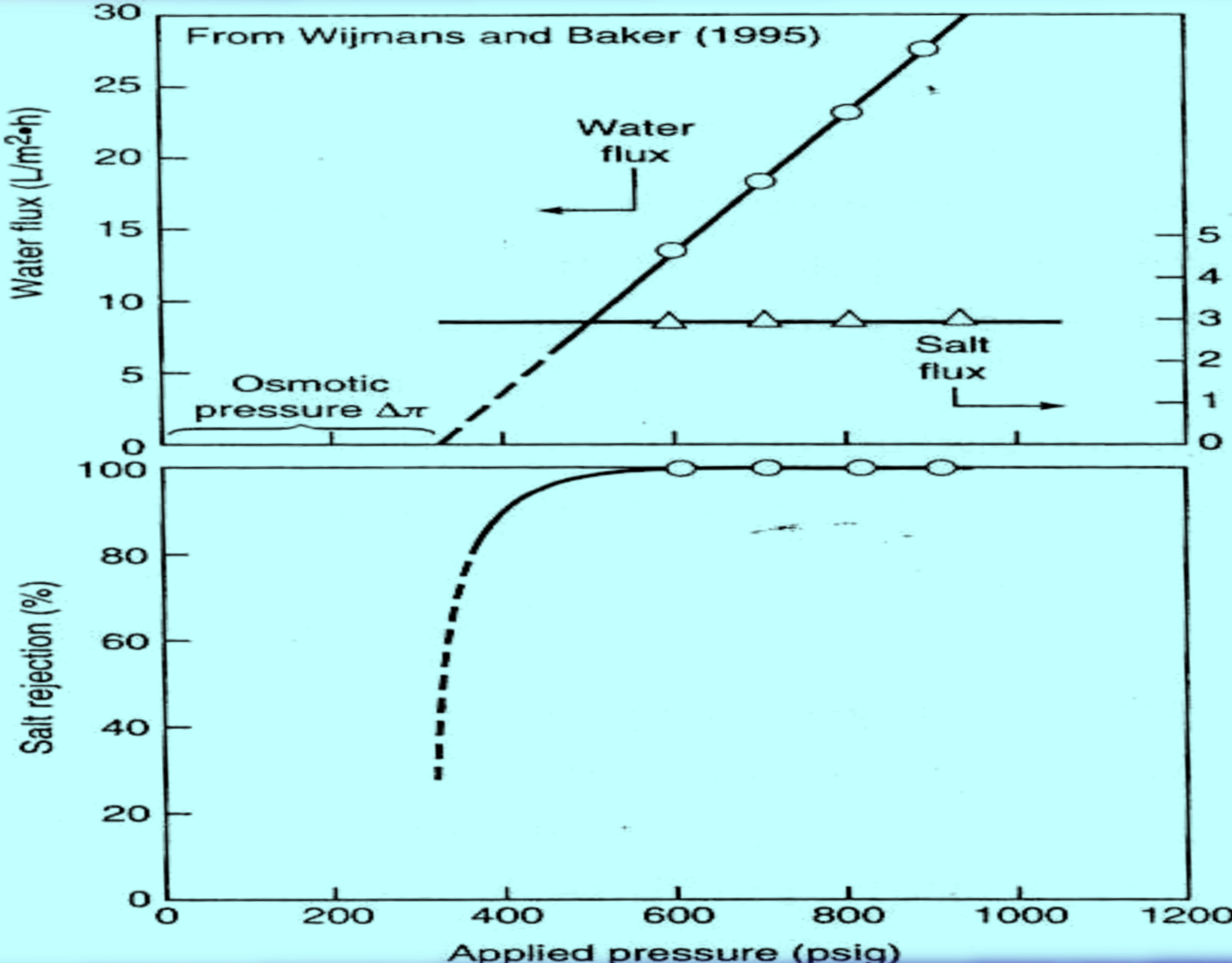
เนื่องจาก Recovery rate ของระบบมีค่าต่ำ

ฉะนั้น AFS = $0.5\ C_f(1+1/(1-R)) = 0.5\ (1500)(1+1/(1-0.15)) = 1632$ ppm

เพราะฉะนั้น C_{fm} = AFS = 1,632 ppm

SP = 100% (4.5/1632) = 0.28%

SR = 100% - 0.28% = 99.72%



From Wijmans and Baker (1995)
Water flux
Salt flux
Osmotic pressure $\Delta\pi$
Water flux (L/m²•h)
Salt flux (g/m²•h)
Salt rejection (%)
Applied pressure (psig)
0
5
10
15
20
25
30
0
1
2
3
4
5
0
20
40
60
80
100
0
200
400
600
800
1000
1200

$$Q_p = (PCF)\,(TCF)\,(MFRC)\,Q_i \qquad (2)$$

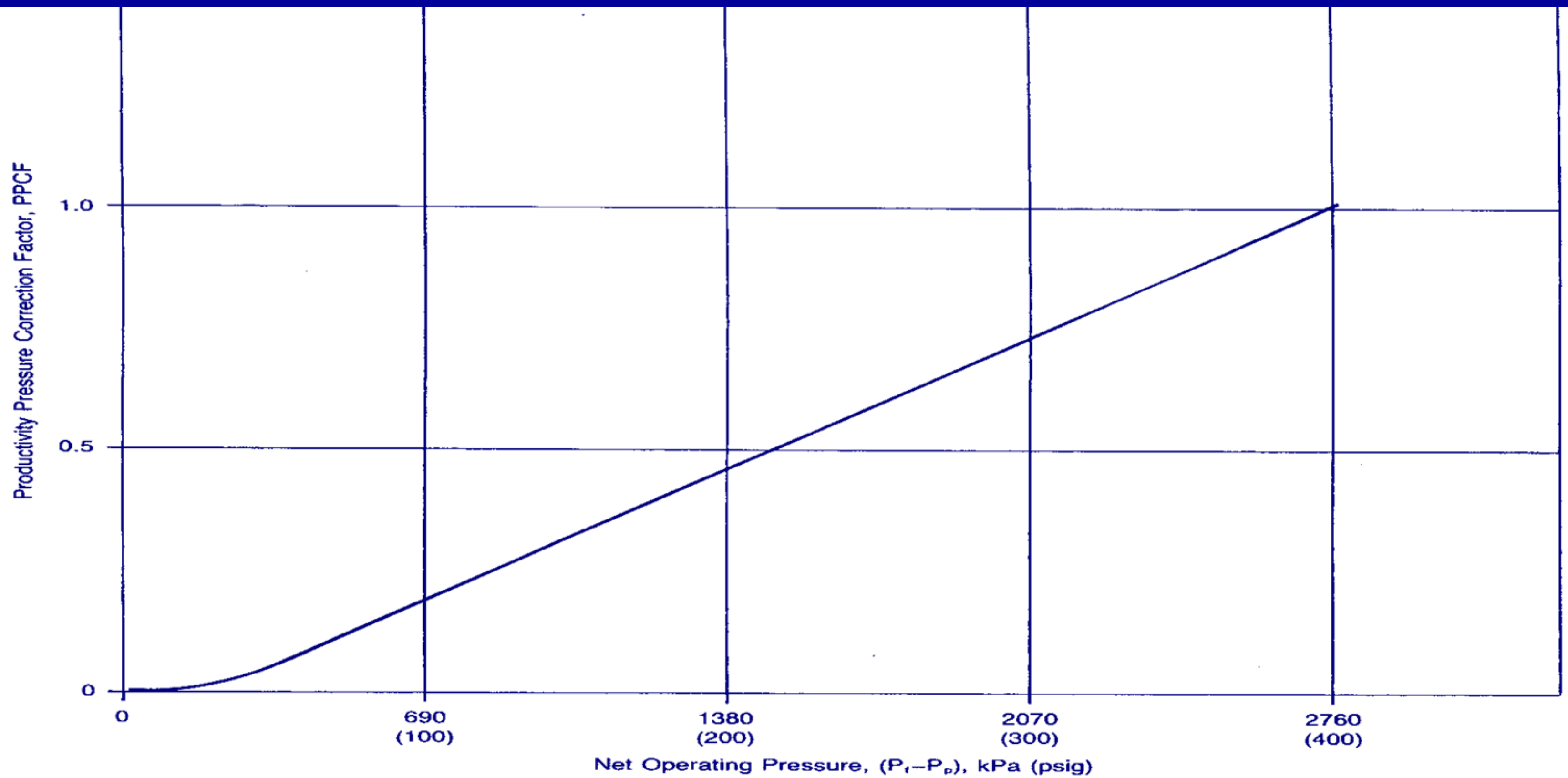
Where:

Q_p = permeator capacity at operating conditions
PCF = pressure correction factor
TCF = temperature correction factor
$MFRC$ = membrane flux retention coefficient
Q_i = initial permeator capacity at standard test conditions

$$PCF = 0.00283\left(P_f - \frac{\Delta P_{fb}}{2} - P_p - \pi_{fb}\right) \quad (3)$$

Where:

P_f = feed pressure
P_{fb} = bundle pressure drop
P_p = product pressure
π_{fb} = average feed-brine osmotic pressure in the permeator



$$MFRC = \frac{Q_{wt}}{Q_{wi}} \tag{4}$$

Where:
Q_{wt} = permeator flow rate at time (t)
Q_{wi} = permeator flow rate at initial startup.

- For $T > 25$ degrees C,

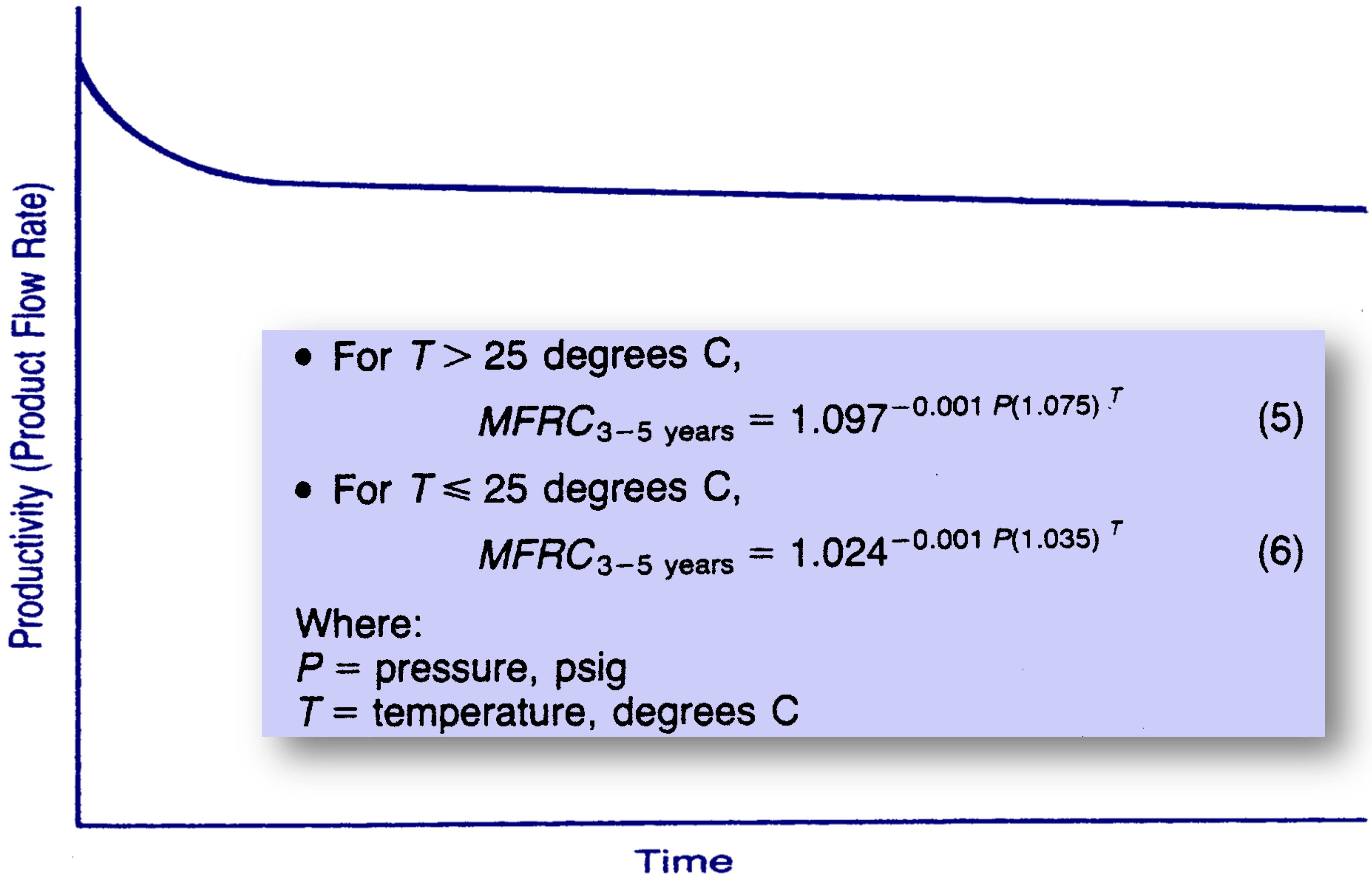
$$MFRC_{3-5 \text{ years}} = 1.097^{-0.001\, P(1.075)^{T}} \tag{5}$$

- For $T \leqslant 25$ degrees C,

$$MFRC_{3-5 \text{ years}} = 1.024^{-0.001\, P(1.035)^{T}} \tag{6}$$

Where:
P = pressure, psig
T = temperature, degrees C

Figure 1. Permeator Productivity vs. Time



- For $T > 25$ degrees C,

$$MFRC_{3-5\ \text{years}} = 1.097^{-0.001\,P(1.075)^{T}} \qquad (5)$$

- For $T \leqslant 25$ degrees C,

$$MFRC_{3-5\ \text{years}} = 1.024^{-0.001\,P(1.035)^{T}} \qquad (6)$$

Where:
P = pressure, psig
T = temperature, degrees C

Temperature → Viscosity → Permeability

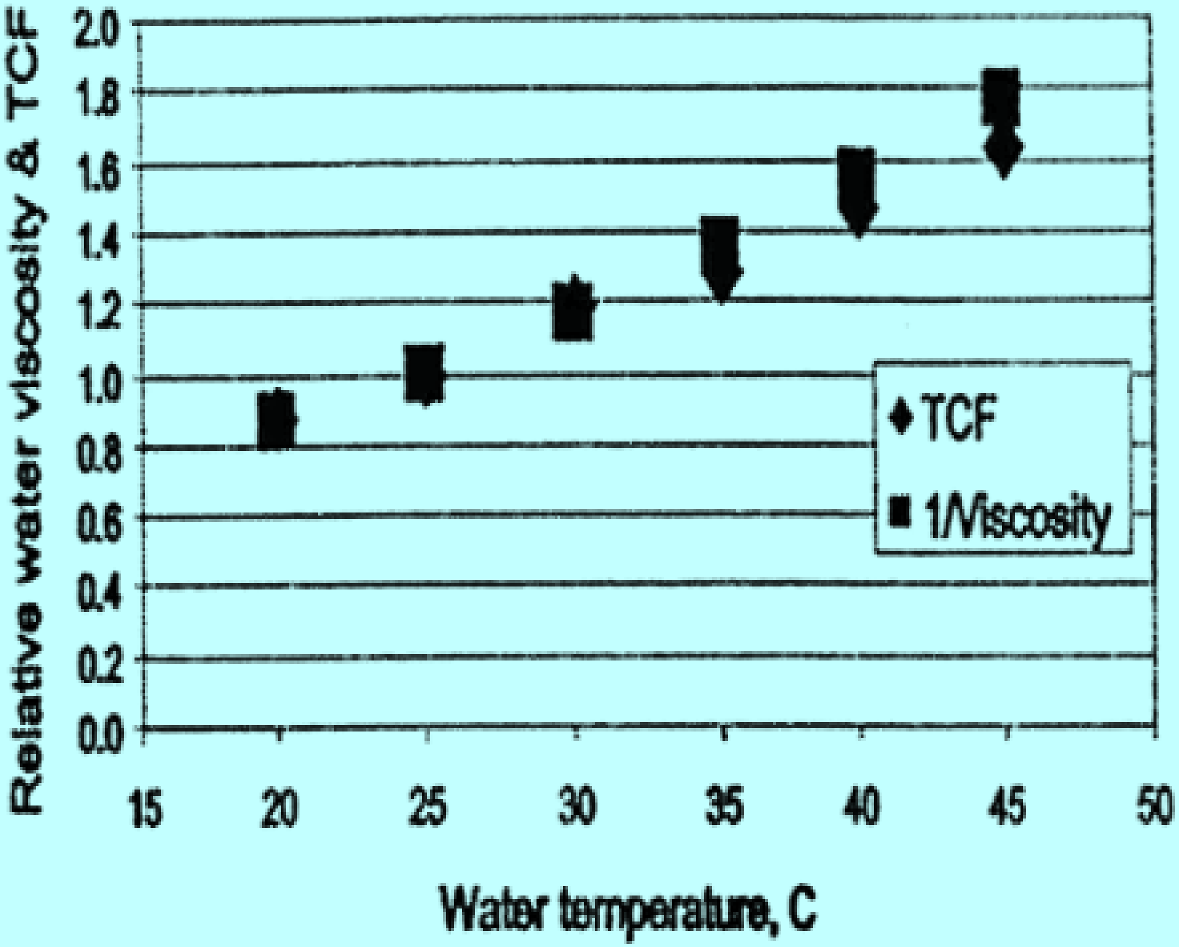
- อุณหภูมิมีผลต่อความหนืดของน้ำ ความหนืดของน้ำมีผลต่อความสามารถในการข้ามผ่านเมมเบรน ดังสมการ

$$\boxed{TCF = 1/\exp(C(1/273+t)-1/298)} \quad \text{—(9)}$$

; t = อุณหภูมิ (°C) โดยปกติจะทำที่อุณหภูมิ 25°C (77°F)

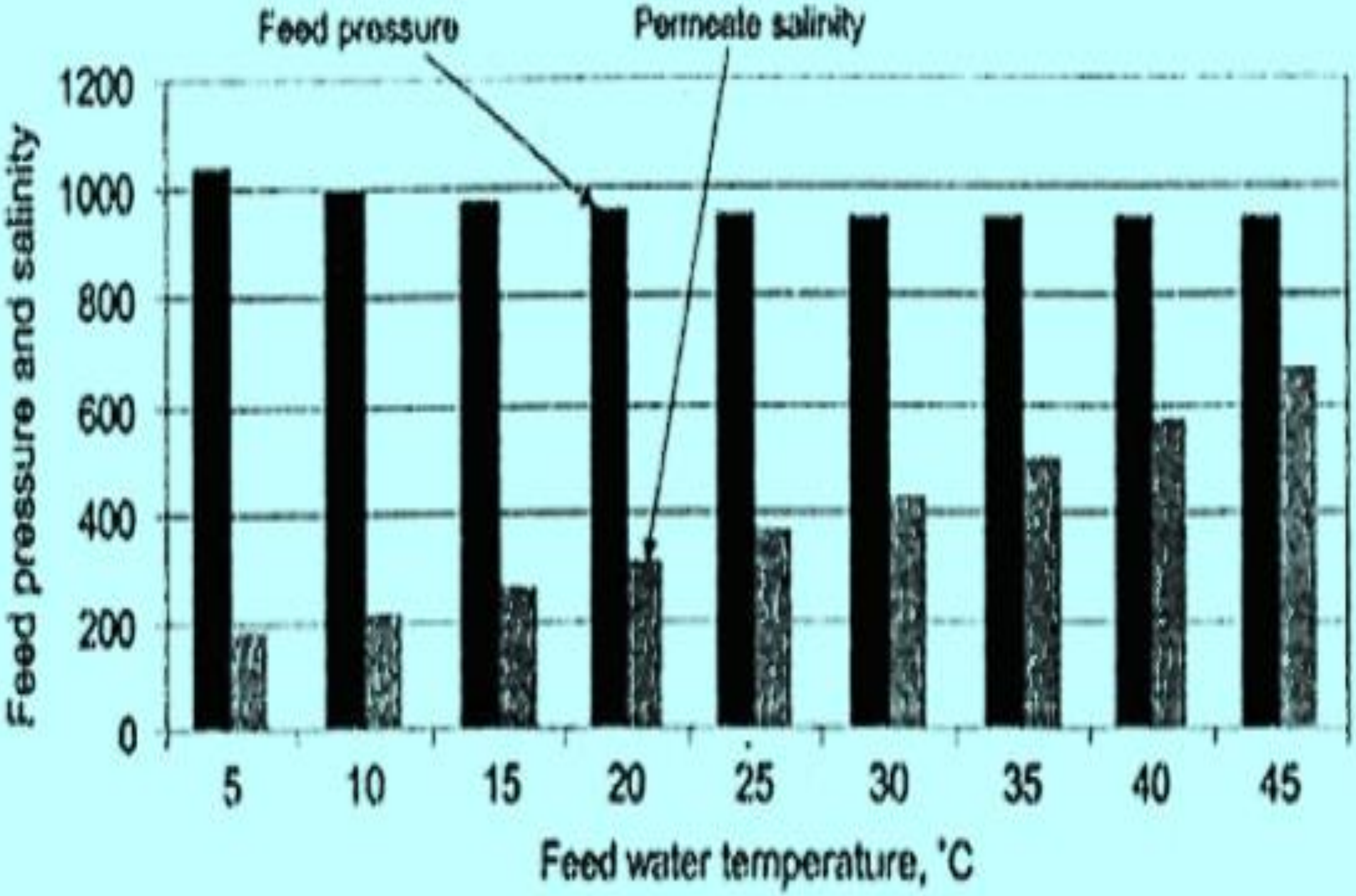
; C = สัมประสิทธิค่าคงที่ เป็นคุณลักษณะเฉพาะของเมมเบรนที่ใช้

=2500 ถึง 3000 กรณีเมมเบรนทำจาก polyamide



- รูปที่2 : ภาพแสดงความสัมพันธ์ ระหว่างอุณหภูมิ VS. ความหนืดของน้ำ และ ความสามารถในการแพร่ของน้ำผ่านเมมเบรน

ผลกระทบของอุณหภูมิต่ออัตราการส่งผ่านน้ำของเมมเบรน



- <u>รูปที่3</u> : *ภาพแสดงความสัมพันธ์ ระหว่างความดันที่ป้อนระบบ VS ความเข้มข้นของเกลือที่สามารถผ่าน RO เมมเบรนในระบบบำบัดน้ำทะเล ไปได้*

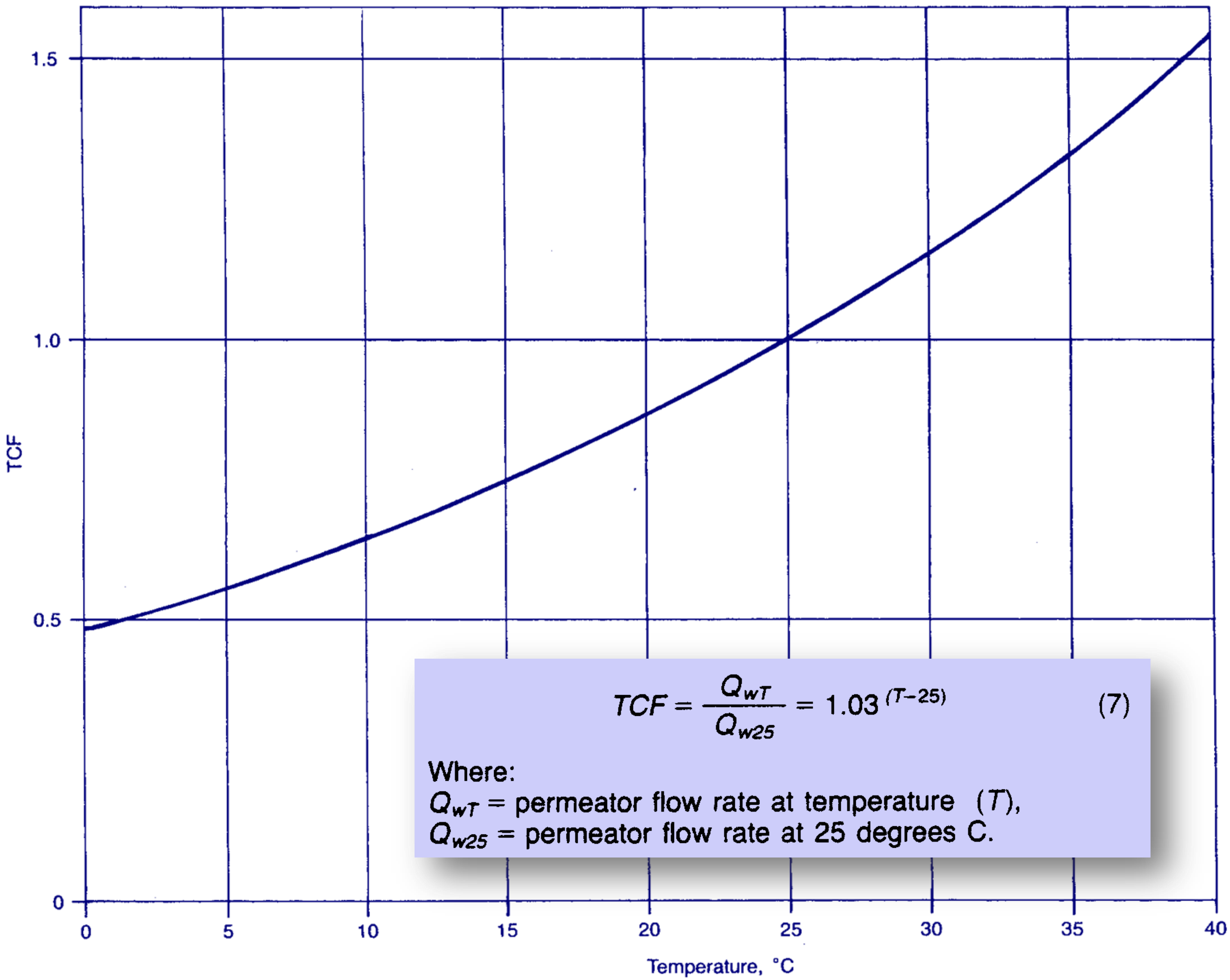
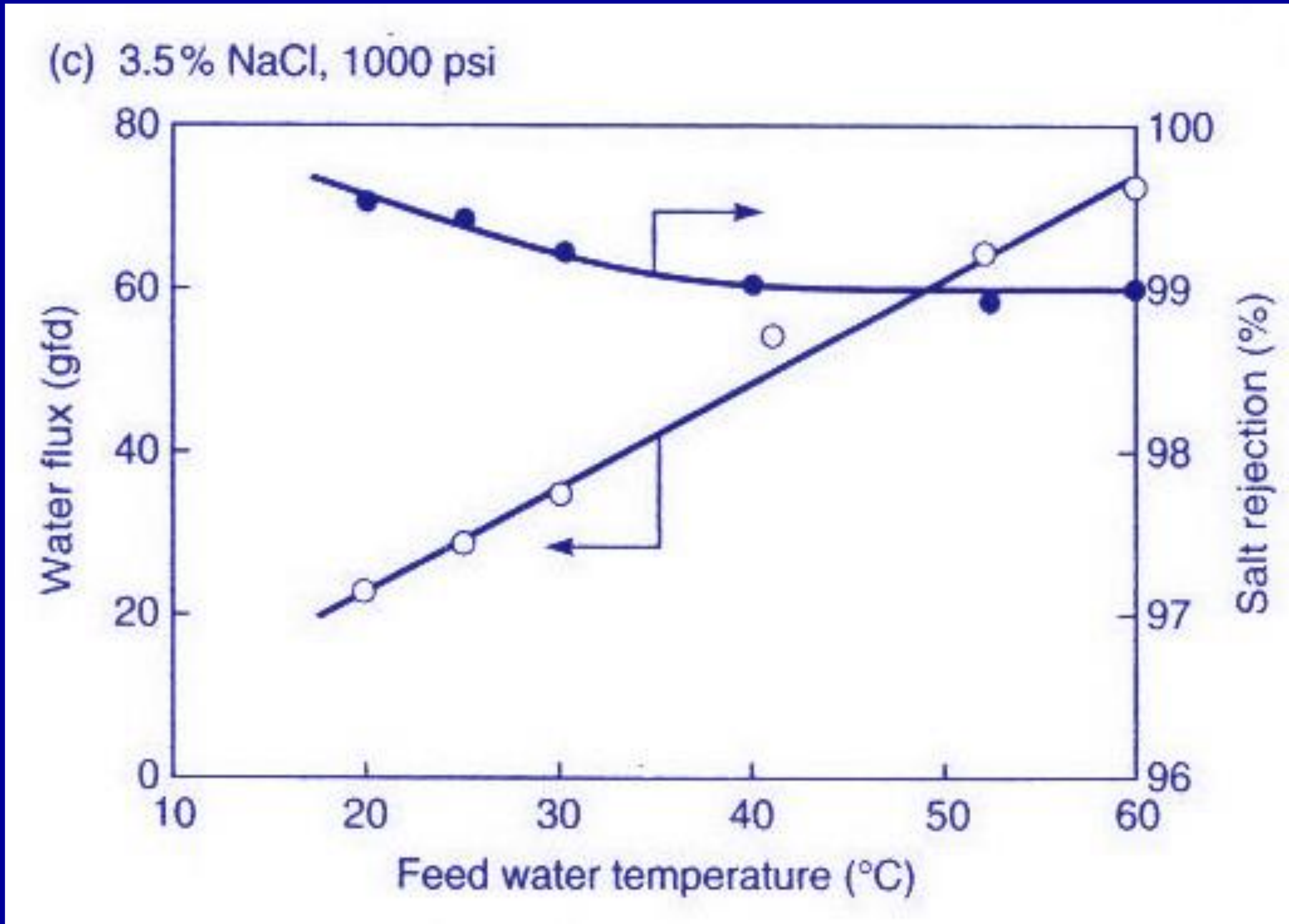
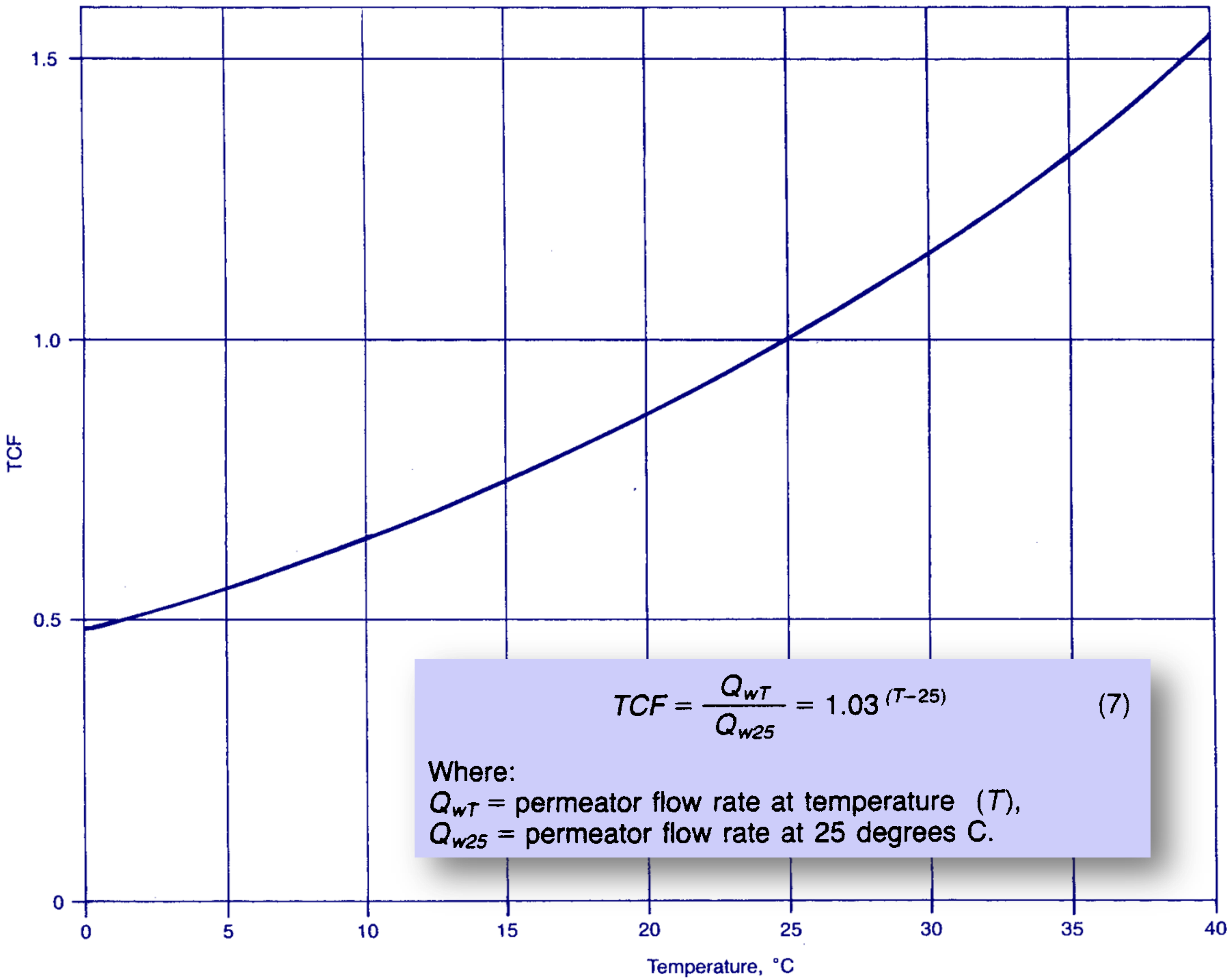


Figure 2. Temperature Correction Factor (TCF) for B-9 Permeator

$$TCF = \frac{Q_{wT}}{Q_{w25}} = 1.03^{(T-25)} \qquad (7)$$

Where:
Q_{wT} = permeator flow rate at temperature (T),
Q_{w25} = permeator flow rate at 25 degrees C.


(c) 3.5% NaCl, 1000 psi
Water flux (gfd)
Salt rejection (%)
Feed water temperature (°C)
0
20
40
60
80
96
97
98
99
100
10
20
30
40
50
60



$$TCF = \frac{Q_{wT}}{Q_{w25}} = 1.03^{(T-25)} \qquad (7)$$

Where:
Q_{wT} = permeator flow rate at temperature (T),
Q_{w25} = permeator flow rate at 25 degrees C.

Figure 2. Temperature Correction Factor (TCF) for B-9 Permeator

Temperature Correction Factors for RO Membrane Systems

Permeate Flow × Correction Factor = Permeate Flow @ 77 °F

°F	Divisor	Factor	°F	Divisor	Factor
35	0.52	1.92	63	0.82	1.22
36	0.53	1.89	64	0.83	1.2
37	0.54	1.85	65	0.85	1.18
38	0.55	1.82	66	0.86	1.16
39	0.56	1.78	67	0.87	1.15
40	0.57	1.75	68	0.88	1.14
41	0.58	1.72	69	0.89	1.12
42	0.59	1.69	70	0.90	1.11
43	0.60	1.67	71	0.91	1.10
44	0.61	1.64	72	0.93	1.08
45	0.62	1.61	73	0.94	1.06
46	0.63	1.59	74	0.95	1.05
47	0.64	1.56	75	0.97	1.03
48	0.65	1.53	76	0.98	1.02
49	0.67	1.49	77	1.00	1.00
50	0.68	1.47	78	1.01	0.99
51	0.69	1.45	79	1.02	0.98
52	0.70	1.43	80	1.04	0.96
53	0.71	1.41	81	1.05	0.95
54	0.72	1.39	82	1.06	0.94
55	0.73	1.37	83	1.07	0.93
56	0.74	1.35	84	1.08	0.92
57	0.75	1.33	85	1.10	0.91
58	0.76	1.31	86	1.11	0.90
59	0.77	1.29	87	1.12	0.89
60	0.78	1.27	88	1.14	0.88
61	0.80	1.25	89	1.15	0.87
62	0.81	1.23	90	1.17	0.86

ผลกระทบของอุณหภูมิต่ออัตราการส่งผ่านน้ำของเมมเบรน

โจทย์ ระบบรีเวิร์สออสโมซีส ระบบหนึ่ง ปฏิบัติการในอุณหภูมิช่วง *15°C - 28°C*

หากน้ำที่ป้อนเข้าระบบมีอุณหภูมิ *28°C* จะต้องใช้ ค่า *NDP* เท่ากับ *7.5 bar (108.9 psi)*

จงหา ค่า*NDP* เมื่อดำเนินการที่อุณหภูมิ *15°C*

กำหนด ค่าคงที่ *C* ของระบบ *RO* ระบบนี้ เท่ากับ *2700*

วิธีทำ

เนื่องจาก $NDP \; \alpha \; TCF$

ดังนั้น $\dfrac{NDP_1}{NDP_2} = \dfrac{TCF_1}{TCF_2}$ ——(*)

เพราะ TCF = 1/exp(*C*(1/273+*t*)-1/298)

@ $t = 28°C$; TCF = 1/exp(*2700*(1/273+28)-1/298) = 0.914 = TCF_1

@ $t = 15°C$; TCF = 1/exp(*2700*(1/273+15)-1/298) = 1.370 = TCF_2

จาก (*) ; จะได้ $NDP_2 = NDP_1 \dfrac{TFC_2}{TFC_1} = 7.5 \times \dfrac{1.370}{0.914} = 11.2 \; bar$ หรือ $162.4 \; psi$

Temperature → Viscosity → Permeability

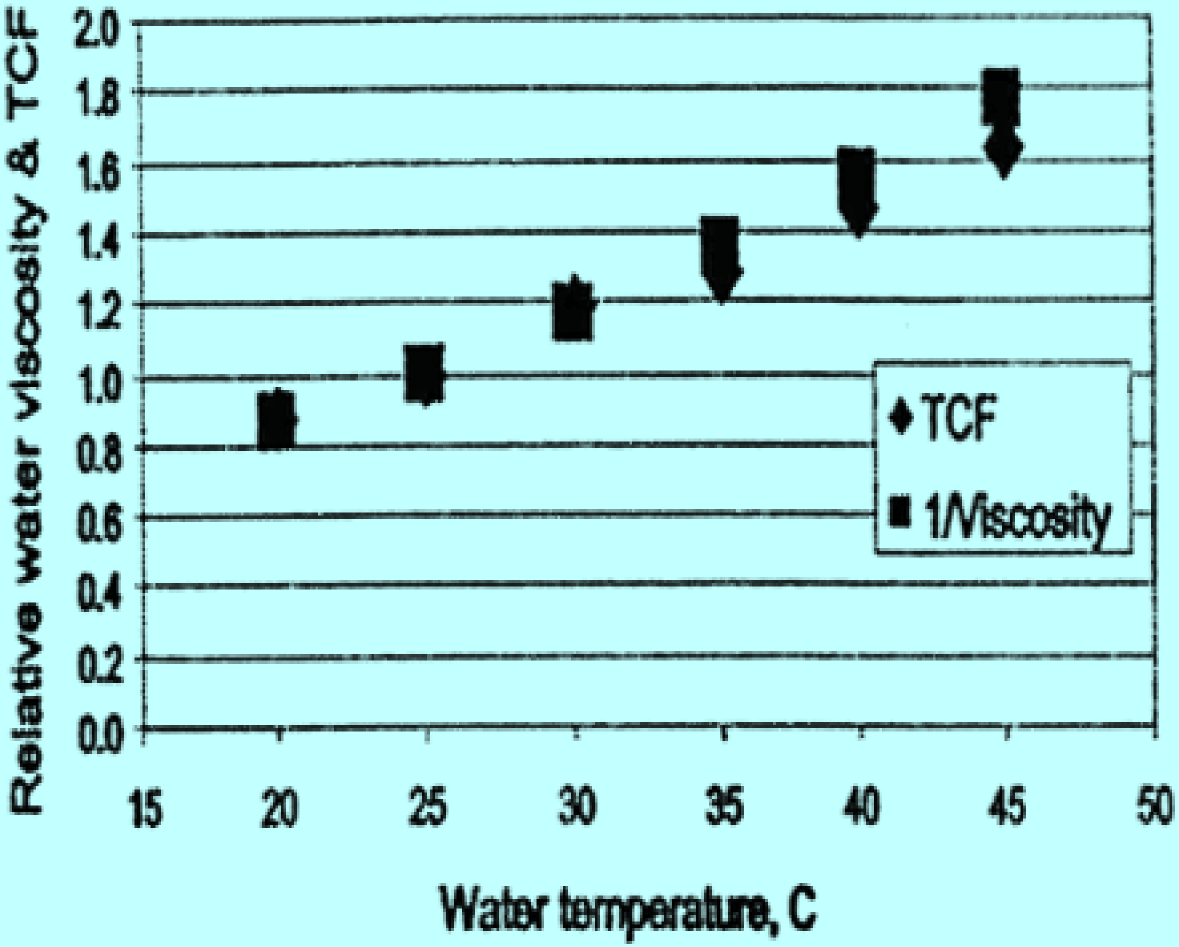
- อุณหภูมิมีผลต่อความหนืดของน้ำ ความหนืดของน้ำมีผลต่อความสามารถในการข้ามผ่านเมมเบรน ดังสมการ

$$\boxed{TCF = 1/\exp(C(1/273+t)-1/298)} \qquad \text{—(9)}$$

; t = อุณหภูมิ (°C) โดยปกติจะทำที่อุณหภูมิ 25°C (77°F)

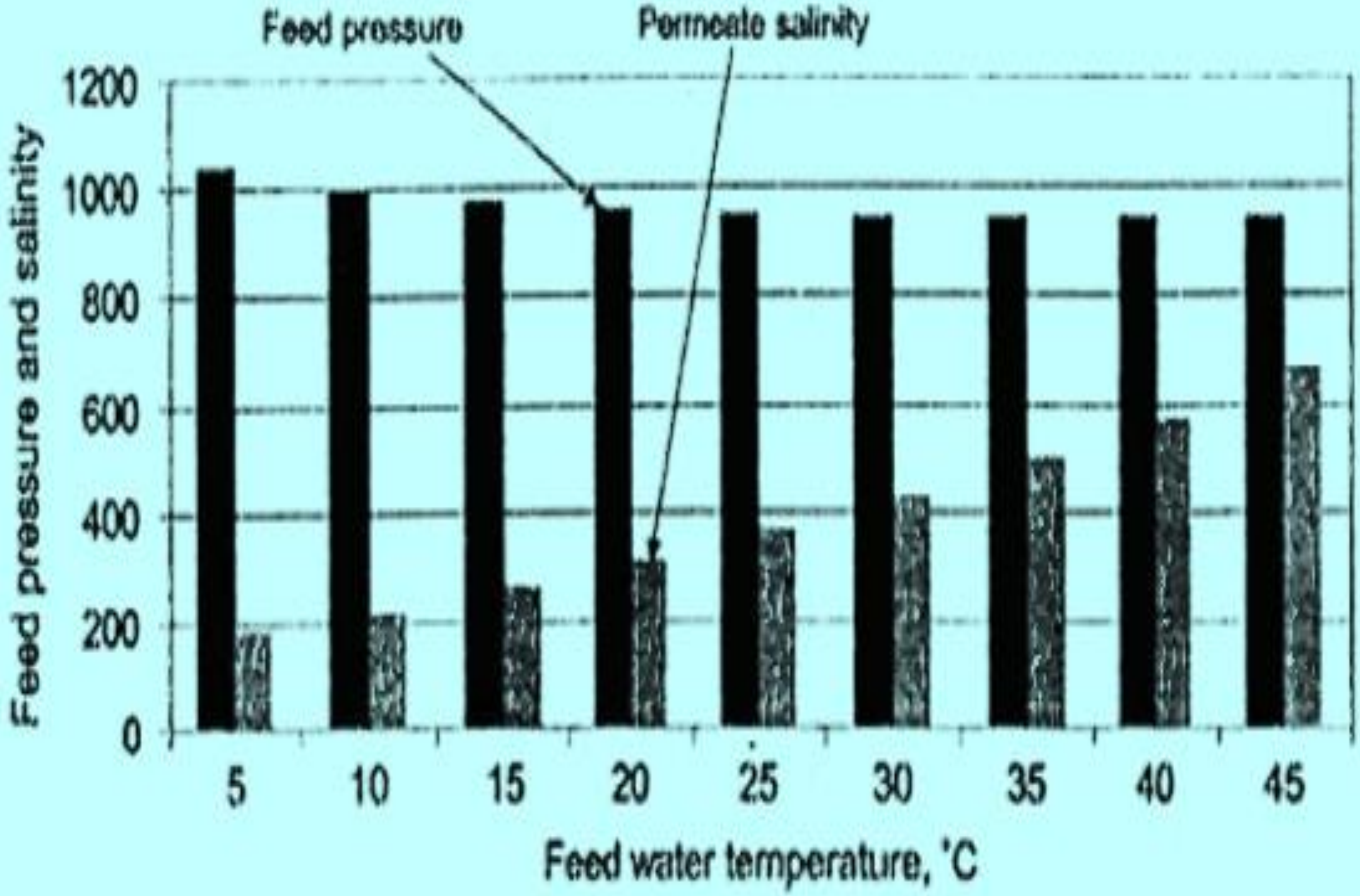
; C = สัมประสิทธิ์ค่าคงที่ เป็นคุณลักษณะเฉพาะของเมมเบรนที่ใช้

=2500 ถึง 3000 กรณีเมมเบรนทำจาก polyamide

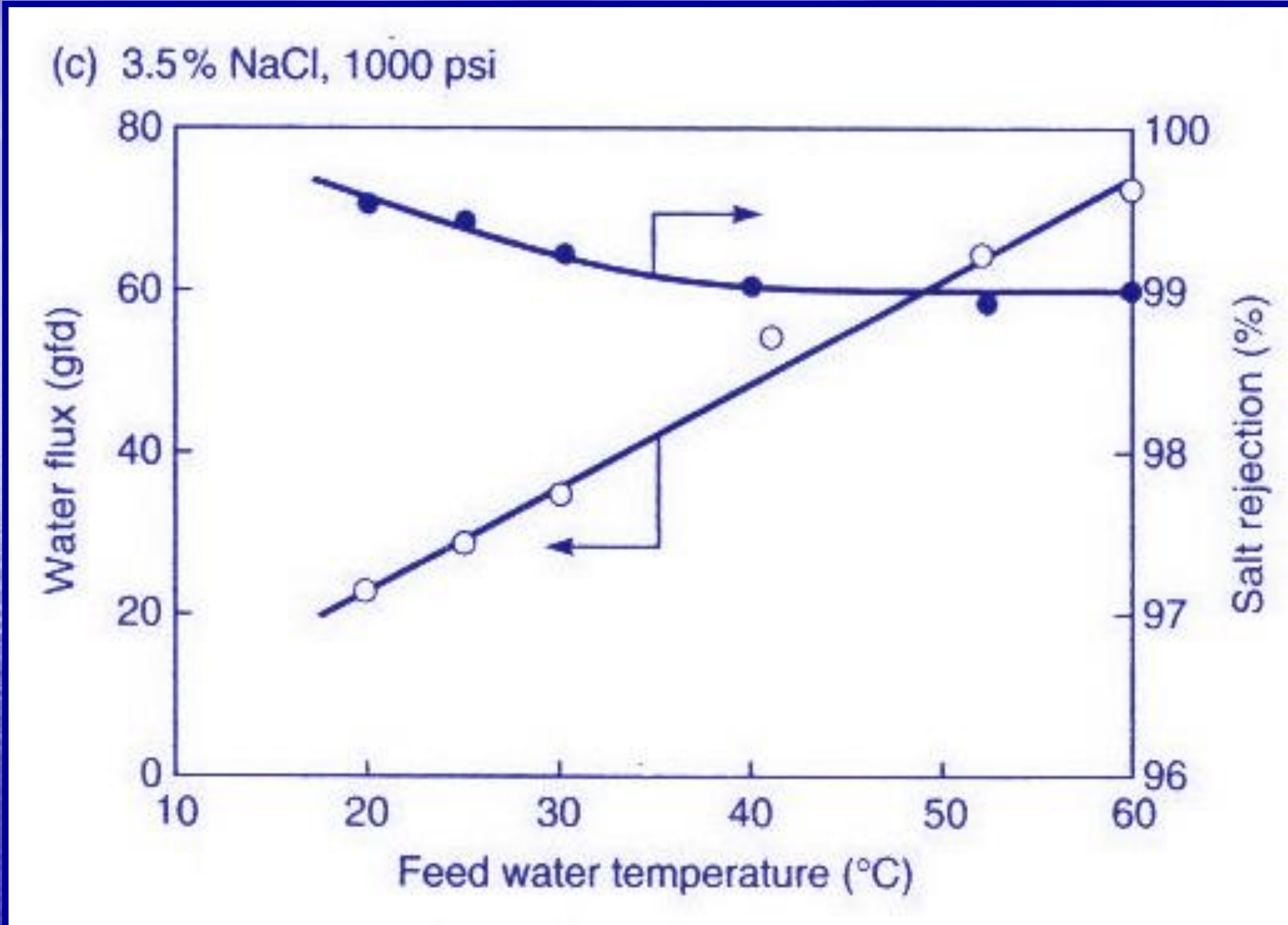


- <u>รูปที่2</u> : *ภาพแสดงความสัมพันธ์ ระหว่างอุณหภูมิ VS. ความหนืดของน้ำ และ ความสามารถในการแพร่ของน้ำผ่านเมมเบรน*

ผลกระทบของอุณหภูมิต่ออัตราการส่งผ่านน้ำของเมมเบรน



- *<u>รูปที่3</u> : ภาพแสดงความสัมพันธ์ ระหว่างความดันที่ป้อนระบบ VS ความเข้มข้นของเกลือที่สามารถผ่าน RO เมมเบรนในระบบบำบัดน้ำทะเล ไปได้*


(c) 3.5% NaCl, 1000 psi
80
60
40
20
0
10
20
30
40
50
60
100
99
98
97
96
Water flux (gfd)
Salt rejection (%)
Feed water temperature (°C)

ผลกระทบของอุณหภูมิต่ออัตราการส่งผ่านน้ำของเมมเบรน

โจทย์ ระบบรีเวิร์สออสโมซีส ระบบหนึ่ง ปฏิบัติการในอุณหภูมิช่วง *15°C - 28°C*

หากน้ำที่ป้อนเข้าระบบมีอุณหภูมิ *28°C* จะต้องใช้ ค่า *NDP* เท่ากับ *7.5 bar (108.9 psi)*

จงหา ค่า *NDP* เมื่อดำเนินการที่อุณหภูมิ *15°C*

กำหนด ค่าคงที่ *C* ของระบบ *RO* ระบบนี้ เท่ากับ *2700*

วิธีทำ

เนื่องจาก $NDP \; \alpha \; TCF$

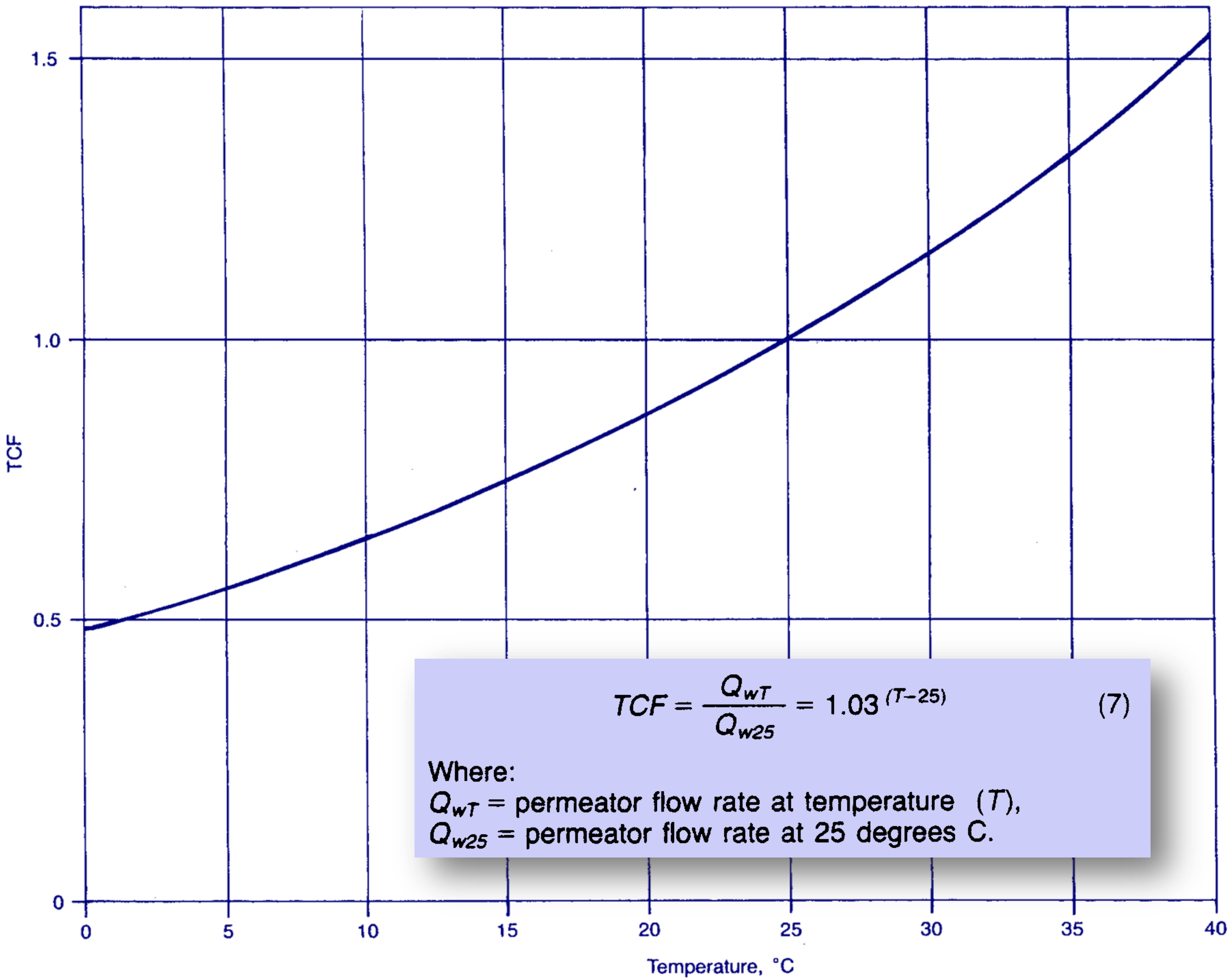
ดังนั้น $\frac{NDP_1}{NDP_2} = \frac{TCF_1}{TCF_2}$ ——(*)

เพราะ TCF = 1/exp(*C*(1/273+*t*)-1/298)

@ $t = 28°C$; TCF = 1/exp(*2700*(1/273+28)-1/298) = 0.914 = TCF_1

@ $t = 15°C$; TCF = 1/exp(*2700*(1/273+15)-1/298) = 1.370 = TCF_2

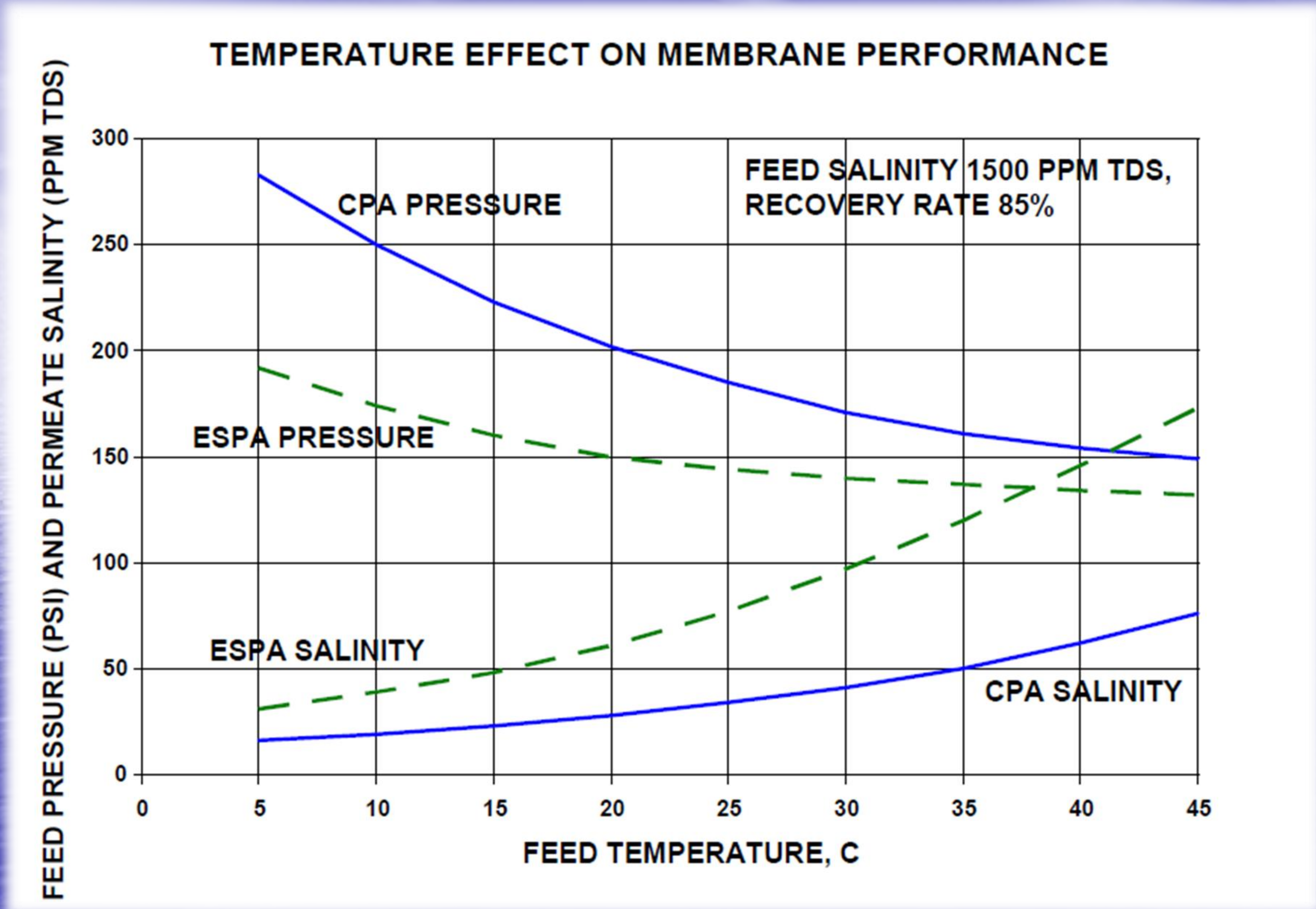
จาก (*) ; จะได้ $NDP_2 = NDP_1 \frac{TFC_2}{TFC_1} = 7.5 \times \frac{1.370}{0.914} = 11.2 \; bar$ หรือ $162.4 \; psi$



$$TCF = \frac{Q_{wT}}{Q_{w25}} = 1.03^{(T-25)} \qquad (7)$$

Where:
Q_{wT} = permeator flow rate at temperature (T),
Q_{w25} = permeator flow rate at 25 degrees C.

Figure 2. Temperature Correction Factor (TCF) for B-9 Permeator

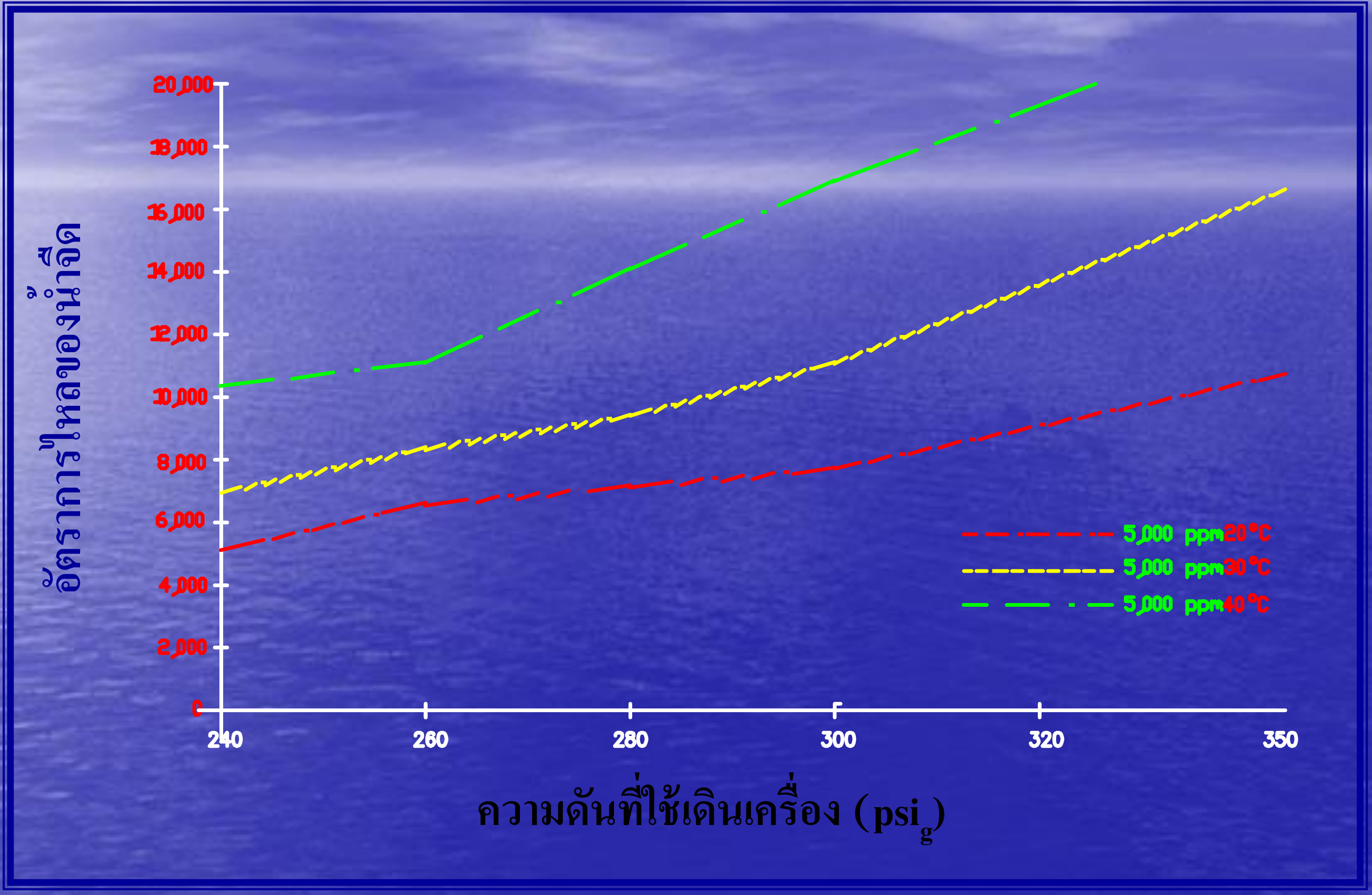

TEMPERATURE EFFECT ON MEMBRANE PERFORMANCE
FEED SALINITY 1500 PPM TDS,
RECOVERY RATE 85%
CPA PRESSURE
ESPA PRESSURE
ESPA SALINITY
CPA SALINITY
FEED PRESSURE (PSI) AND PERMEATE SALINITY (PPM TDS)
FEED TEMPERATURE, C
0
50
100
150
200
250
300
0
5
10
15
20
25
30
35
40
45

Temperature Correction Factors for RO Membrane Systems

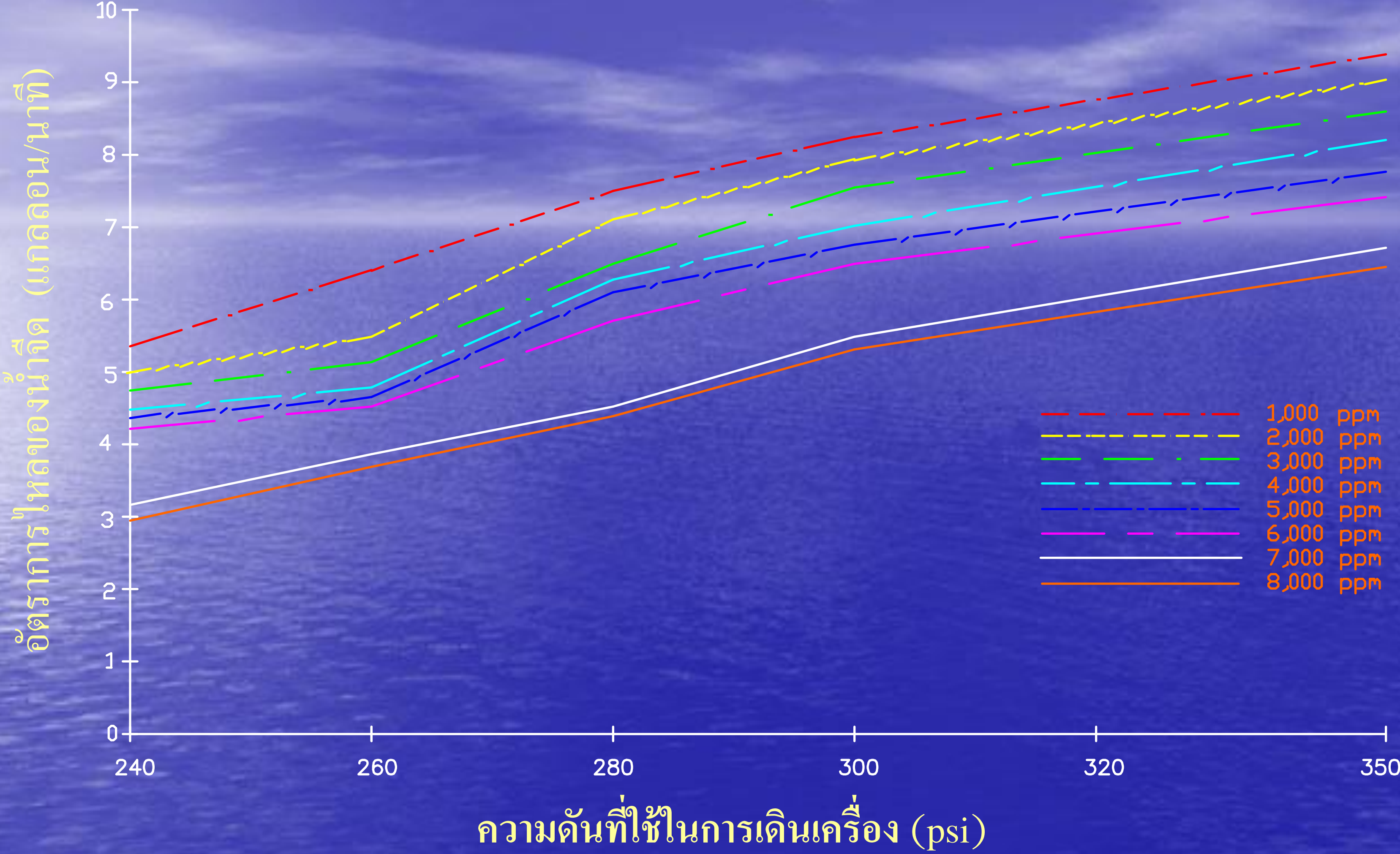
Permeate Flow × Correction Factor = Permeate Flow @ 77 °F

°F	Divisor	Factor	°F	Divisor	Factor
35	0.52	1.92	63	0.82	1.22
36	0.53	1.89	64	0.83	1.2
37	0.54	1.85	65	0.85	1.18
38	0.55	1.82	66	0.86	1.16
39	0.56	1.78	67	0.87	1.15
40	0.57	1.75	68	0.88	1.14
41	0.58	1.72	69	0.89	1.12
42	0.59	1.69	70	0.90	1.11
43	0.60	1.67	71	0.91	1.10
44	0.61	1.64	72	0.93	1.08
45	0.62	1.61	73	0.94	1.06
46	0.63	1.59	74	0.95	1.05
47	0.64	1.56	75	0.97	1.03
48	0.65	1.53	76	0.98	1.02
49	0.67	1.49	77	1.00	1.00
50	0.68	1.47	78	1.01	0.99
51	0.69	1.45	79	1.02	0.98
52	0.70	1.43	80	1.04	0.96
53	0.71	1.41	81	1.05	0.95
54	0.72	1.39	82	1.06	0.94
55	0.73	1.37	83	1.07	0.93
56	0.74	1.35	84	1.08	0.92
57	0.75	1.33	85	1.10	0.91
58	0.76	1.31	86	1.11	0.90
59	0.77	1.29	87	1.12	0.89
60	0.78	1.27	88	1.14	0.88
61	0.80	1.25	89	1.15	0.87
62	0.81	1.23	90	1.17	0.86

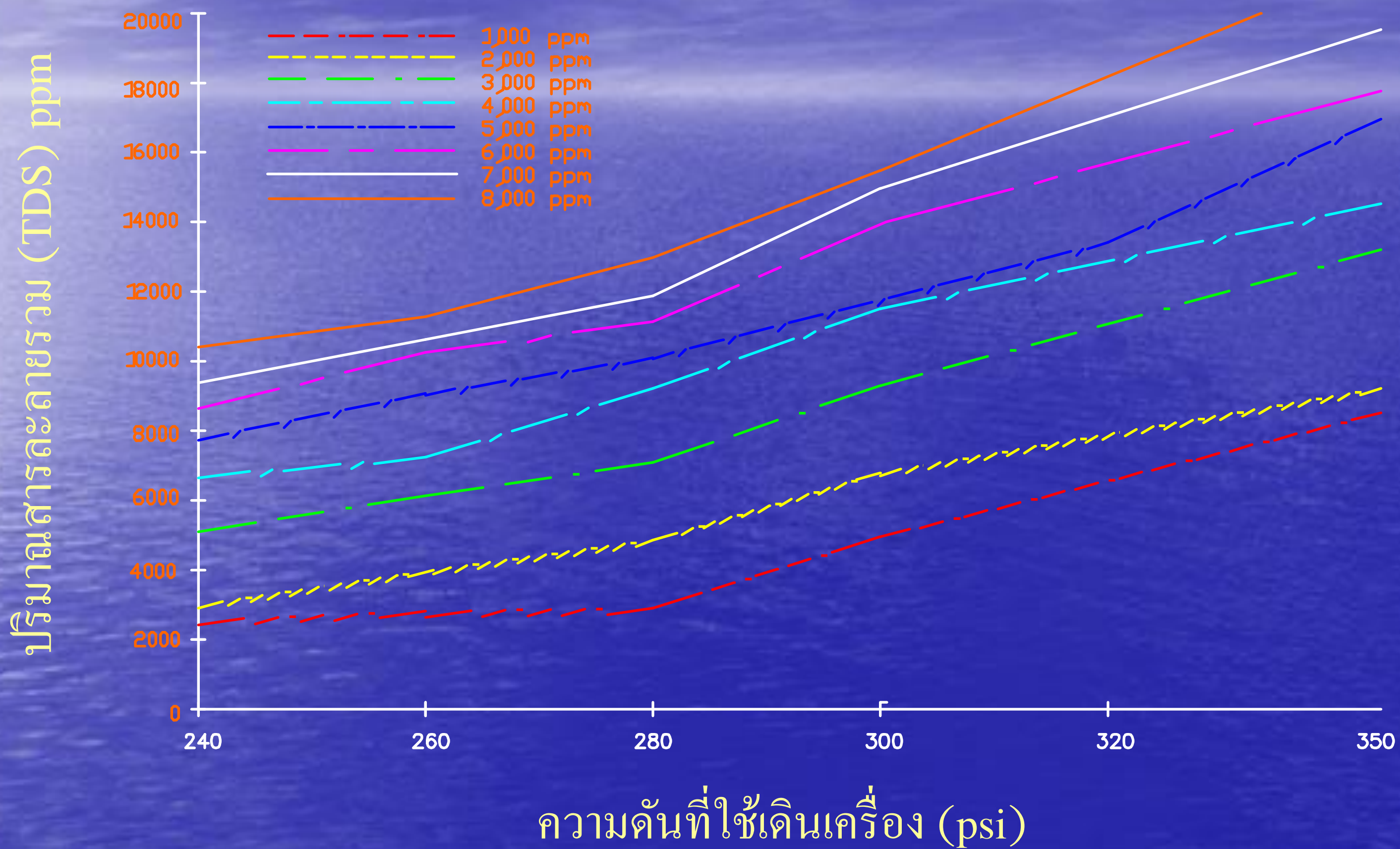

2 4 200



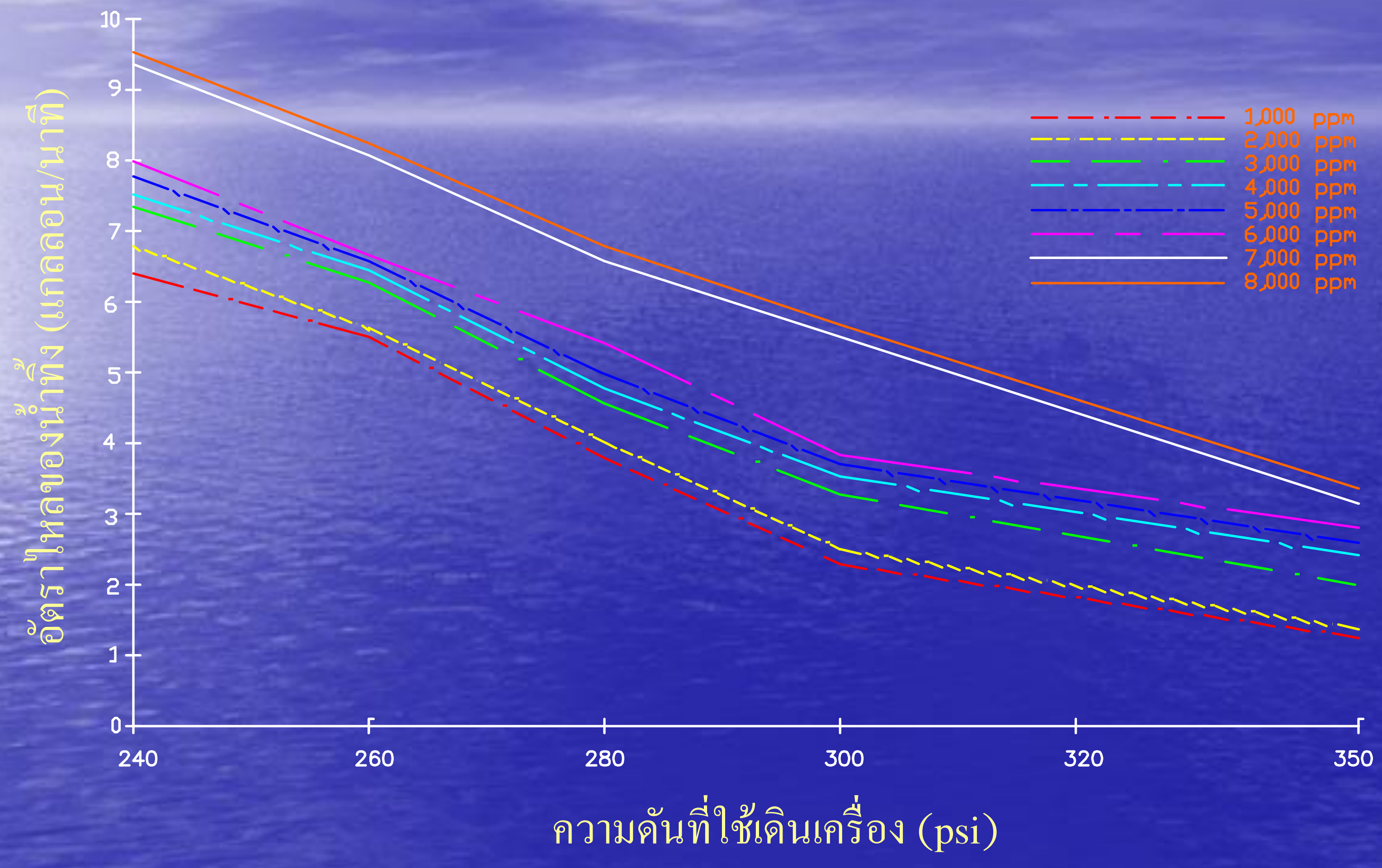
กราฟแสดงผล ของอุณหภูมิและความดัน ที่มีผลต่ออัตราการกรอง



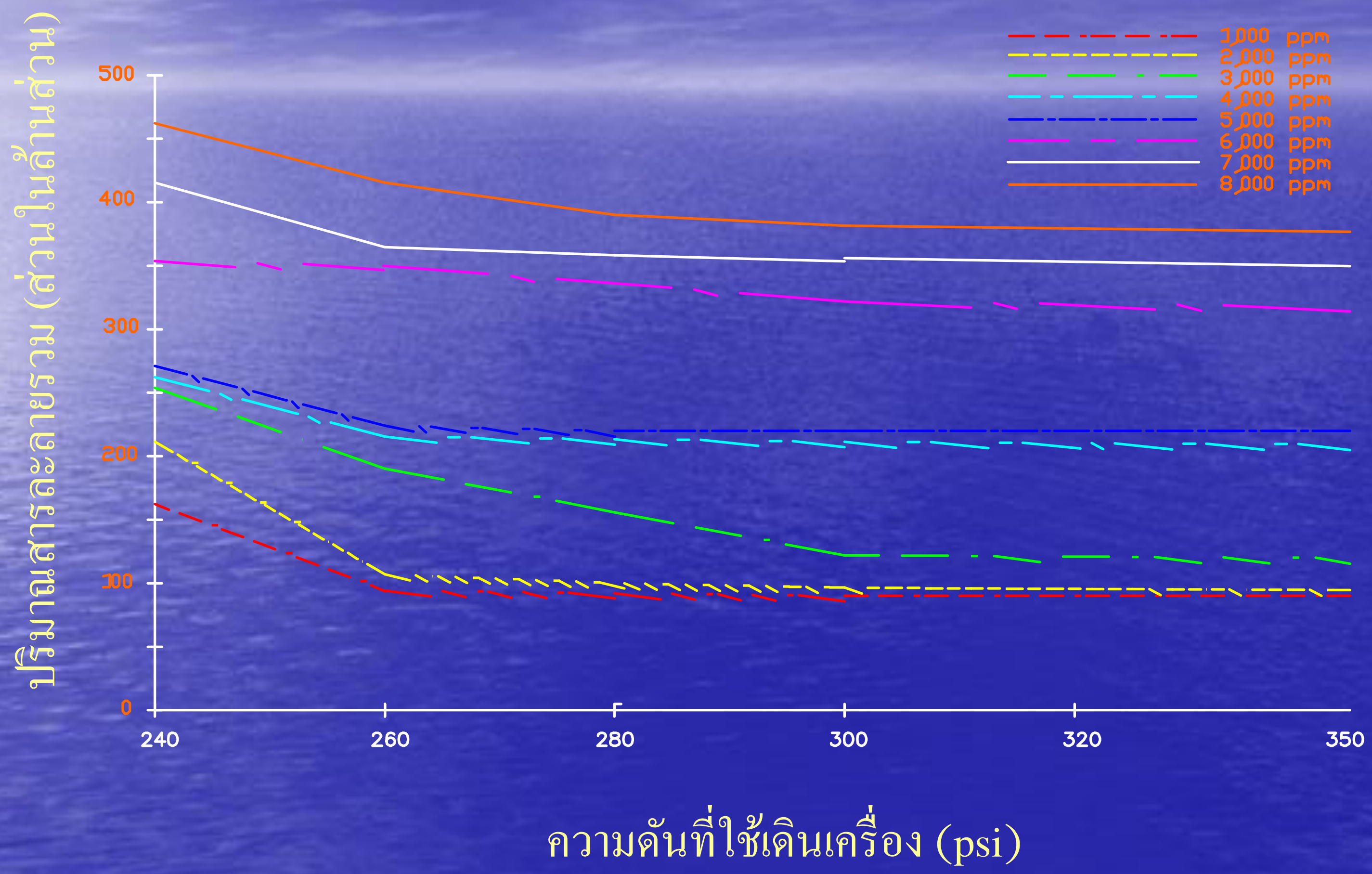
กราฟแสดงอัตราการผลิตน้ำจืดที่ความดันต่าง ๆ



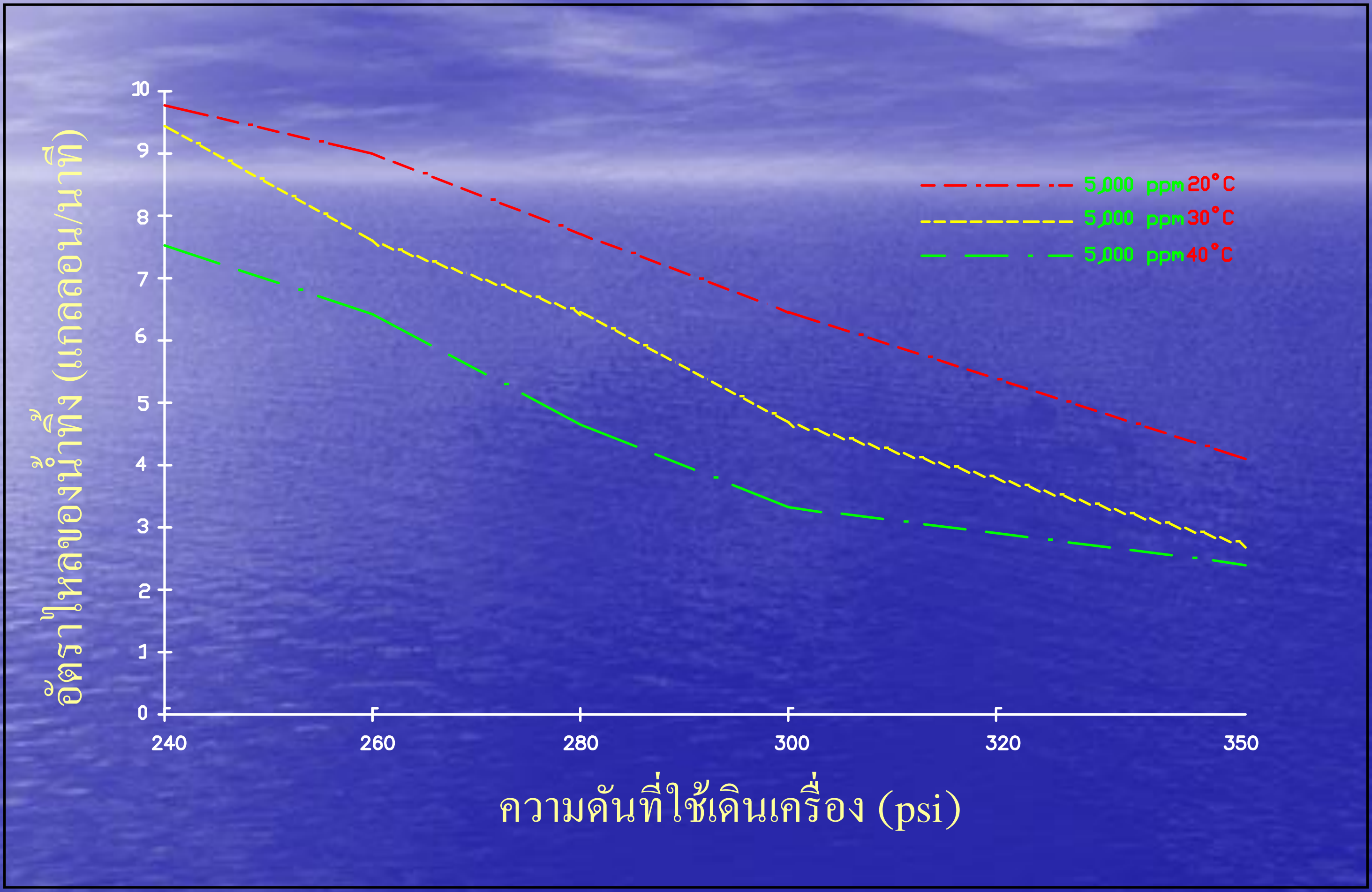
กราฟแสดงความเข้มข้นของน้ำทิ้ง (TDS) ที่ความดันต่าง ๆ



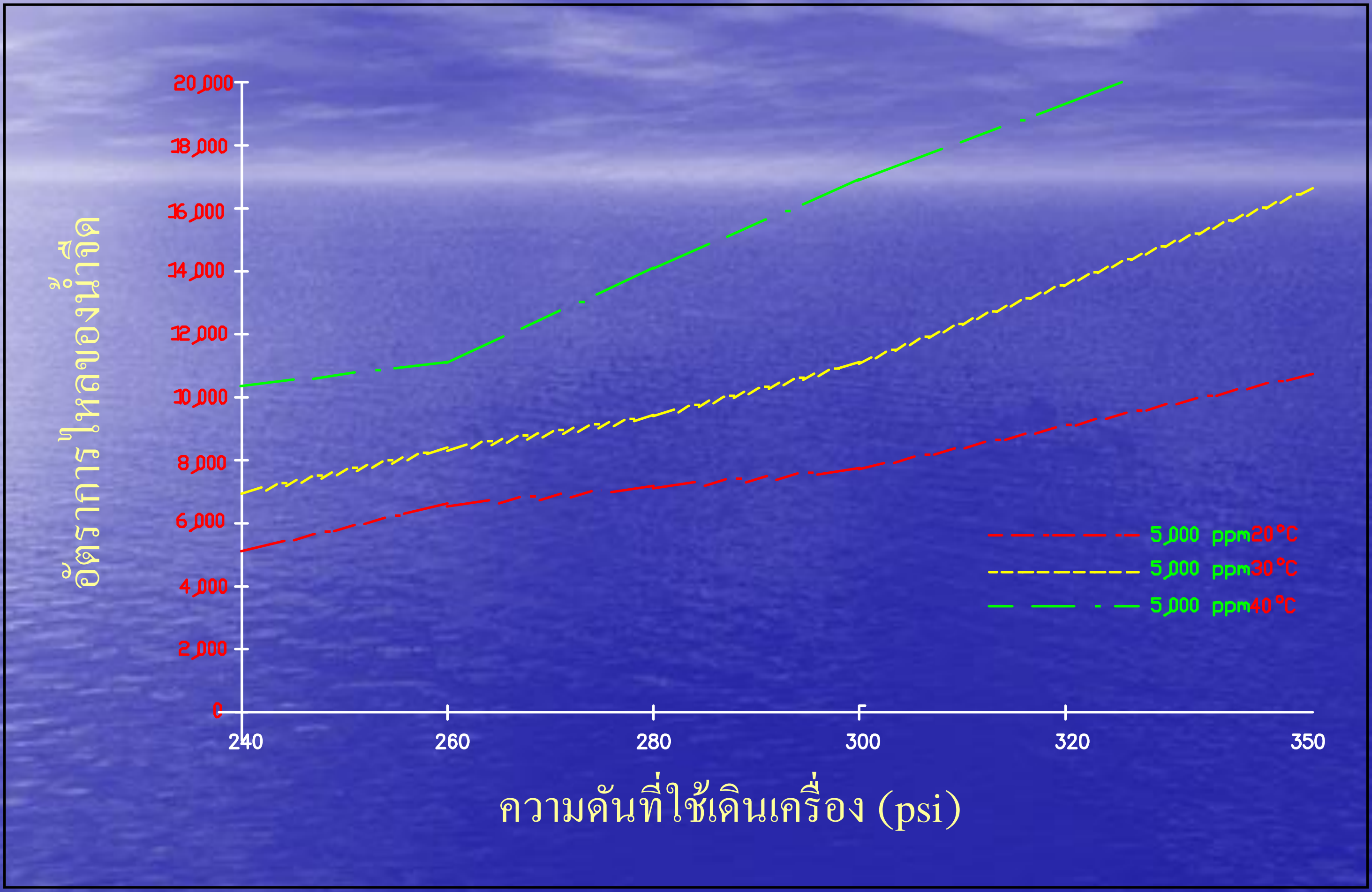
กราฟแสดงปริมาณน้ำทิ้งที่ความดันต่าง ๆ



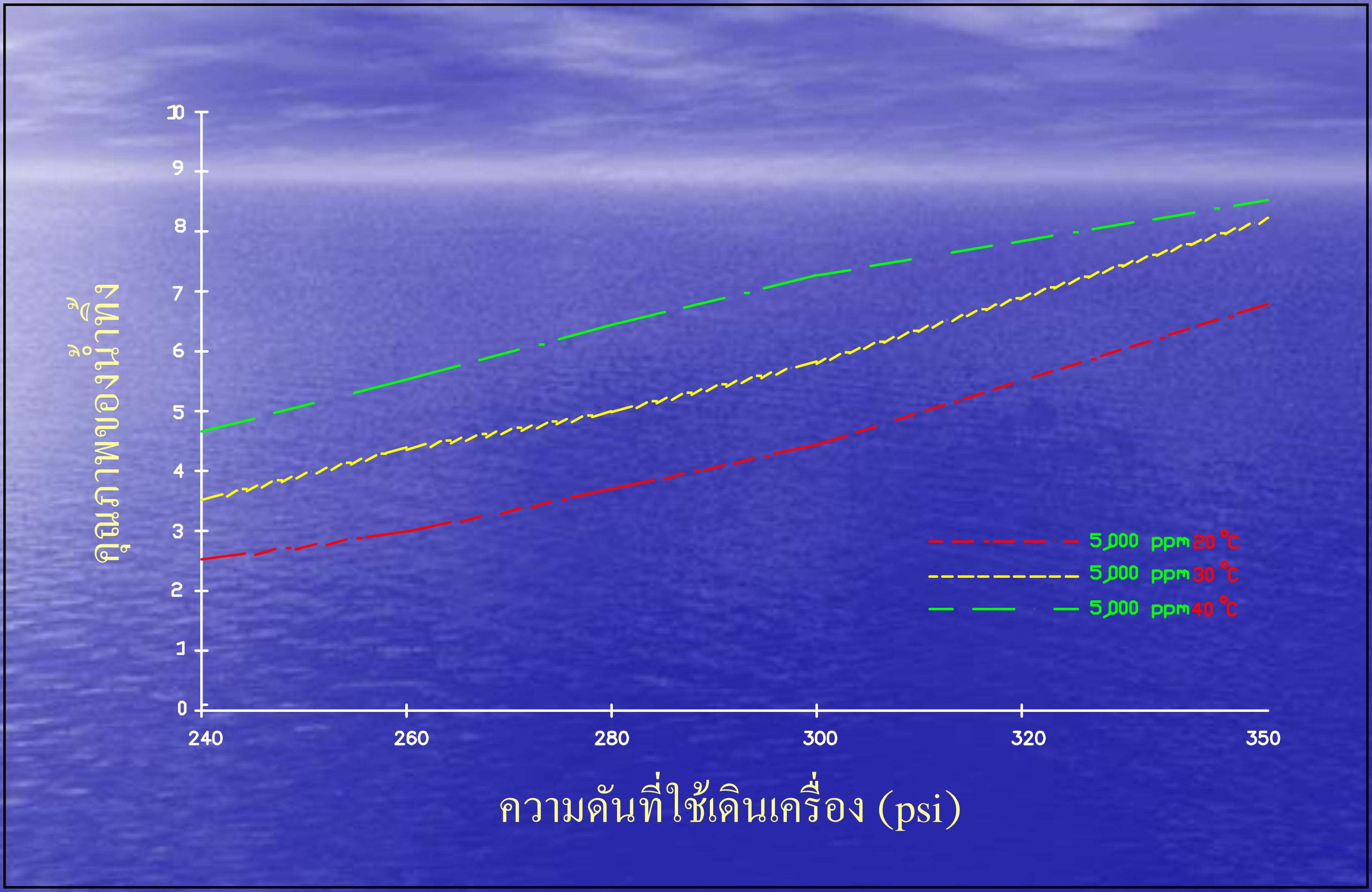
กราฟแสดงคุณภาพน้ำจืดที่ผลิตได้ที่ความดันต่าง ๆ



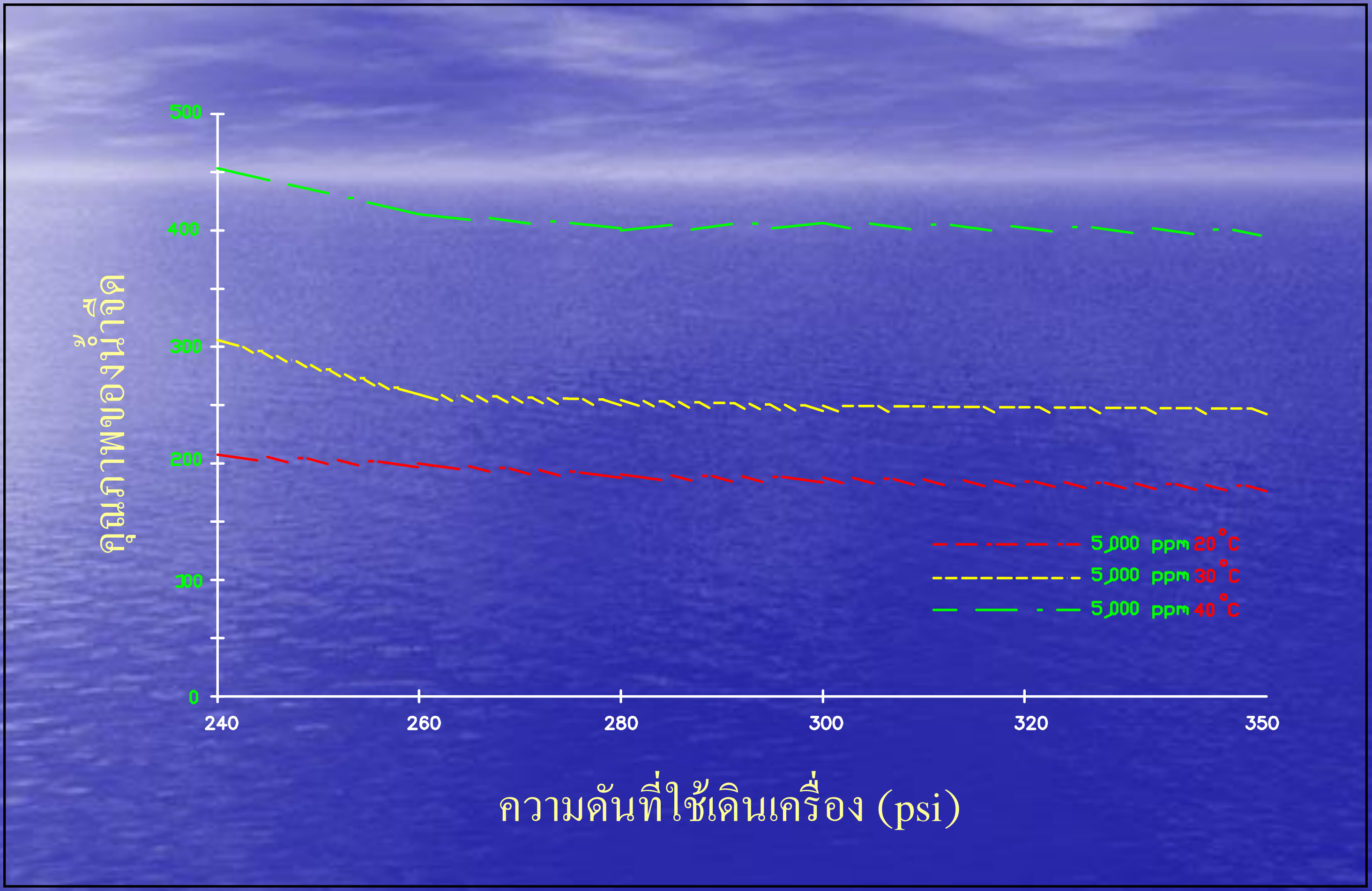
กราฟแสดงผลของอุณหภูมิที่มีผลต่ออัตราการไหลของน้ำทิ้ง



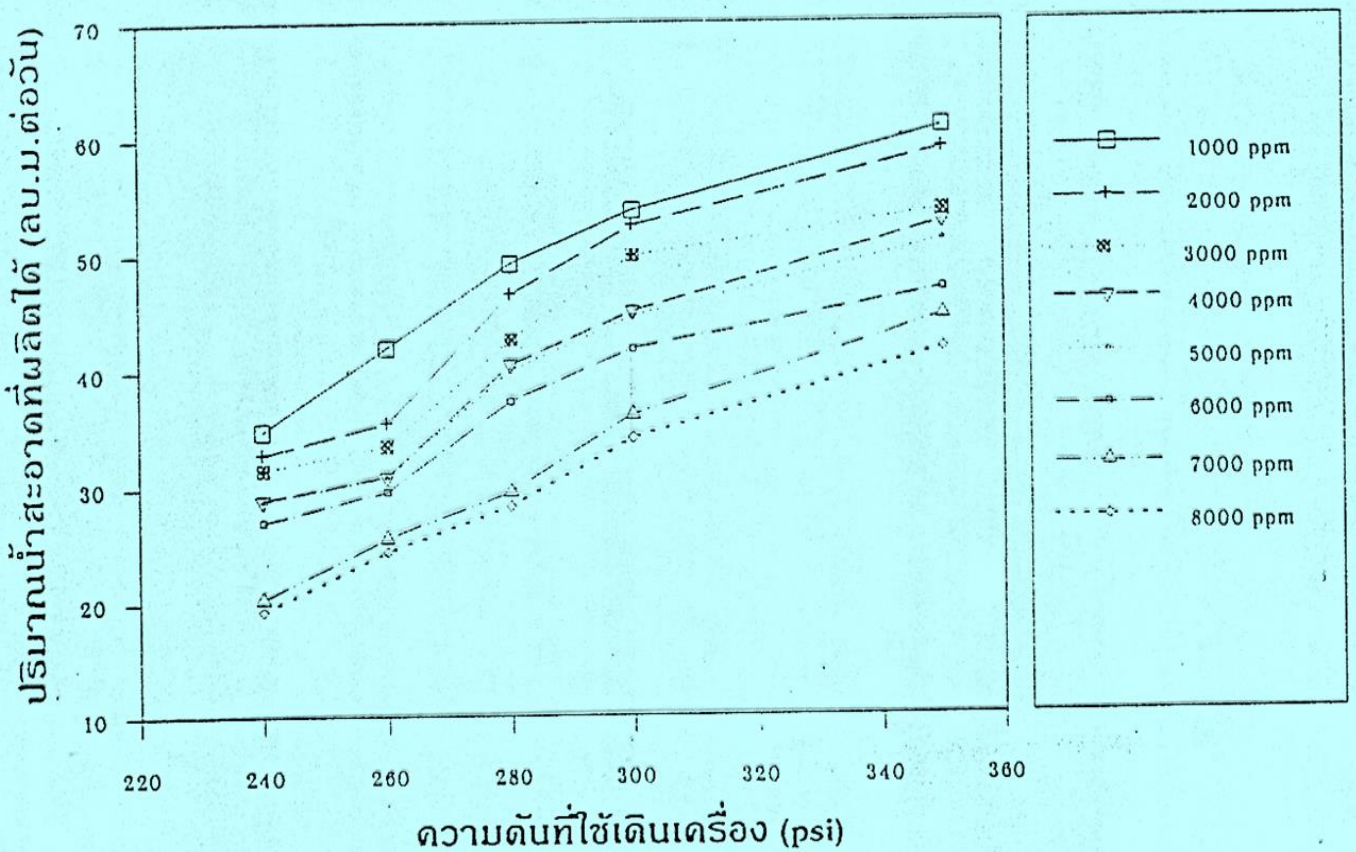
กราฟแสดงผลของอุณหภูมิที่มีผลต่ออัตราการผลิตน้ำจืด



กราฟแสดงผลของอุณหภูมิที่มีต่อความเข้มข้น (TDS) ของน้ำทิ้ง



กราฟแสดงผลของอุณหภูมิที่มีต่อคุณภาพน้ำจืด



กราฟความสัมพันธ์ระหว่างปริมาณการผลิตน้ำสะอาดของเครื่องกรองน้ำที่ความดันและความเข้มข้นของสารละลายน้ำป้อนต่าง ๆ กัน

Average permeate flux (APF)

$$\boxed{APF = \frac{permeate\ flow}{total\ membrane\ area} = \frac{Q_p}{EN \times MA}} \quad (10)$$

; $Q_p = permeate\ flow\ rate =$ อัตราการแพร่ของน้ำผ่านเมมเบรน

; $EN =$ จำนวนเมมเบรน

; $MA =$ พื้นที่ผิวของเมมเบรนแต่ละอัน

; $APF = average\ permeate\ flux\ (\frac{\frac{l}{m^2}}{h}$ หรือ $\frac{\frac{gal}{ft^2}}{d})$

Average permeate flux (APF)

<u>โจทย์</u> ระบบรีเวิร์สออสโมซีสระบบหนึ่งผลิตน้ำได้ 400,000 ลิตร/วัน ในหนึ่งชุดเมมเบรน ประกอบด้วยท่อส่งความดันทั้งหมด 3 ท่อ ในแต่ละท่อมีบรรจุ 6 เมมเบรน ซึ่งเมมเบรนแต่ละอันมีพื้นที่ผิว 400 ft^2 จงหา อัตราความดันเฉลี่ยของระบบ (APF)

<u>วิธีทำ</u>

เพราะ $$APF = \frac{Q_p}{EN \times MA}$$

เพราะฉะนั้น $$APF = \frac{400{,}000\,\frac{l}{d}}{3 \times 6 \times 37m^2} = 600.6\ \frac{\frac{l}{m^2}}{h}$$

Specific permeability of membrane

- Specific permeability of a membrane หรือ specific flux (SP)

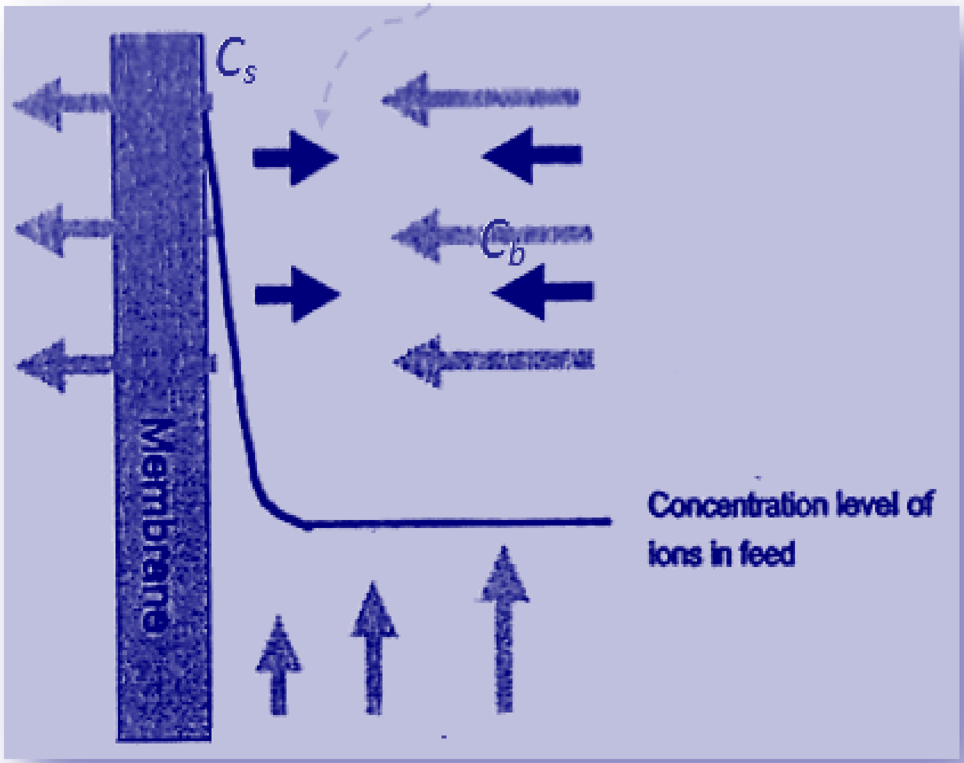
$$\boxed{SF = \frac{APF}{NDP}} \qquad (11)$$

$$;SP = Specific\ flux\ rate\ \left(\frac{\frac{l}{m^2}}{h \bullet bar}\right)$$

- Concentration polarization
  - คือ ปรากฏการณ์ การเพิ่มขึ้นของเกลือที่ผิวเมมเบรน ซึ่งเกิดจากการเลือกผ่านของเยื่อเมมเบรน

น้ำแพร่กลับเนื่องจาเกิด Concentration polarization (ที่ผิวเมมเบรนมีความเข้มข้นของเกลือมาก)

ดังนั้นการเกิด Concentration polarization จึงเป็นการลด อัตราการแพร่ผ่านเยื่อของน้ำ



Concentration Polarization Factor (CPF)

$$\boxed{CPF = \frac{C_s}{C_b}} \qquad (12.1)$$

; C_s = ความเข้มข้นของเกลือที่วเมมเบรน

; C_b = ความเข้มข้นของสารละลาย (bulk concentration)

- *รูปที่3* : ปรากฏการณ์ Concentration polarization

- CPF ยังสามารถหาได้จาก

$$\boxed{CPF = K_p \exp(Q_p/Q_{favg})} \quad \text{—(12.2)}$$

; K_p = ค่าคงที่ โดยค่านี้ขึ้นกับ ลักษณะรูปลักษณ์ ของเมมเบรน

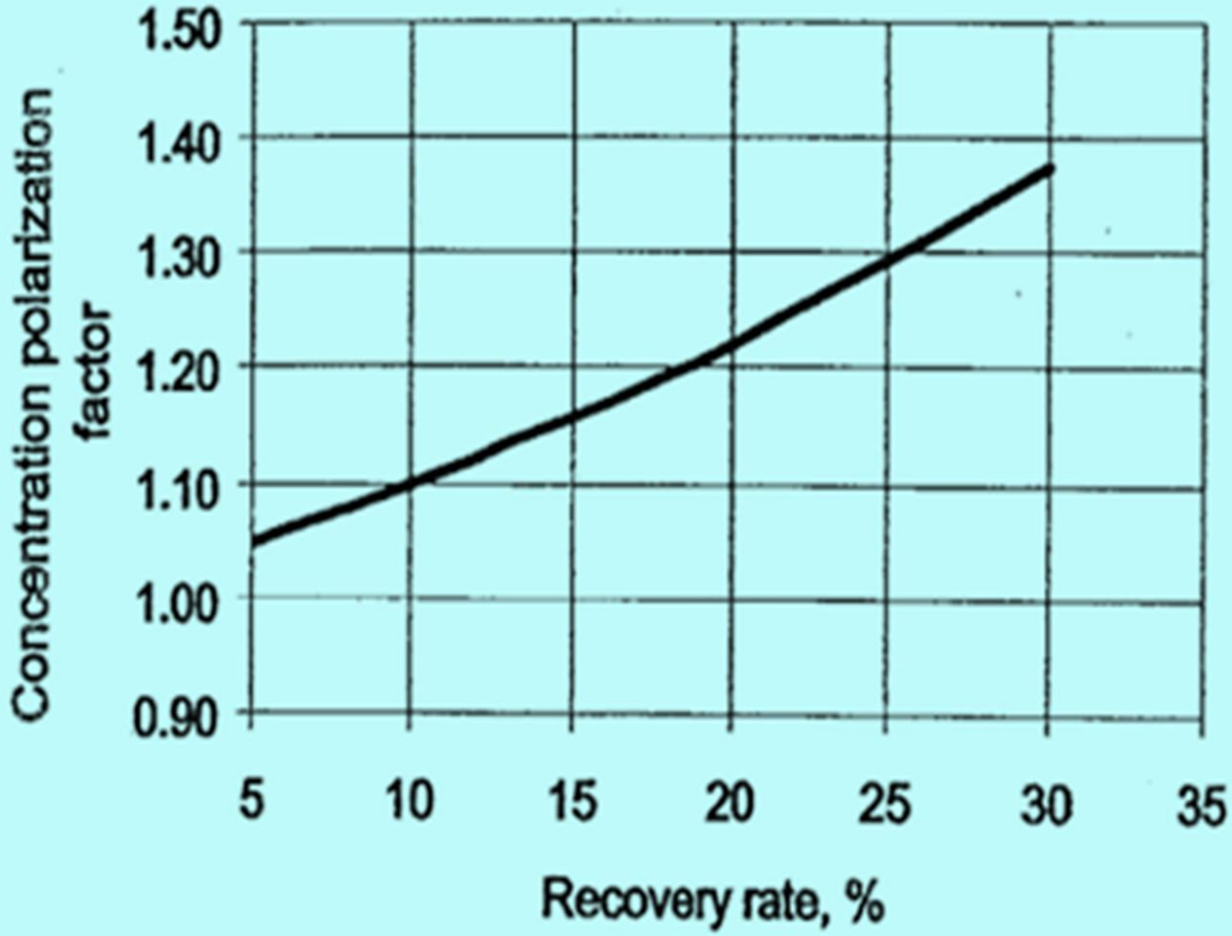
; Q_p = permeate flow = อัตราการไหลของน้ำที่กรองได้

; Q_{favg} = average feed flow = อัตราการไหลของน้ำที่ป้อนเข้าระบบ

>> <u>ในกรณีที่ค่าตัวแปรต่างๆที่ใช้ในการคำนวณเป็นค่าเฉลี่ย เช่นการใช้ค่าเฉลี่ยอัตราการไหลของน้ำแทน อัตราการไหลของน้ำ CPFสามารถหาได้จาก</u>

$$\boxed{CPF = K_p \exp(2\,R_i/(2- R_i))} \quad \text{—(12.3)}$$

; R_i = อัตราการแพร่ของน้ำผ่านเมมเบรน'i'



- *<u>รูปที่4</u> : ภาพแสดงความสัมพันธ์ ระหว่าง CPF กับ Recovery Rate ของเมมเบรน*

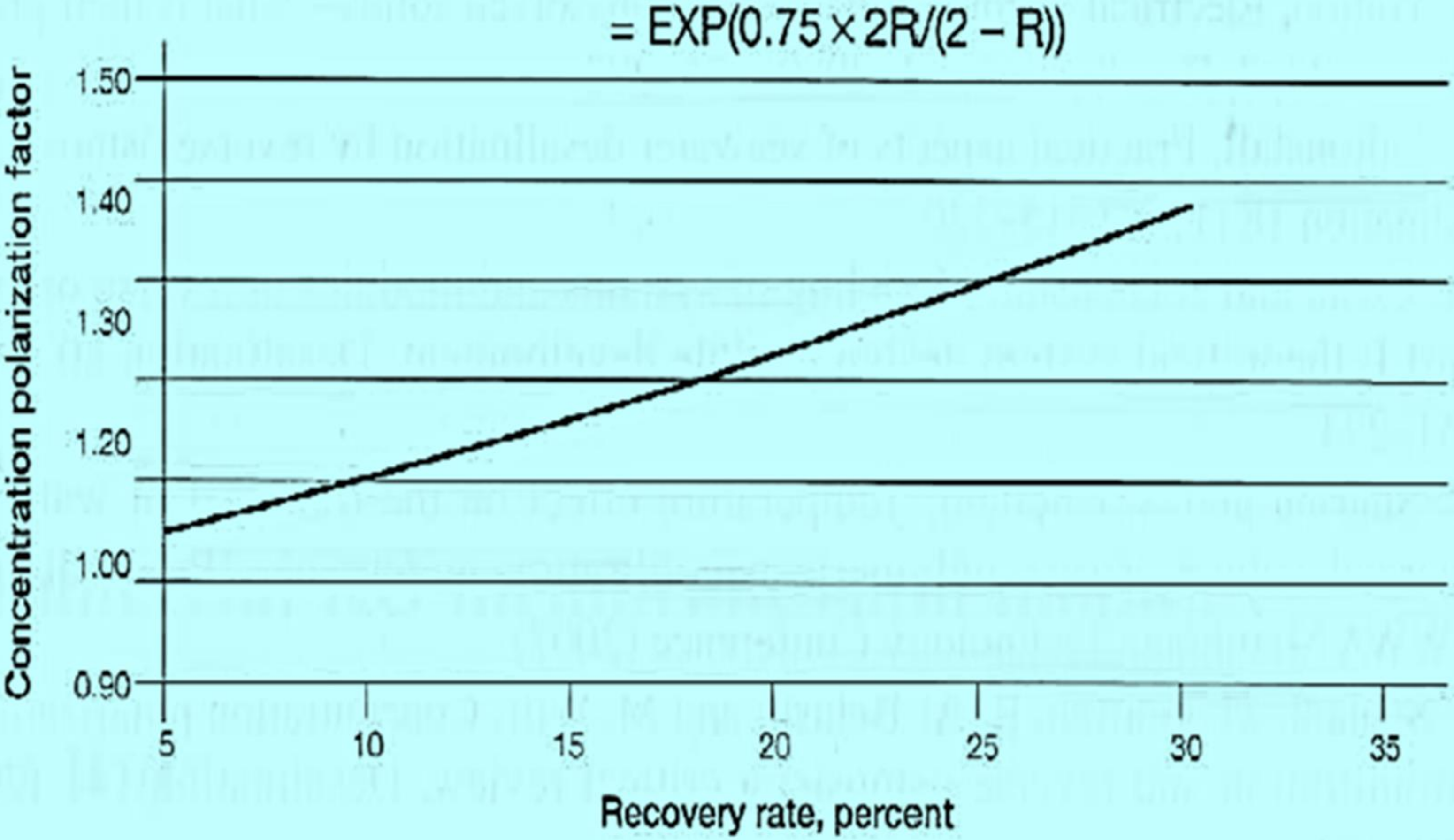


FIG. 11.11 Relation of concentration polarization factor (CPF) to membrane element recovery rate (R_i).

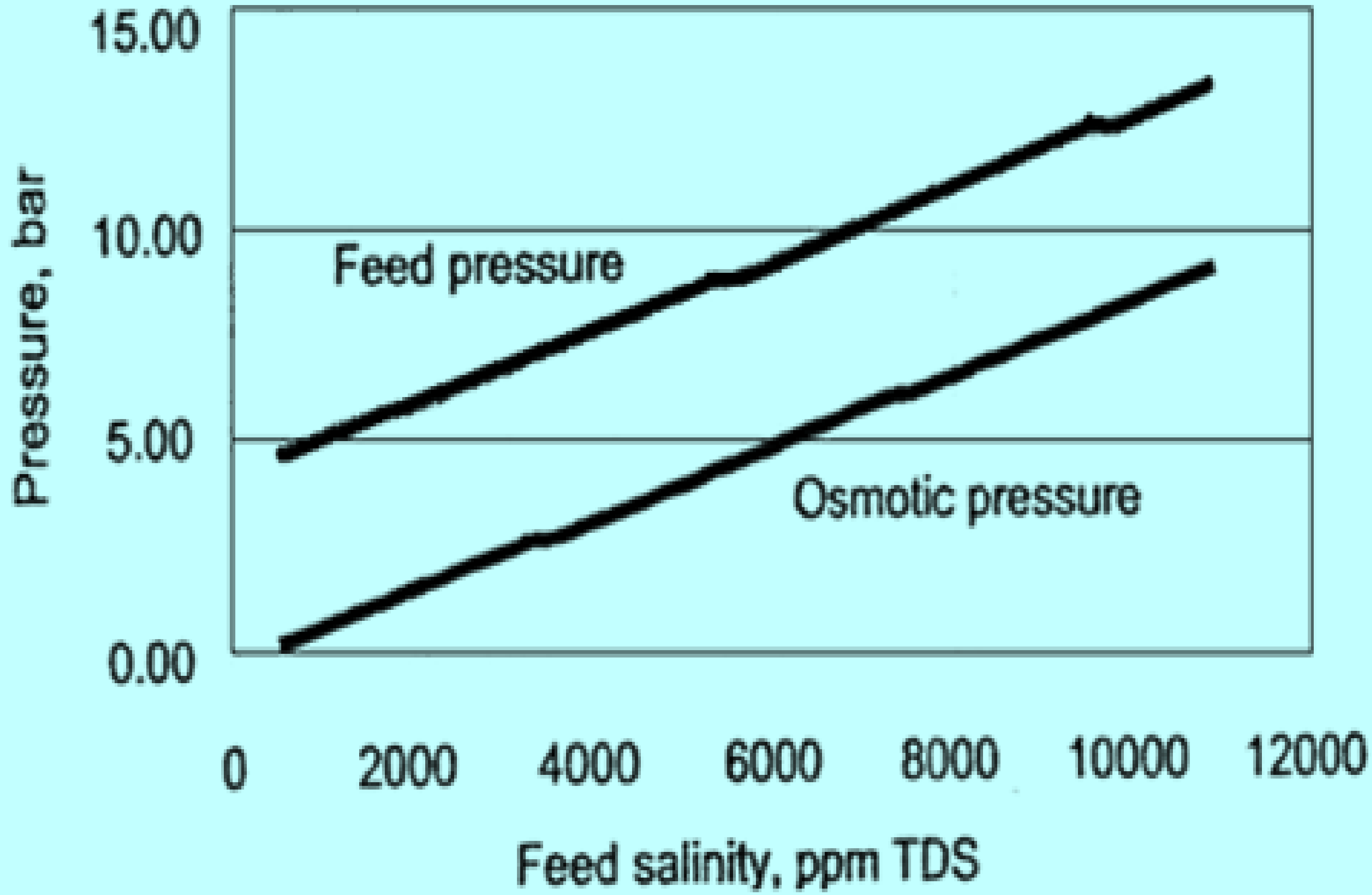


FIG. Effect of feed water temperature on permeate salinity in a brackish RO unit. Permeate average flux $28 l/m^2/h$.

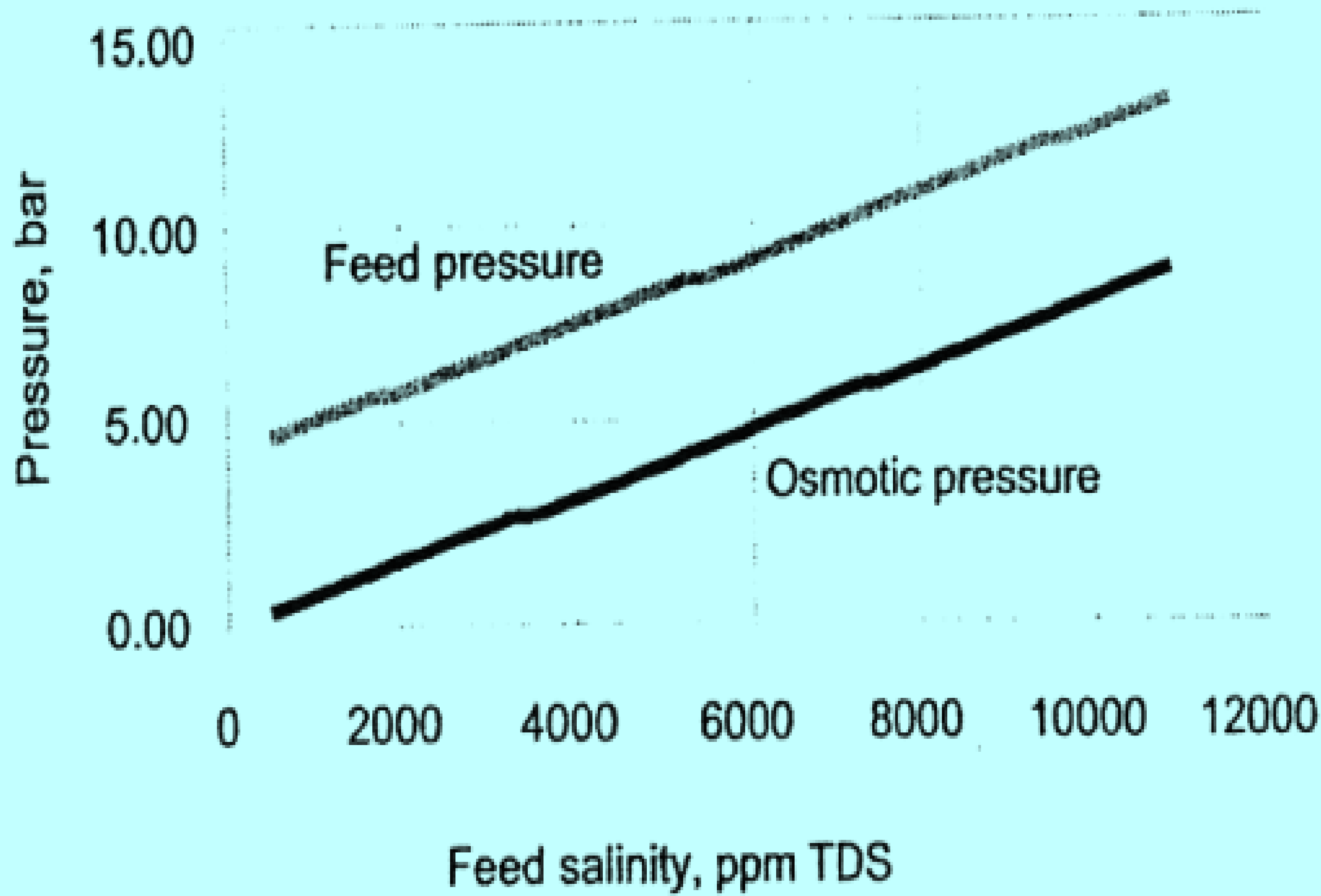


FIG. Effect of feed water temperature on permeate salinity in a brackish RO unit. Permeate average flux $28 l/m^2/h$.

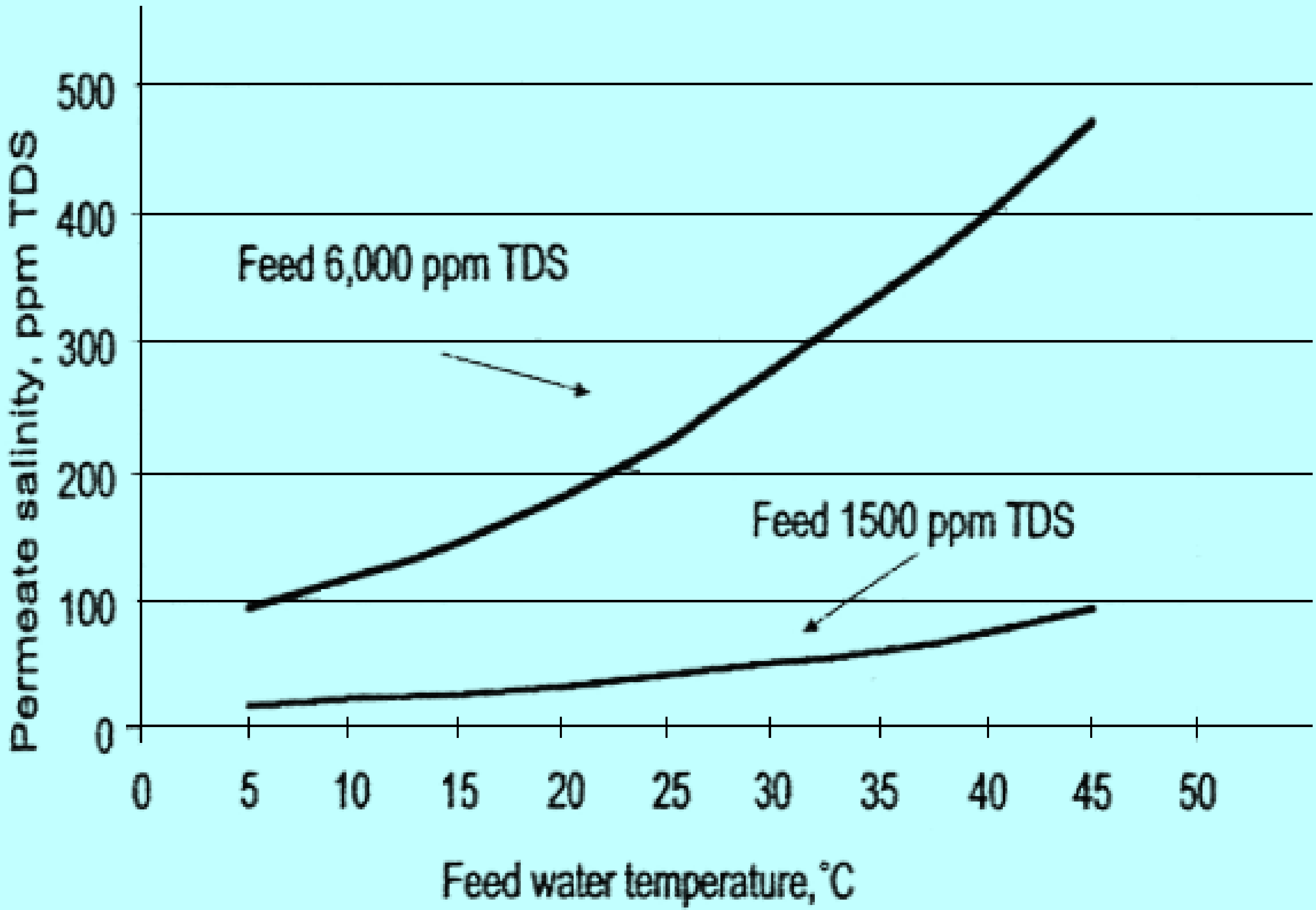


FIG. Effect of feed water temperature on permeate salinity in a brackish RO unit. Average permeate flux 28 $l/m^2/h$.

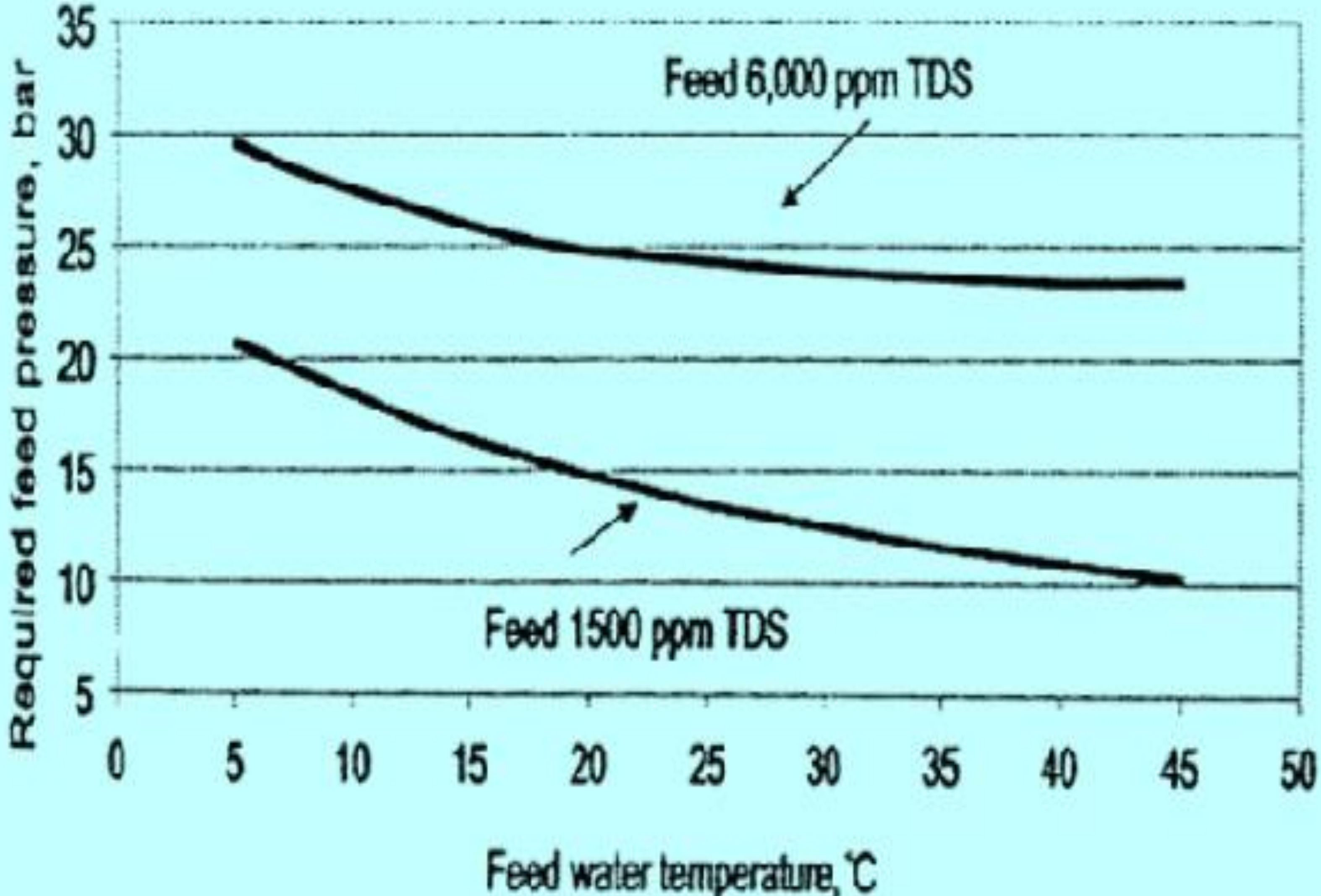


FIG. Effect of feed water temperature on required feed pressure in a brackish RO unit. Average permeate flux 28 $l/m^2/h$.

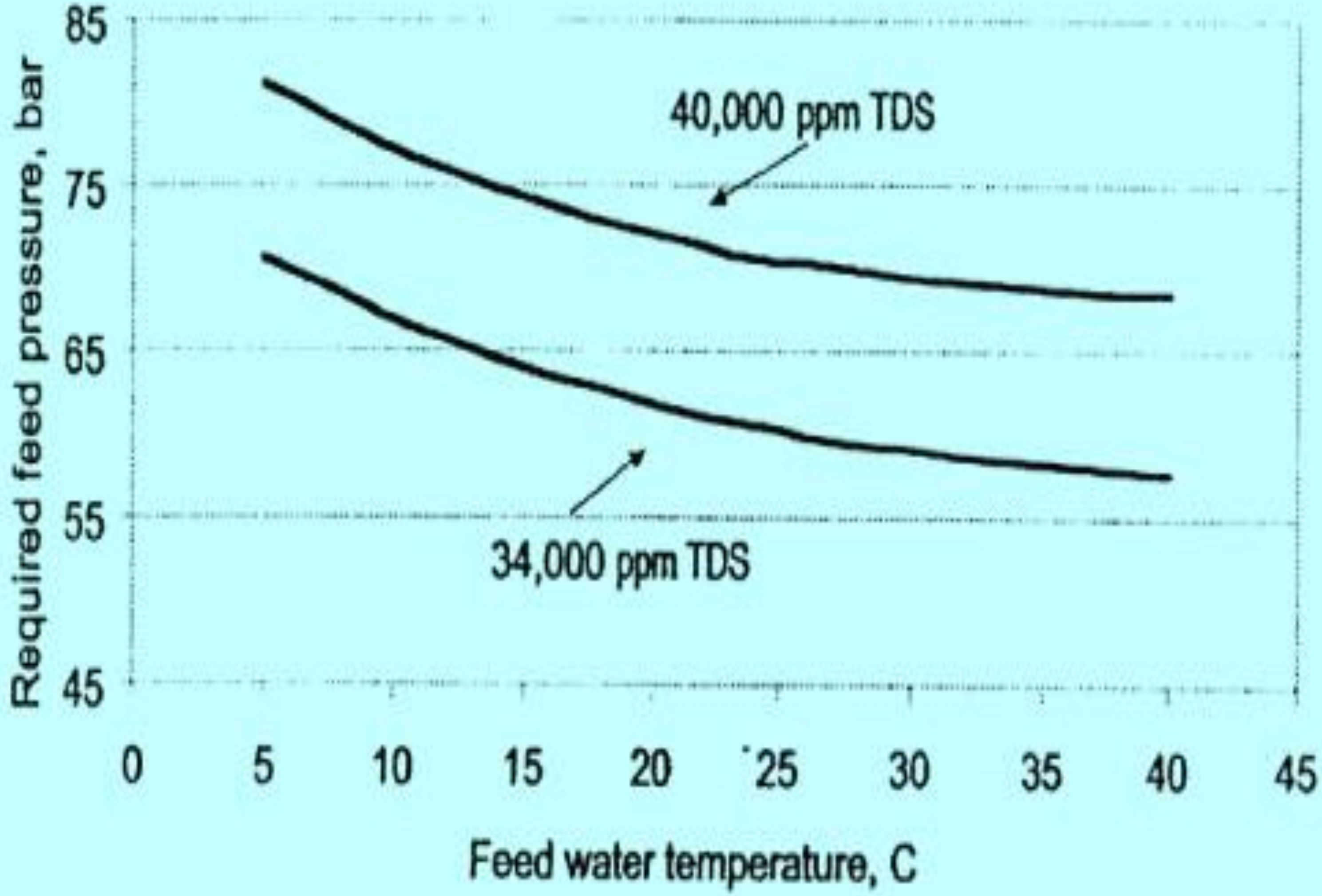


FIG. Effect of feed water temperature on required feed pressure in a seawater RO unit. Recovery rate 50%, average permeate flux 14 $l/m^2/h$.

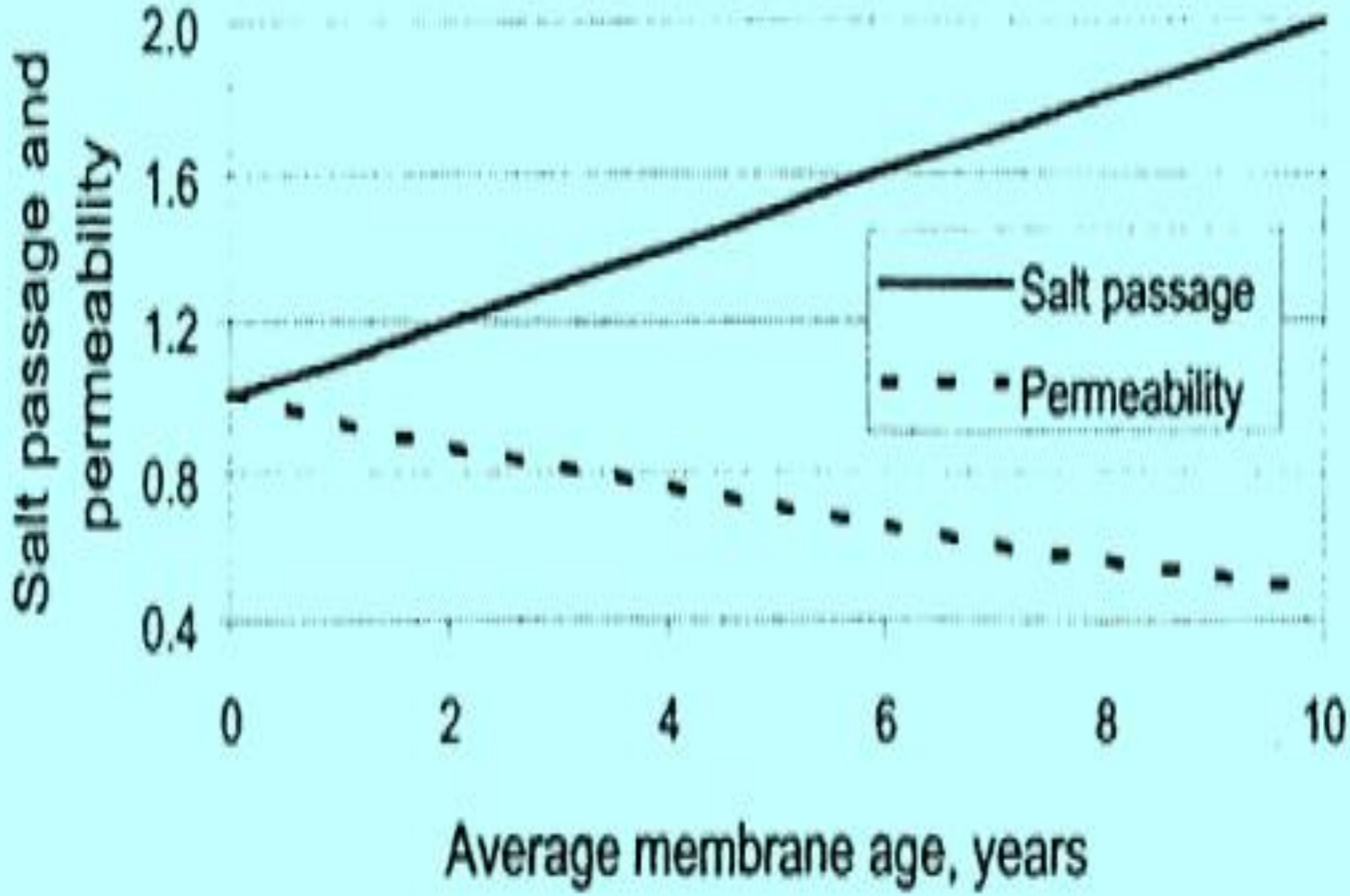


FIG. Projected changes of membrane performance (salt passage and water permeability) with operating time.

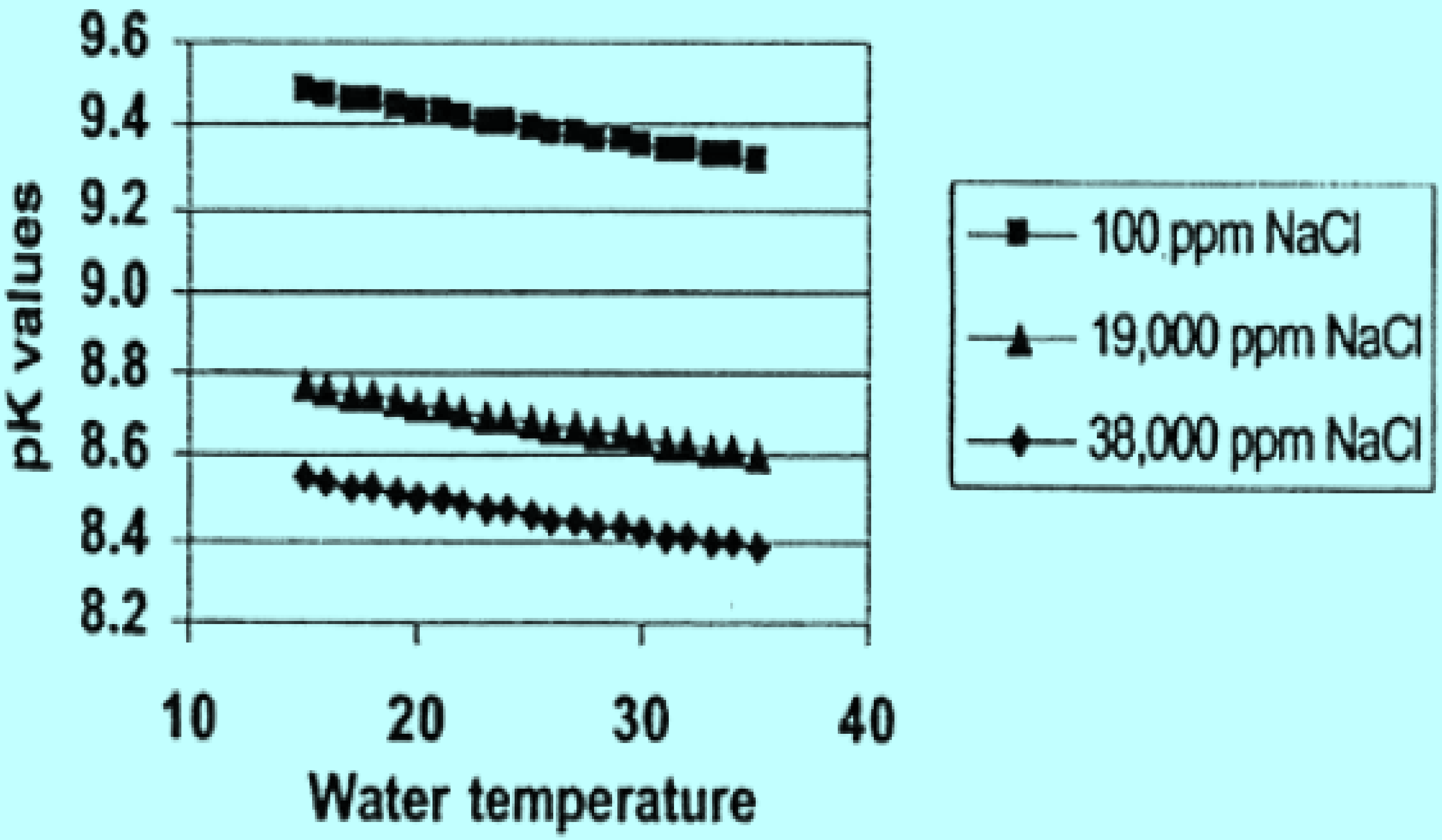


FIG. Dissociation constant(pK) of boric acid as function of temperature and salinity

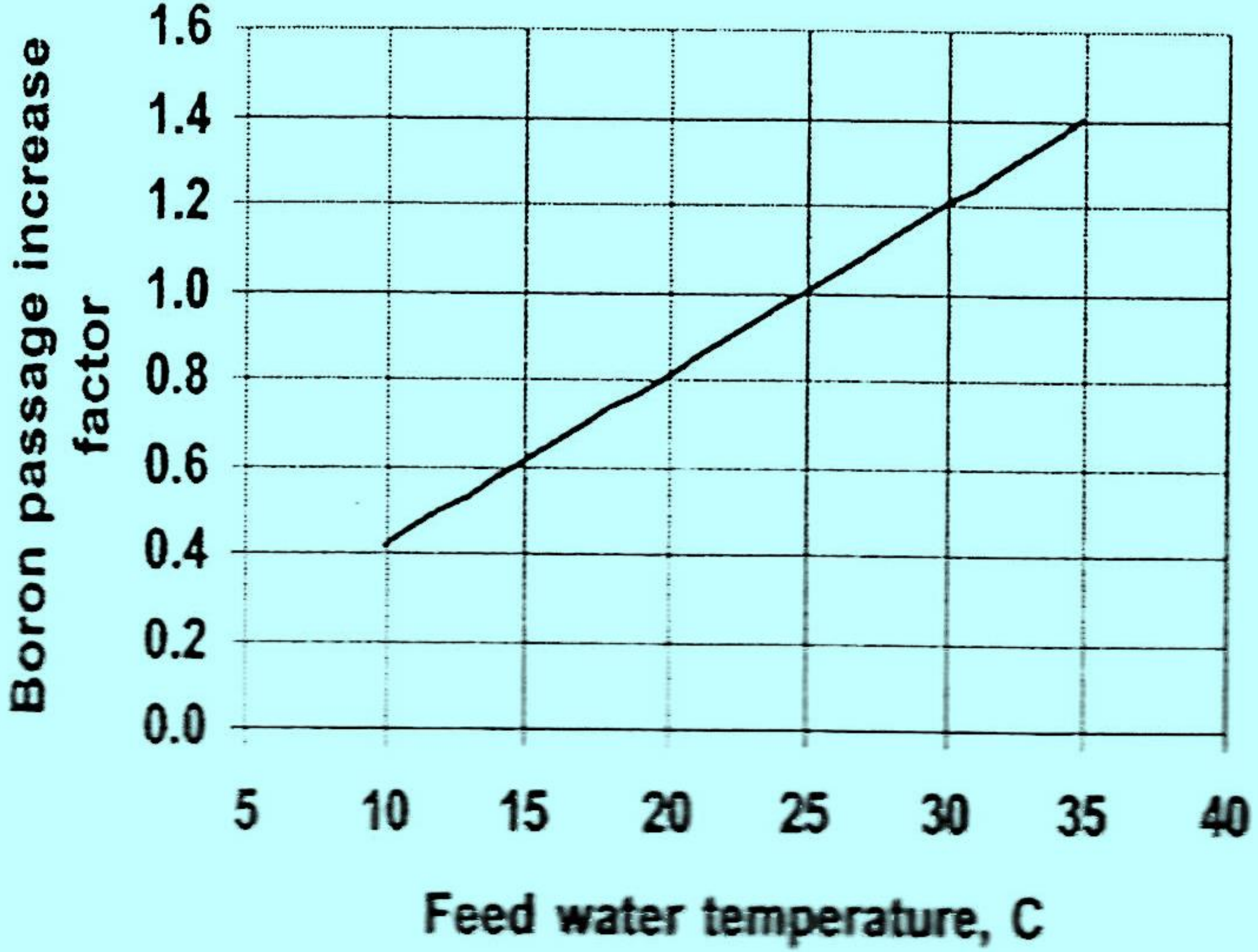


FIG. 11.26 Effect of temperature on boron passage through RO membranes.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ฝ่ายวิศวกรรม
Thailand Institute of Scientific and Technological Research
PRE FILTER INLET PRESSURE
PRE FILTER OUTLET PRESSURE
MEMBRANE OUTLET PRESSURE
MEMBRANE INLET PRESSURE
OPERATION
FEED SELECTION
PUMP SPEED CONTROLER
TISTR
เครื่องกรองน้ำทะเล

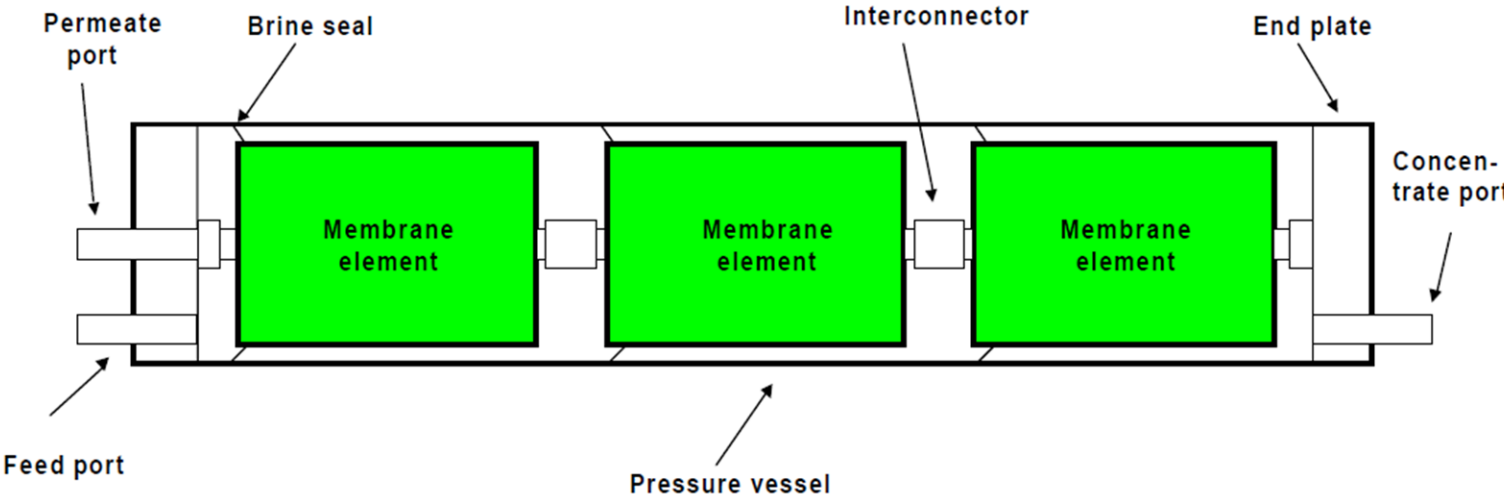

(SEAWATER REVERSE OSMOSIS)
LINE IN
FEED PUMP
FEED PRESSURE
HIGH PRESSURE PUMP
PRE FILTER INLET PRESSURE
PRE FILTER OUTLET PRESSURE
MEMBRANE OUTLET PRESSURE
MEMBRANE INLET PRESSURE
ON
OFF
OPERATION
FEED SELECTION
PUMP SPEED CONTROLLER
TISTR

Reverse Osmosis

Membrane/System Configurations

Presented by

Sawaeng Gerdpratoom
Numsai Thai Co;Ltd



Pressure vessel with three membrane elements

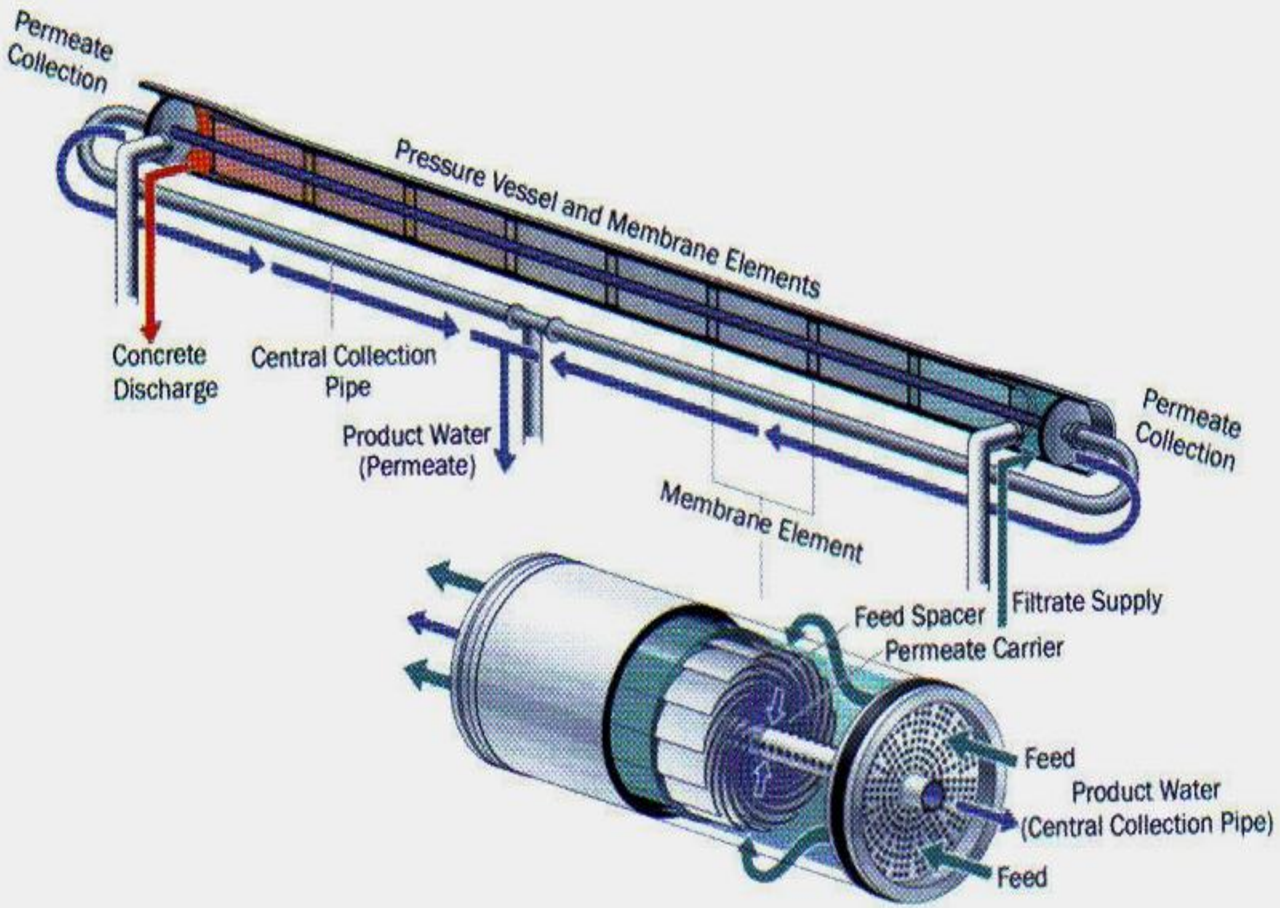
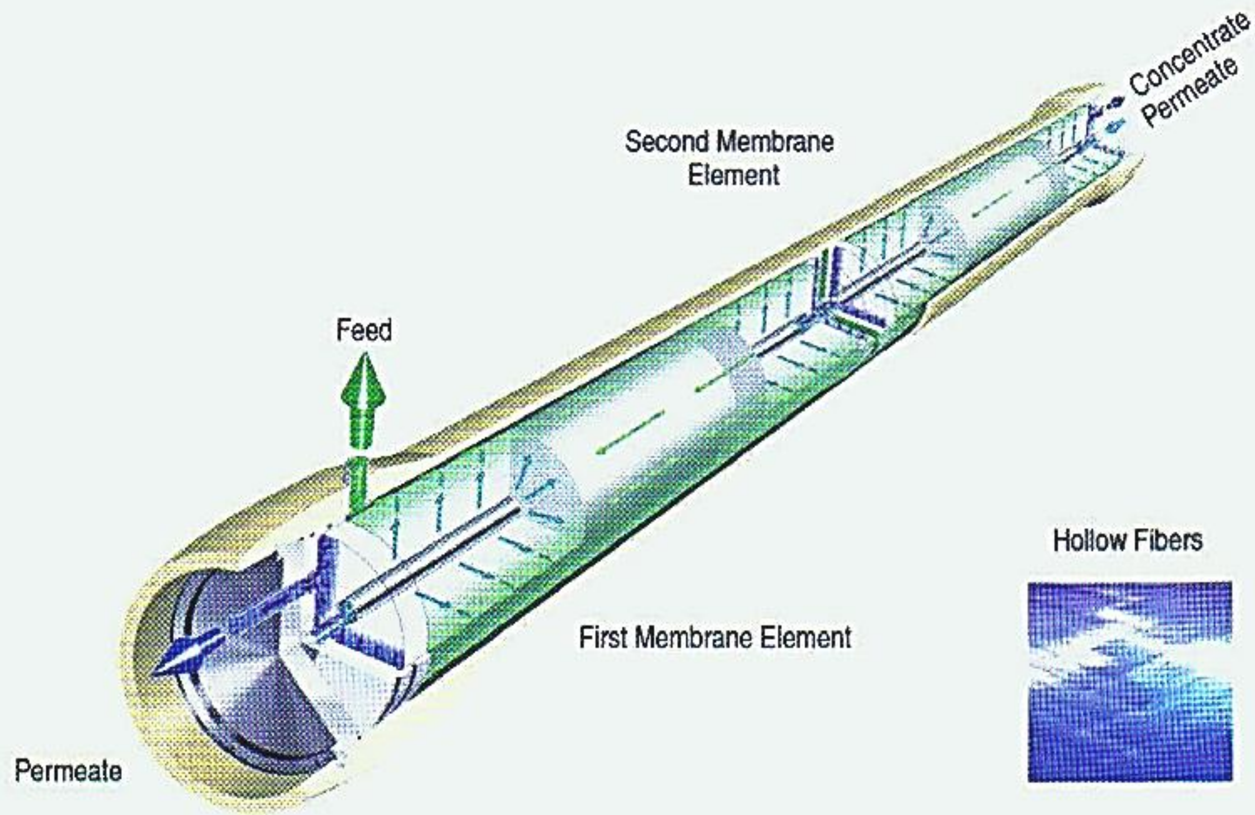
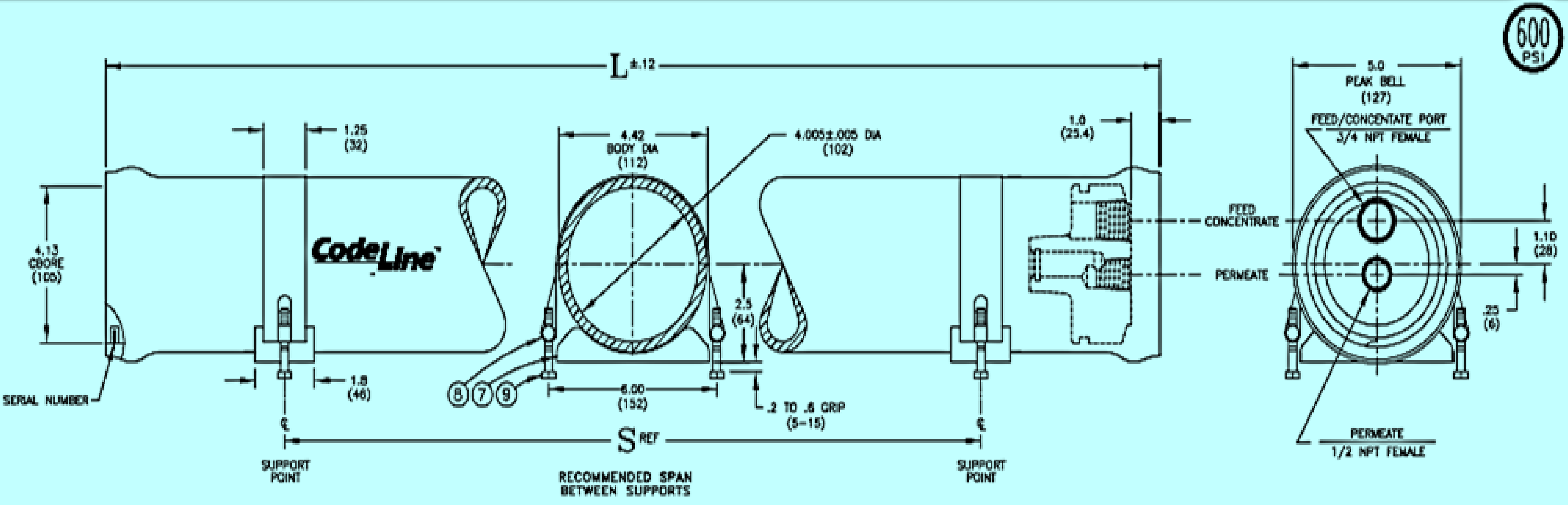


Figure 1-10 Membrane pressure vessel with eight elements



Courtesy of Toyobo, Co., LTD.

Figure 1-11 Hollow fiber membrane module



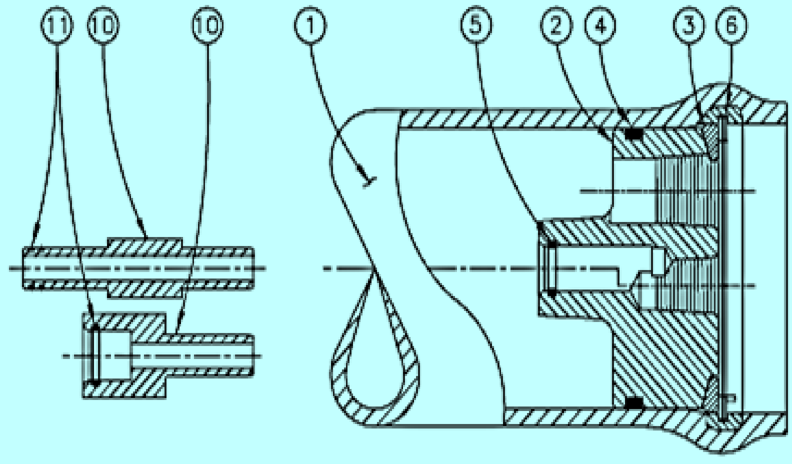
CENTER VESSEL ON 2 OR 3 SUPPORTS AT SPAN(S) "S" : 3 SUPPORTS REQUIRED FOR LENGTHS -4 AND OVER

Shell Length Code	L L.O.A. IN (MM)	S Span IN (MM)	APPROX. ASSEMBLY Weight LB (KG)
1	49.9 (1268)	28 X 1 (711)	13.8 (6.3)
2	89.9 (2283)	56 X 1 (1422)	22.2 (10.1)
3	129.9 (3299)	80 X 1 (2032)	30.7 (13.9)
4	169.9 (4315)	64 X 2 (1626)	39.2 (17.8)
5	209.9 (5331)	78 X 2 (1981)	47.6 (21.6)
6	249.9 (6347)	92 X 2 (2337)	56.1 (25.4)

* PART LISTED ARE STANDARD OPTIONS

Dwg. Ref.	Qty. Per	* Item Number	Description	Materials/Remarks
SHELL				
1	1		Shell	Filament wound epoxy/glass composite. Head locking grooves integrally wound in place. Shell exterior coated with white high gloss polyurethane paint.
HEAD				
2	2	50420	End Plug	Engineering Thermoplastic
3	2	50440	Bearing Ring	Nickel-plated Alloy Steel
4	2	45317	Plug Seal	Ethylene Propylene - O-Ring
5	2	45294	Adapter Seal	Ethylene propylene O-Ring
HEAD INTERLOCK				
6	2	45260	Retaining Ring	316 SST
VESSEL SUPPORT				
7	*2	45058	Saddle	Engineering Thermoplastic
8	*2	47459	Strap Assembly	304 SST - PVC Cushion
9	4	47458	Strap Screw	5/16-18 UNC, 18-8 SST
ELEMENT INTERFACE				
10	2	As Required	Adapter	Engineering Thermoplastic
11	A/R	As Required	PWT Seal	Ethylene propylene O-Ring

*3 each furnished with length code 4, 5 & 6



SECTION THROUGH END CLOSURE

NOTES
- DIMENSIONS IN INCHES (MM APPROX)
- NOT TO BE USED FOR CONSTRUCTION UNLESS CERTIFIED
- PATENT APPLIED FOR

CodeLine
Pentair Water

DRW. AXA	MODEL 40E60			
APPR. RM	BRACKISH PRESSURE MEMBRANE HOUSING			
DATE 11JUL05	ECN 730	SHEET 1 OF 2	SIZE B	NUM 518017 D

Sunday, Janu

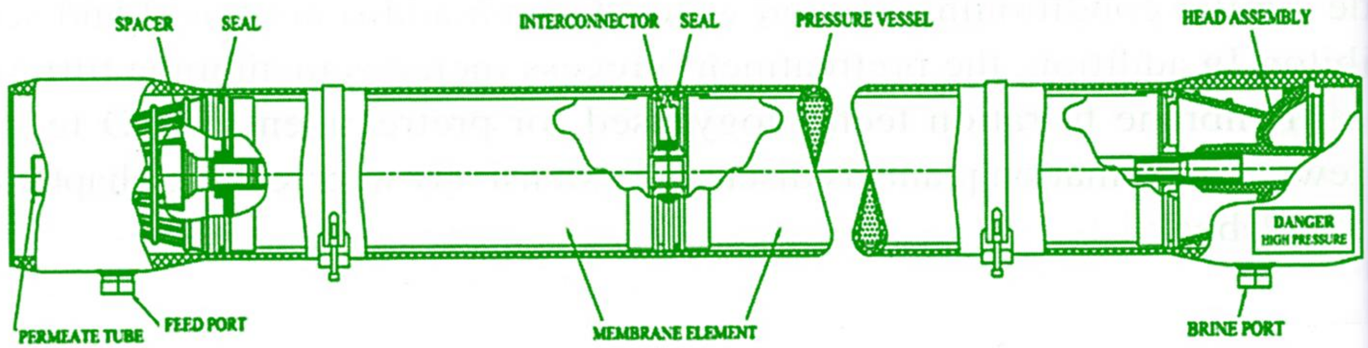


FIG. 13.1 Configuration of sideport pressure vessel with membrane elements (courtesy of Bell Industries).

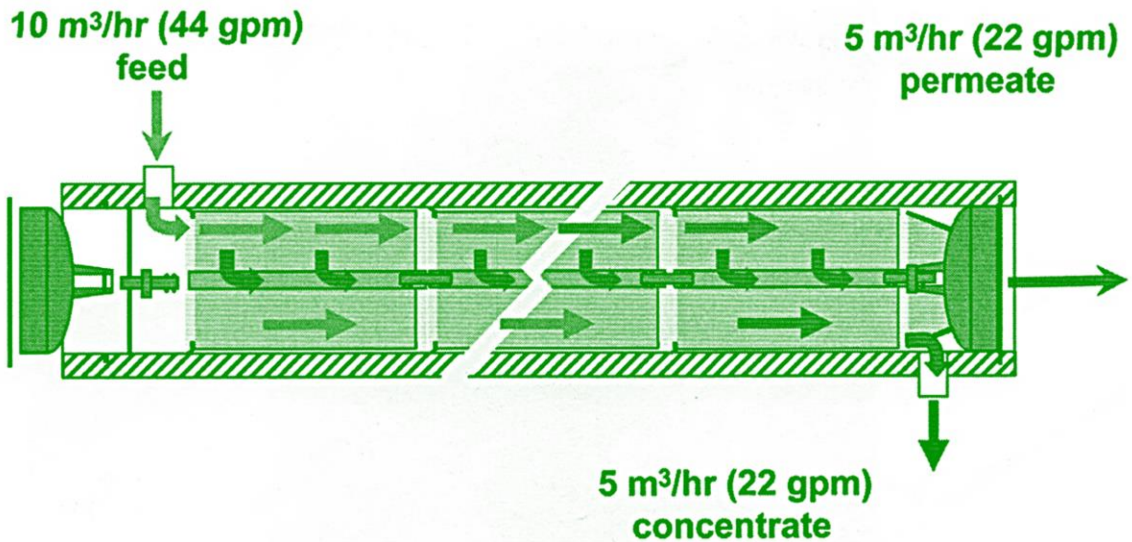
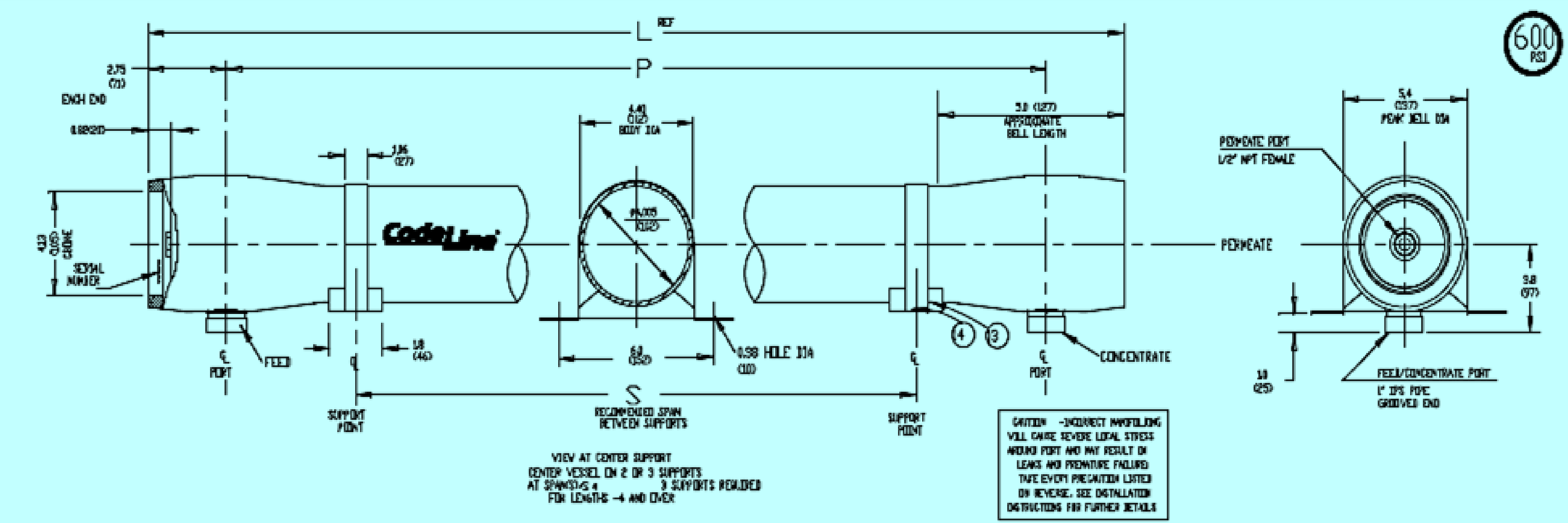
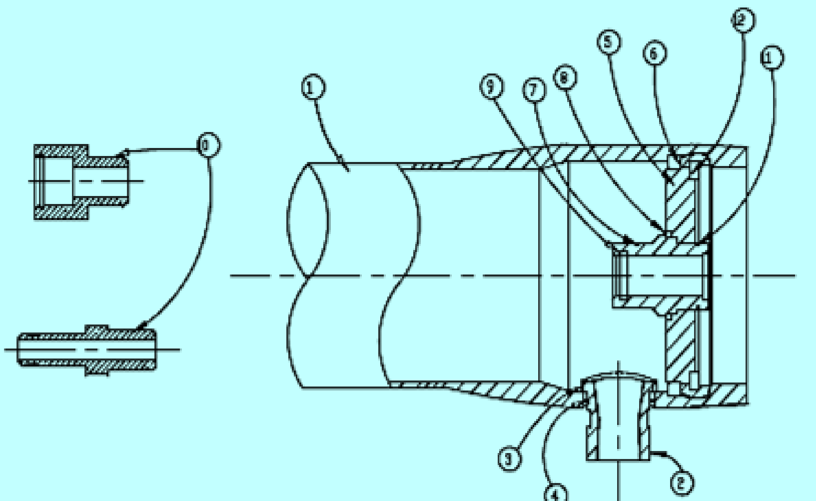


FIG. 12.15 Schematics of configuration and hydraulic operation of a pressure vessel (courtesy R. Chmielewski–SPI).



Dwg. Ref.	Qty. Per	Part Number	Description	Materials/Remarks
			SHELL	
1	1		Shell	Filament wound epoxy/glass composite- S.S Head locking grooves integrally wound in-place, with white high gloss polyurethane paint
2	2		F/C Port	CF3M ASME SA -351
3	2	47135	F/C Port Seal	Ethylene Propylene - square cut
4	2	43231	F/C Port Retainer	300 series SST
			HEAD	
5	2	45140	Bearing Plate	Fiber Reinforced Epoxy Laminate
6	2	43352	Plate Seal	Ethylene Propylene - Square Cut
7	2	50898	Permeate Port	Engineering Thermoplastic
8	2	45335	Permeate Port Seal	Ethylene Propylene - Square Cut
9	4	45296	PWT/Adapter Seal	Ethylene Propylene - O-ring
10	2	As required	Adapter	Engineering Thermoplastic
11	2	45242	Port Retainer	300 Series SST
			HEAD INTERLOCK	
12	2	45260	Retaining Ring	316L SST
			VESSEL SUPPORT	
S	*3	45058	Saddle	Cast Urethane Elastomer
T	*3	47459	Strap	304 Stainless Steel - PVC cushion
			*2 each furnished with length code 1, 2 & 3	
			FOR REFERENCE ONLY	



SECTION THROUGH END CLOSURE

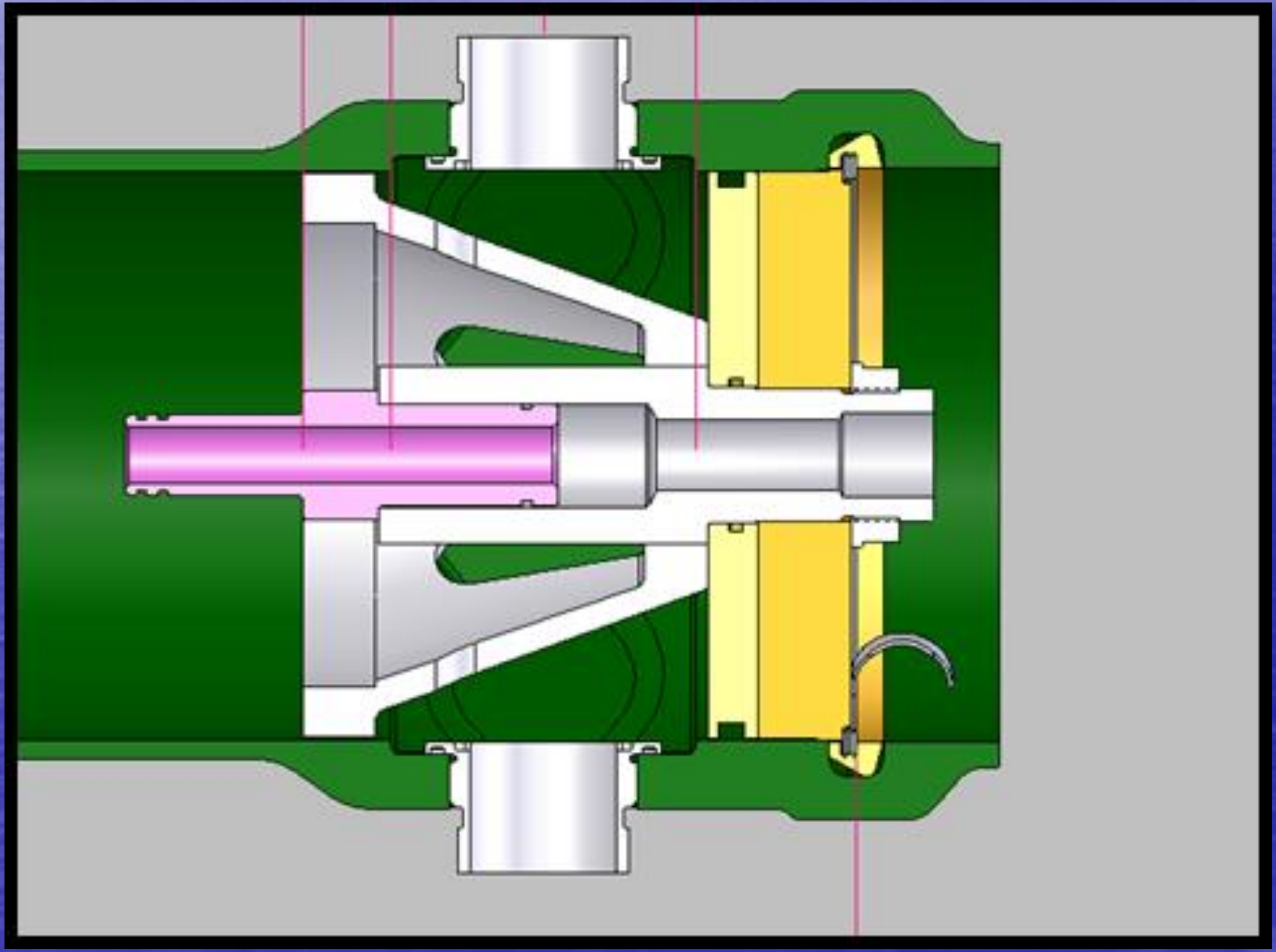
ENDS ARE IDENTICAL

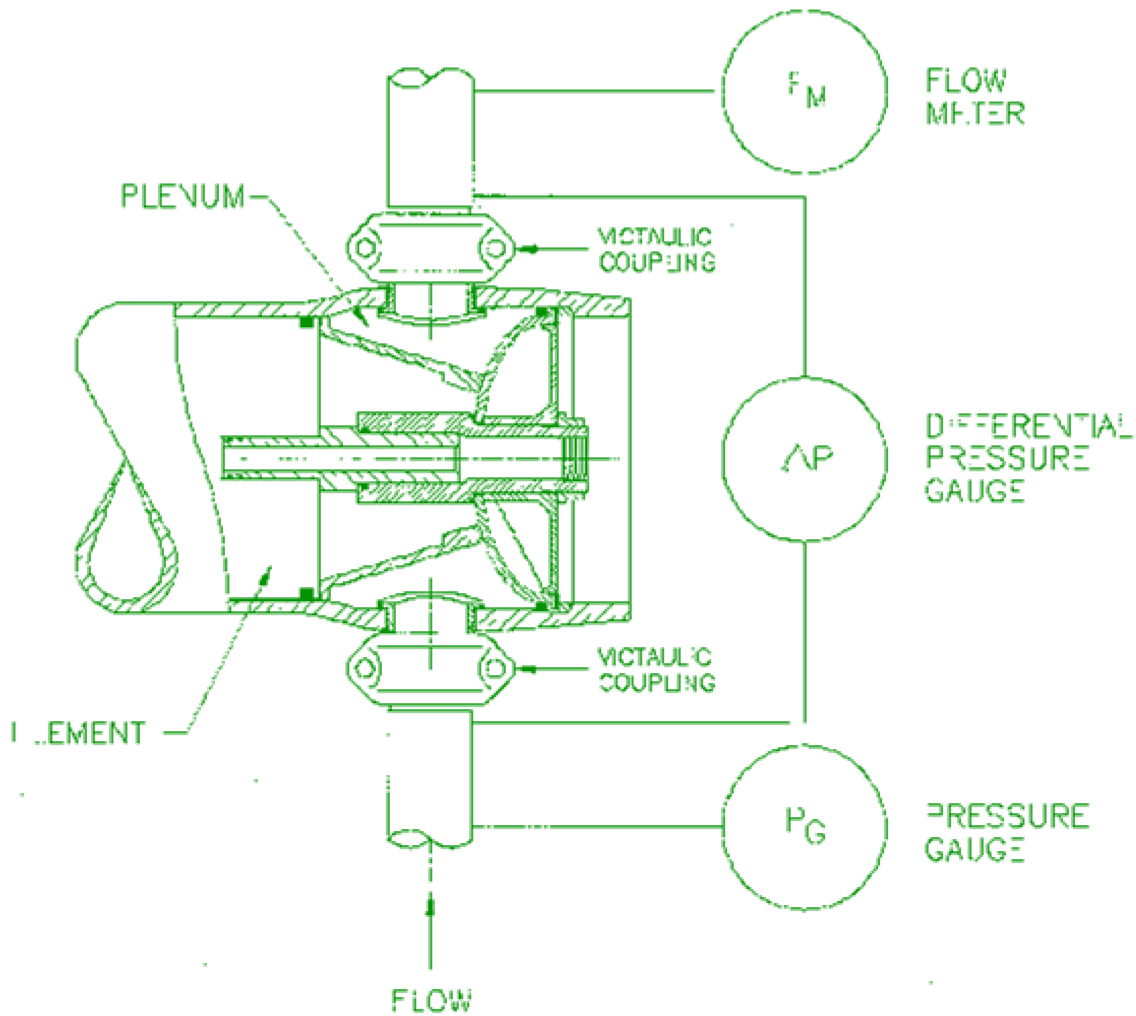
NOTES
- SHELL EXTERIOR COATED WITH WHITE, HIGH GLOSS POLYURETHANE PAINT
- DIMENSION IN INCHES (MM APPROX)
- NOT TO BE USED FOR CONSTRUCTION UNLESS CERTIFIED

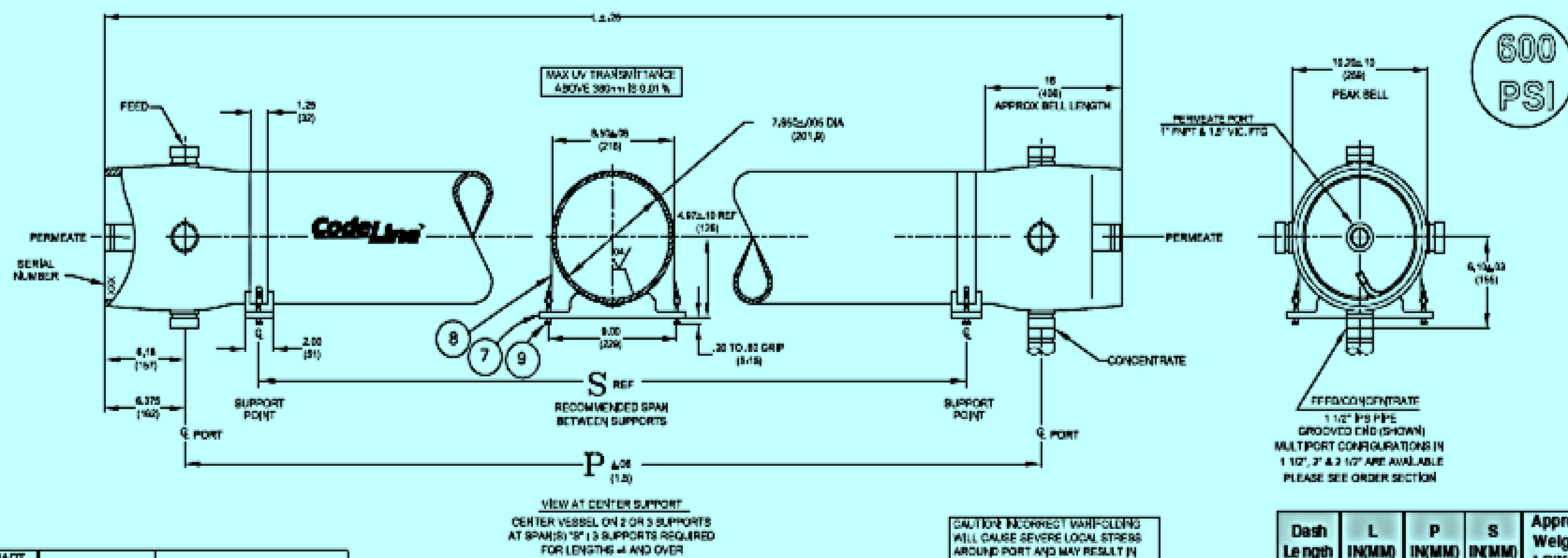
Shell Length Code	L LOA IN (MM)	P Span IN (MM)	S Span IN (MM)	Approx Weight LB (KG)
1	47.5 (1206)	42 (1067)	28 X 1 (711)	13.25 (6.0)
2	87.5 (2222)	82 (2083)	56 X 1 (1422)	13.25 (8.8)
3	127.5 (3238)	122 (3099)	80 X 1 (2032)	26.75 (12.2)
4	167.5 (4254)	162 (4115)	64 X 2 (1626)	34.25 (15.6)
5	207.5 (5270)	202 (5131)	78 X 2 (1981)	41.75 (19.0)
6	247.5 (6286)	242 (6147)	92 X 2 (2337)	49.25 (22.4)

CodeLine
Pentair Water

DRAWN ARAF	MODEL 40A60 MEMBRANE HOUSING				
CHECKED SM					
SCALE NONE	ECN 978	SHEET 1 OF 2	SIZE A3	NUMBER 99128	REV F



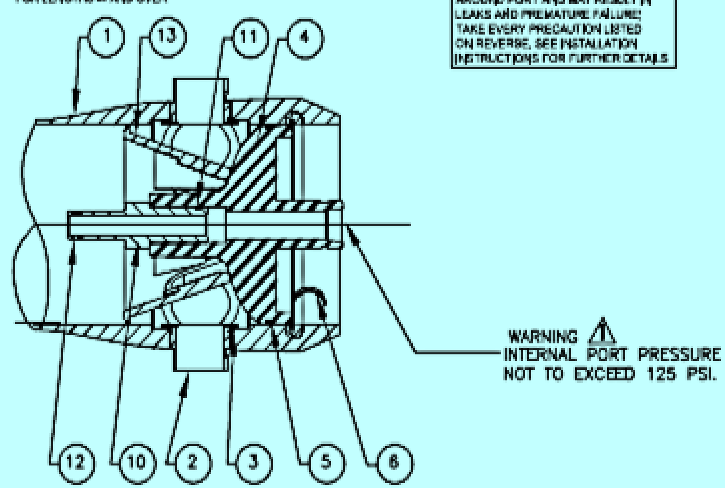

PLENUM
VICTAULIC COUPLING
FM
FLOW METER
ΔP
DIFFERENTIAL PRESSURE GAUGE
VICTAULIC COUPLING
ELEMENT
PG
PRESSURE GAUGE
FLOW



CAUTION: INCORRECT MANIFOLDING WILL CAUSE SEVERE LOCAL STRESS AROUND PORT AND MAY RESULT IN LEAKS AND PREMATURE FAILURE; TAKE EVERY PRECAUTION LISTED ON REVERSE. SEE INSTALLATION INSTRUCTIONS FOR FURTHER DETAILS

DWG REF	QTY	PART NUMBER	DESCRIPTION	MATERIAL
SHELL				
1	1	ORDER SECTION	SHELL	Filament Wound Epoxy/Glass composites - Head locking grooves integrally wound in place.
2	A/R		P/C Port	316 L Stainless Steel / Equivalent.
3	A/R		P/C Port Seal	Ethylene Propylene.
HEAD - NON CODED				
4	2	96244	Elliptical Head Assy.	Engineering Thermoplastic.
5	2	96000	Head Seal	Ethylene Propylene - O - Ring
HEAD INTERLOCK				
6	2	47336	Quik Release Spiral Ring	316 Stainless Steel.
VESSEL SUPPORT				
7	* 2	52169	Saddle	Engineering Thermoplastic.
8	* 2	45042	Strap Assy.	304 Stainless Steel-PVC Cushion.
9	4	45265	Strap screw.	5/16-18 UNC, 18-8 Stainless Steel.
ELEMENT INTERFACE				
10	2	A/R	Adapter	Engineering Thermoplastic.
11	2	52245	Adapter seal	Ethylene Propylene - O - Ring
12	4	A/R	PWT Seal	Ethylene Propylene - O - Ring
13	1	52609	Thrust Cone	Engineering Thermoplastic.

* 3 each furnished with length code 4,5,6,7 & 8.



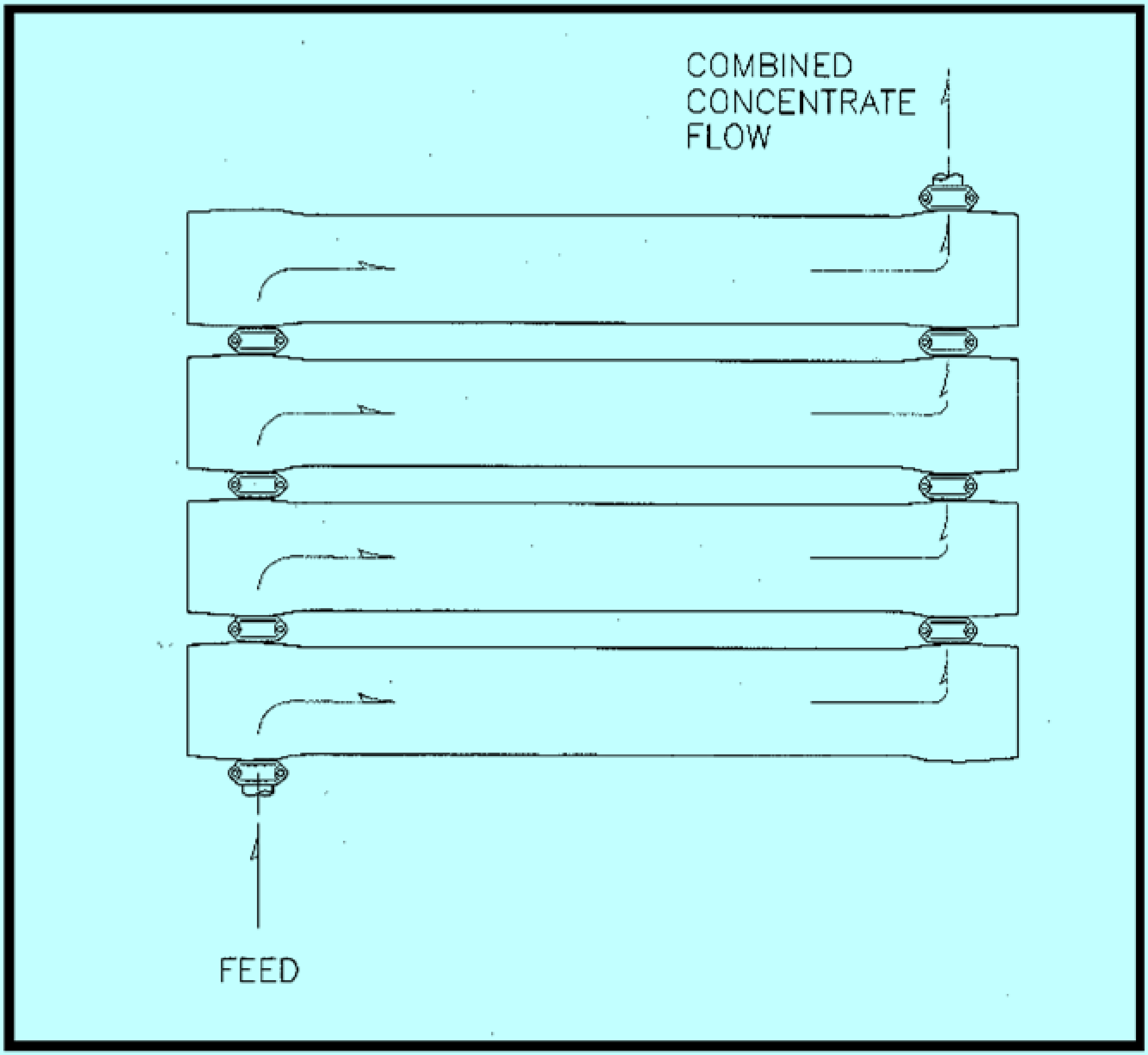
SECTION THROUGH END CLOSURE

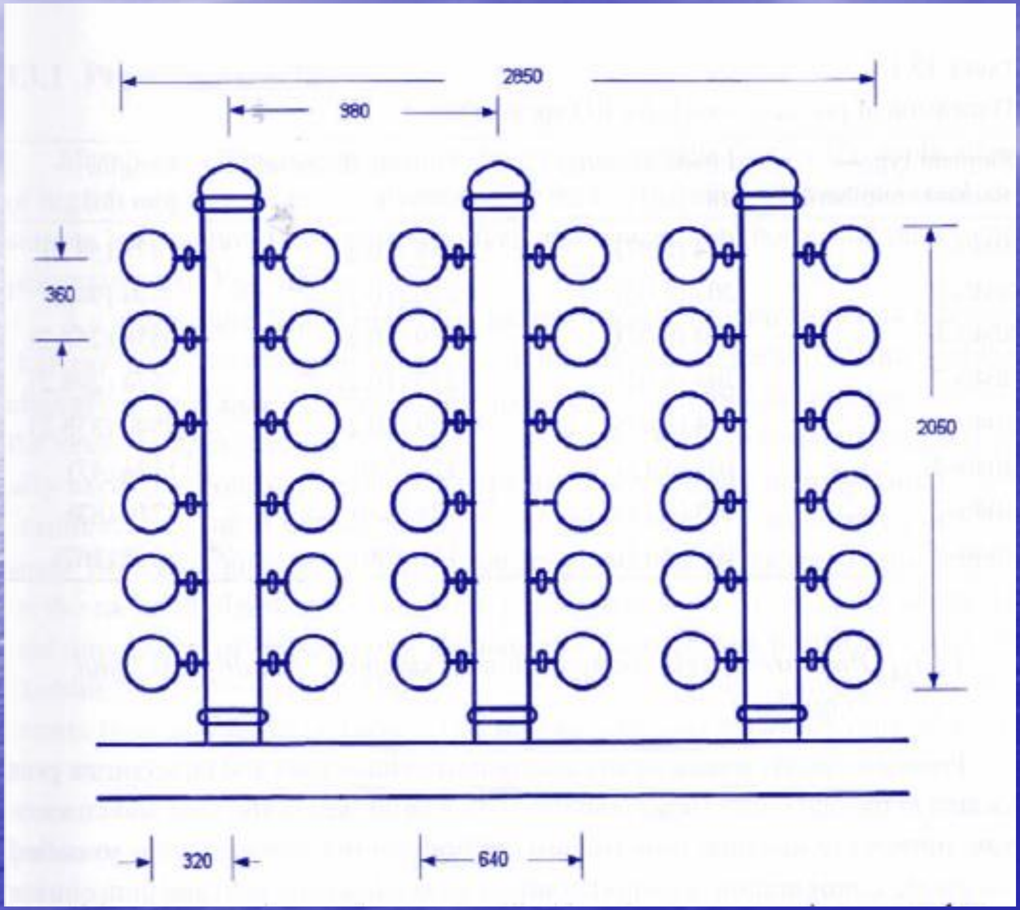
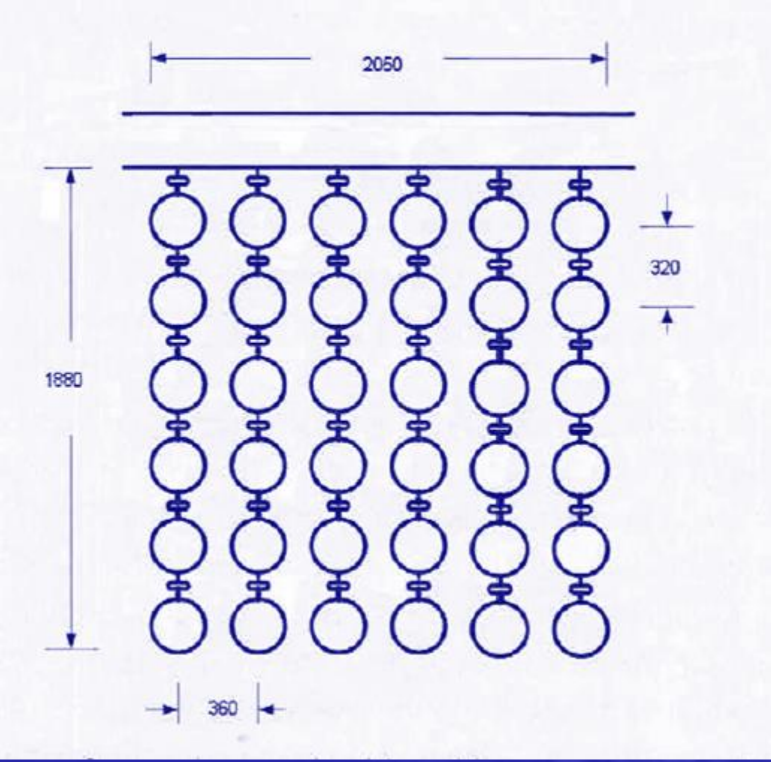
NOTES:
- MAX. ANGULAR VARIATION BETWEEN ANY PORTS ±0.5°.
- DIMENSION IN INCHES (MM APPROX.)
- SHELL EXTERIOR COATED WITH WHITE, HIGH GLOSS POLYURETHANE PAINT.
- NOT TO BE USED FOR CONSTRUCTION UNLESS CERTIFIED.
- ITEM 13 DOWNSTREAM ONLY.

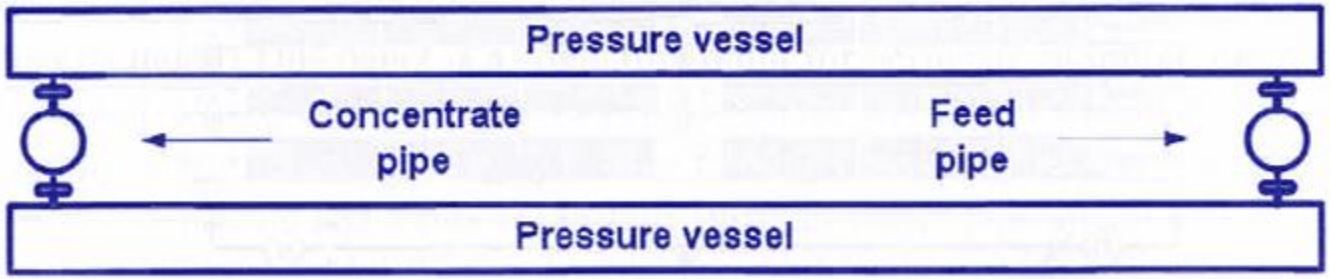
Dash Length	L IN(MM)	P IN(MM)	S IN(MM)	Approx Weight LB(KG)
-1	59.75 (1518)	47 (1194)	25X1 (711)	84 (38)
-2	99.75 (2534)	87 (2210)	56X1 (1422)	106 (48)
-3	139.75 (3550)	127 (3226)	80X1 (2032)	128 (58)
-4	179.75 (4566)	167 (4242)	64X2 (1626)	150 (68)
-5	219.75 (5582)	207 (5258)	78X2 (1981)	172 (78)
-6	259.75 (6598)	247 (6274)	92X2 (2337)	194 (88)
-7	299.75 (7614)	287 (7290)	106X2 (2692)	216 (98)
# -8	339.75 (8630)	327 (8306)	120X2 (3048)	238 (108)

CodeLine
Pentair Water

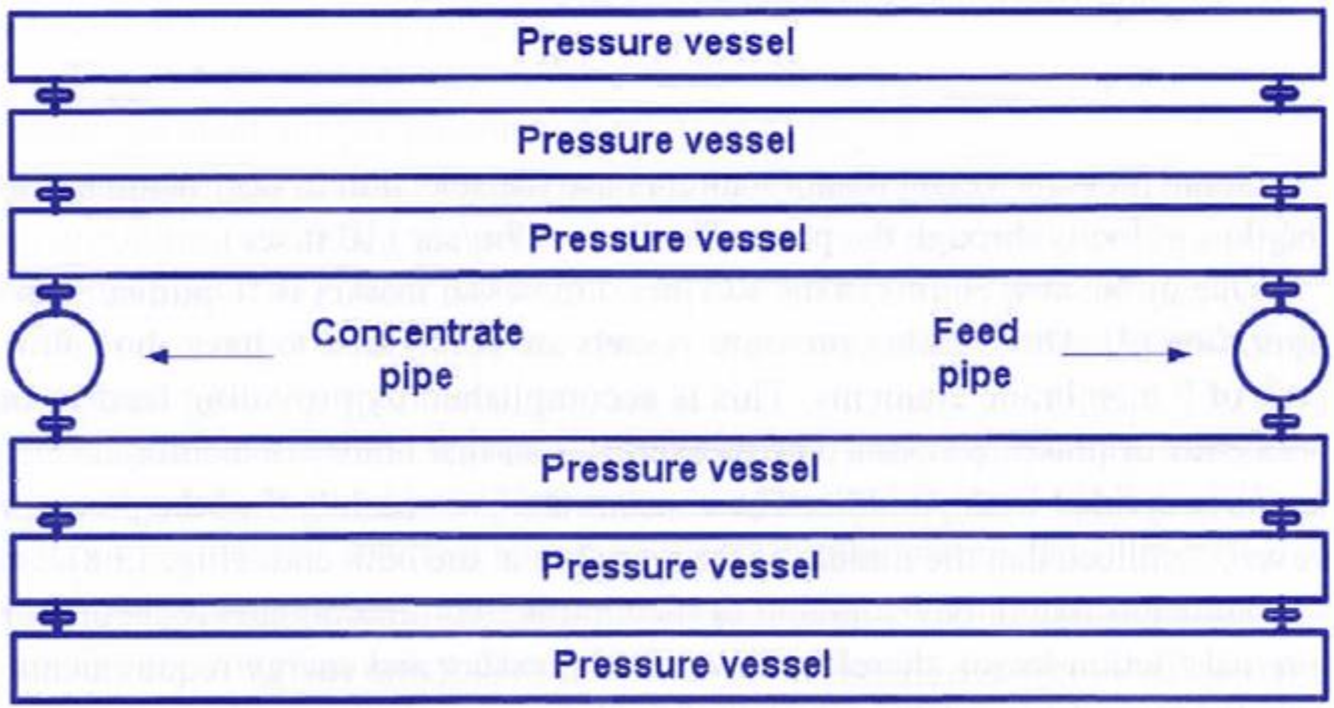
DRAWN	KR	CODELINE - 80S60 (NON-CODED) MEMBRANE HOUSING			
CHECKED	MD	DATE 05NOV07	DWG. NO. 99174		REV. C
APPROVED	SS	ECN 1104	SCALE NONE	SIZE A3	SHEET 1 OF 2


COMBINED
CONCENTRATE
FLOW
FEED

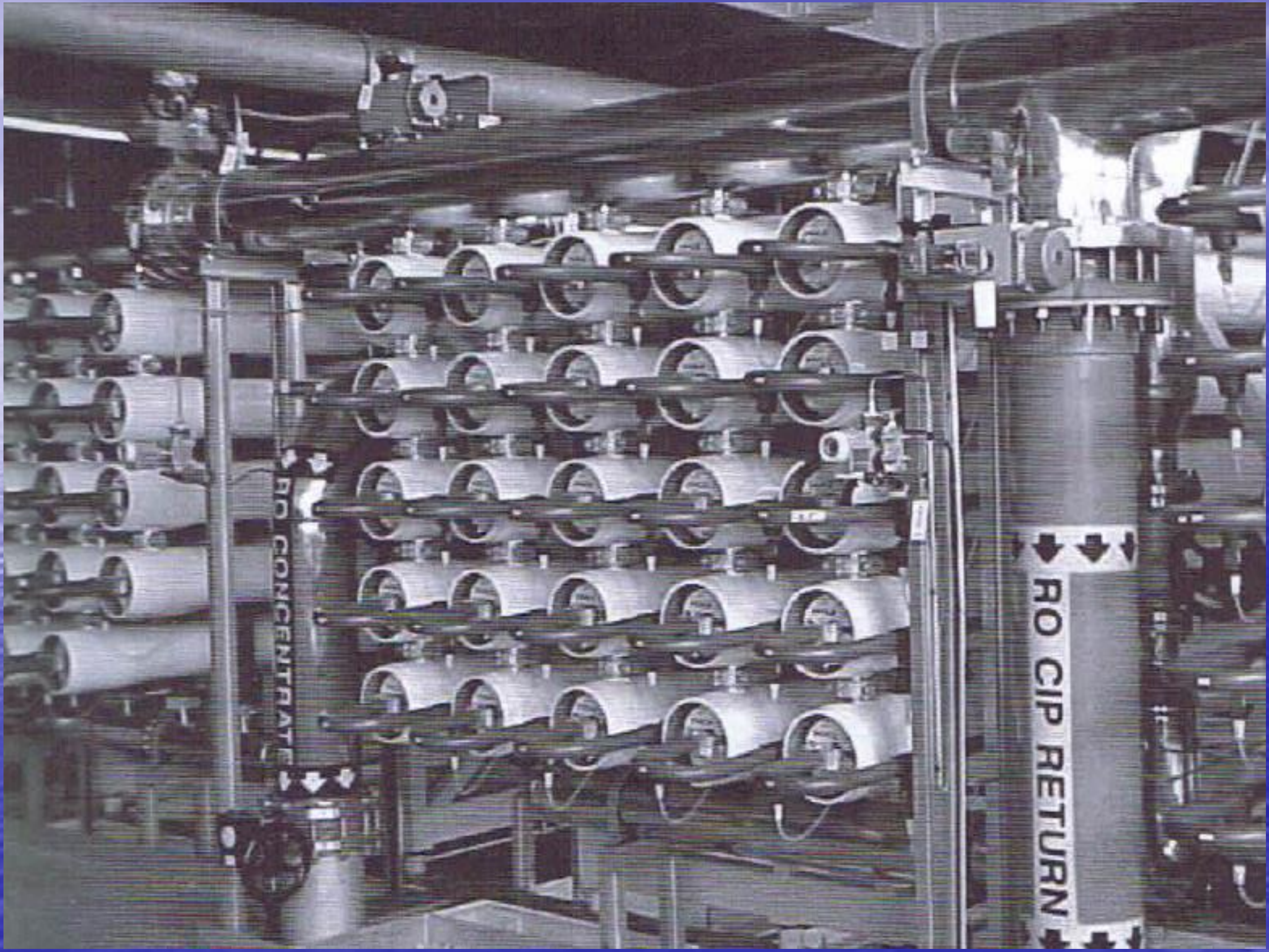

2850
980
360
2050
320
640

2050
320
1880
360



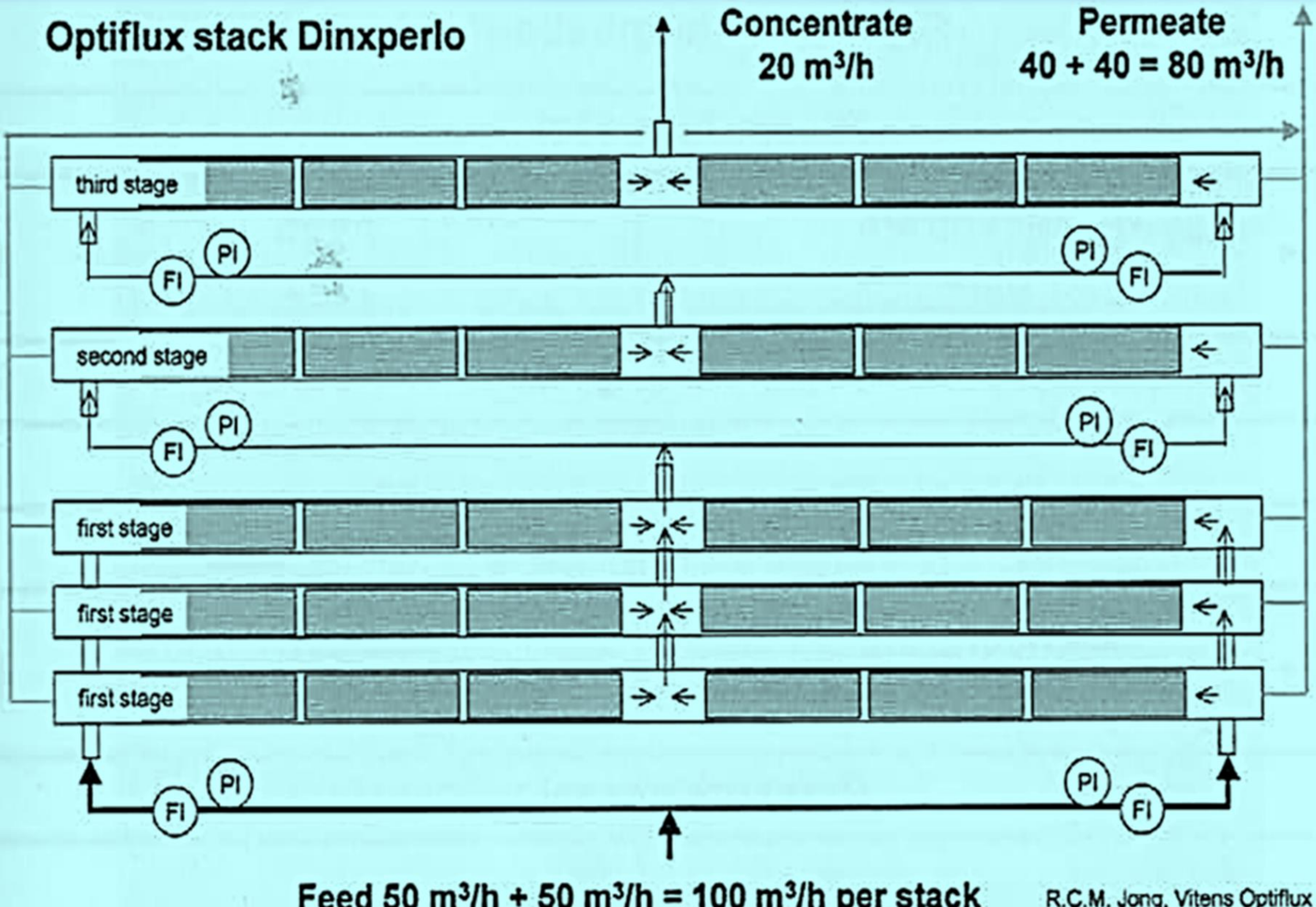
Multiport configuration




CodeLine


RO CONCENTRATE
RO CIP RETURN

Optiflux stack Dinxperlo

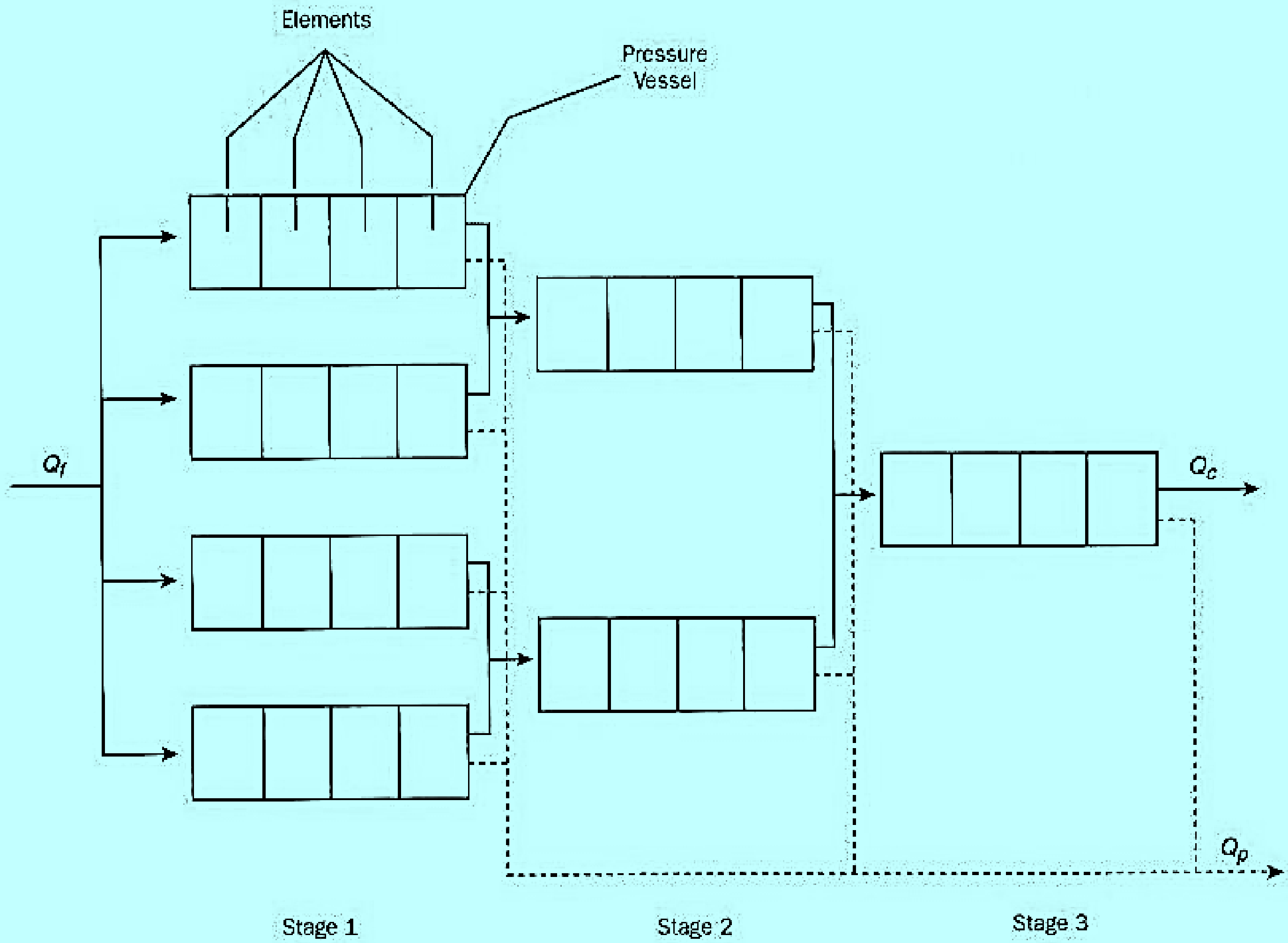


R.C.M. Jong, Vitens Optiflux

TABLE 16.5

Recommended flow velocity in manifold piping.

Material type	Flow velocity, m/sec (ft/sec)
Stainless steel	2.5–3.5 (8–12)
PVC, schedule 80	1.5–2.0 (5–7)
PVC, schedule 40	1.0–1.5 (3–5)
FRP (GRP)	1.5–2.0 (5–7)

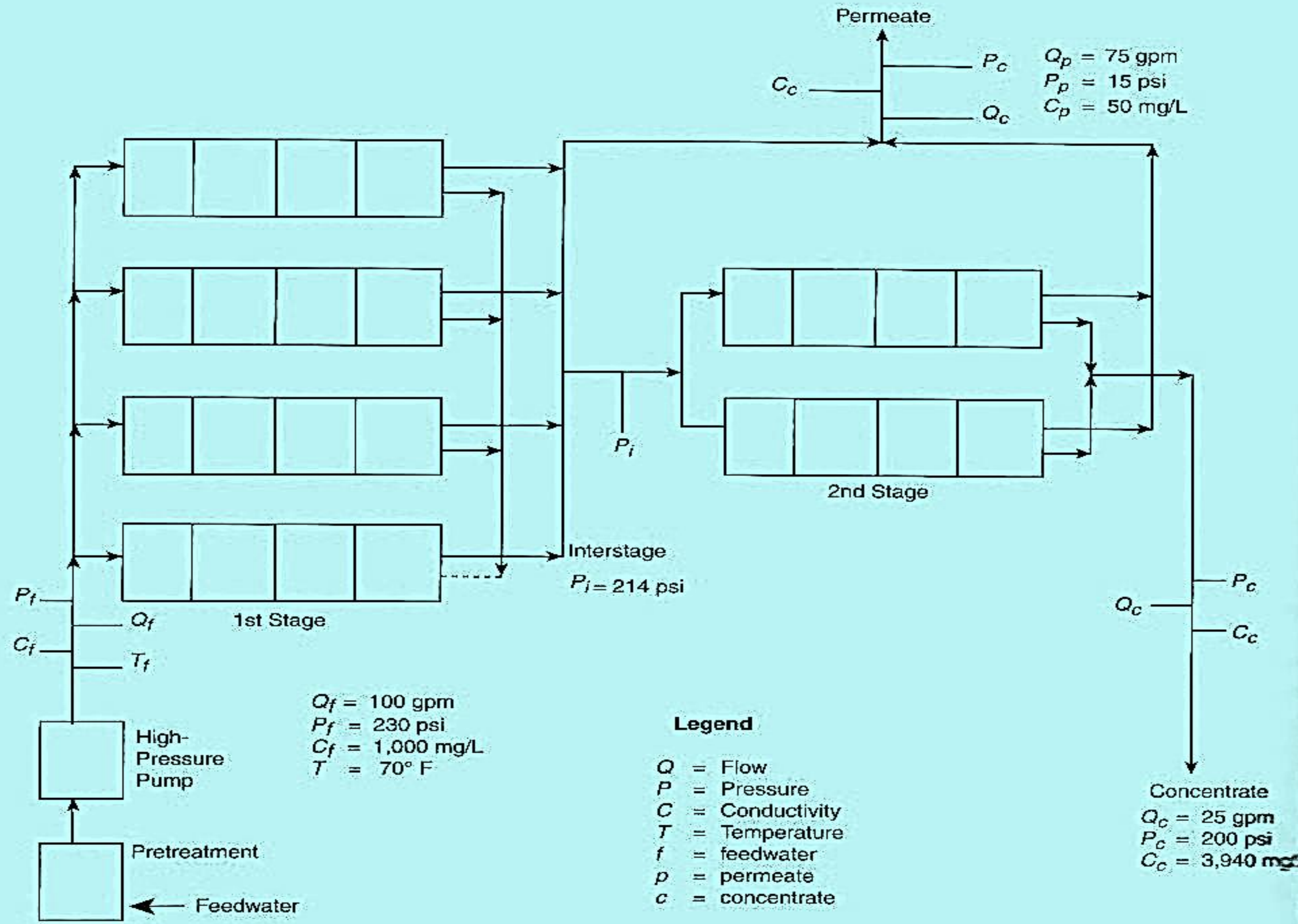


Where:

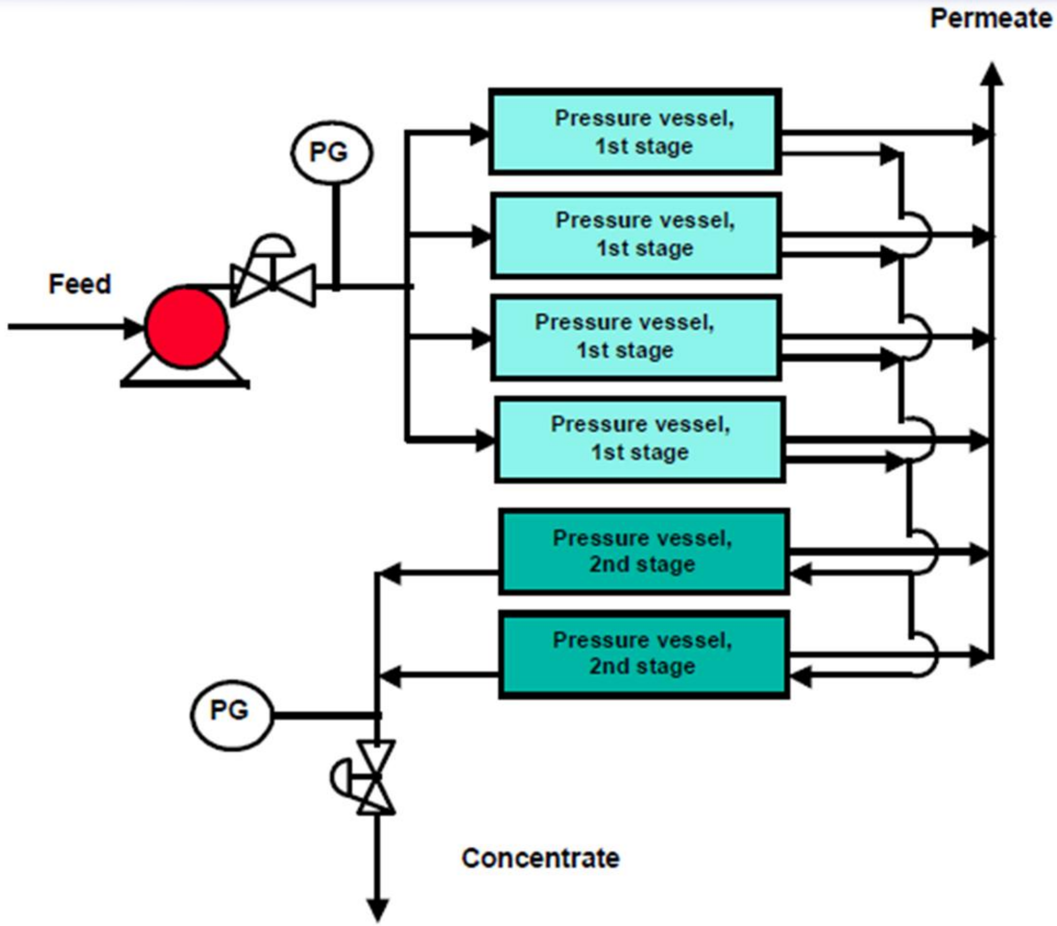
Q_f = Feedwater flow rate

Q_p = Permeate flow rate

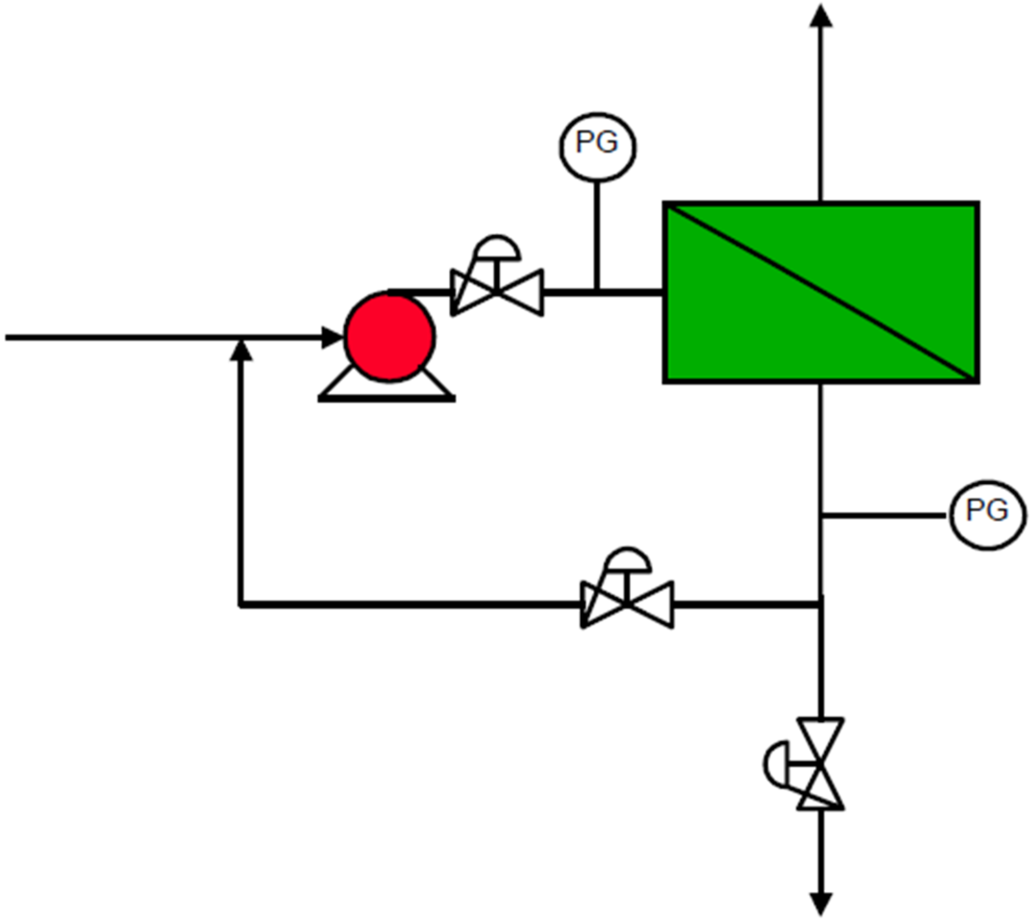
Q_c = Concentrate flow rate



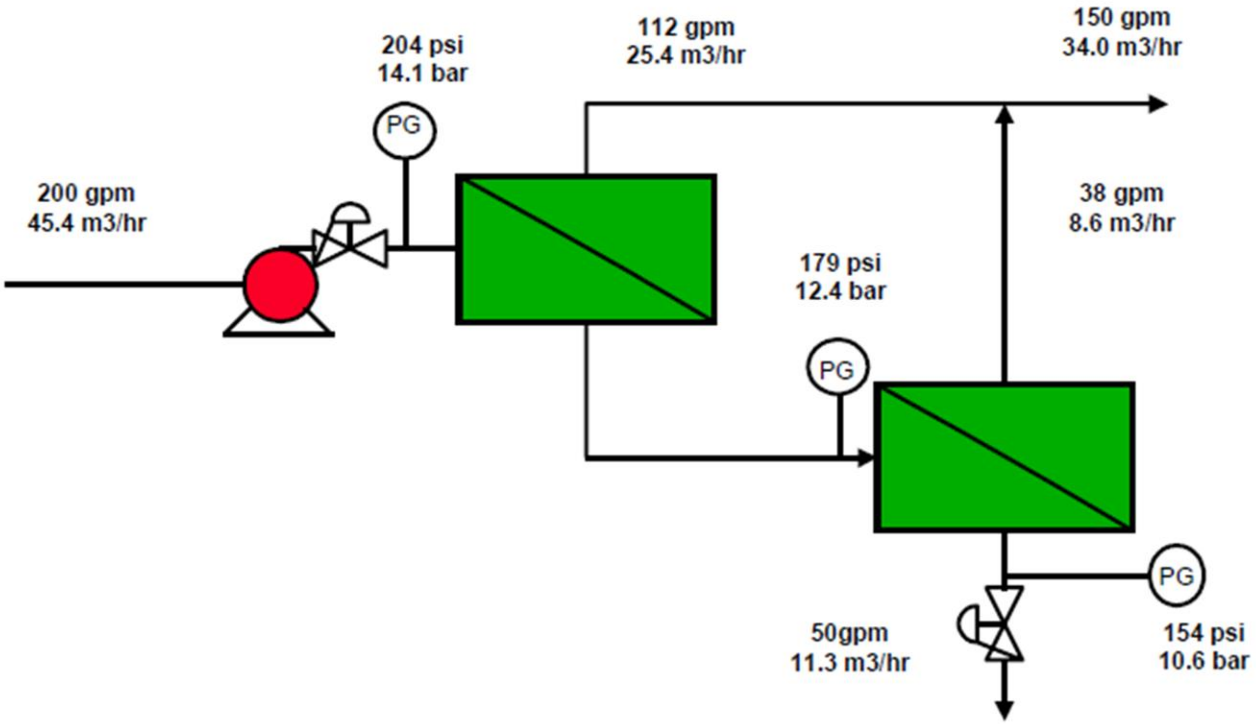
Permeate
P_c
C_c
Q_c
Q_p = 75 gpm
P_p = 15 psi
C_p = 50 mg/L
P_i
2nd Stage
Interstage
P_i = 214 psi
P_f
Q_f
C_f
T_f
1st Stage
P_c
Q_c
C_c
Q_f = 100 gpm
P_f = 230 psi
C_f = 1,000 mg/L
T = 70° F
High-Pressure Pump
Pretreatment
Feedwater
Legend
Q = Flow
P = Pressure
C = Conductivity
T = Temperature
f = feedwater
p = permeate
c = concentrate
Concentrate
Q_c = 25 gpm
P_c = 200 psi



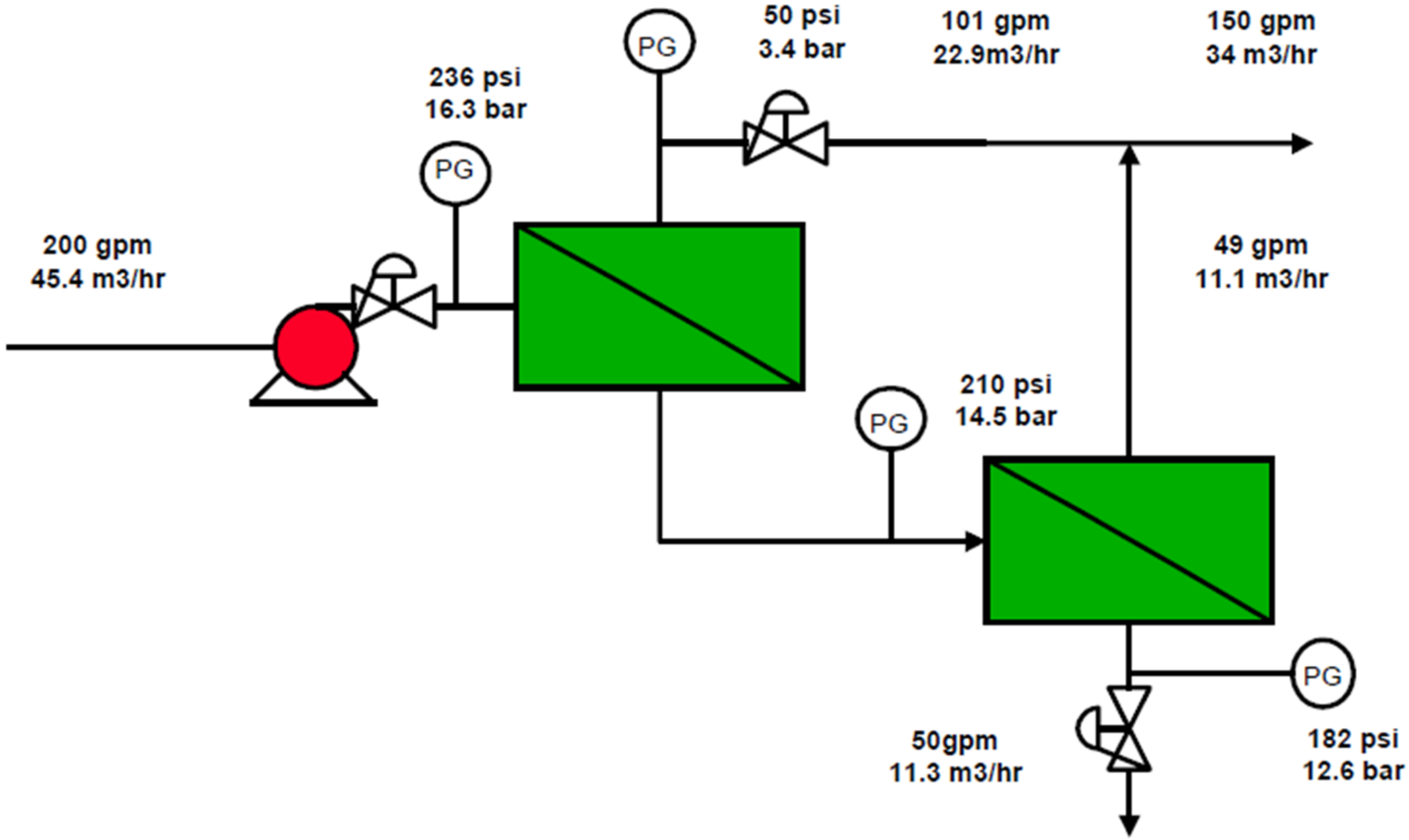
Flow diagram of a two stage RO system



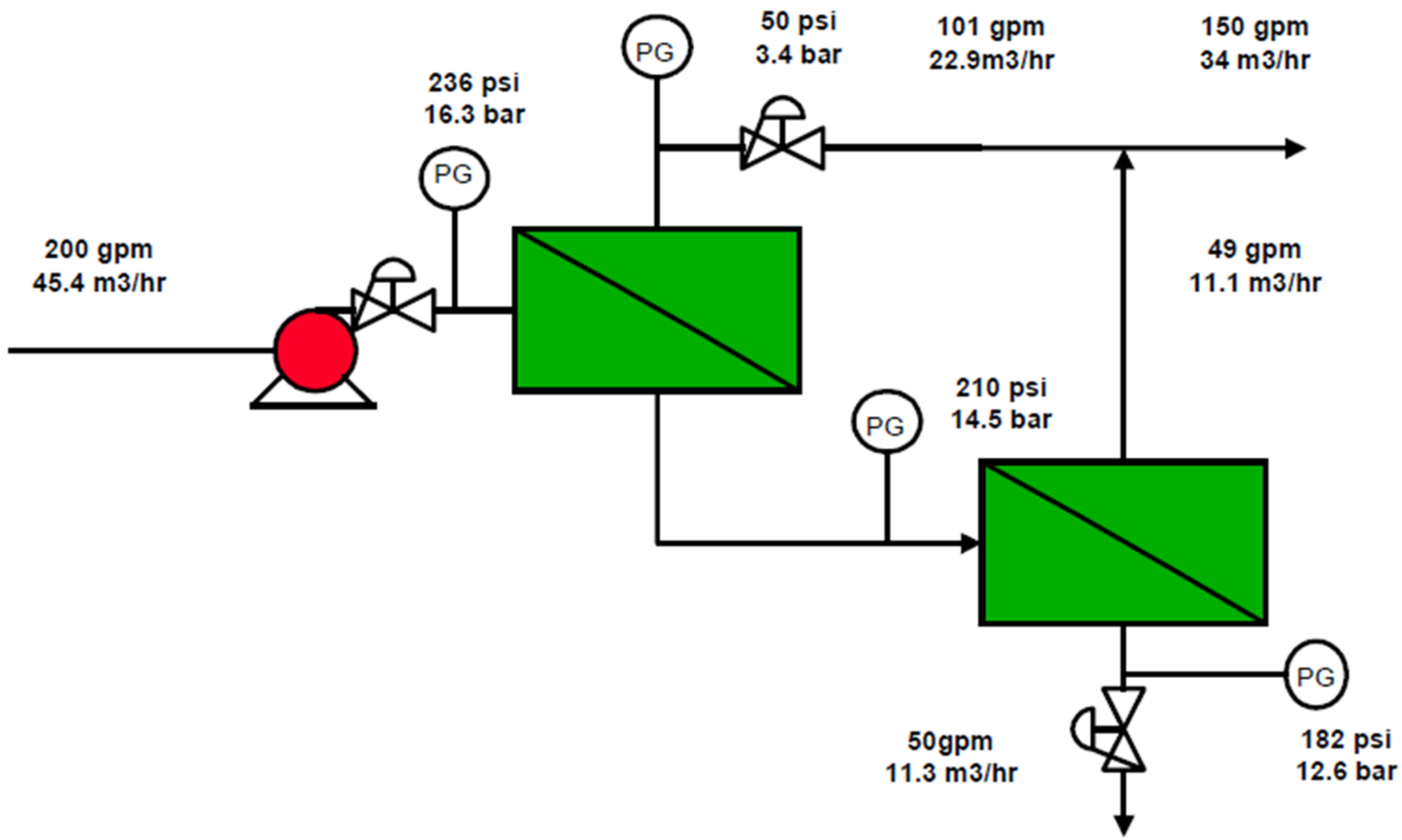
Flow diagram of a single stage RO unit with concentrate recirculation



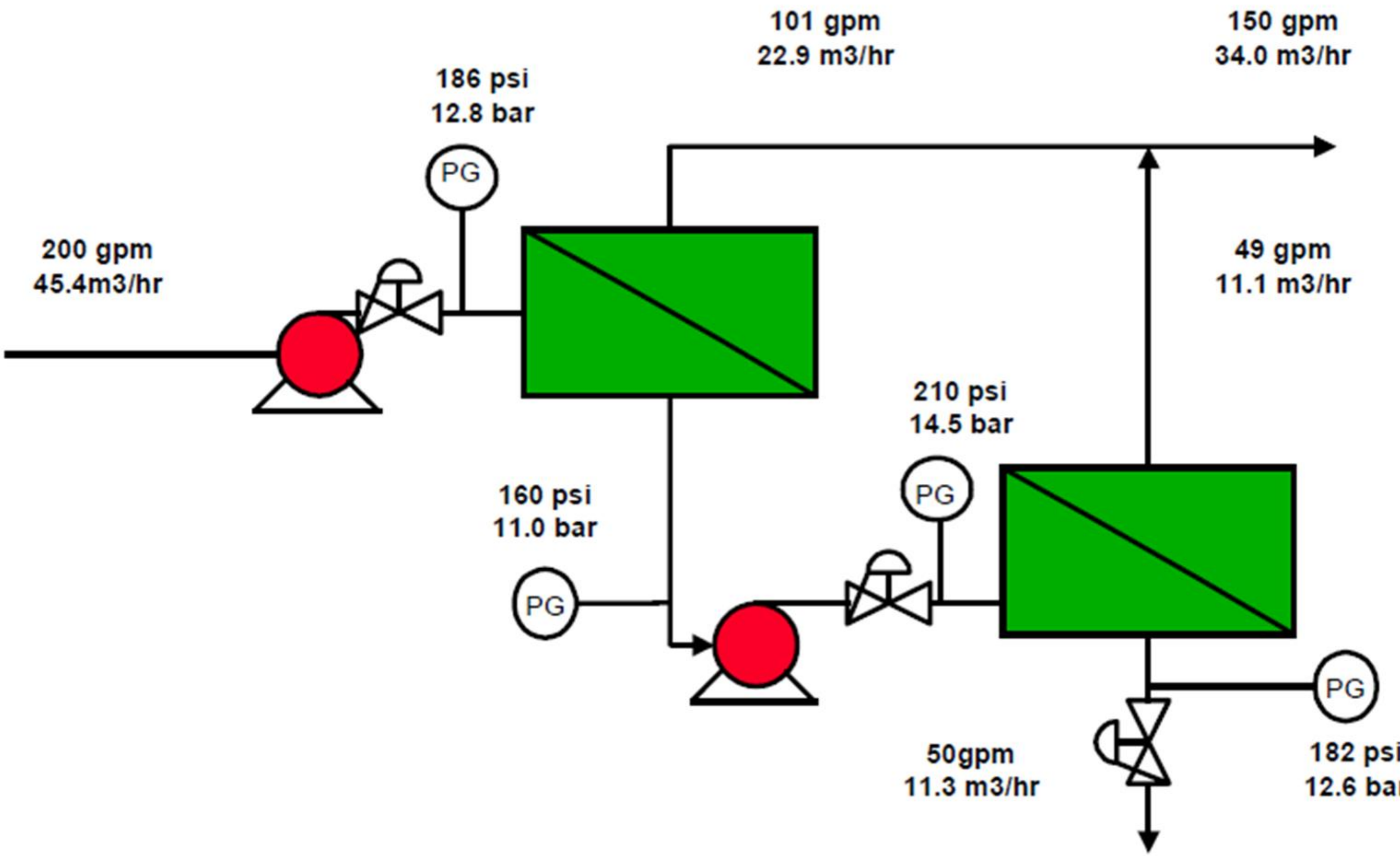
Flow diagram of a two stage RO system



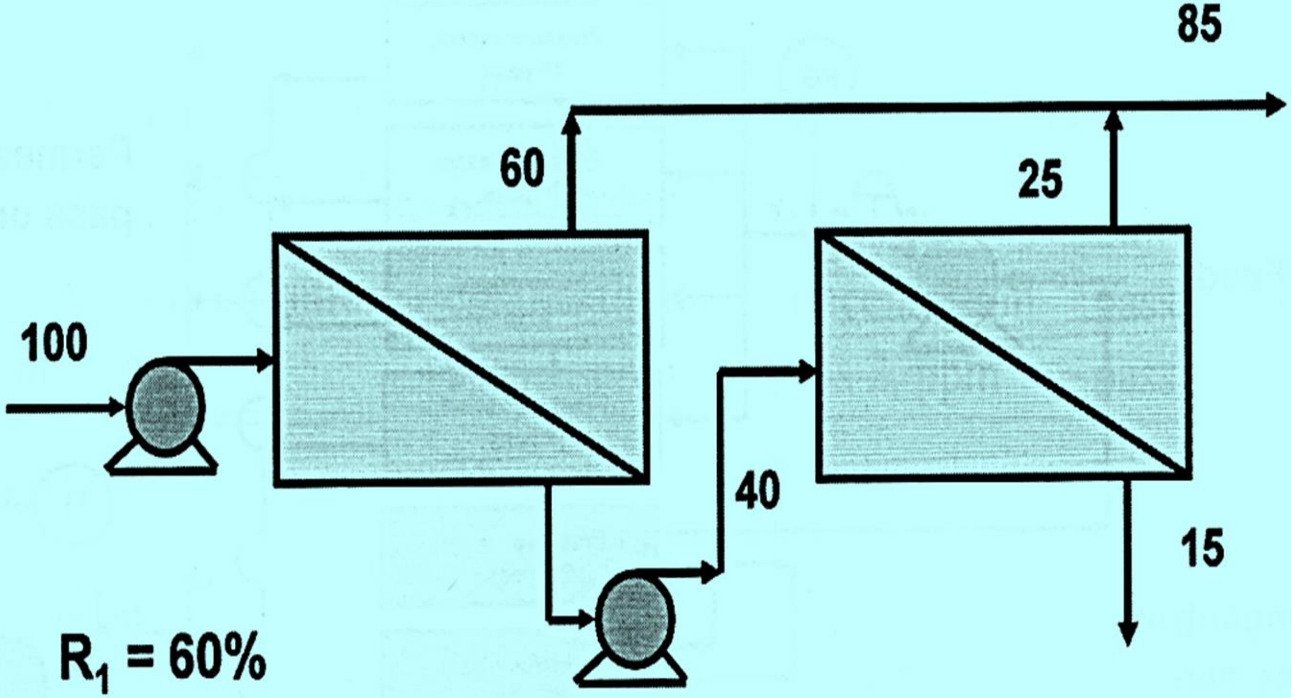
Flow diagram of a two stage RO system with permeate throttling



Flow diagram of a two stage RO system with permeate throttling



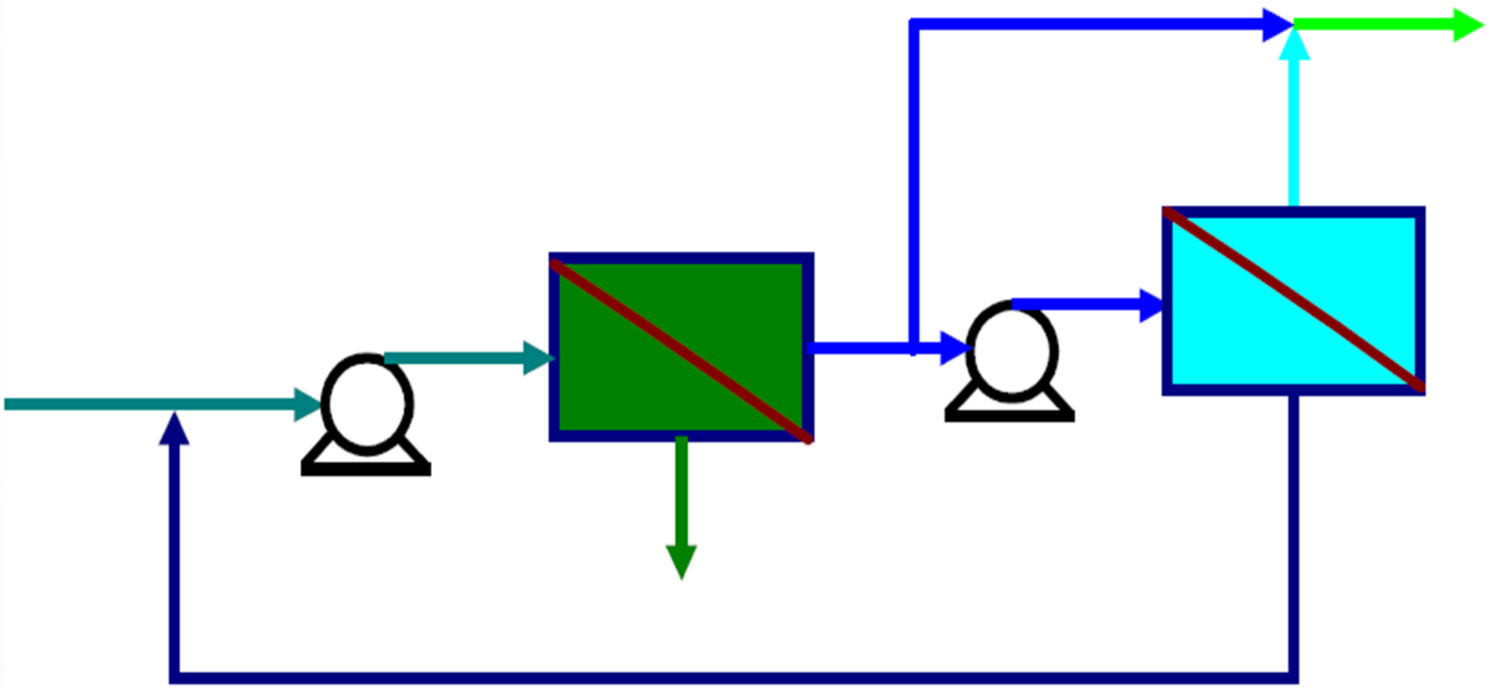
Flow diagram of a two stage RO system with interstage pump



$R_1 = 60\%$

$R_2 = 62\%$

$R_t = 85\%$



Flow diagram of a partial two pass RO system

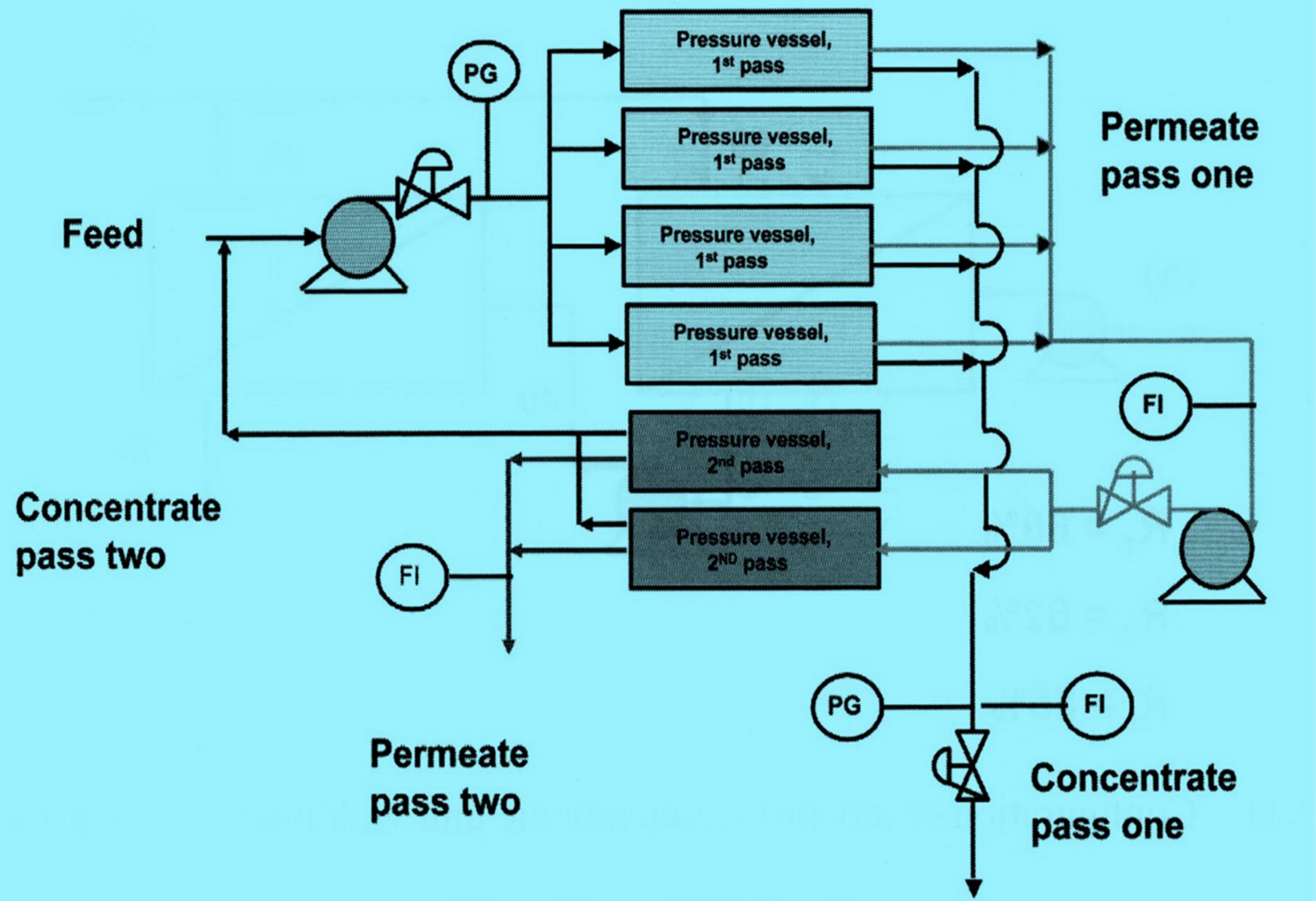
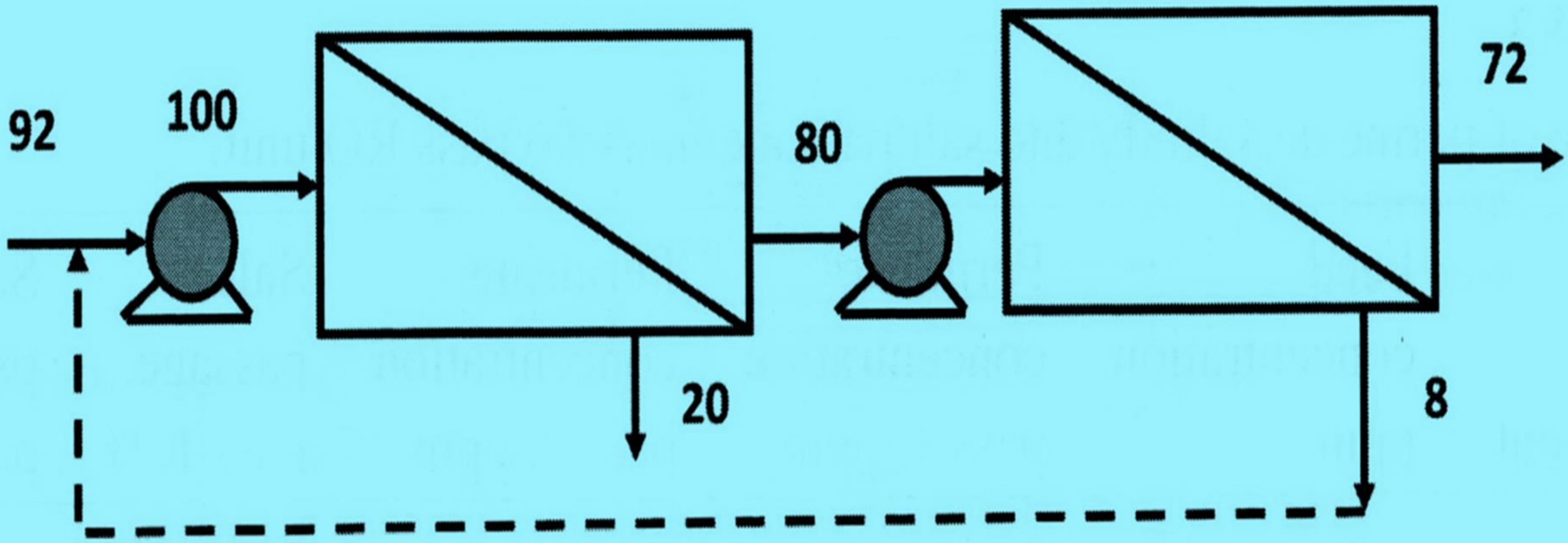


FIG. 13.12 Configuration of a two pass RO unit.

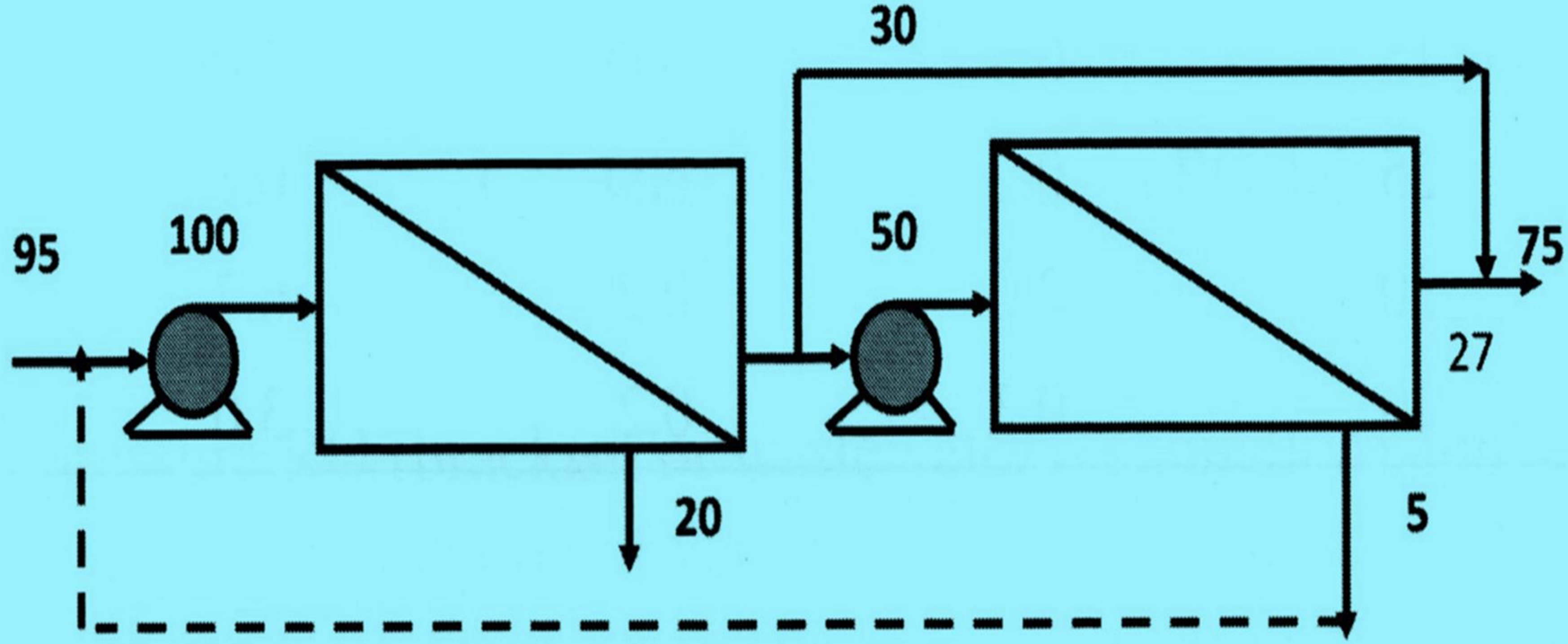


$$R1 = 100*80/100 = 80\%$$

$$R2 = 100*72/80 = 90\%$$

$$Rt = 100*72/92 = 78.2\%$$

FIG. 13.13 Recovery rate in a two pass unit.



R1 = 100 * 80/100 = 80%

R2 = 100 * 45/50 = 90%

Rt = 100 * 75/95 = 78.9%

FIG. 13.14 Recovery rate in a partial two pass unit.

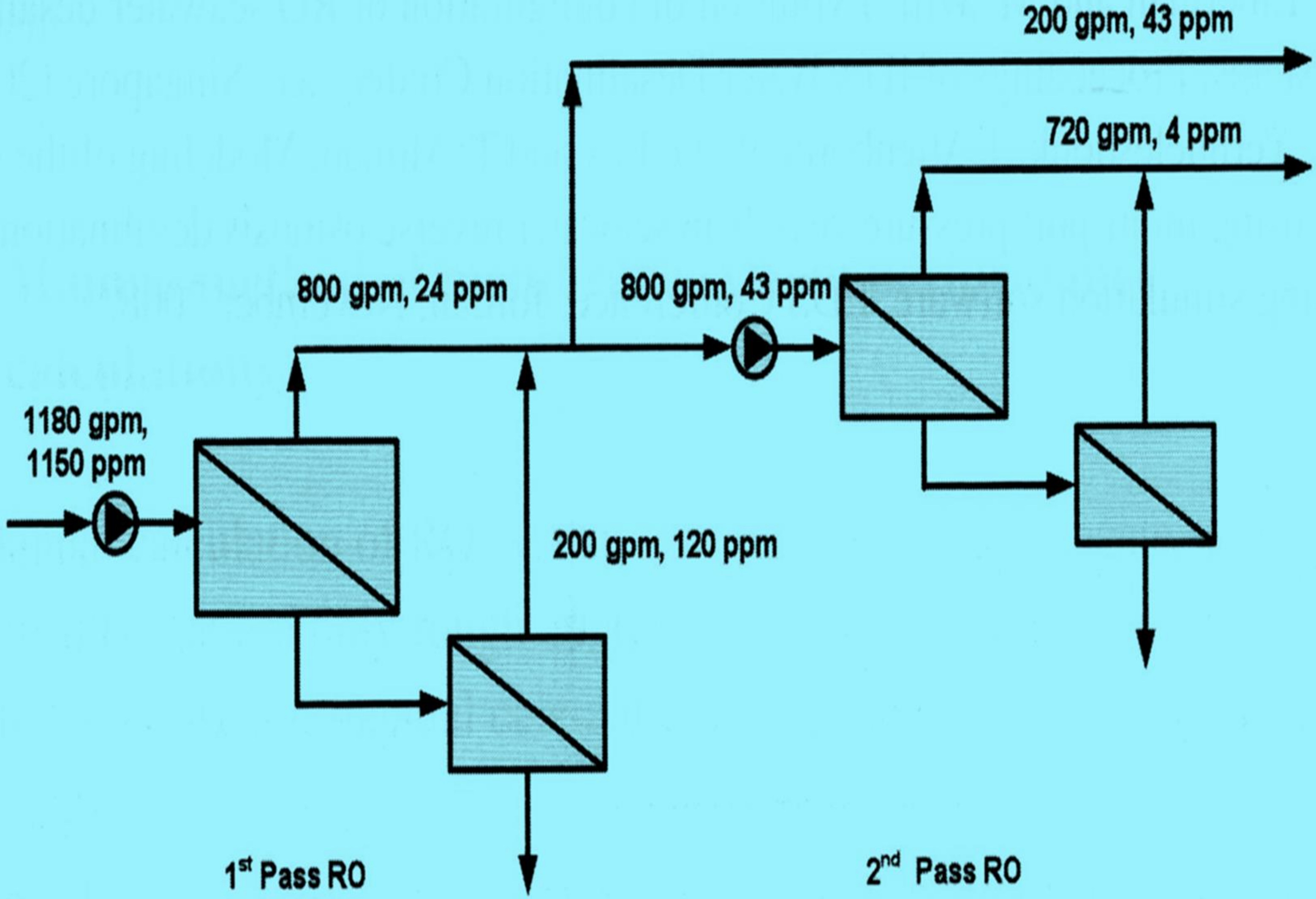


FIG. 13.15 Configuration of two pass system with processing of combined permeate from the 1st pass RO unit.

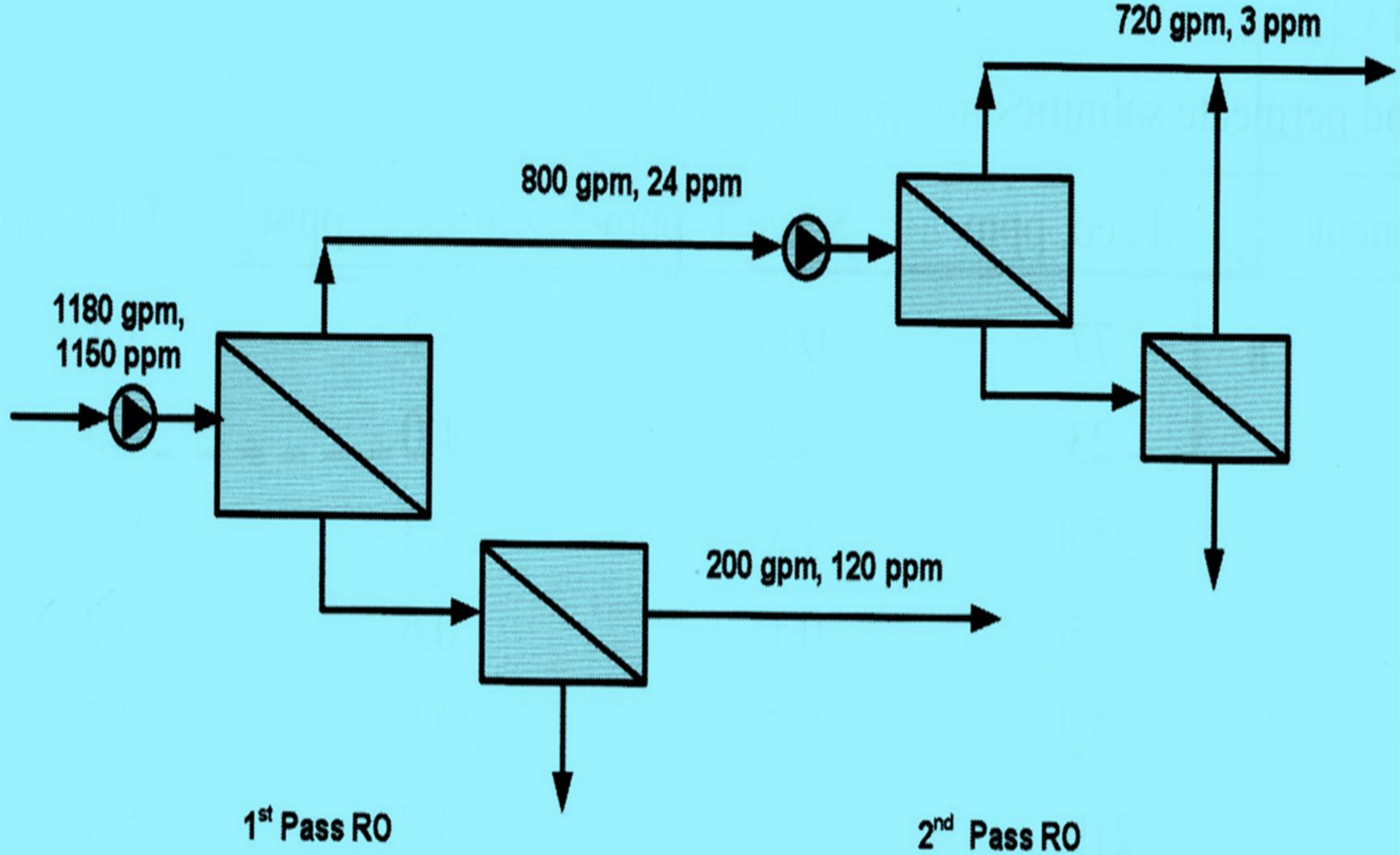
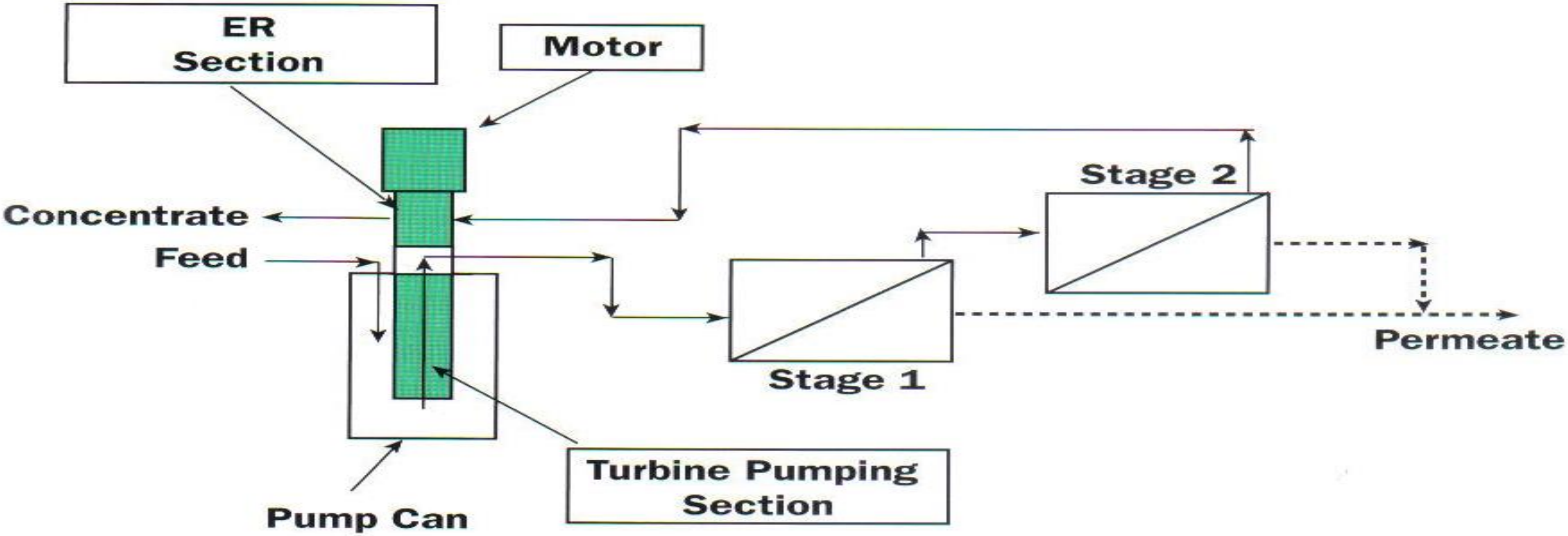


FIG. 13.16 Configuration of two pass system with processing of low salinity permeate (1st stage) from the 1st pass RO unit.

Example of permeate salinity and salt passage in a two pass RO unit.

Constituent	Feed concentration, ppm	Permeate concentration pass 1, ppm	Permeate concentration pass 2, ppm	Salt passage, pass 1, %	Salt passage, pass 2, %
Conductivity	1120	31	2.5	2.8	8.0
Alkalinity	150	11.0	ND	7.3	
Sulfate	168	ND	ND		
Chloride	123	2.2	1.8	1.8	8.1
Calcium	38	0.02	ND	0.05	
Magnesium	17	0.01	ND	0.05	
Sodium	110	2.7	0.2	2.4	7.4
Potassium	15	0.3	ND	2.0	
Silica	25	0.2	ND	0.1	
Ammonia	30	2.0	0.2	6.7	10
TOC	10	0.3	0.2	3.0	67



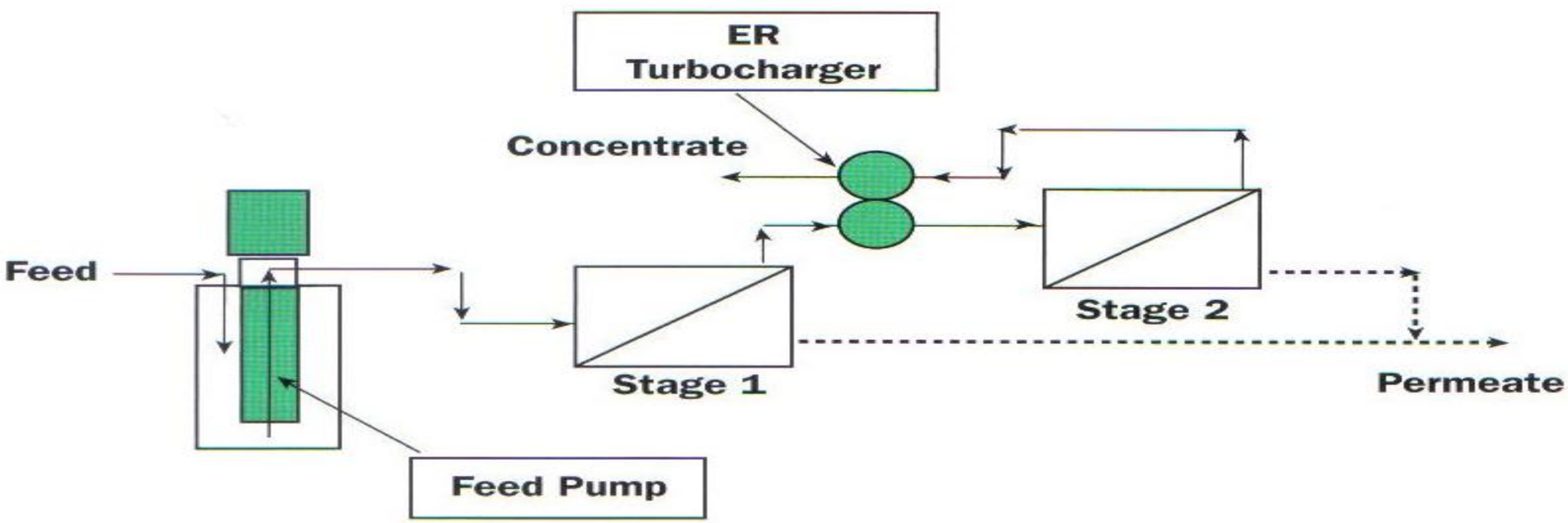
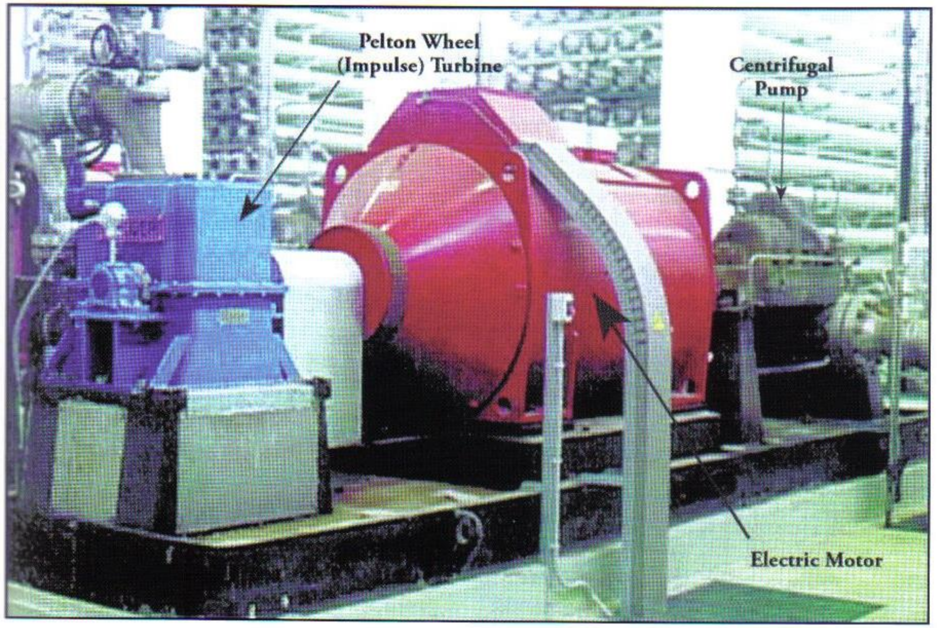
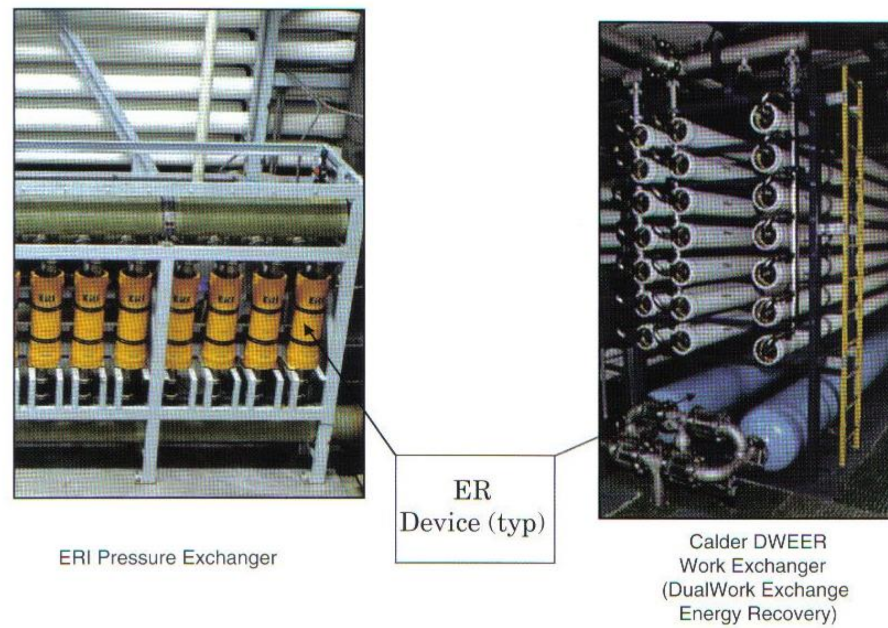


Figure 3-19 Hydraulic turbocharger for interstage pressure boost



igure 3-17 ER impulse turbine (Calder AG)



Courtesy of Energy Recovery Inc. and Calder AG

Figure 3-20 Pressure/work exchangers

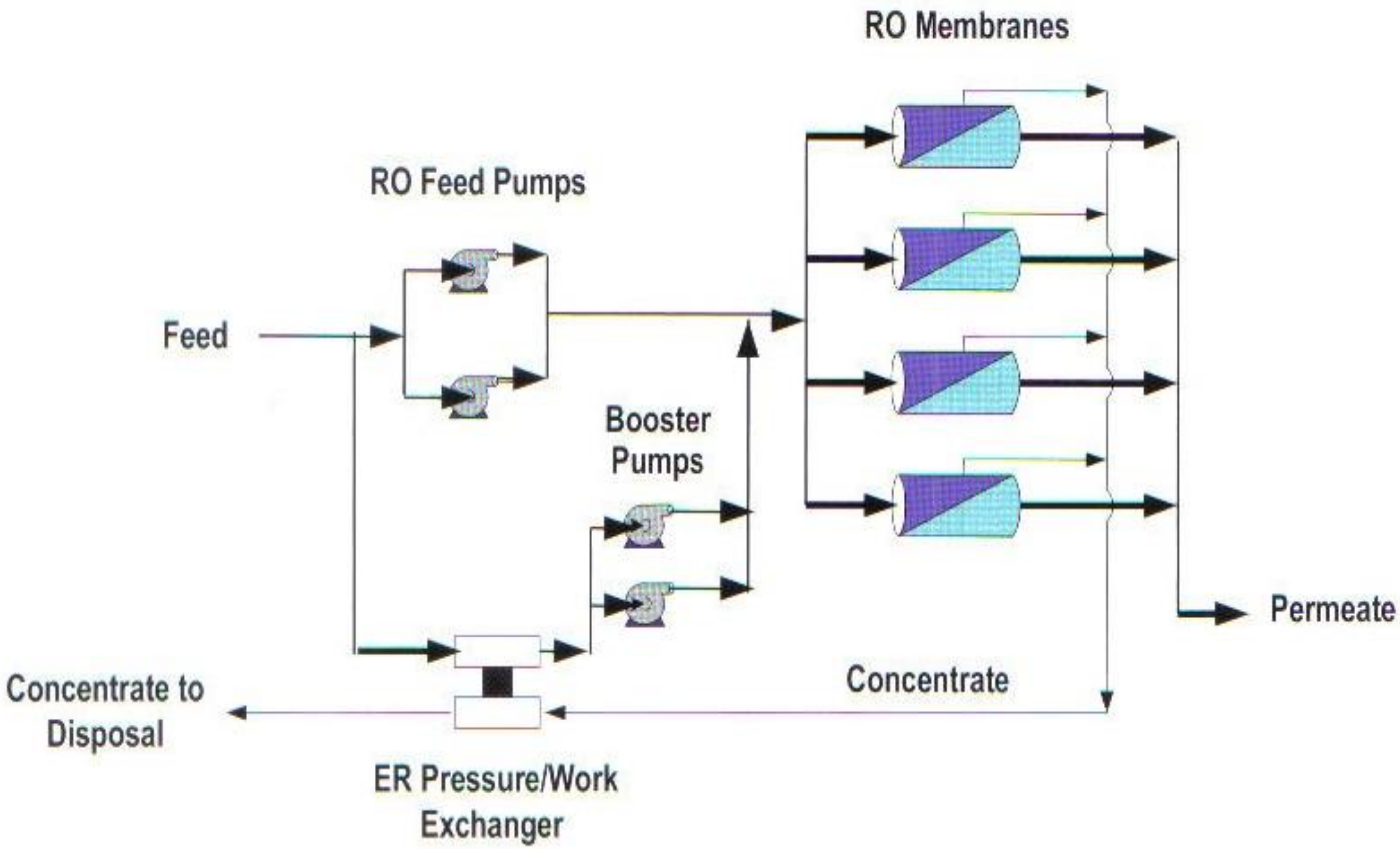
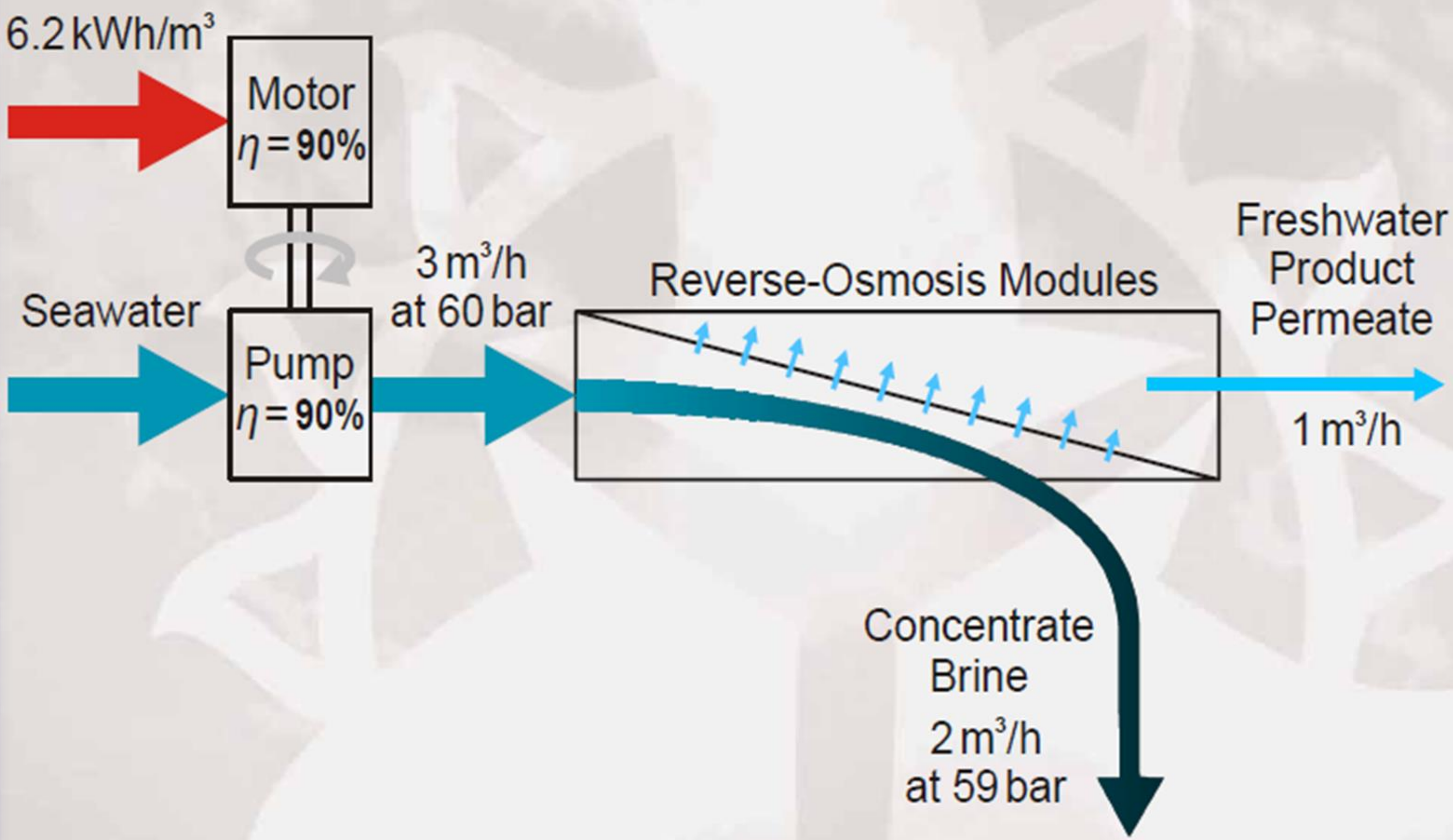
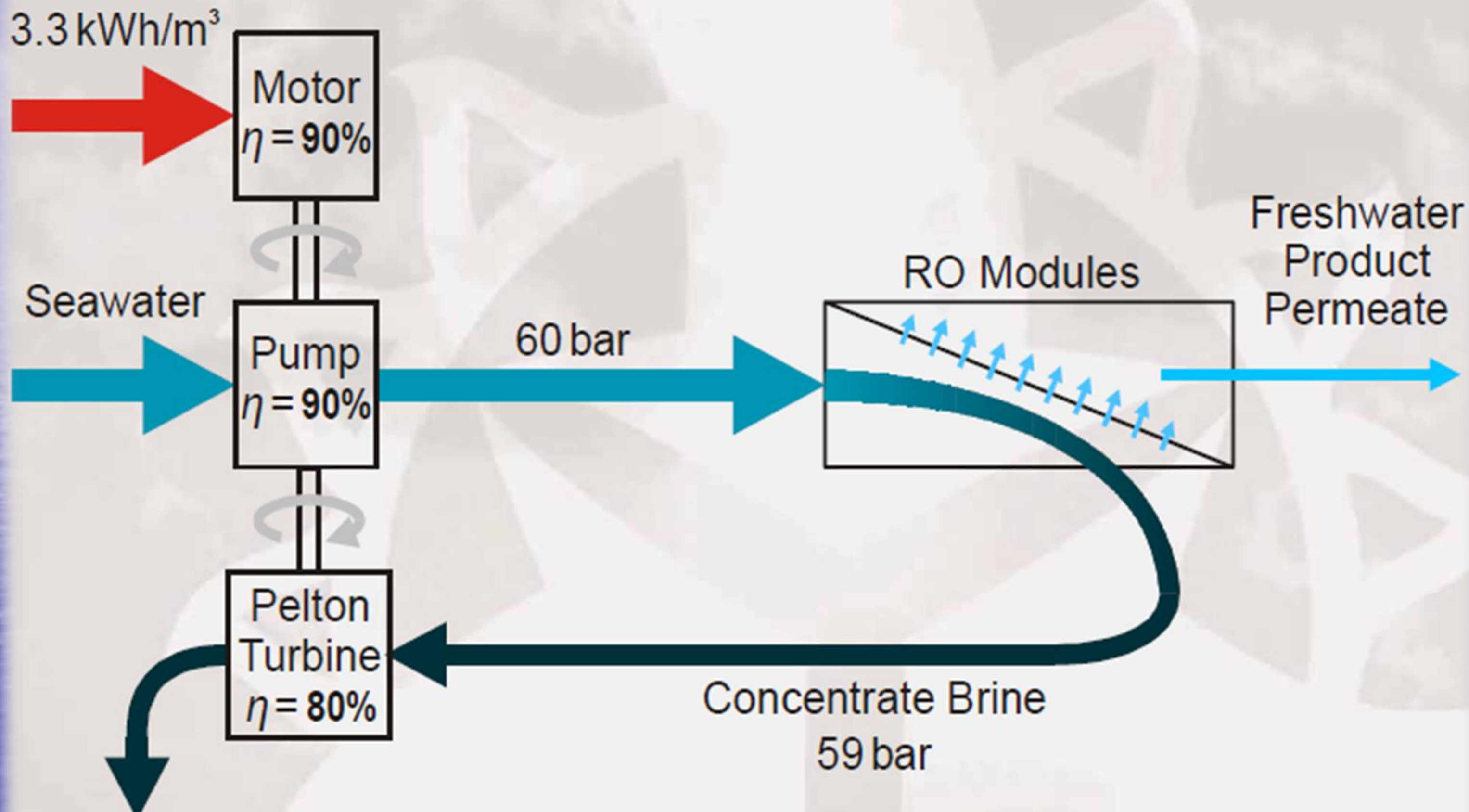


Figure 3-21 RO system with isobaric pressure/work exchangers and boost pumps

Pumping requirements

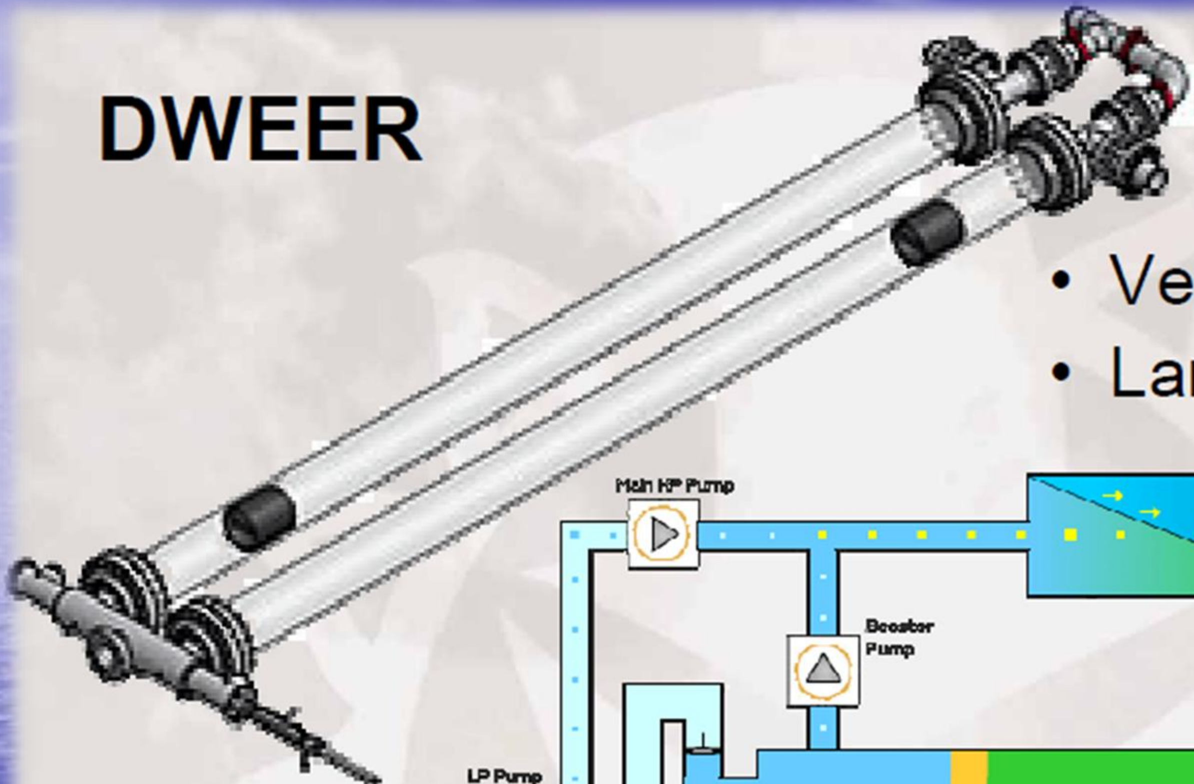


Pelton turbine energy recovery

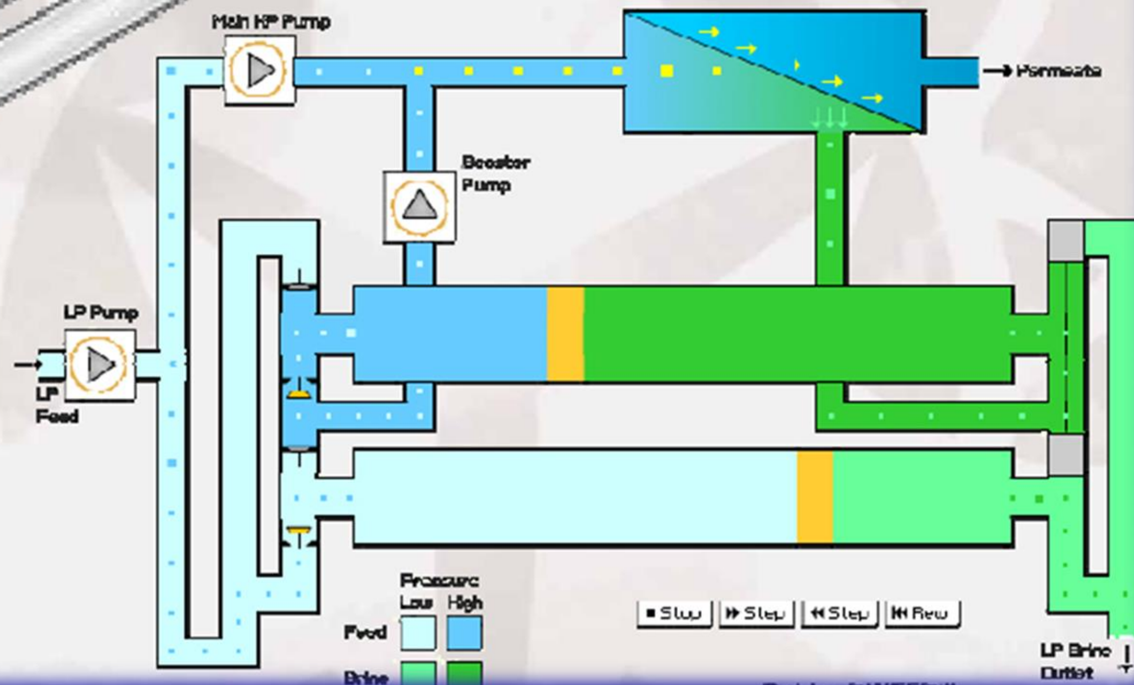


- Only for medium and large scale

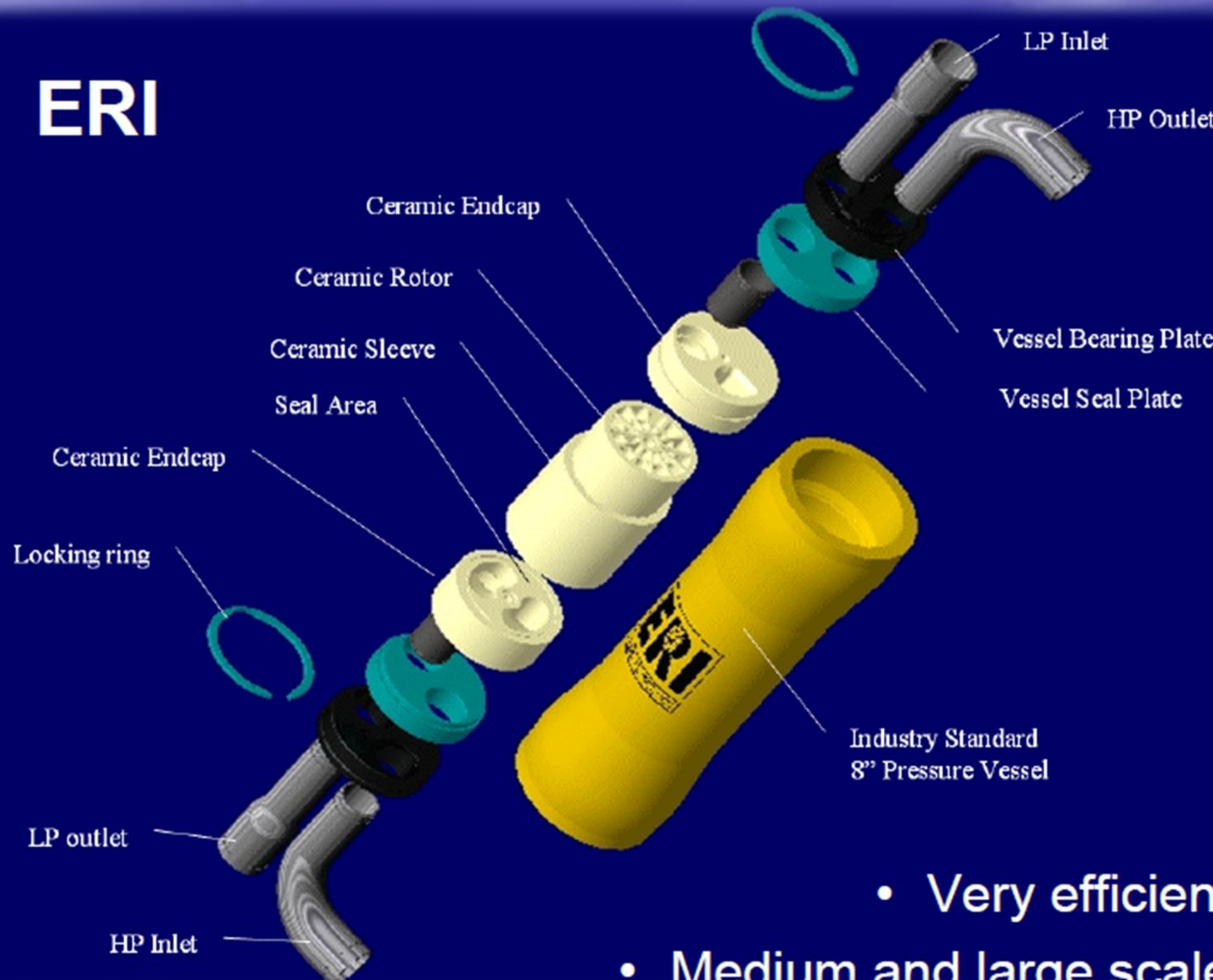
DWEER



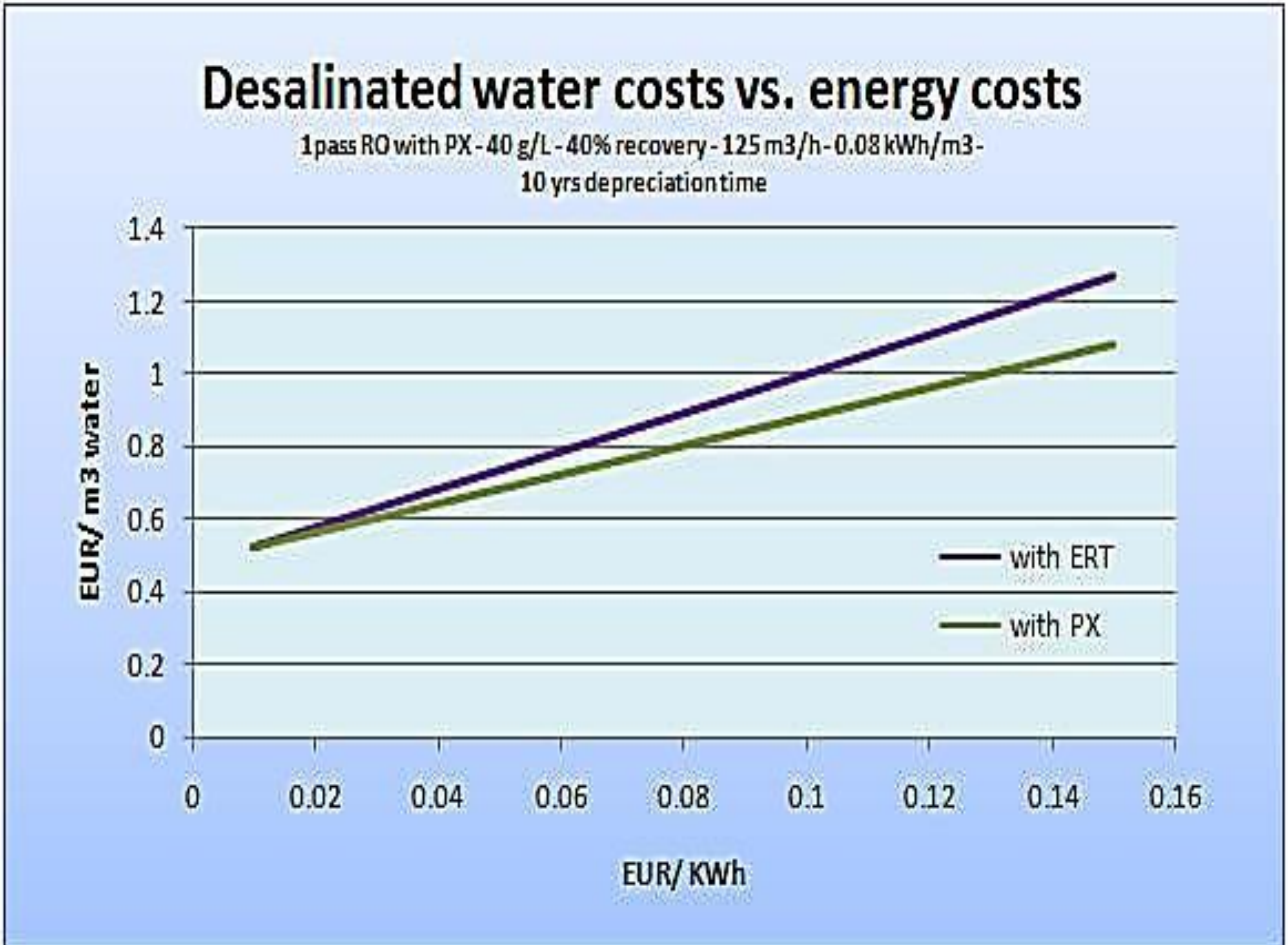
- Very efficient
- Large scale



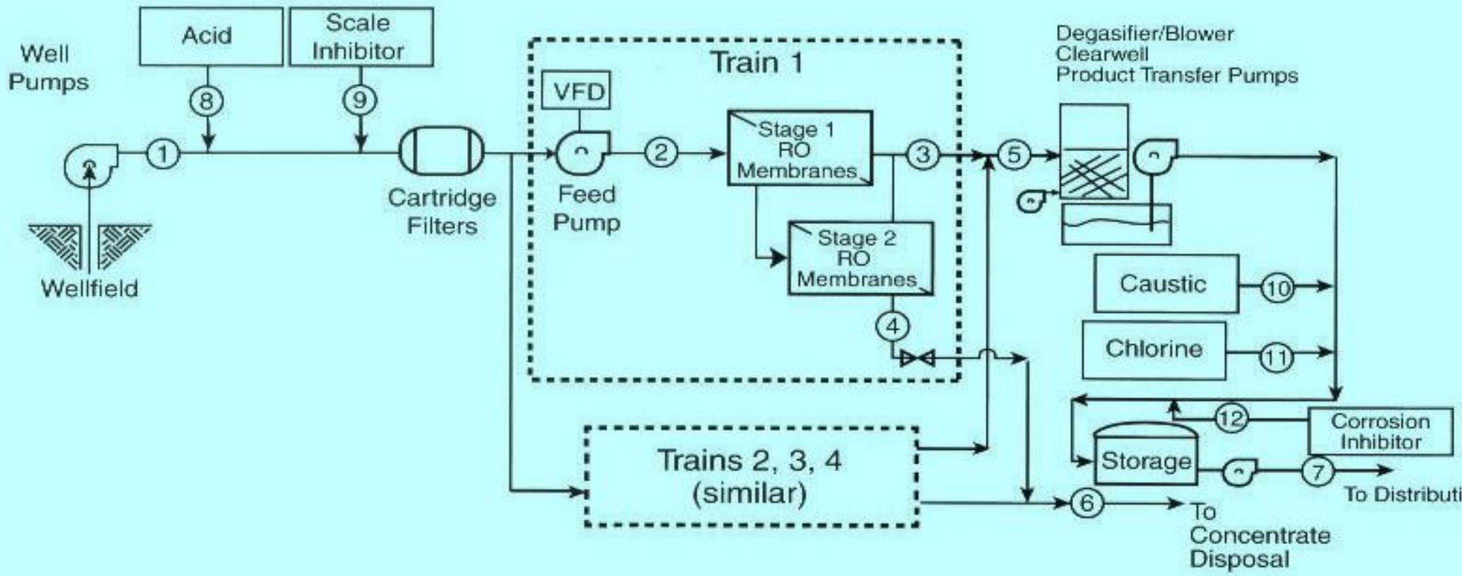
ERI



- Very efficient
- Medium and large scale

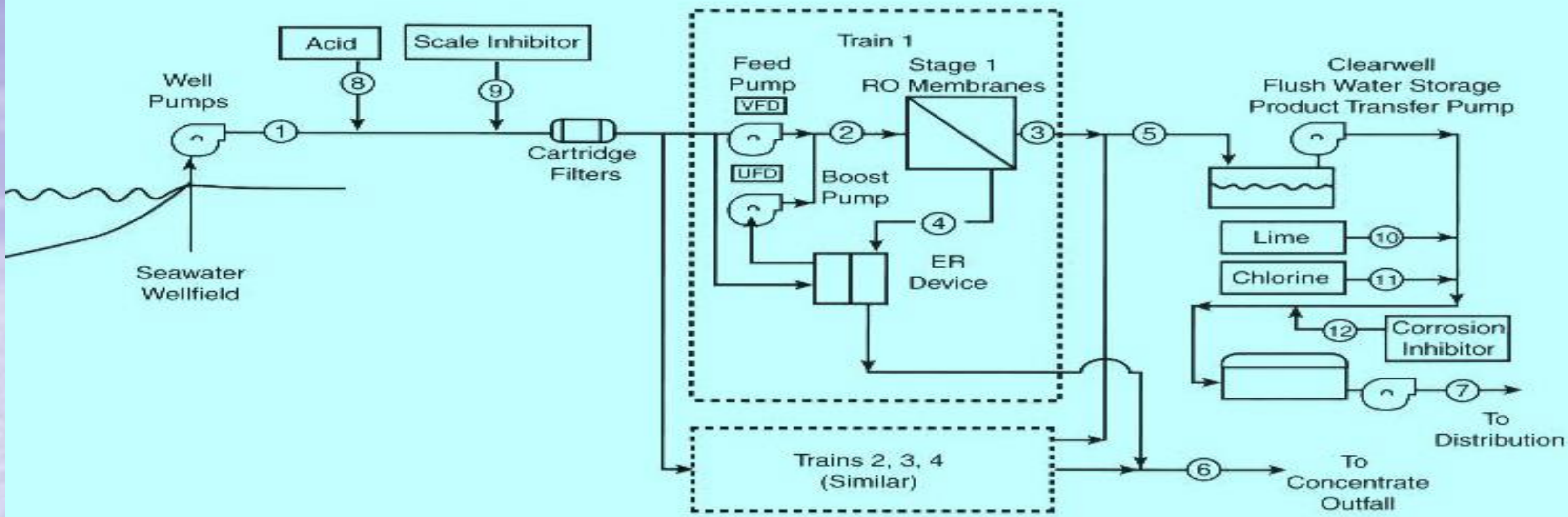


Desalinated water costs vs. energy costs
1pass RO with PX - 40 g/L - 40% recovery - 125 m3/h - 0.08 kWh/m3 -
10 yrs depreciation time
EUR/ m3 water
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
EUR/ KWh
with ERT
with PX



Process Stream	1 Raw Water	2 Train Feed Water	3 Train Permeate	4 Train Concentrate	5 Total Permeate	6 Total Concentrate	7 Finished Water	8 Acid (H_2SO_4)	9 Scale Inhibitor	10 Caustic	11 Chlorine	12 Corrosion Inhibitor
Flow, *mgd*	12.5	3.125	2.5	0.625	10.0	2.5	10.0					
Pressure, *psi*	50	215	15	165	15	30	80					
TDS, *mg/L*	2,000	1,995	70	9,695	70	9,695	85					
Dose, *mg/L* (100% concentration)								20	4	10	2	1

Figure 3-34 Brackish groundwater reference design



Process Stream	(1) Raw Water	(2) Train Feedwater	(3) Train Permeate	(4) Train Concentrate	(5) Total Permeate	(6) Total Concentrate	(7) Finished Water	(8) Acid (H_2SO_4)	(9) Scale Inhibitor	(10) Lime	(11) Chlorine	(12) Corrosion Inhibitor
Flow, *mgd*	22.2	5.56	2.5	3.06	10.0	12.2	10.0					
Pressure, *psi*	50	950	10	925	10	20	80					
TDS, *mg/L*	35,000	35,000	185	63,500	185	63,500	190					
Dose, *mg/L* (100% concentration)								5	4	5	2	1

Seawater reference design

Hydranautics Design Limits.

The Following System Design Limits should be observed when designing a Reverse Osmosis system.

Average flux rates and expected % decrease in flux per year:

Water Type	SDI	Flux	% Flux Decline/year
Surface water	(SDI 2 - 4)	8 - 14 GFD	7.3 - 9.9
Well water	(SDI < 2)	14 - 18 GFD	4.4 - 7.3
RO Permeate	(SDI < 1)	20 - 30 GFD	2.3 - 4.4

Expected % Salt Passage Increase per year:

MembraneType	Abbreviation	% SP Increase/year
Cellulosic membrane	CAB1, CAB2, CAB3	17 - 33
Composite Membrane		
Brackish, Low Pressure	ESPA1, ESPA2, ESPA3	3 -- 17
Brackish, High Rejection	CPA2, CPA3, CPA4	3 -- 17
Low Fouling	LFC1, LFC2	3 -- 17
Seawater	SWC1, SWC2, SWC3	3 -- 17
Softening, PolyVinyl Deriv.	PVD1, ESNA1, ESNA2	3 -- 17

Maximum Feed Flow and Minimum Concentrate Flow Rates per Vessel:

Membrane Diameter (in)	Max (GPM)	Max (m^3/hr)	Min (GPM)	Min (m^3/hr)
4	16	3.6	3	0.7
6	30	8.8	7	1.6
8	75	17.0	12	2.7
8.5	85	19.3	14	3.2

Hydranautics Design Limits.

Saturation Limits for Sparingly Soluble Salts in the Concentrate:

Salt	Saturation %
$CaSO_4$	230
$SrSO_4$	800
$BaSO_4$	6000
SiO_2	100

Limits of Saturation Indices:

Condition*	LSI Value
LSI and SDSI without scale inhibitor	≤ -0.2
LSI & SDSI with SHMP	≤ 0.5
LSI & SDSI with organic scale inhibitor	≤ 1.8

* Langelier and Stiff & Davis Saturation Indices

Table 2-7 Common scales and other inorganic foulants and methods for controlling them

	Method of Control	
Species	Primary	Secondary
Calcium carbonate ($CaCO_3$)	Mineral acid Threshold inhibitor	Soften
Calcium sulfate ($CaSO_4$)	Threshold inhibitor Soften	Limit recovery
Barium sulfate ($BaSO_4$)	Threshold inhibitor Soften	Limit recovery
Strontium sulfate ($SrSO_4$)	Threshold inhibitor Soften	Limit recovery
Calcium fluoride (CaF_2)	Threshold inhibitor Soften	Limit recovery
Calcium phosphate ($CaPO_4$)	Mineral acid Threshold inhibitor	Limit recovery
Silica (SiO_2)	Threshold inhibitor Limit recovery	Raise pH to greater than 8.5 (if carbonate scale is not an issue) or increase temperature
Ferric hydroxide [$Fe(OH)_3$]	Precipitation and filtration Chelating agent	Soften
Aluminum hydroxide [$Al(OH)_3$]	Precipitation and filtration at pH of minimum solubility Chelating agent	—
Sulfur (S) (from hydrogen sulfide)	Exclude air and other oxidants prior to membranes	—

Table 2-6 Common limiting salts

Salt	Solubility Product of Salt, pK_{sp} at 25°C
Calcium carbonate ($CaCO_3$)	8.30
Calcium fluoride (CaF_2)	8.27
Calcium phosphate ($CaPO_4$)	25.00
Calcium sulfate ($CaSO_4$)	4.70
Barium sulfate ($BaSO_4$)	9.70
Strontium sulfate ($SrSO_4$)	6.20
Silica (SiO_2)	2.70

Table 2-8 Example of an ionic strength calculation

Species	Assumed Concentration, mg/L	Number of Milligrams per Mole	m_i^*	z_i^2	$m_i z_i^2$
Calcium (Ca^{2+})	409	40,000	0.0102	4	0.0408
Magnesium (Mg^{2+})	169	24,300	0.00695	4	0.0278
Sodium (Na^+)	314	23,000	0.0137	1	0.0137
Bicarbonate (HCO_3^-)	150	61,000	0.00246	1	0.00246
Sulfate (SO_4^{2-})	1,510	96,100	0.0157	4	0.0628
Chloride (Cl^-)	500	35,500	0.0141	1	0.0141
				$\sum m_i z_i^2$	= 0.1617
				$I = \frac{1}{2}\sum m_i z_i^2$	= 0.0808

*Determined by dividing the value in column 2 by the value in column 3.

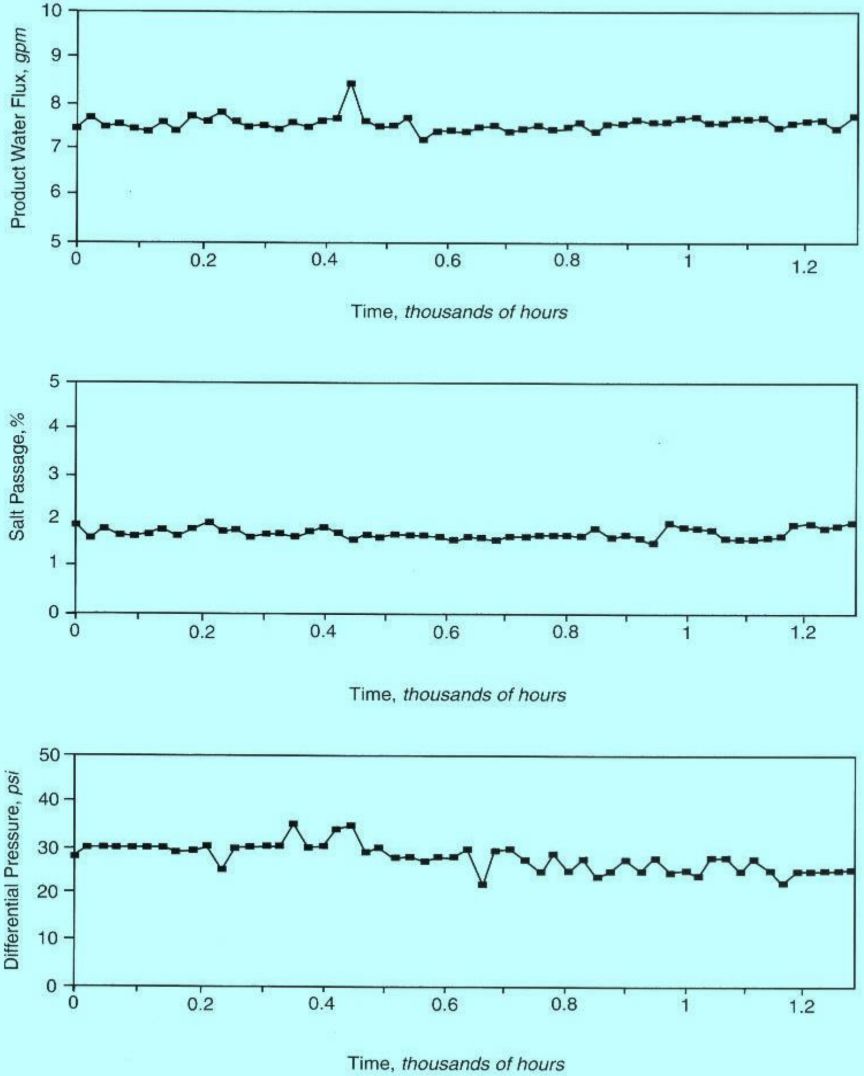
Location: Sanibel, Fla.
RO Feed: 3,700 mg/L TDS

Membrane: Thin-film composite spiral wound
Recovery: 80 percent

Scaling Potential:

LSI:	+2.0
Strontium Sulfate:	156 percent of Saturation
Barium Sulfate:	226 percent of Saturation

Antiscalant Dose: 3 mg/L



Scale inhibition study, Sanibel, Fla.

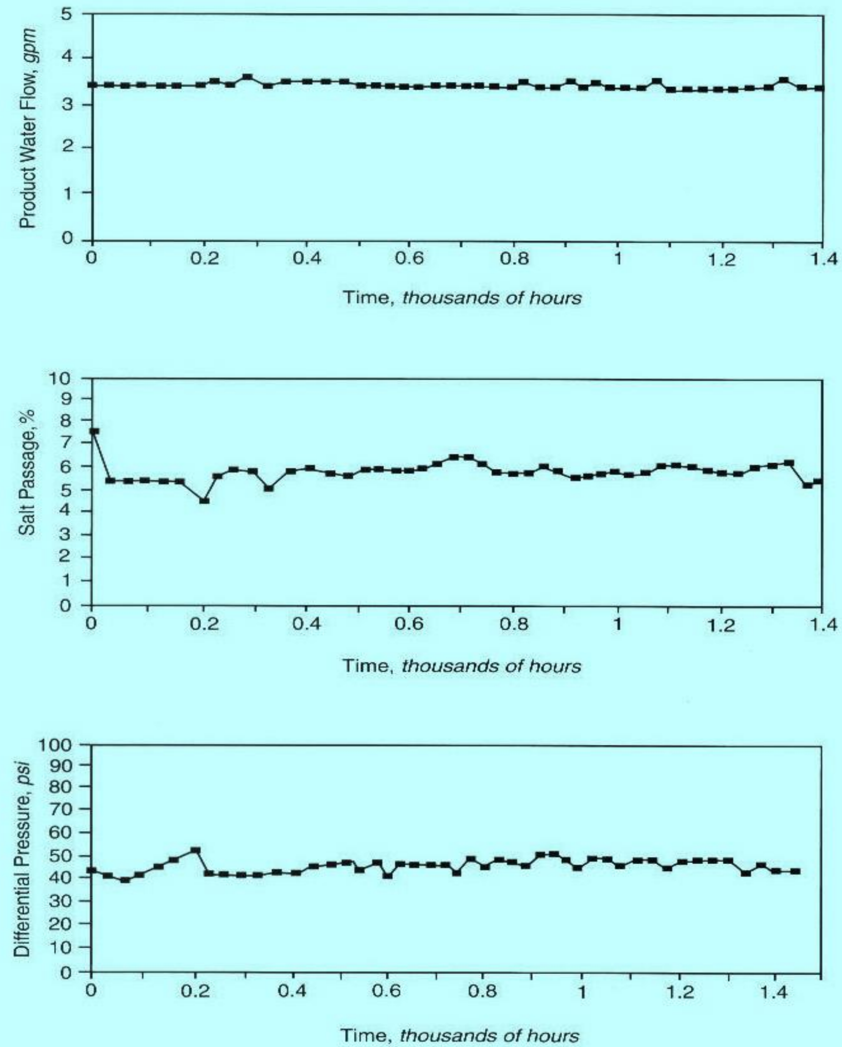
Location: Venice, Fla.
RO feed: 2,600 mg/L TDS

Membrane: Hollow Fiber
Recovery: 57 percent

Scaling Potential:

LSI:	+1.3
Calcium Sulfate :	157 percent of Saturation
Strontium Sulfate :	271 percent of Saturation
Barium Sulfate :	1,816 percent of Saturation

Antiscalant Dose: 5 mg/L

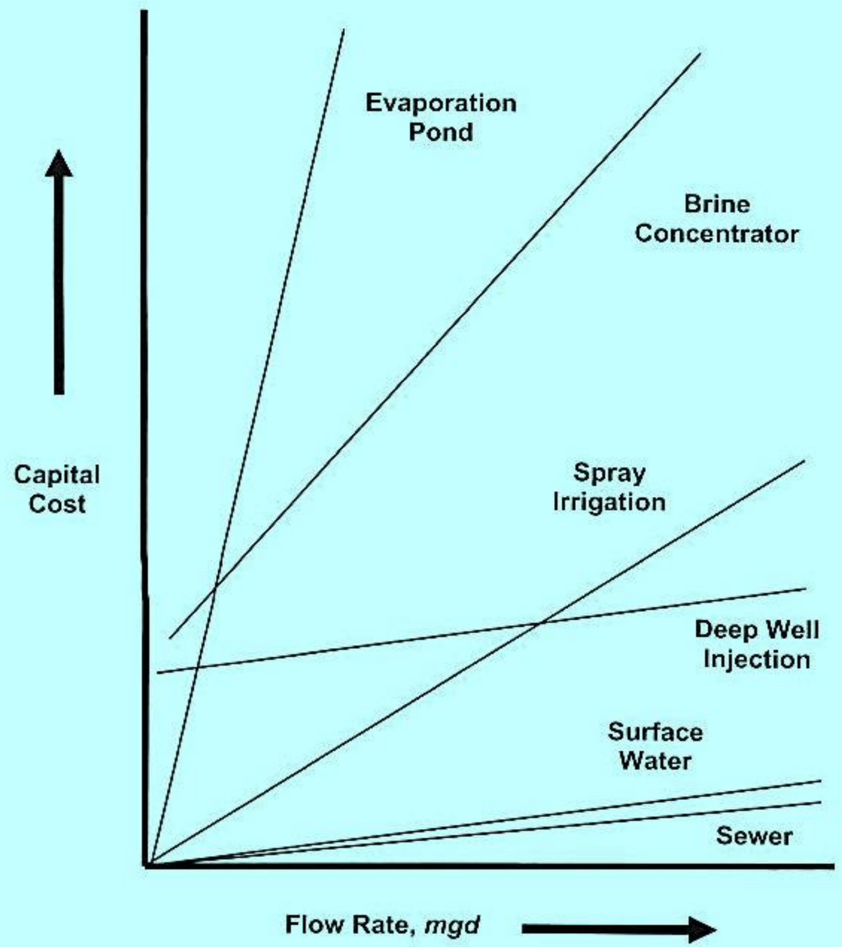


Scale inhibition study, Venice, Fla.

Table 3-12 Reference design parameters

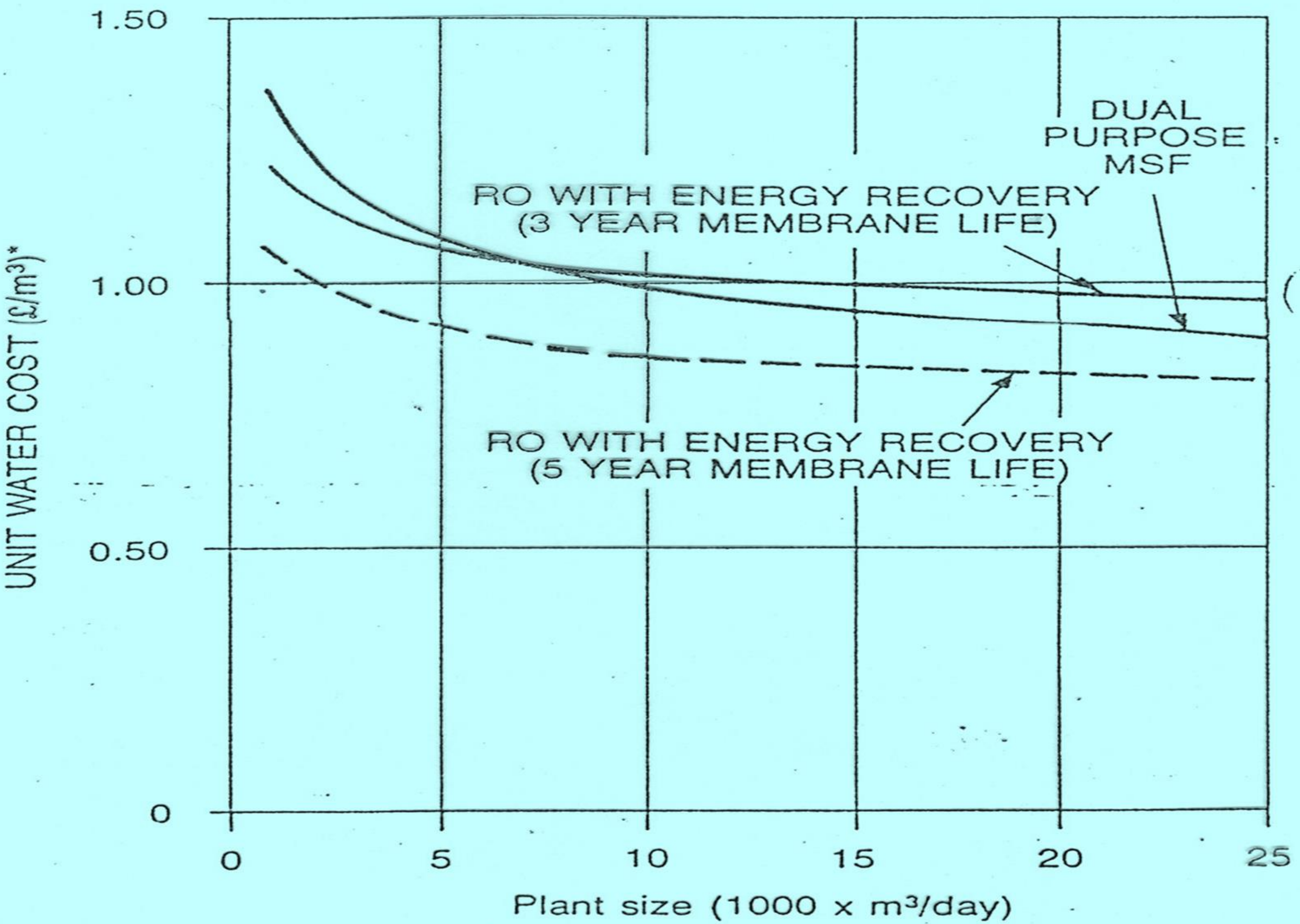
Parameter	Value or Type	
Water supply source	Groundwater	Seawater
Raw water TDS, *mg/L*	2,000	35,000
Permeate TDS, *mg/L*	70	185
Permeate quantity per train, *mgd*	2.5	2.5
Finished water quantity, *mgd*	10.0	10.0
Finished water TDS, *mg/L*	90	190
Number of trains	4	4
Pressure vessel staging (total per train)	44:21 (65)	97
Number of membranes (total per train)	455	679

Table continued next page.



Relative capital cost of concentrate management options

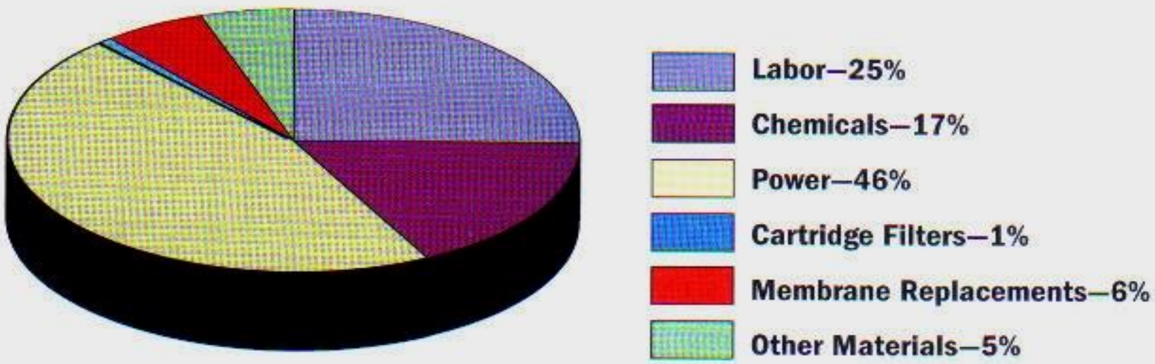
Figure 6. Total Water Cost—
Dual-Purpose MSF versus RO



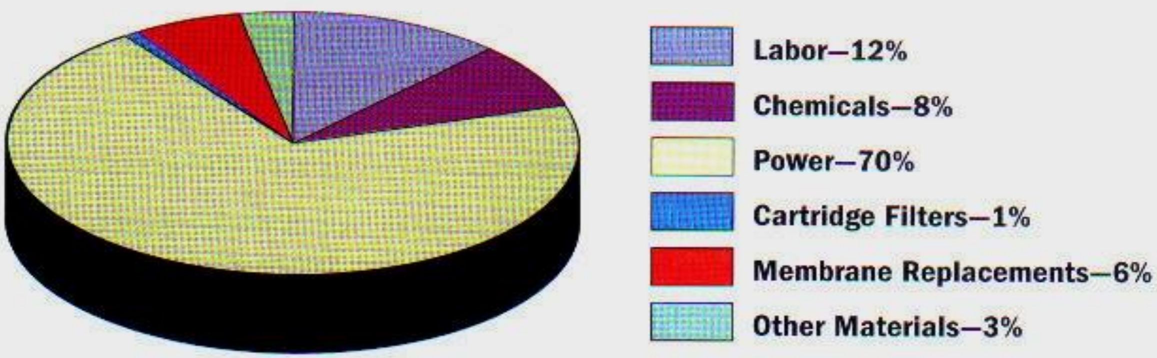
Energy required to desalinate seawater

• Theoretical minimum:	~ 1 kWh/m^3
• Simple distillation (theoretical):	~ 627 kWh/m^3
• Thermal desalination (Large MED, MSF & VC):	6 - 16 kWh/m^3
• Typical RO:	3 - 8 kWh/m^3
• Best practice RO:	2 kWh/m^3

Brackish Groundwater RO Reference Plant



Seawater RO Reference Plant



O&M cost breakdown for reference plants (assumes relative costs in 2004)

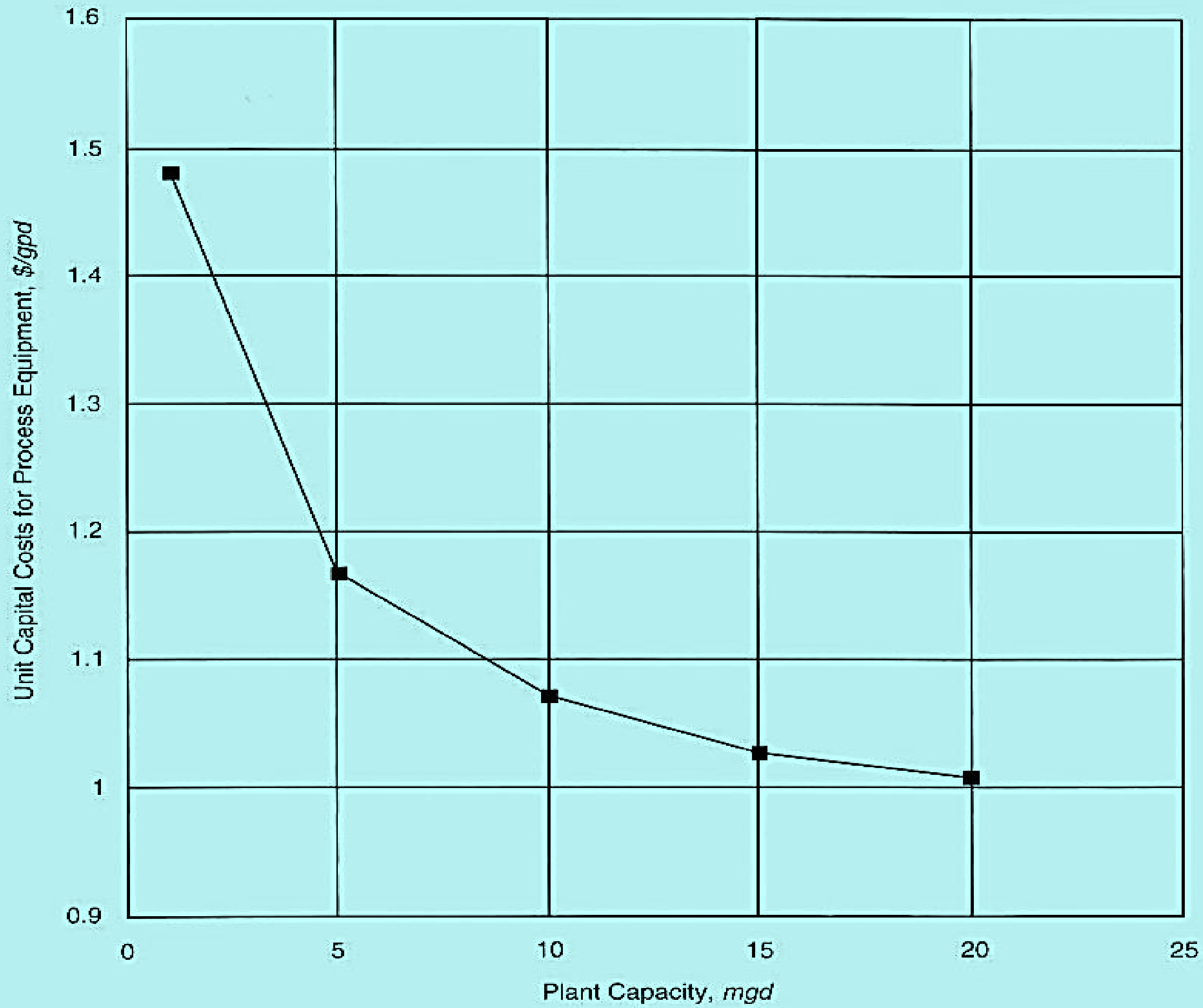
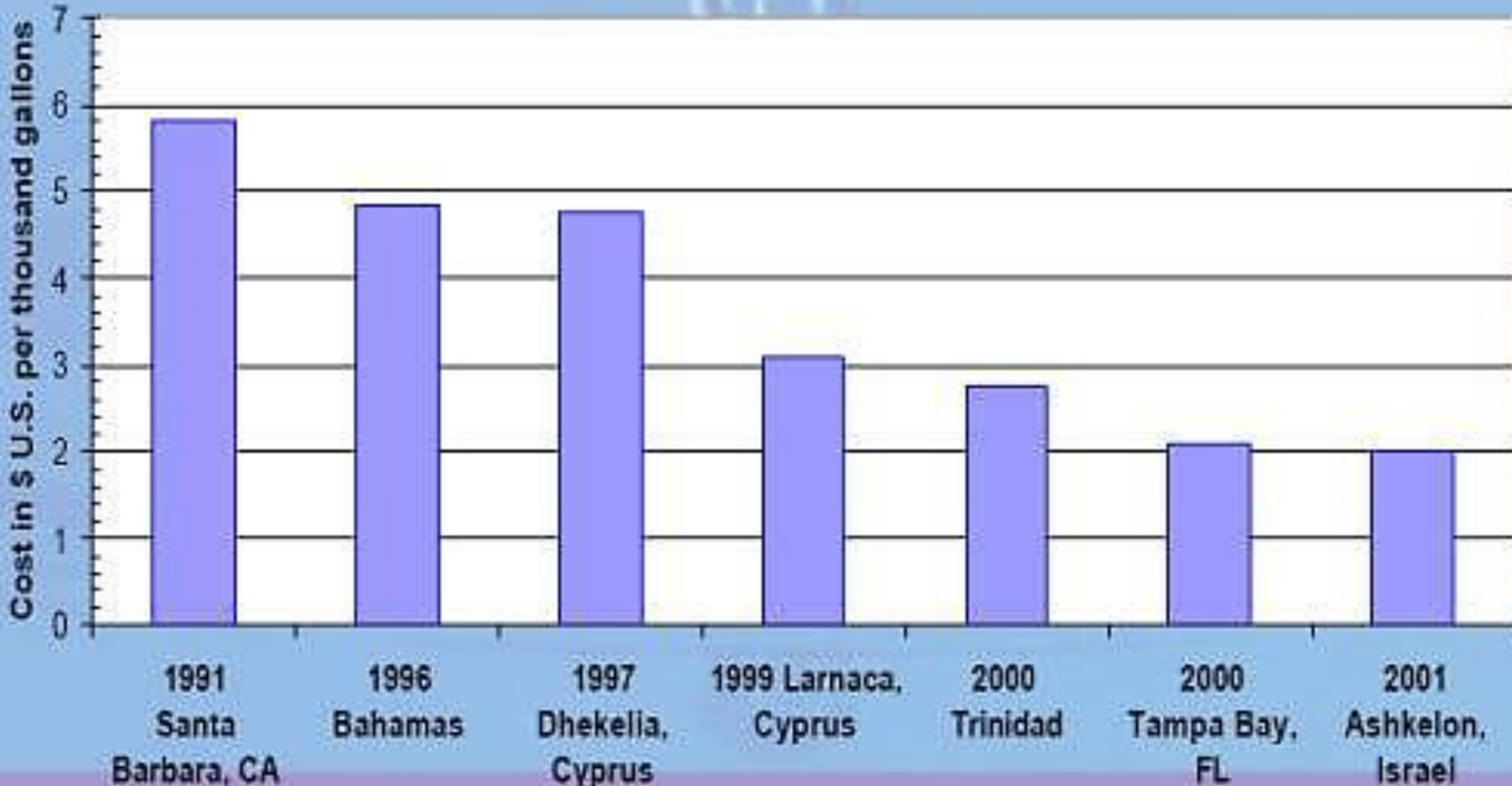


Figure 3-36 Economy of scale for RO plant process equipment

Decline in Seawater Desalination Costs Represents Evolution in Technology and Facility Size



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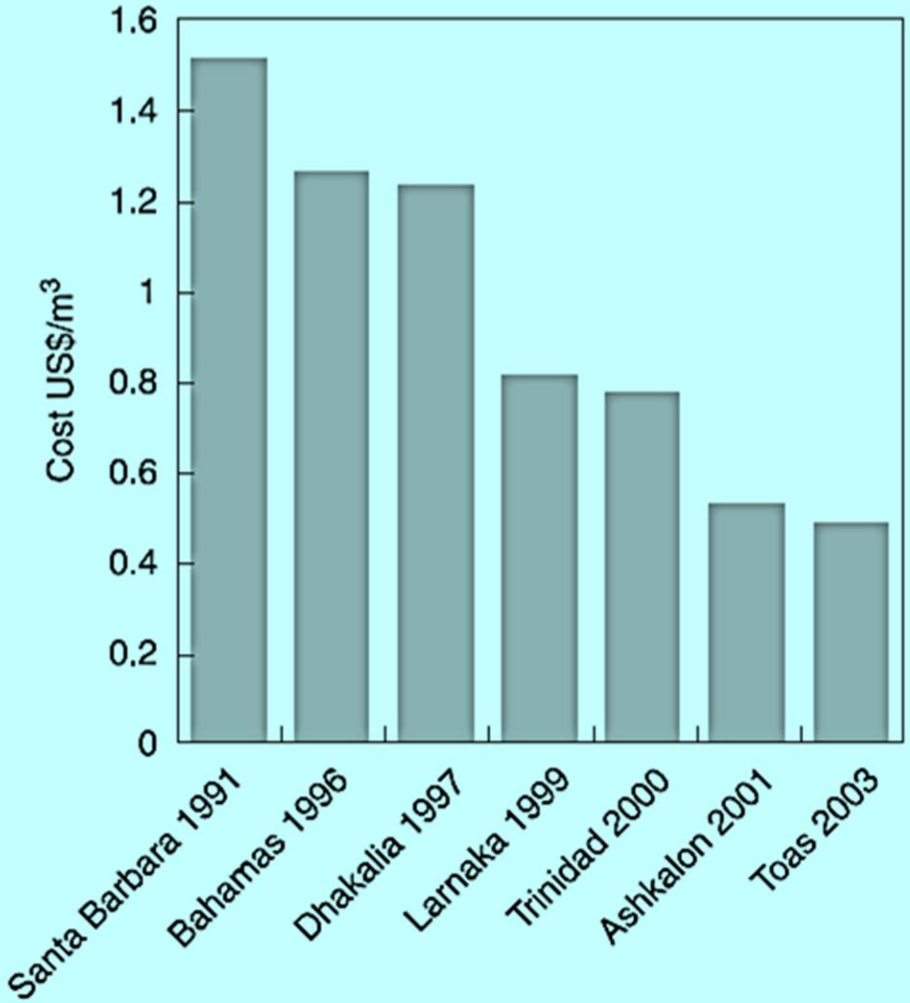


Figure 3.20 Seawater desalination cost reduction during last 20 years. (Taken from papers in Semiat et al., 2004.)

TABLE 3.6 Product Water Cost Components of 200,000 m^3/day SWRO Plant

Product Water Cost Component	US$/$m^3$
Capital cost, including land (25 years @ 6.0% interest)	0.203–0.338
Electric power ($0.060/kWh)	0.180–0.240
RO membrane replacement (5 years membrane life)	0.025–0.035
MF membrane replacement (7 years membrane life)	0.019–0.030
Chemicals	0.020–0.025
Maintenance and spare parts	0.023–0.038
Labor	0.030–0.044
Total product water cost	0.50–0.75

TABLE 3.7 O&M Cost Breakdown for Ashkelon Seawater Desalination Project

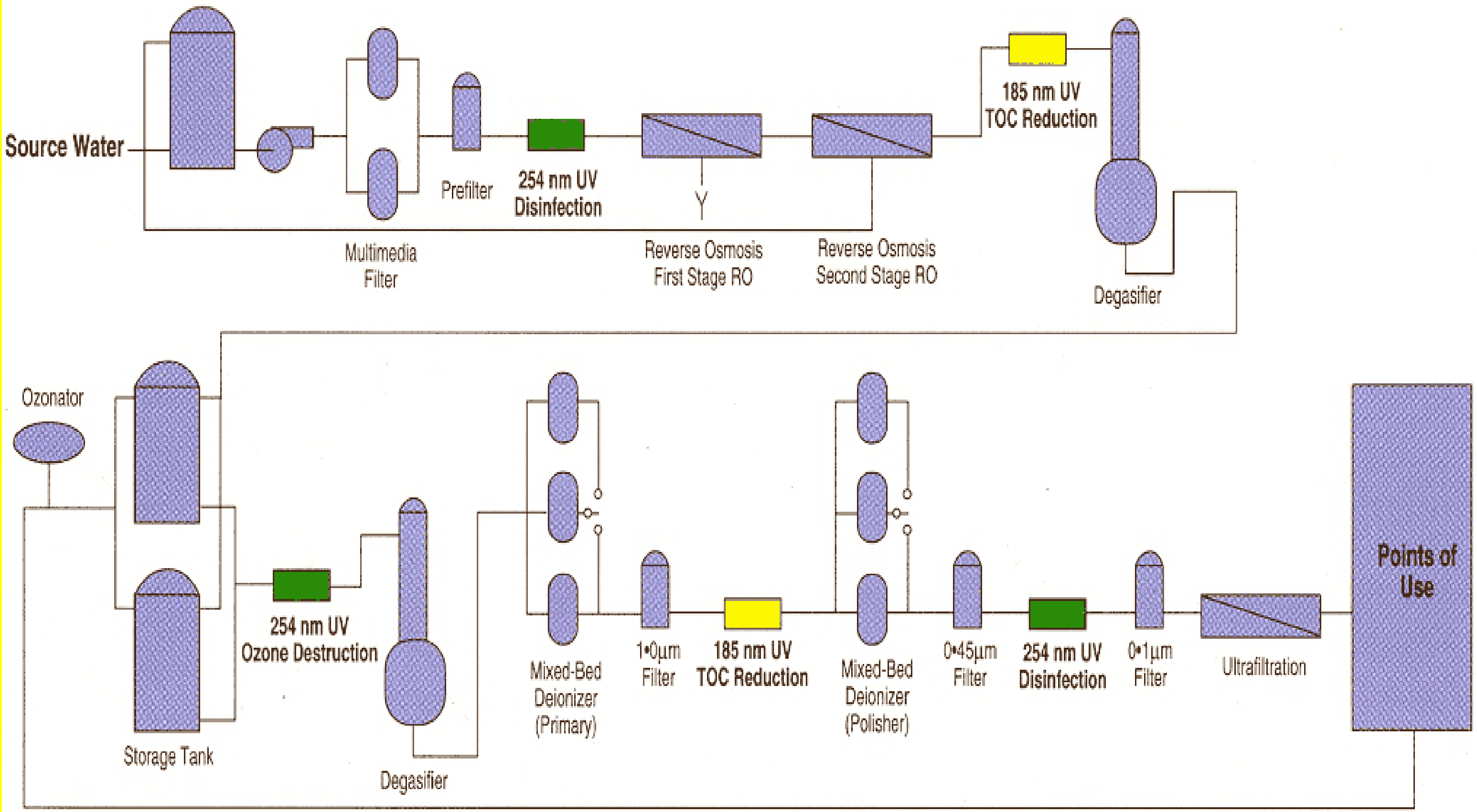
O&M Cost Component	First 5 Years (%)	Subsequent Years (%)
Chemicals	25	22
Membranes	19	24
Maintenance	23	33
Labor	25	16
Other costs	8	5
Total	0.110	0.174
	In US$ 2002 per m^3	In US$ 2002 per m^3

Source: (Velter, 2004).

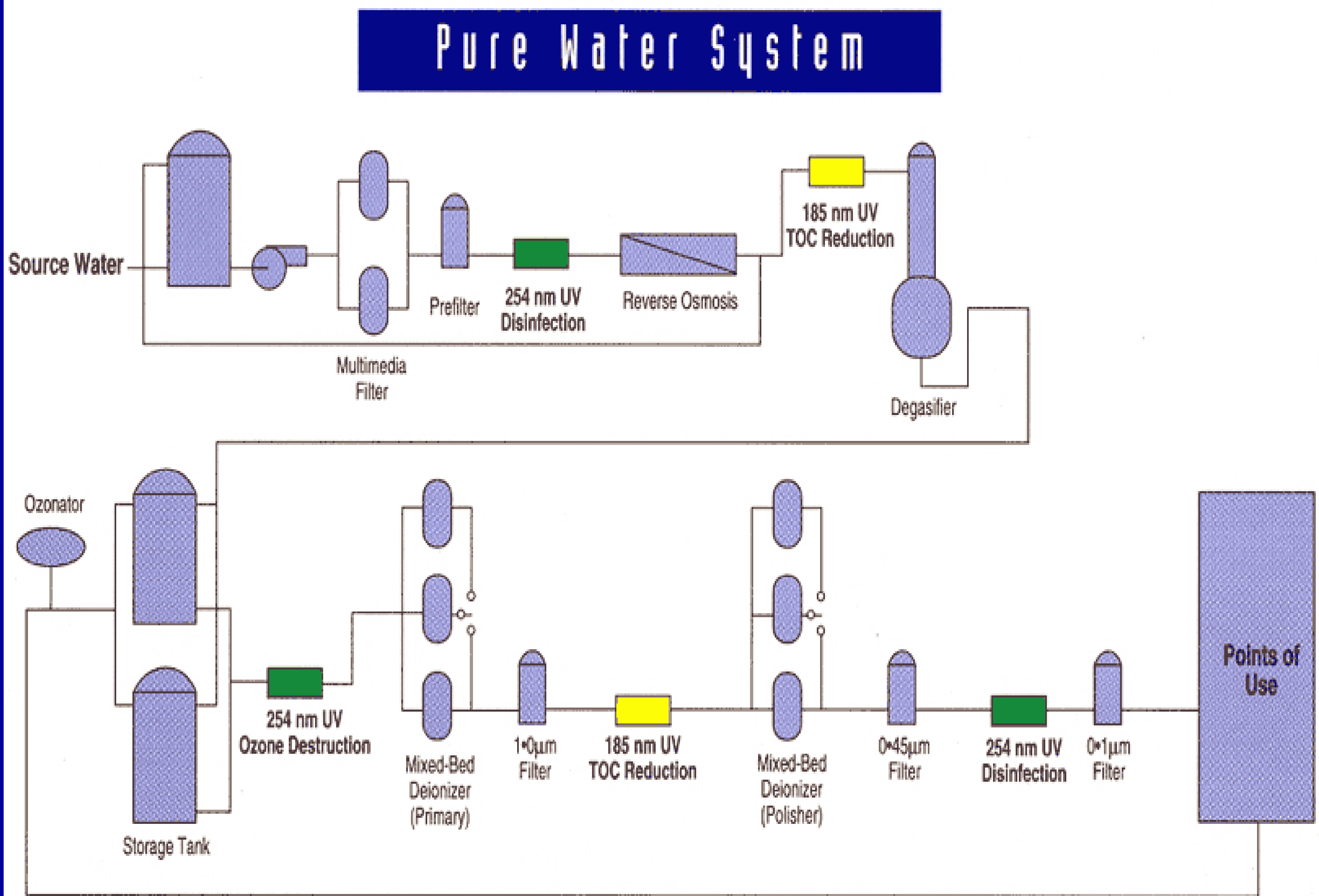
TABLE 1.3 Typical Performance of Toray's Brackish Water RO Elements

	Low Pressure		Ultralow Pressure	Super-ultralow Pressure
Type of Membrane	I	II	III	IV
Name of membrane element (in market: year)	SU-720 (1987)	SU-720L (1988)	SUL-G20 (1996)	SUL-H20 (1999)
Performance				
Salt rejection (%)	99.4	99.0	99.4	99.4
Water permeability (m^3/day)	26.0	22.0	26.0	26.0
Test condition				
Operating pressure (MPa)	1.5	1.0	0.75	0.5
Temperature (°C)	25	25	25	25
Feed concentration (mg/L)	1500	1500	1500	1500
Brine flow rate (L/min)	80	80	80	80

Ultrapure Water System

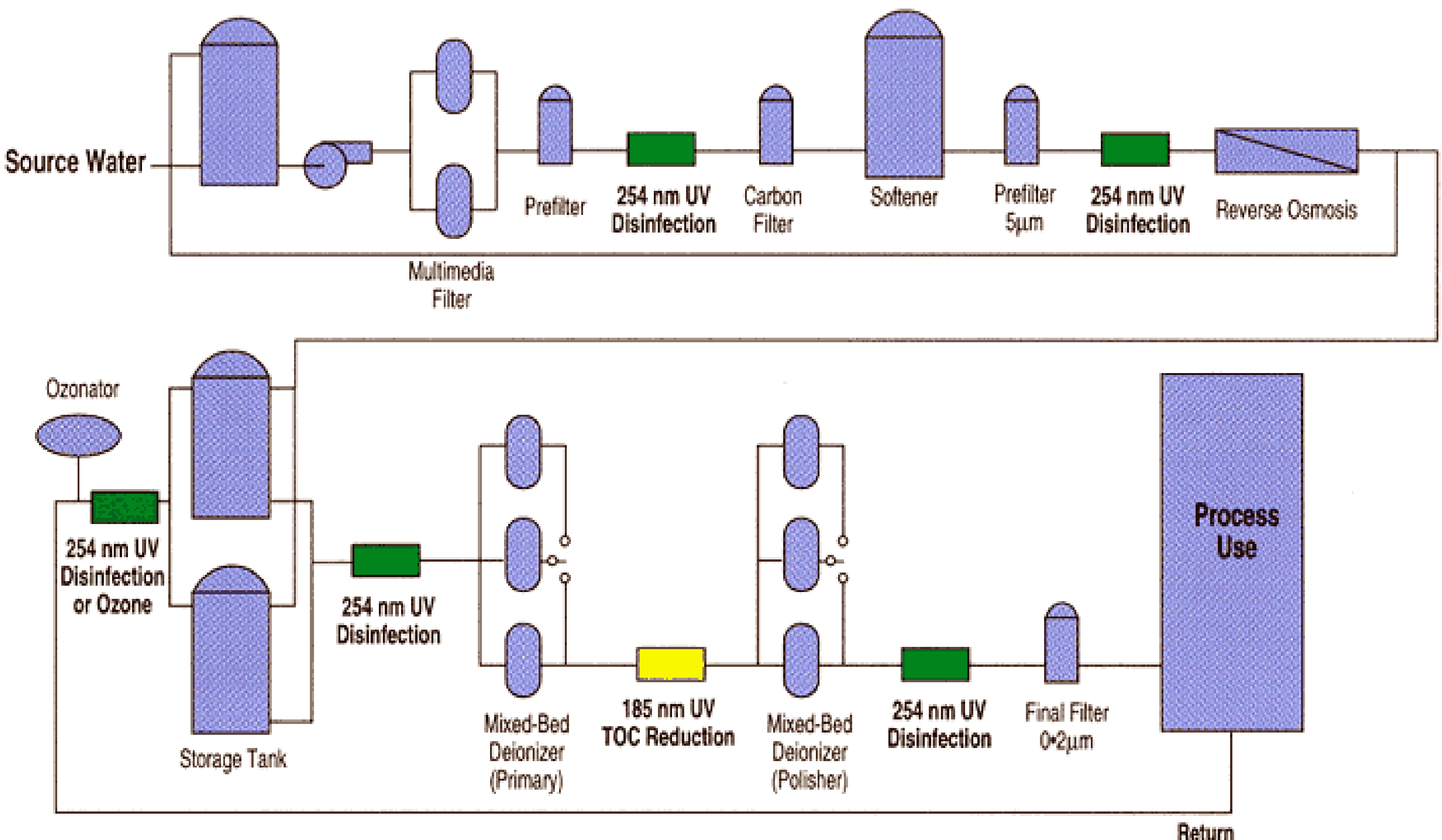


Treatment systems differ and are customized per application



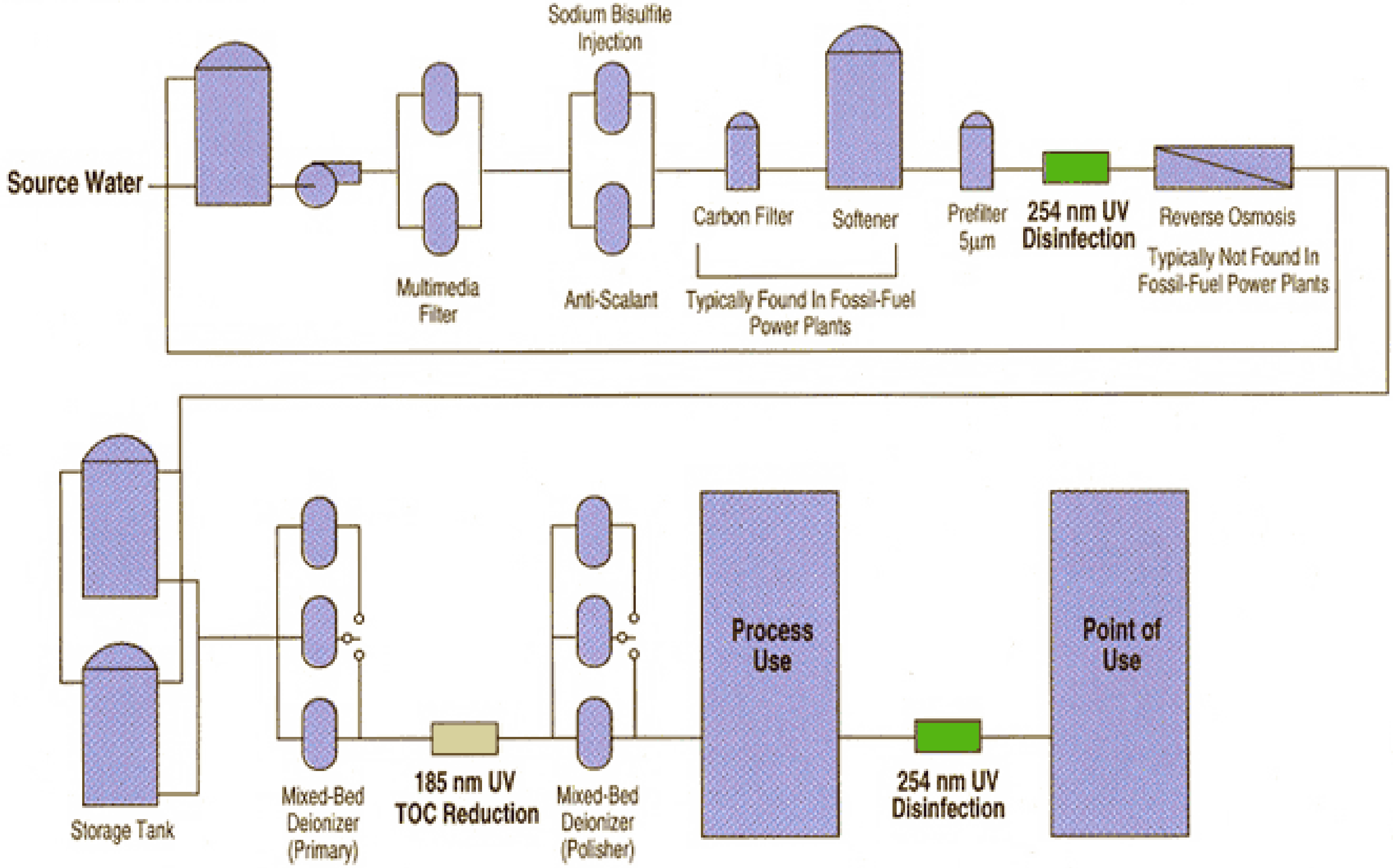
Treatment systems differ and are customized per application

Pharmaceutical Water Treatment System



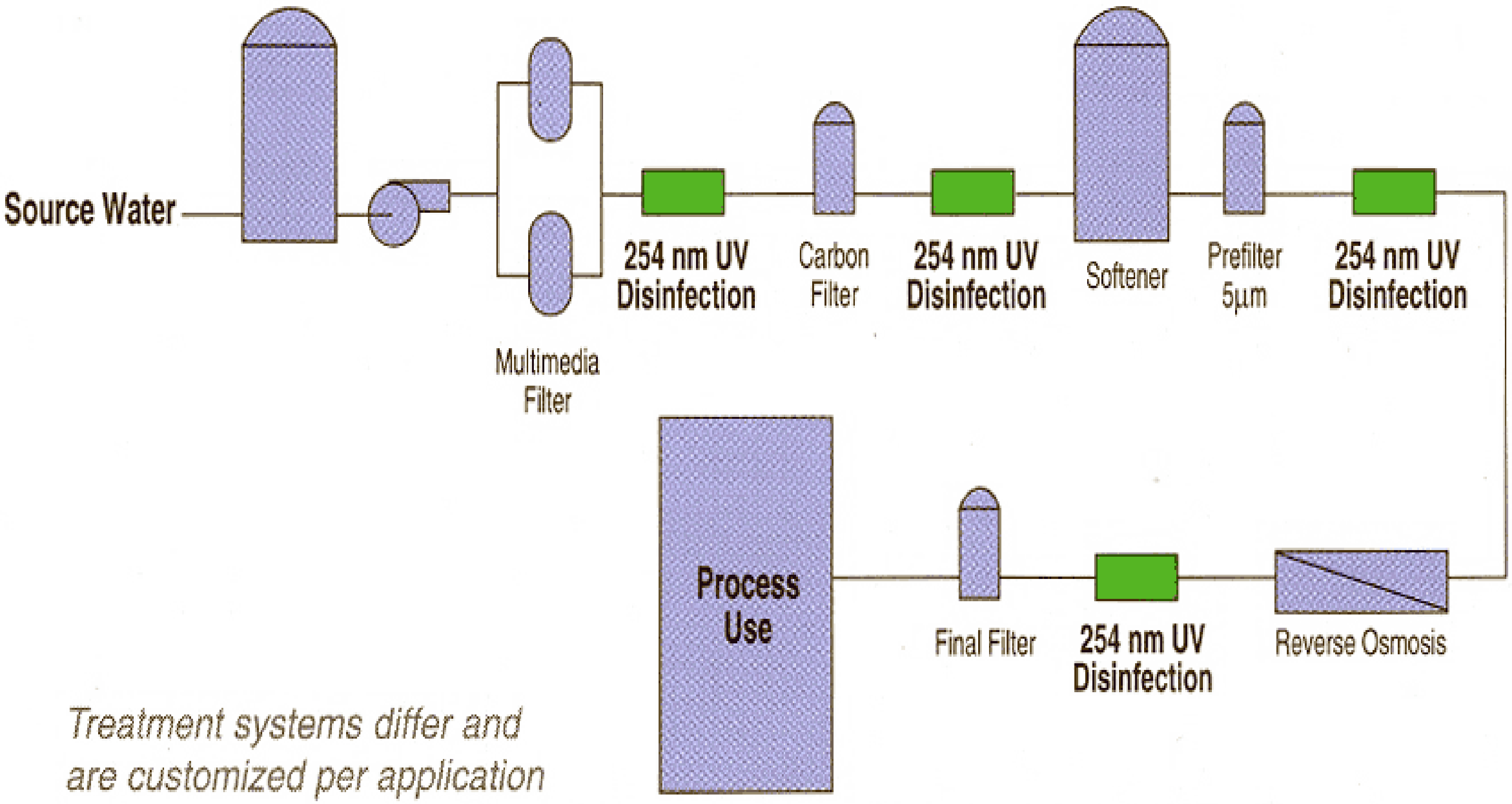
Treatment systems differ and are customized per application

Power Generation Water Treatment System



Treatment systems differ and are customized per application

Beverage Water Treatment System



Treatment systems differ and are customized per application

Reverse Osmosis

Operation and Maintenances

Presented by

Sawaeng Gerdpratoom
Numsai Thai Co;Ltd

ผลของการจัดเรียงเมมเบรน

ที่มีผลต่อการใช้พลังงานในการเดินระบบริเวอร์ออสโมซิส

แบบทดสอบ (Work Shop) การออกแบบระบบริเวอร์ออสโมซิส ขนาดกำลังผลิต 10 ลูกบาศก์เมตรต่อชั่วโมง (m^3/hr) โดยมีการจัดเรียงเมมเบรน 3 แบบดังตาราง

รูปแบบการจัดเรียงเมมเบรน	จำนวนท่อนเมมเบรน	น้ำป้อนเข้าระบบ (m^3/hr)	น้ำกรองที่ผลิตได้ (m^3/hr)	น้ำทิ้ง (m^3/hr)	Recovery R%	ขนาดปั๊ม HP (แรงม้า)	กำลังไฟฟ้า KW. (กิโลวัตต์)	ค่าไฟฟ้า (บาท/hr)	ค่าใช้จ่ายในการผลิตน้ำ (บาท/m^3)
1. เรียงแบบอนุกรมทั้งหมด (1x6) (ต.ย.3)	6	15.5	9.9	5.5	64	14.7	10.9	32.8	3.32
2. เรียงแบบอนุกรม 3 นำมาขนาน 2 (ต.ย.4)	6	28.9	11.6	17.4	40	27.5	20.5	61.5	5.3
3. เรียงแบบอนุกรม 2 นำมาขนาน 3 (ต.ย.5)	6	41.1	12.1	29	30	39.1	29.1	87.5	7.2

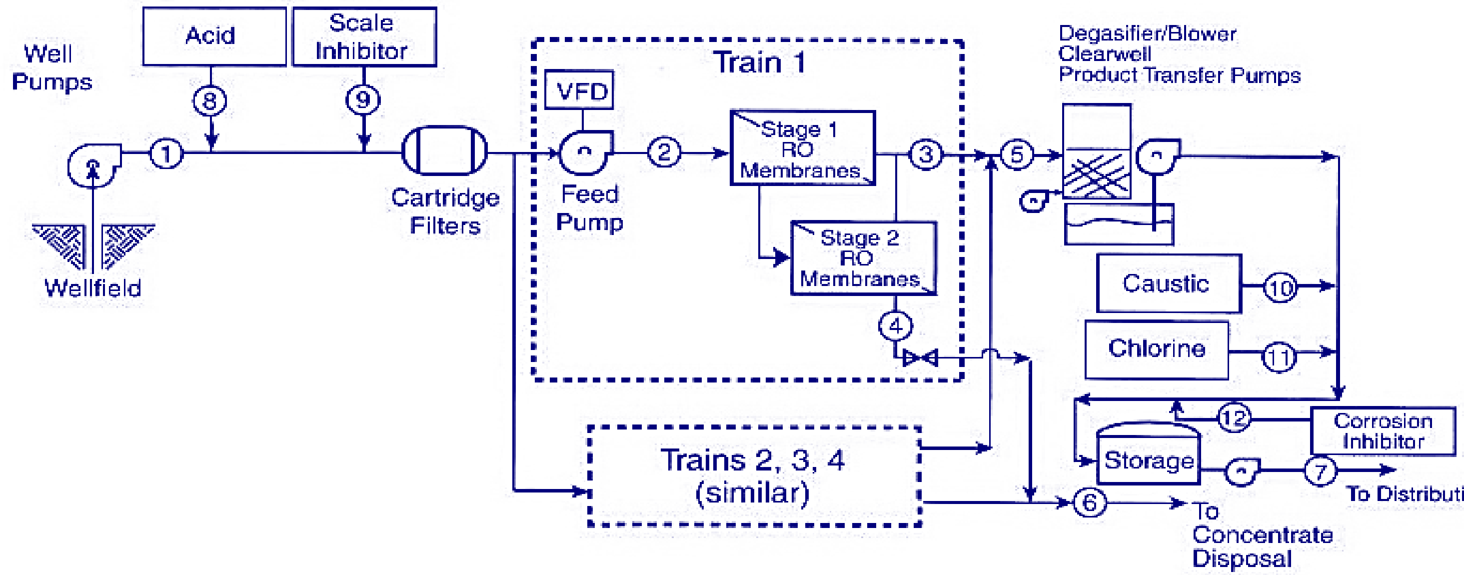
<u>หมายเหตุ</u> เงื่อนไขเมมเบรน *ESPA* 8 นิ้ว ยาว 40 นิ้ว จำนวน 6 ท่อน

น้ำป้อนเข้าระบบ TDS 2000 *ppm*

มีอุณหภูมิ 30 °*c*

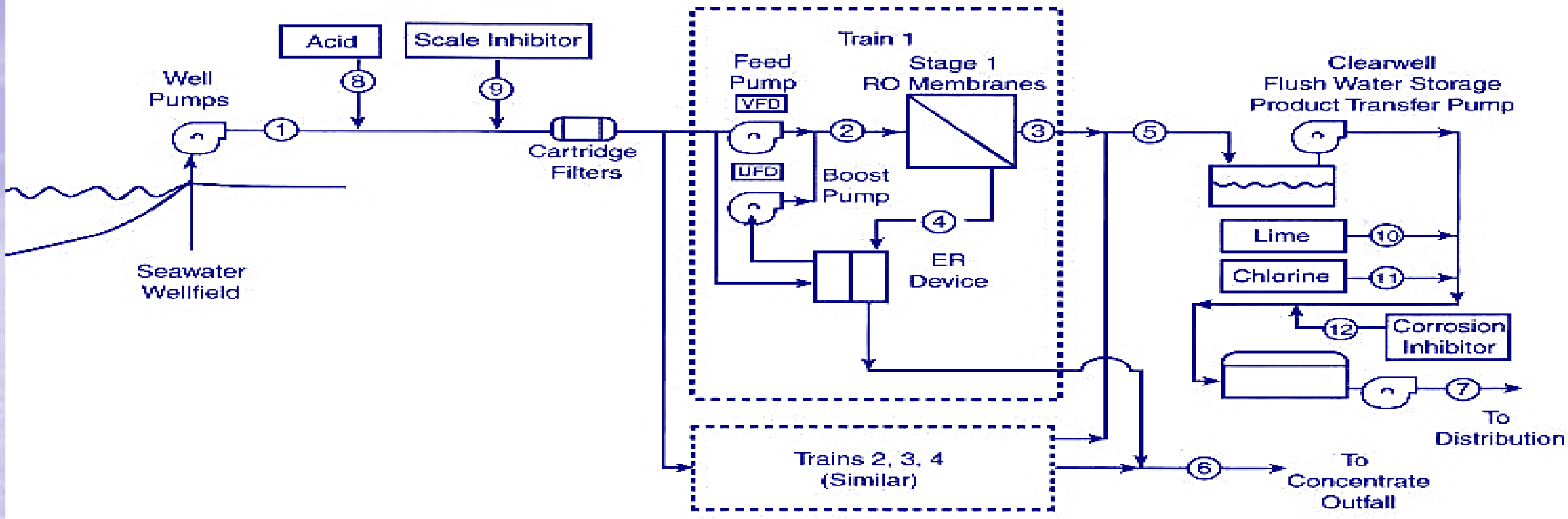
ใช้ความดัน 200 *psi*

ค่ากระแสไฟฟ้าหน่วยละ 3 บาท



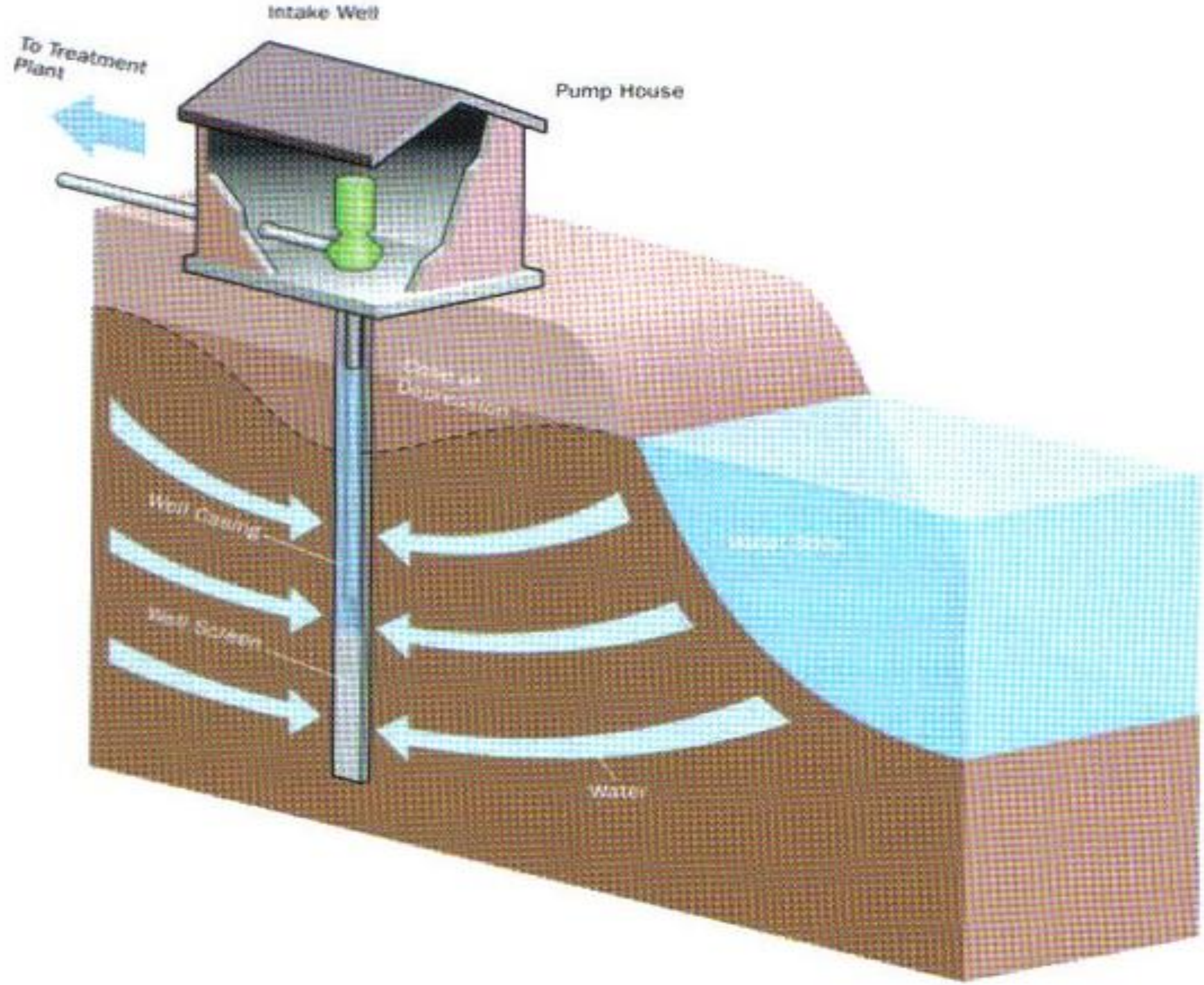
	1	2	3	4	5	6	7	8	9	10	11	12
Process Stream	Raw Water	Train Feed Water	Train Permeate	Train Concentrate	Total Permeate	Total Concentrate	Finished Water	Acid (H_2SO_4)	Scale Inhibitor	Caustic	Chlorine	Corrosion Inhibitor
Flow, *mgd*	12.5	3.125	2.5	0.625	10.0	2.5	10.0					
Pressure, *psi*	50	215	15	165	15	30	80					
TDS, *mg/L*	2,000	1,995	70	9,695	70	9,695	85					
Dose, *mg/L* (100% concentration)								20	4	10	2	1

Figure 3-34 Brackish groundwater reference design

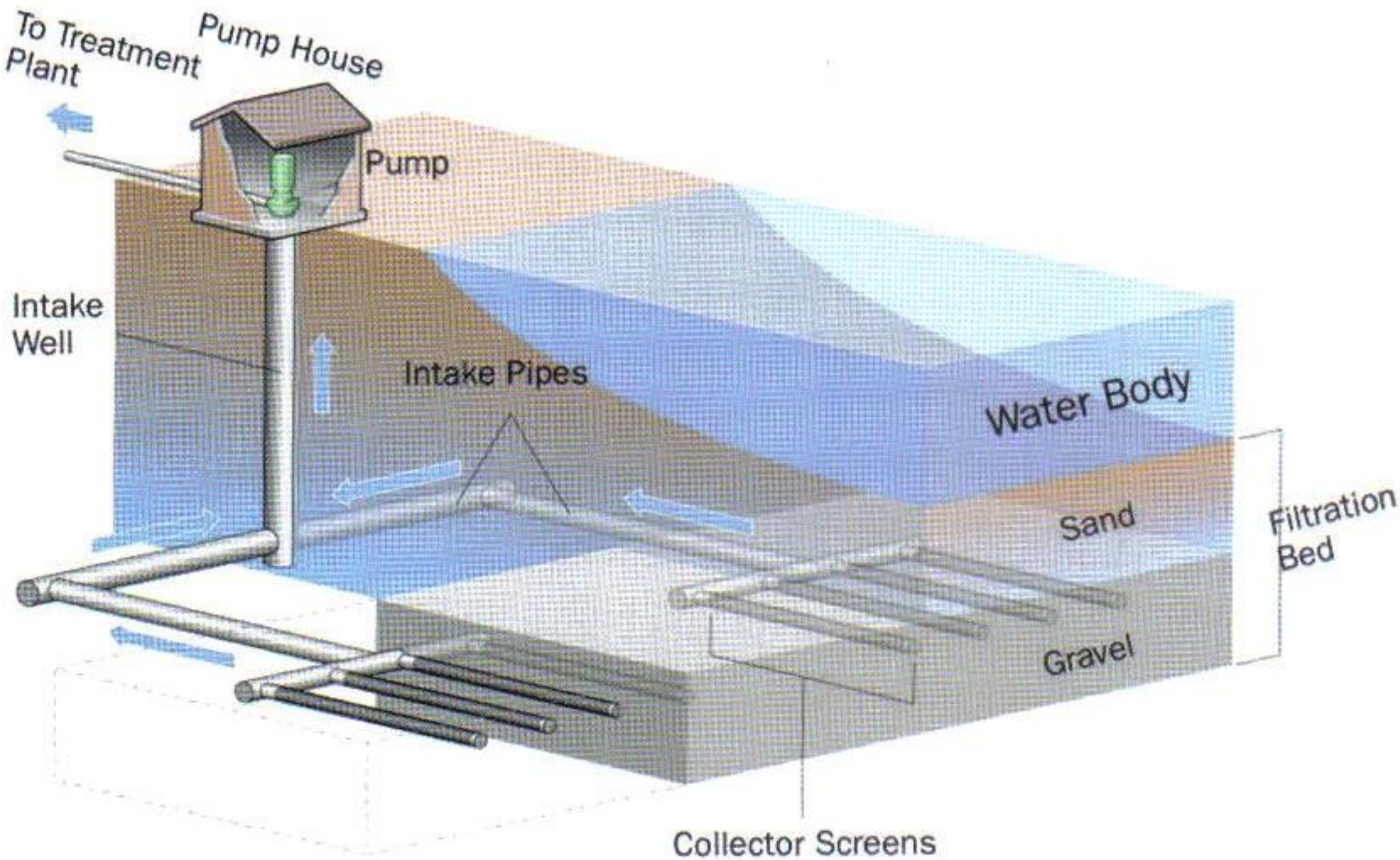


	1	2	3	4	5	6	7	8	9	10	11	12
Process Stream	Raw Water	Train Feedwater	Train Permeate	Train Concentrate	Total Permeate	Total Concentrate	Finished Water	Acid (H_2SO_4)	Scale Inhibitor	Lime	Chlorine	Corrosion Inhibitor
Flow, *mgd*	22.2	5.56	2.5	3.06	10.0	12.2	10.0					
Pressure, *psi*	50	950	10	925	10	20	80					
TDS, *mg/L*	35,000	35,000	185	63,500	185	63,500	190					
Dose, *mg/L* (100% concentration)								5	4	5	2	1

Seawater reference design



Vertical intake well



Riverbed/seabed filtration system

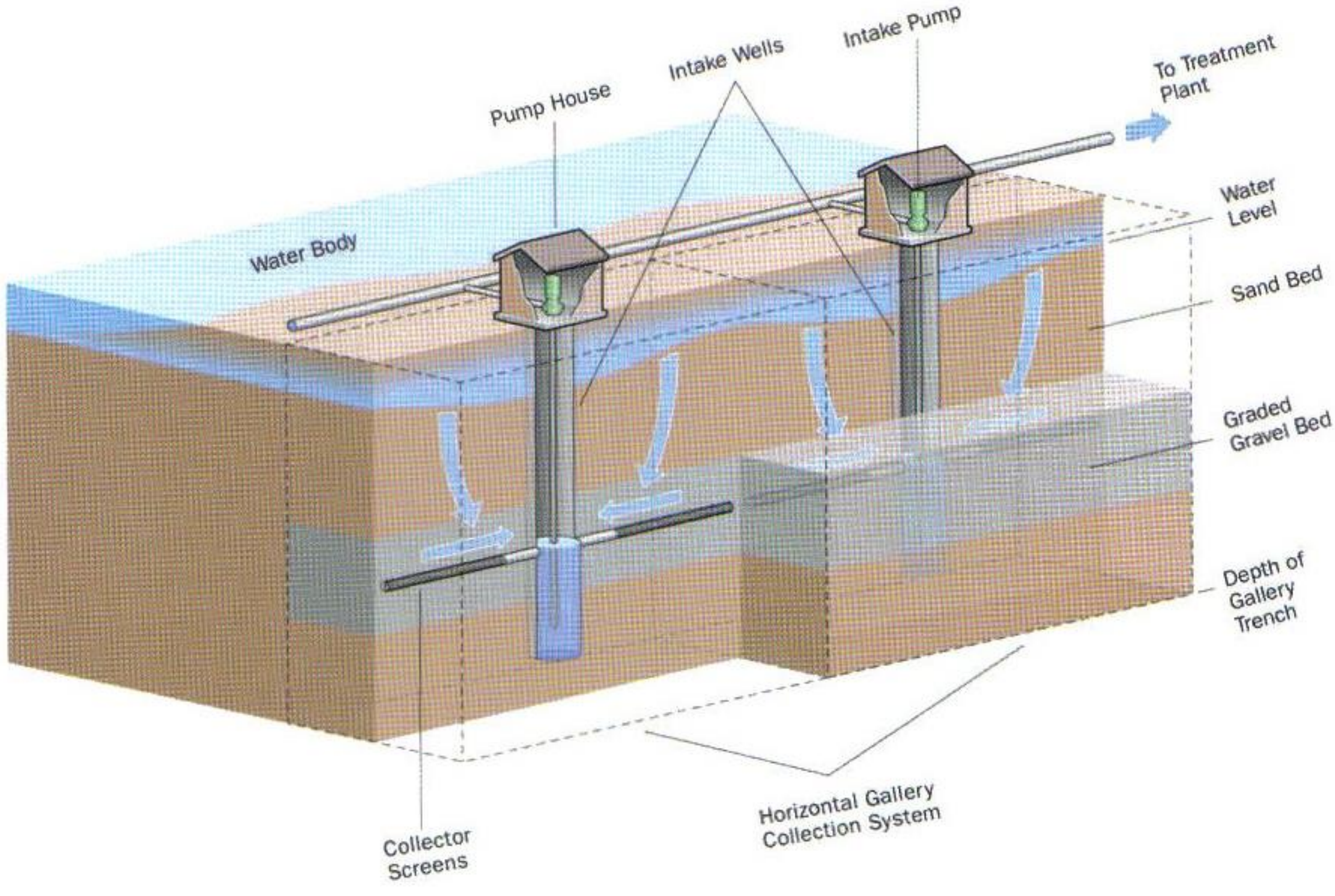
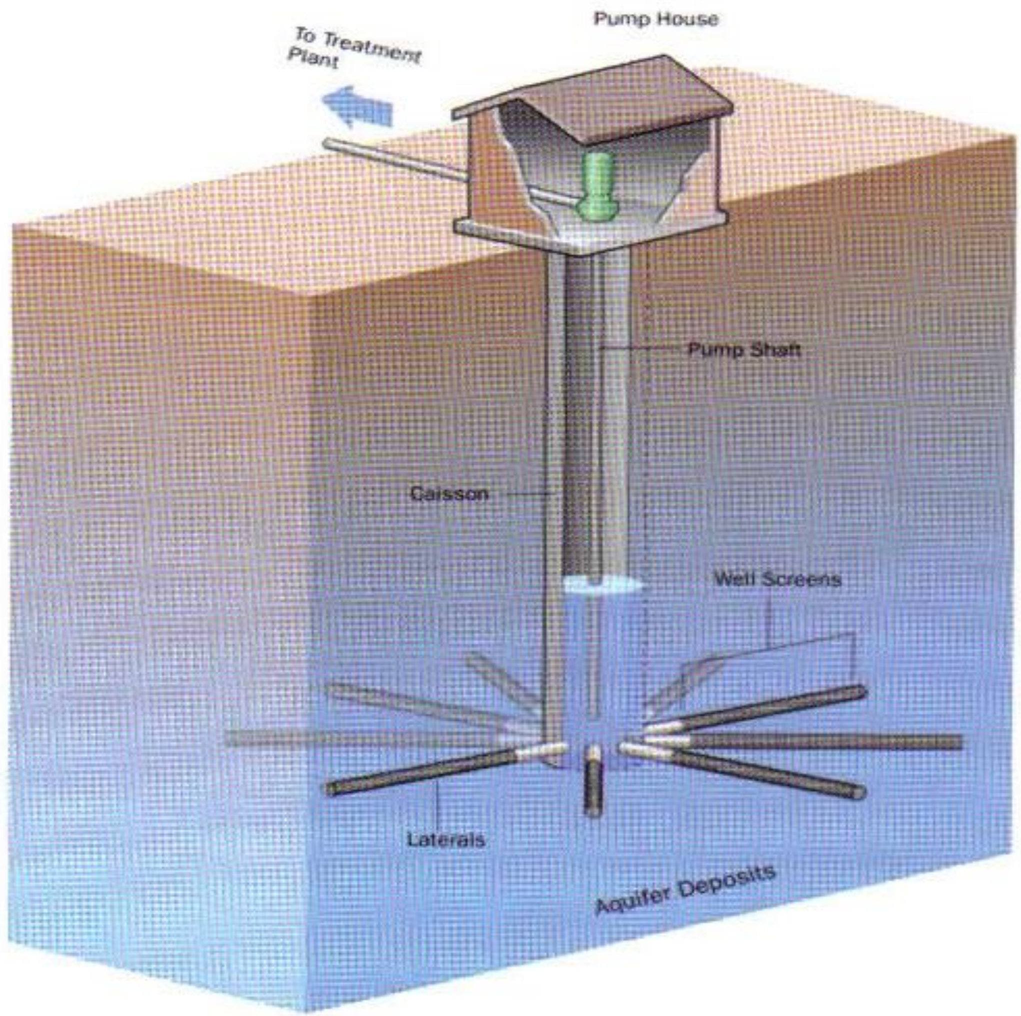


Figure 3-6 Infiltration gallery



Horizontal radial collector well

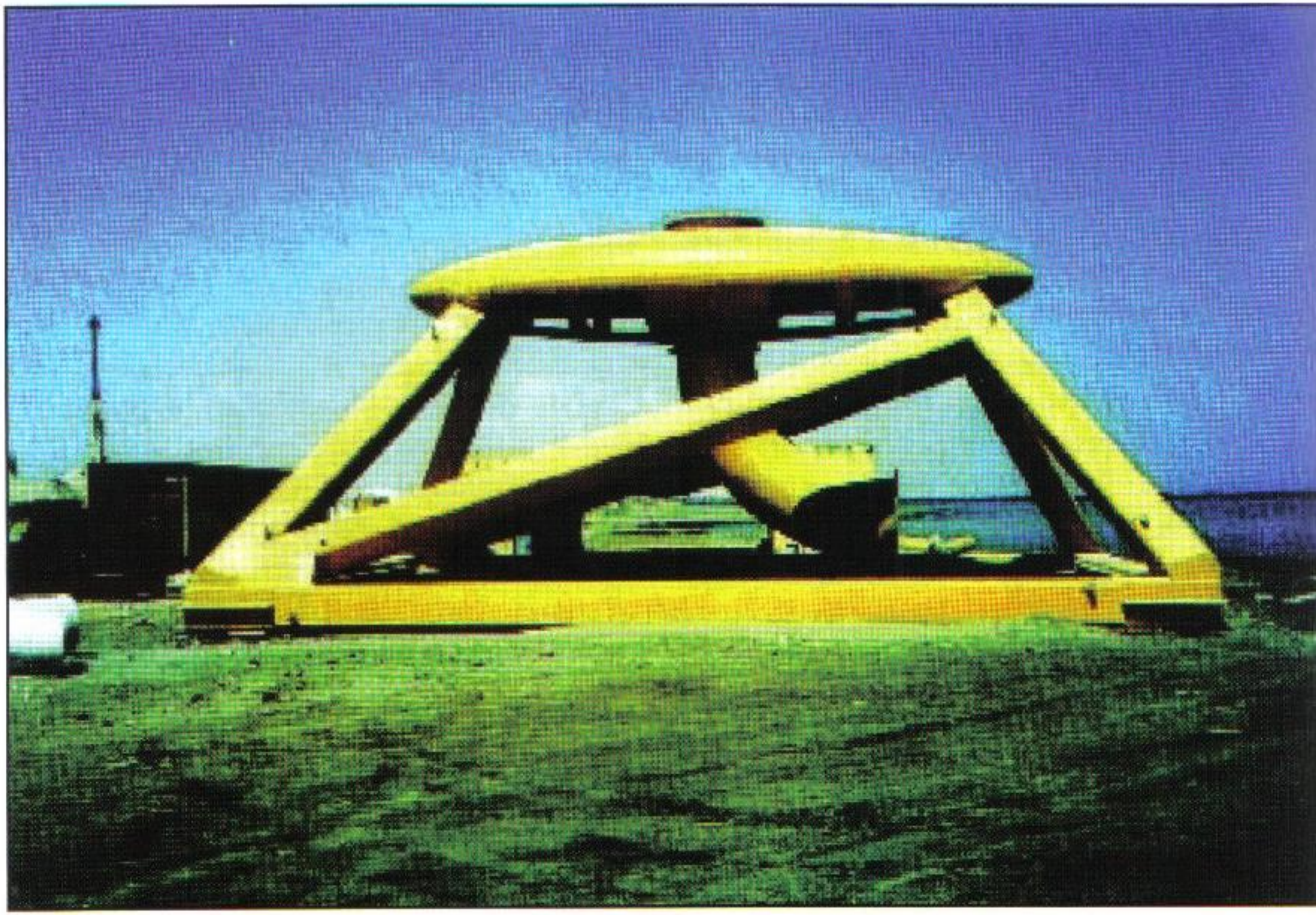
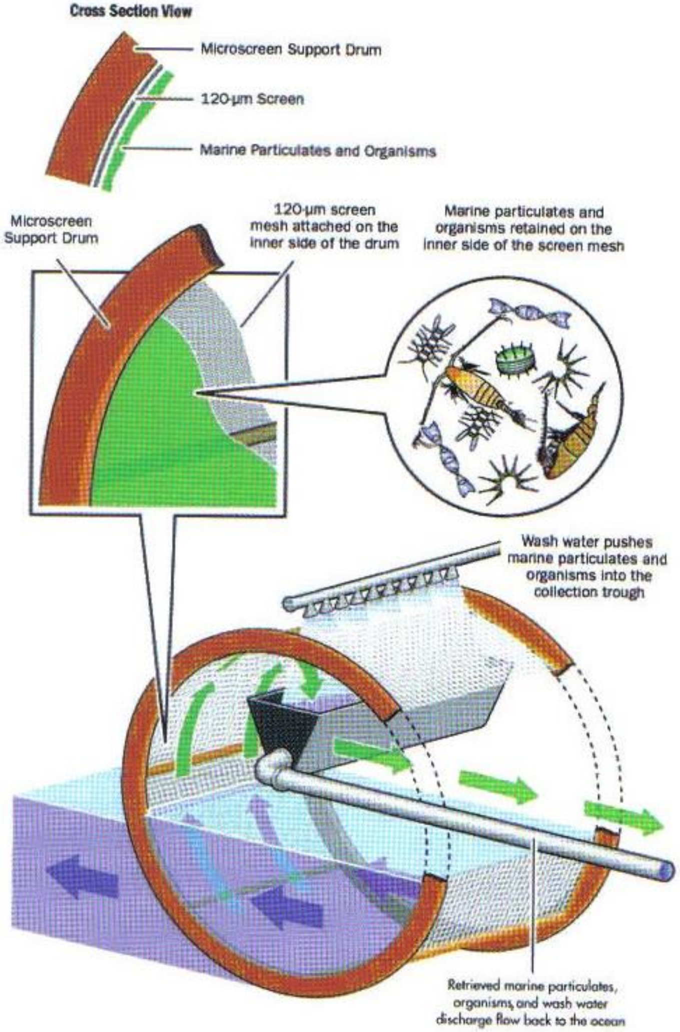


Figure 3-9 Off-shore intake structure, Larnaca, Cyprus



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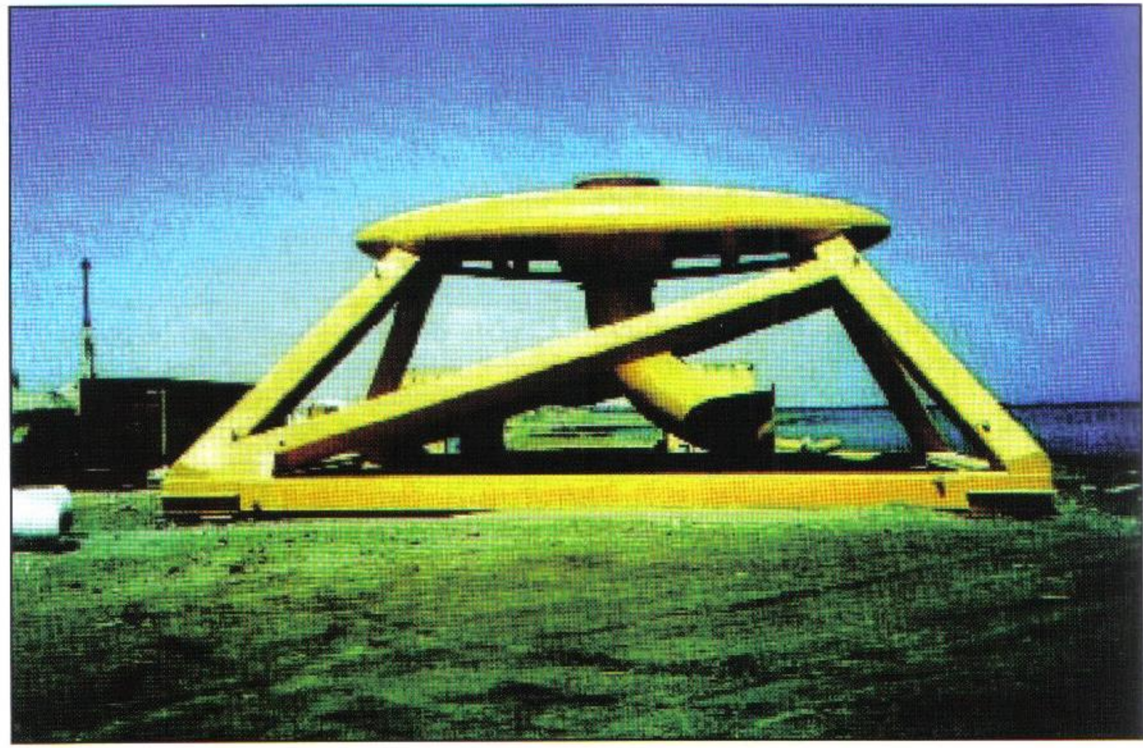
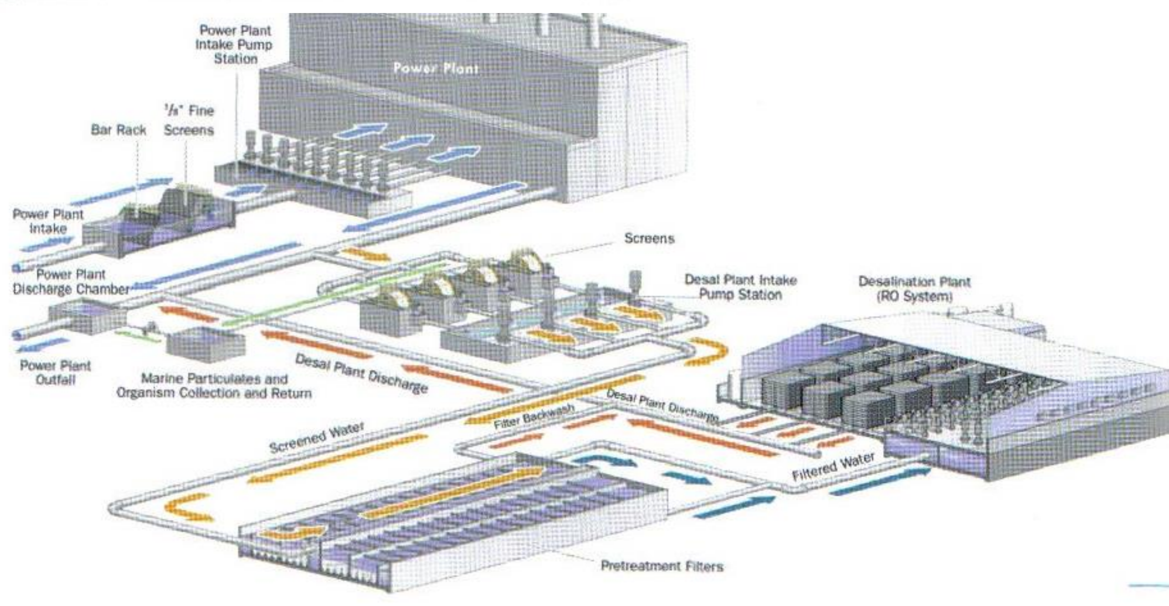


Figure 3-9 Off-shore intake structure, Larnaca, Cyprus



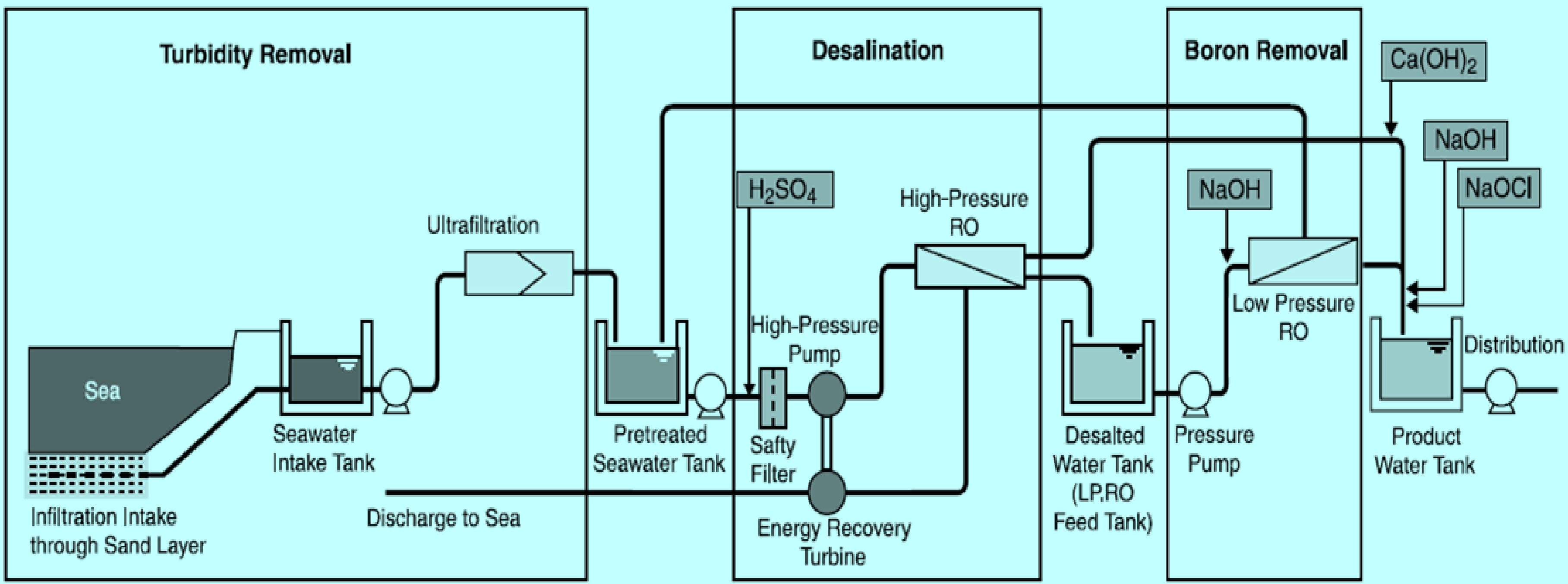


Figure 2.21 Process flow diagram and membrane arrangement.

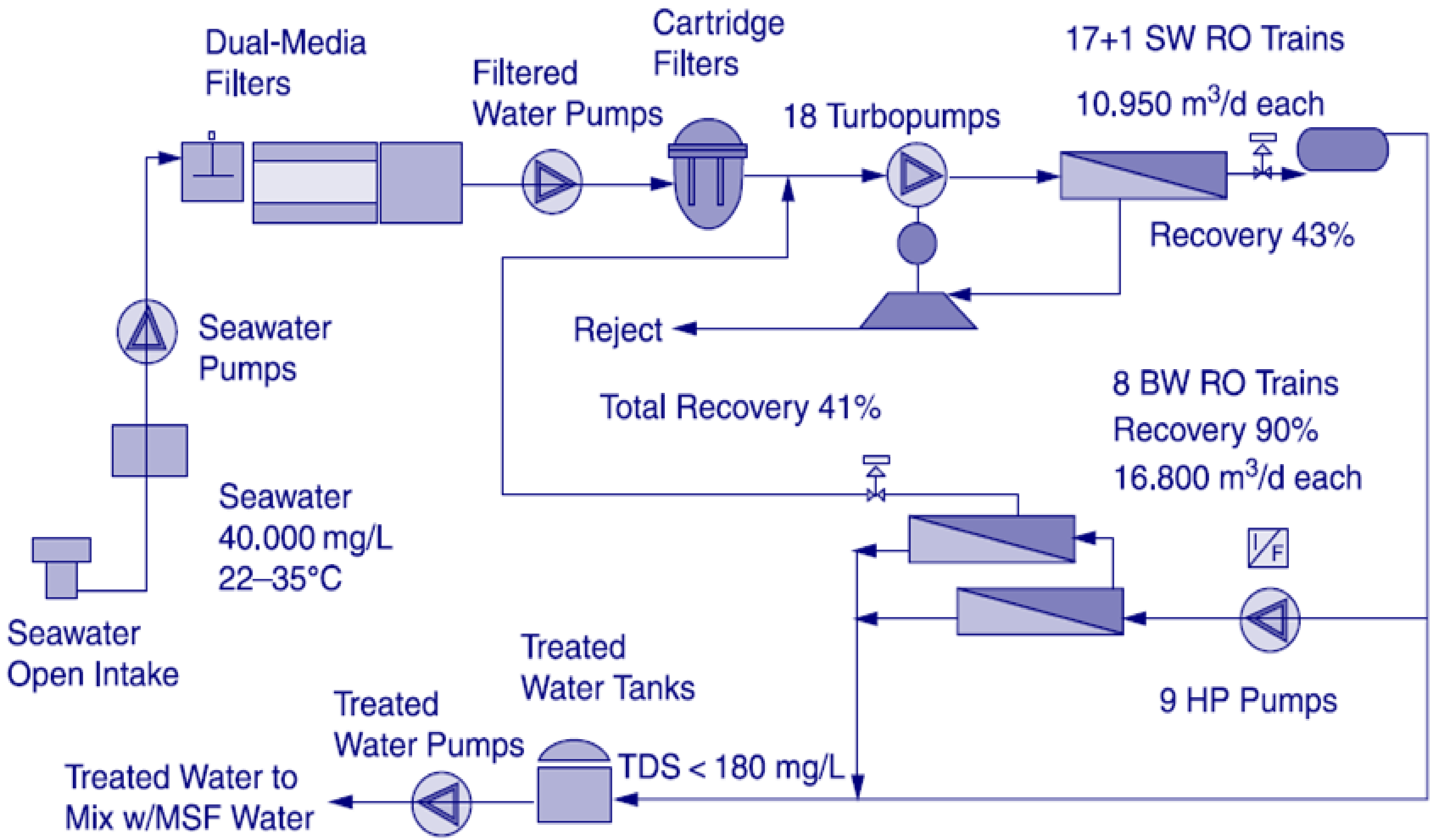


Figure 3.10 Fujairah seawater desalination plant schematic. (From Rovel, 2003.)

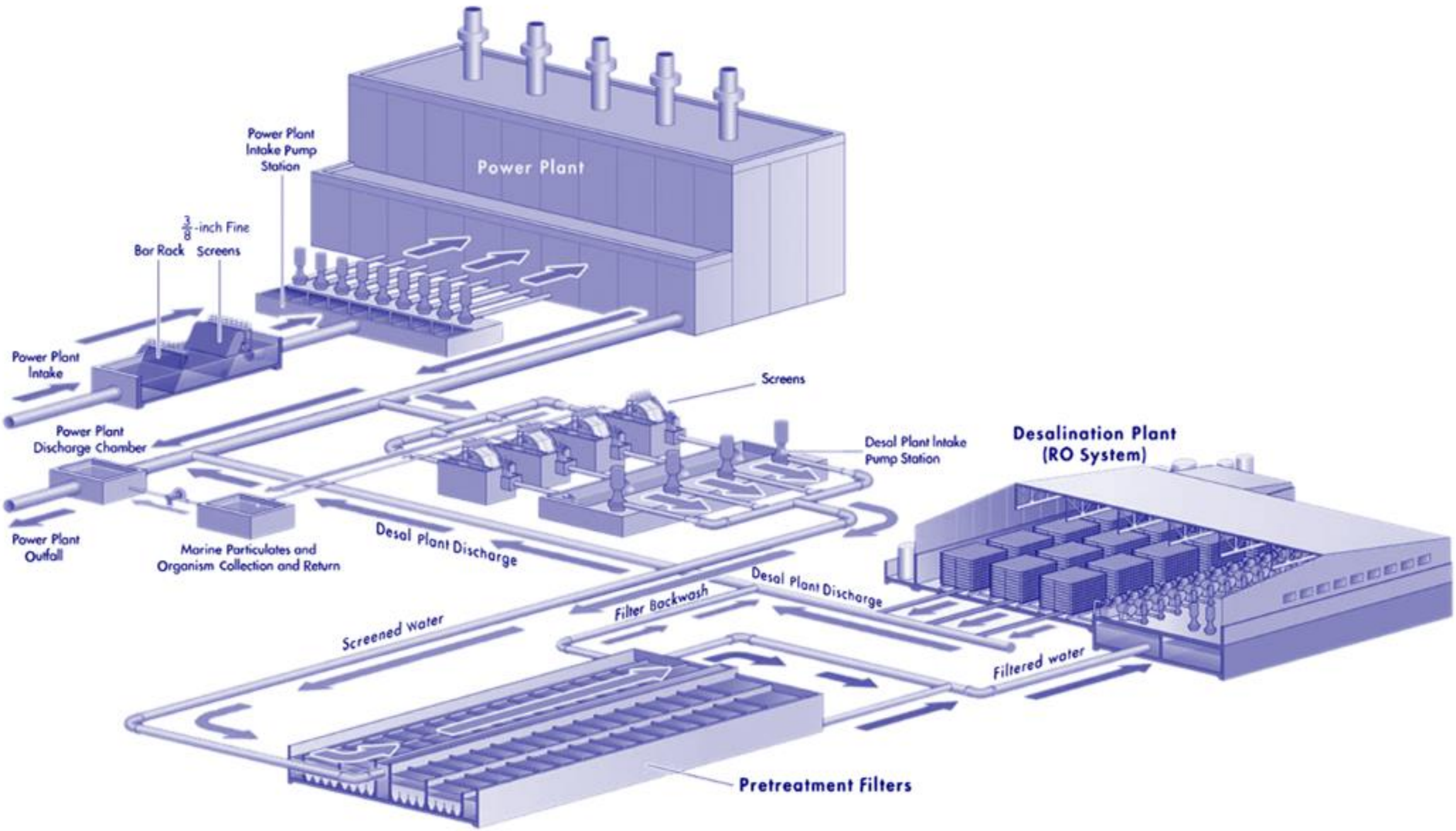
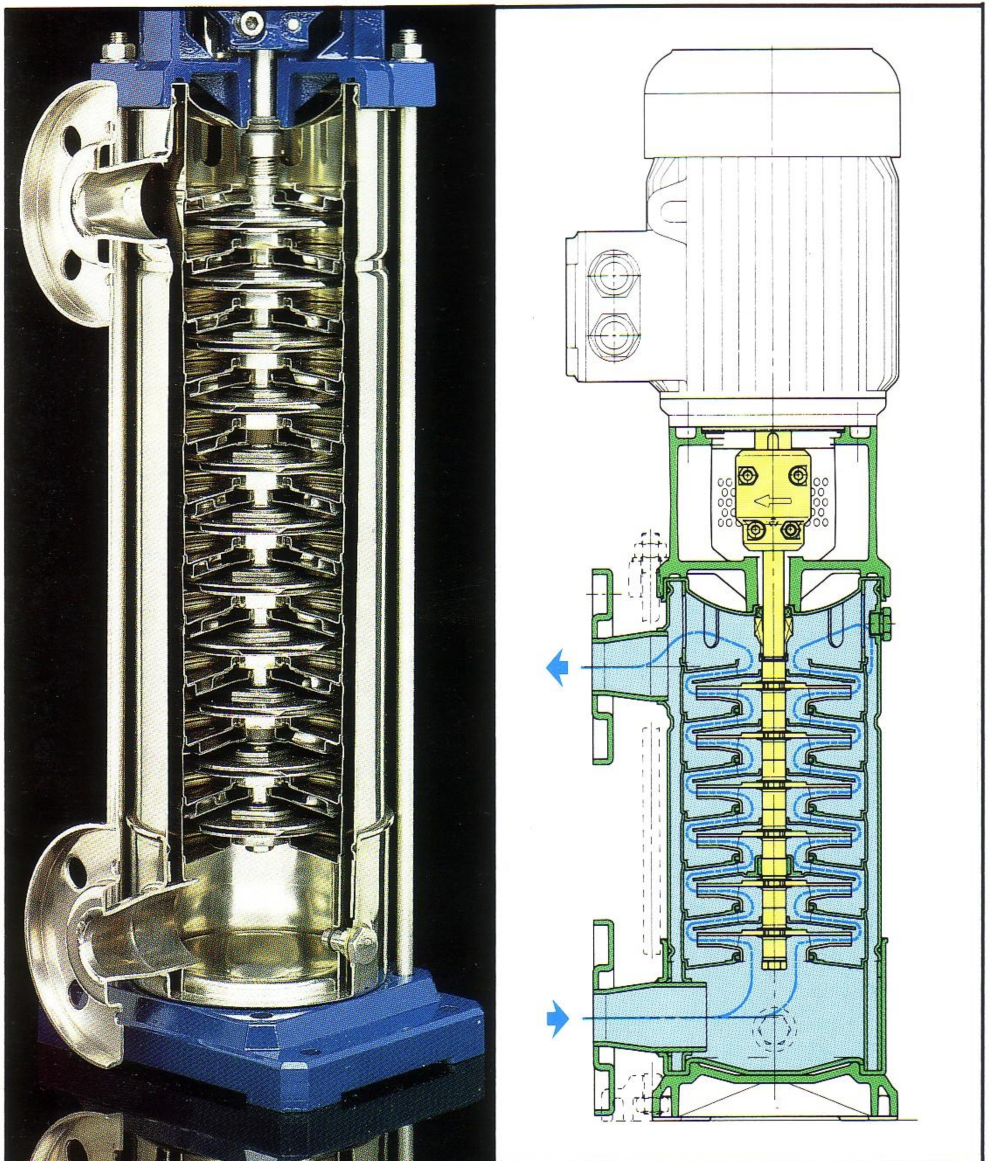
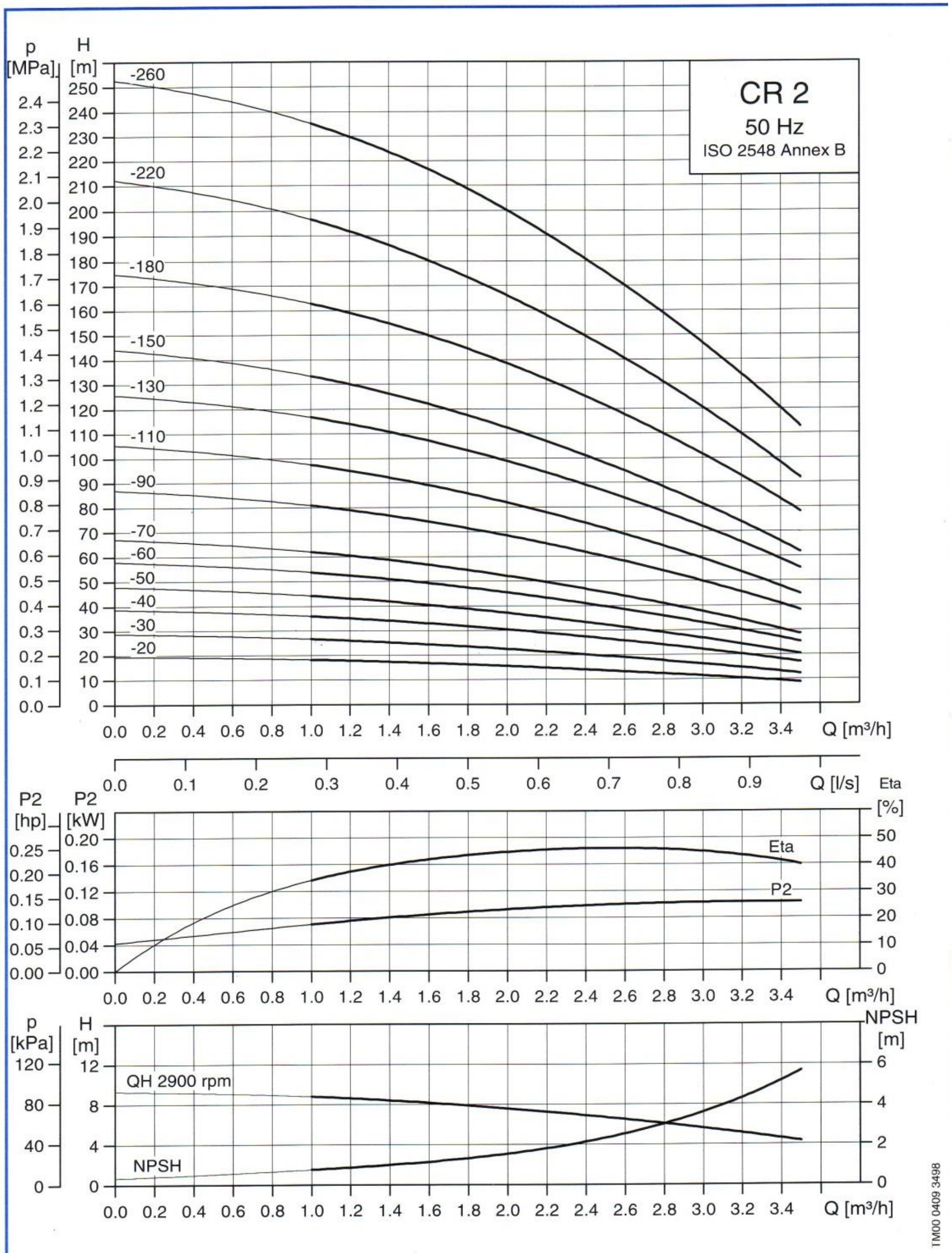


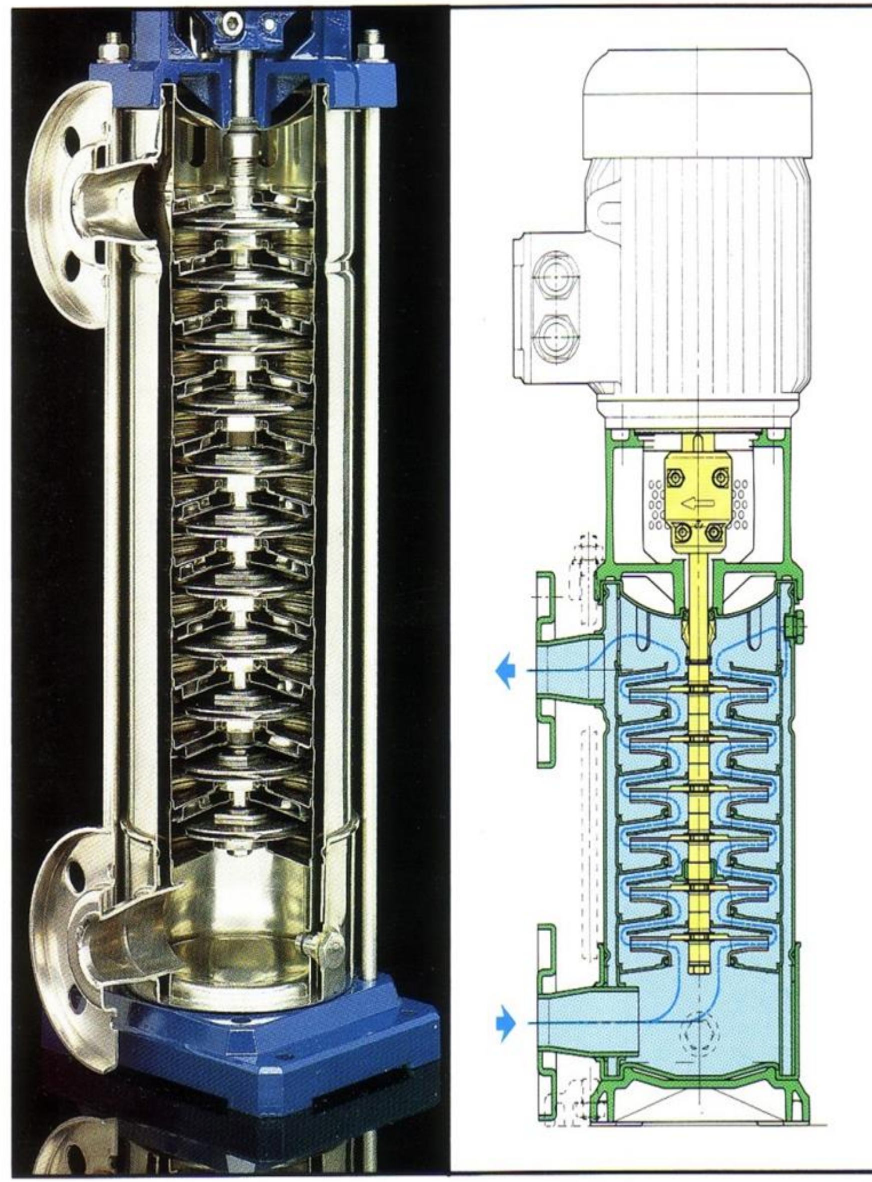
Figure 3.4 Colocation of desalination and power plant intake and discharge.



Bocca di mandata nella
versione a bocche sovrapposte.

Suction port,
top and bottom design.

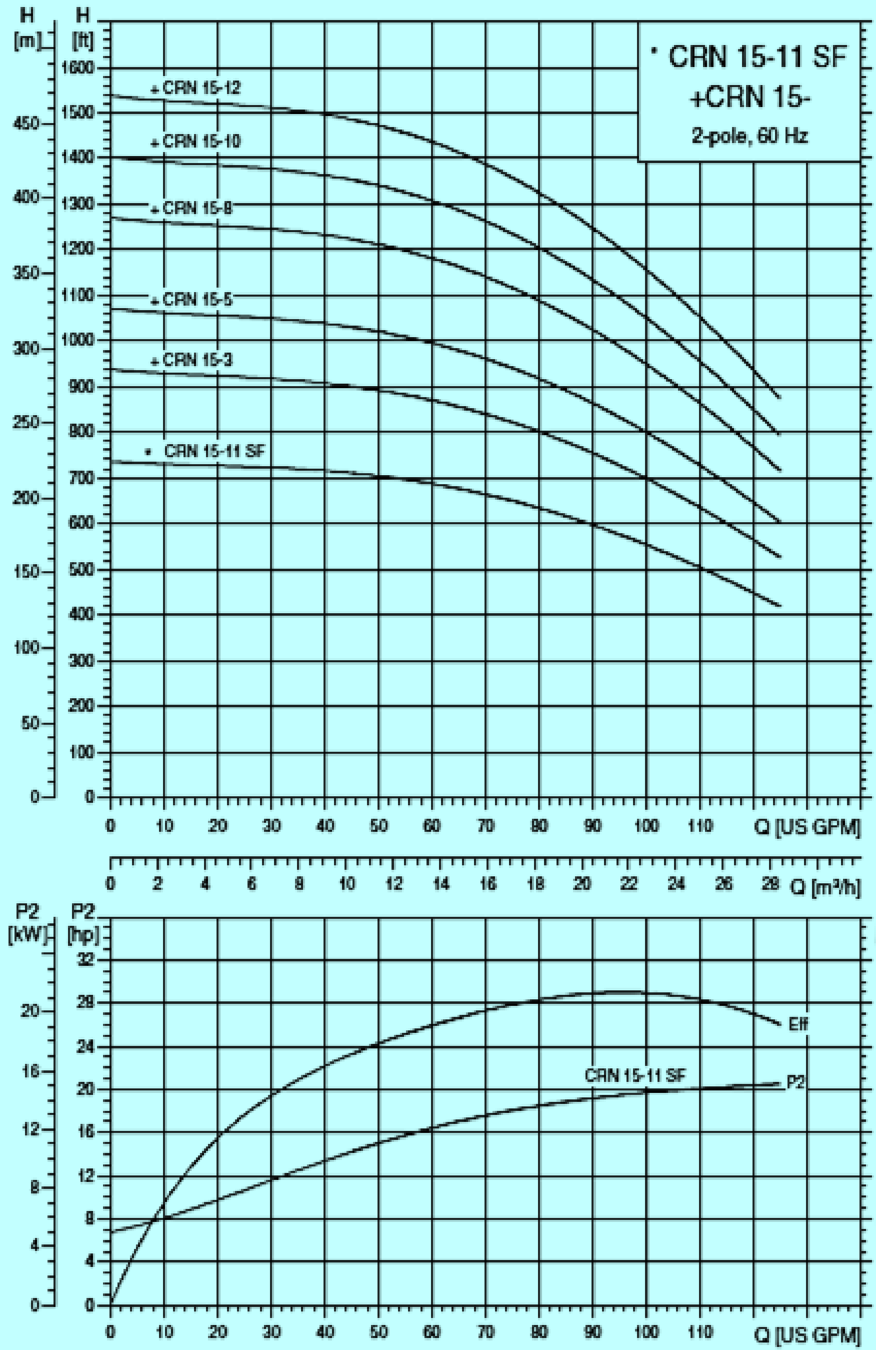




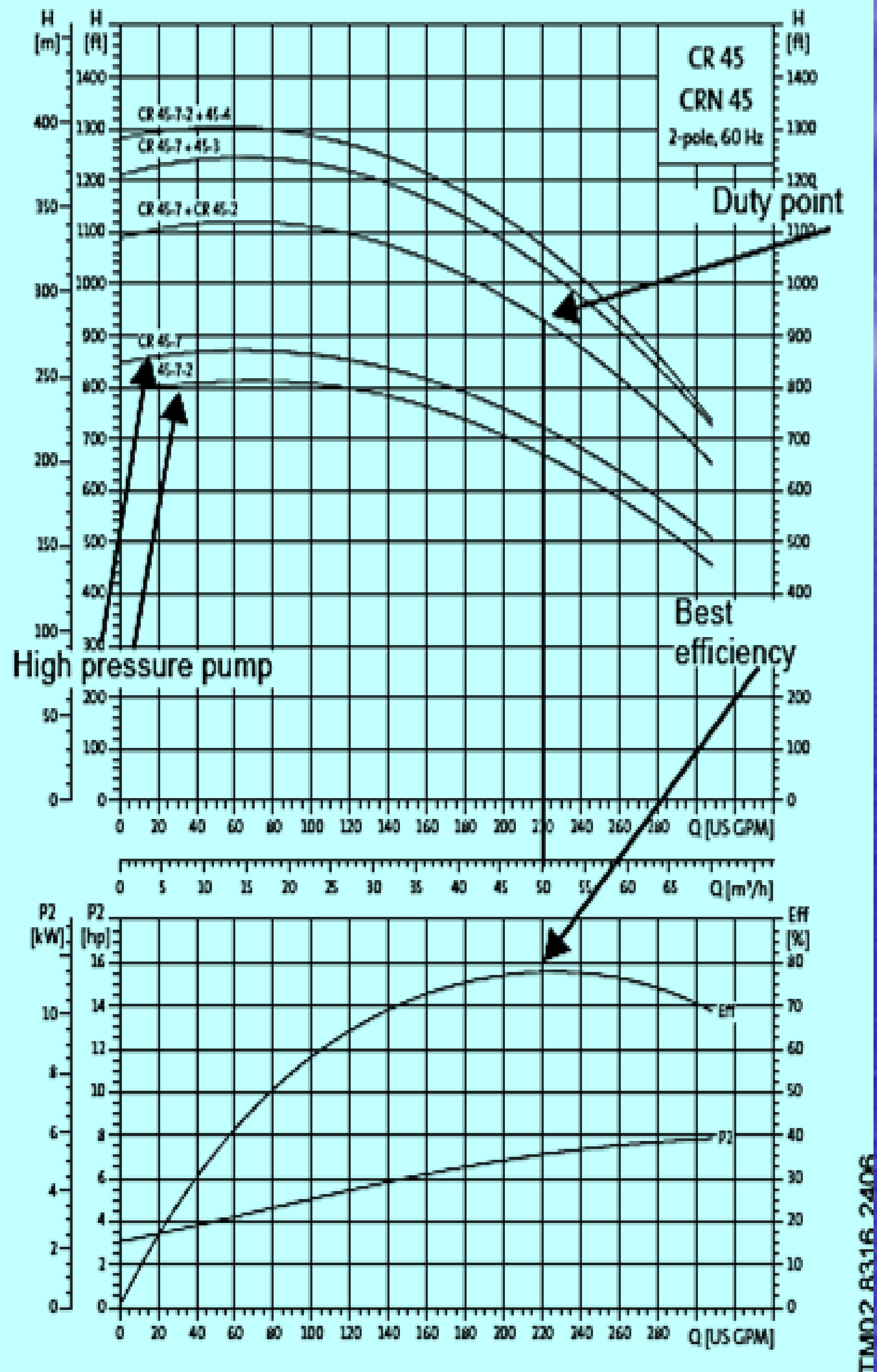
Bocca di mandata nella versione a bocche sovrapposte.

Suction port, top and bottom design.

CRN 15-SF



* CRN 15-11 SF
+CRN 15-
2-pole, 60 Hz
+ CRN 15-12
+ CRN 15-10
+ CRN 15-8
+ CRN 15-5
+ CRN 15-3
* CRN 15-11 SF
H [m]
H [ft]
Q [US GPM]
Q [m³/h]
P2 [kW]
P2 [hp]
Eff [%]
Eff
P2
CRN 15-11 SF



CR 45
CRN 45
2-pole, 60 Hz
Duty point
High pressure pump
Best efficiency
H [m]
H [ft]
Q [US GPM]
Q [m³/h]
P2 [kW]
P2 [hp]
Eff [%]
Eff
P2
TM02 8316 2406

- Hydraulic Horsepower $= \dfrac{(GPM)\ (HEAD)\ (SPGR)}{3{,}960}$

Where

GPM	=	Pump flow rate in gallons per minute
HEAD	=	Differential head in feet of water
	=	1 feet = 0.433 psi
SPGR	=	Specific gravity of the fluid
		Sea water = 1.02
		Concentrate = 1.03

- Pump Shaft Horsepower $= \dfrac{\text{Hydraulic HP}}{\text{Pump eff}}$

- Pump Moter Horsepower $= \dfrac{\text{Pump shaft HP}}{\text{Moter eff}}$

1 HP = 0.7457 kW.

Reverse Osmosis

Fouling and Cleaning

Presented by

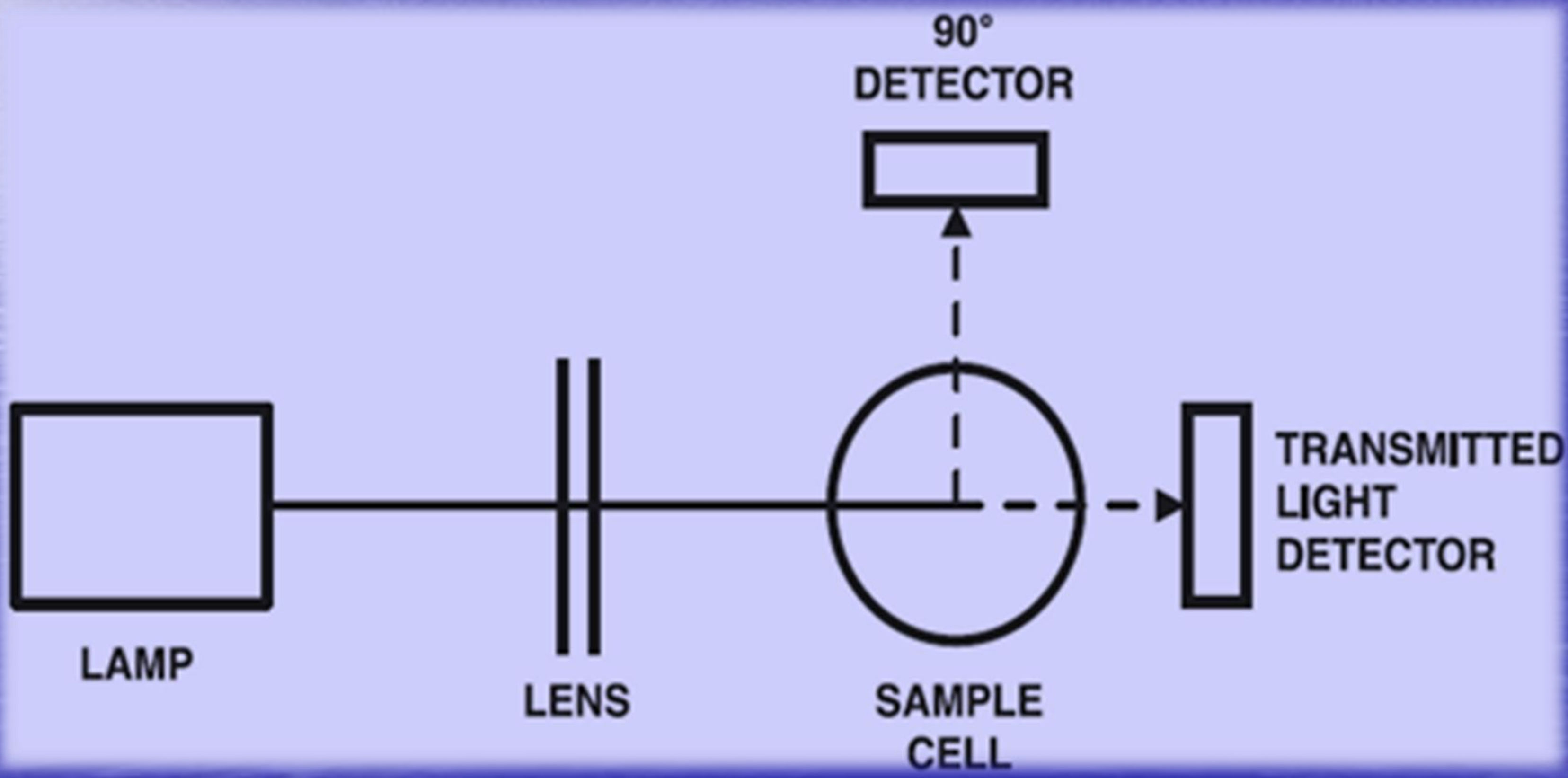
Sawaeng Gerdpratoom
Numsai Thai Co;Ltd

- การอุดตันเนื่องจากตะกอนและสารแขวนลอย (Suspended Solids)
- การอุดตันเนื่องจากคอลลอยด์ (Colloids)
- การอุดตันเนื่องจากการตกผลึก (Membrane Scaling)
- การอุดตันเนื่องจากออกไซด์ของโลหะ (Metal Oxide)
- การอุดตันเนื่องจากสารอินทรีย์ (Organic)
- การอุดตันเนื่องจากจุลินทรีย์ (Microbioorganism)

Example of composition and concentration ranges of constituents in the municipal tertiary effluent (membrane filtration effluent).

Parameter	Units	Concentration
Turbidity	NTU	01.–0.5
pH		6.0–80
Conductivity	S/cm	700–2000
TOC	mg/l	5–15
Ammonia	mg/l	0–20
Chloride	mg/l	60–380
Nitrate	mg/l	5–60
Fluoride	mg/l	0.5–2.0
Sulfate	mg/l	50–110
Calcium	mg/l	30–60
Sodium	mg/l	90–350
Alkalinity (as $CaCO_3$)	mg/l	50–250
Silica (as SiO_2)	mg/l	7–10
Phosphate (as PO_4)	mg/l	1–15

Turbid meter Design Concept

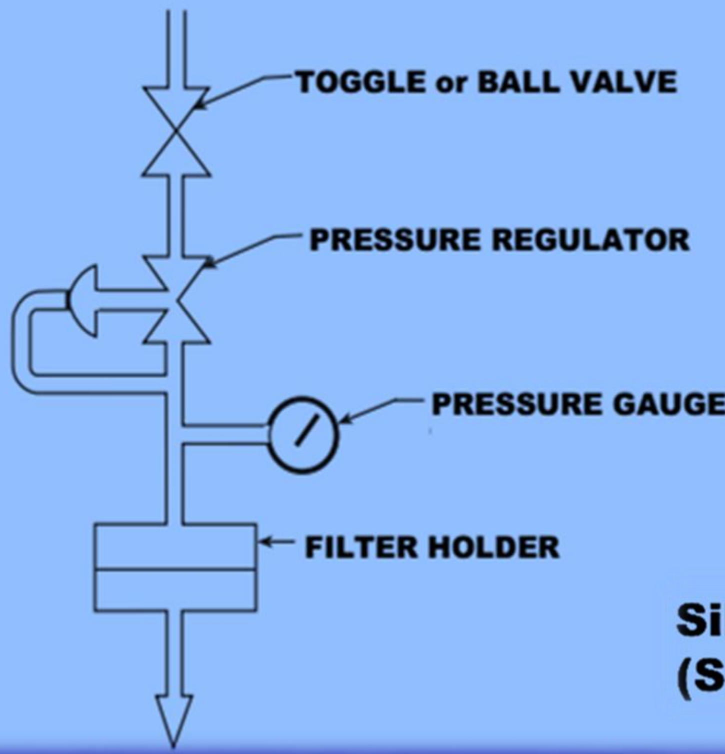


The Standard Test Method has been described in ASTM test D 4189-82.

- 47 mm diameter membrane filter support
- 47 mm diameter membrane filters (0.45 µm pore size)
- 0-70 PSI (0-5 bar) pressure gauge
- Pressure regulator (manual needle valve can be substituted)

Figure 1 shows the equipment arrangement needed to measure SDI. The above equipment is available from Millipore Corporation.

Figure 1. Apparatus for measuring the silt density index (SDI)



Silt Density Index (SDI) Test Procedure

Evaluation of Results

Calculate the silt density index (SDI_T)

$$\mathrm{SDI}_T = \frac{\%\,P_{30}}{T} = \frac{\left[1 - \frac{t_i}{t_f}\right] 100}{T}$$

$\%\,P_{30}$ = percent at 30psi feed pressure

T = total elapsed flow time, min (usually 15min.)

t_i = initial time required to collect 500mL of sample (in seconds)

t_f = time required to collect 500mL of sample after test time T (in seconds)

Expressing Results

The SDI should include a subscript indicating the total elapsed flow time (T) in minutes.

Also include the temperature before and after the test.

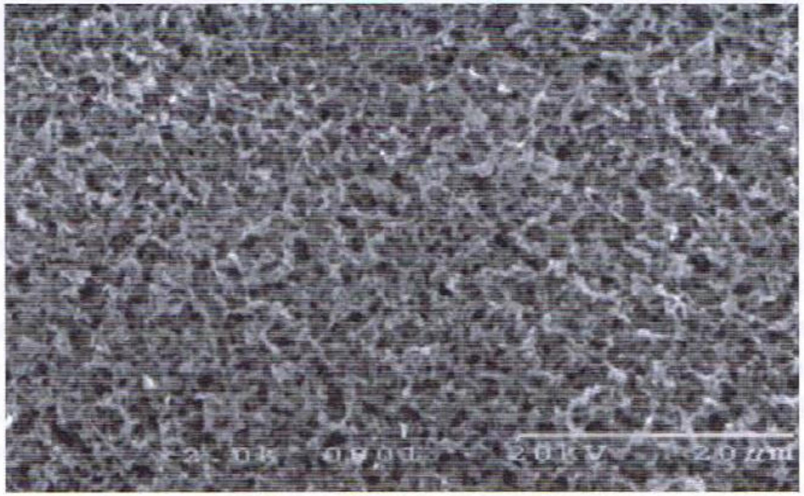


FIG. 15.2 SEM picture of a clean filter pad (reference). Magnification × 2000.

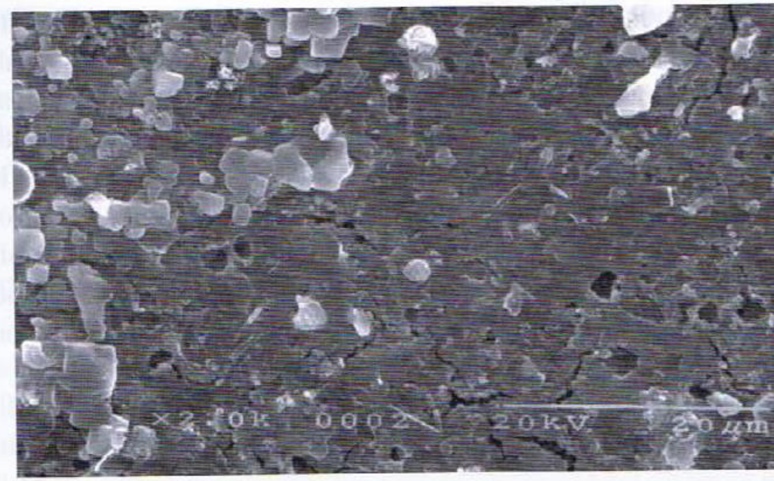


FIG. 15.4 SEM picture of a filter pad after SDI determination. SDI = 4.8. Magnification × 2000.

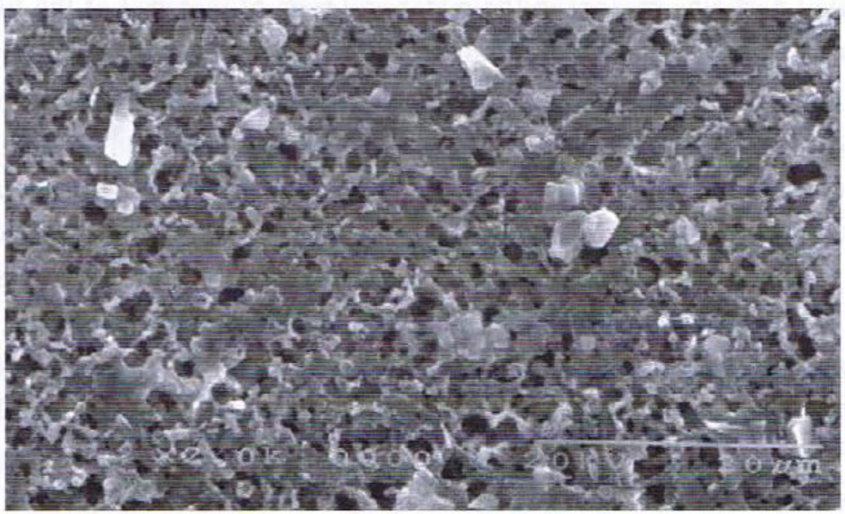


FIG. 15.3 SEM picture of a filter pad after SDI determination. SDI = 2.2. Magnification × 2000.

Silt Density index

$SDI = 100^{*}(1 - t_0/t_{15})/15$

t_0	t_{15}	SDI (15 min)
18	22	1.2
18	32	2.9
18	50	4.3
46	50	0.5 (?)

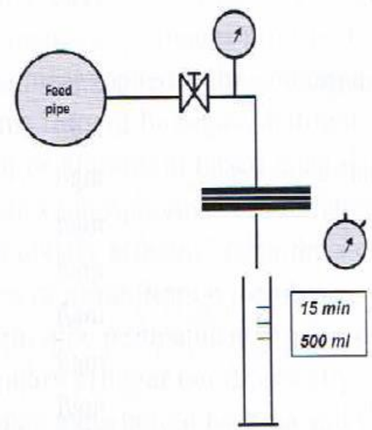


FIG. 15.1 Schematic configuration of device for measurement of SDI.

ตารางที่ 1 การอุดตันจากคอลลอยด์ภายใต้ภาวะตัวบ่งชี้ต่างๆ

SDI	Zeta Potential (mV)	อัตราการอุดตันที่เกิดขึ้นจากคอลลอยด์
<3.0	0 ถึง -30	ไม่เกิดการอุดตันหรืออุดตันเล็กน้อย
3.0-5.0	0 ถึง -30	เกิดปัญหาการอุดตันต้องมีระบบปรับสภาพน้ำเข้าระบบ RO
<5.0	น้อยกว่า -30	ไม่เกิดการอุดตันหรืออุดตันเล็กน้อย
>5.0	น้อยกว่า -30	เกิดปัญหาการอุดตันมากต้องปรับสภาพน้ำก่อนเข้าระบบ RO

* - ข้อมูลจากการทดลองที่ Plant recovery 75 %

- Zeta Potential วัดที่น้ำเข้าระบบ ค่า TDS = 3,000 ppm

ที่มา: Permasep Engineering Manual, Bulletin 504, page1, date 12/1/82

การล้างเมมเบรนที่อุดตันเนื่องจากคอลลอยด์

1. ใช้สบู่เหลว น้ำยาล้างจาน ยาสระผม หรือผงซักฟอกที่ไม่มีสารฟอกขาวและสารออกซิไดซิงเอเจนต์ นำมาผสมกับ NaOH และปรับความเป็นกรดด่างให้อยู่ระหว่าง pH 10-11

2. NaOH pH 10-11 (โซเดียมไฮดรอกไซด์ (NaOH) หรือที่เรียกกันทั่วไปว่าโซดาไฟ ผสมน้ำให้ค่า pH อยู่ที่10-11)

3. HCl pH 2.5 (กรดไฮโดรคลอริก (HCl) หรือที่เรียกทั่วไปว่ากรดเกลือ ละลายน้ำให้มีค่า pH 2.5)

4. กรดมะนาว ปรับ pH = 4 ด้วย NH_4OH (กรดมะนาวหรือกรดซิติก (Citic acid) เข้มข้น 2% โดยน้ำหนัก ปรับ pH ให้ได้เท่ากับ 4 โดยใช้แอมโมเนียมไฮดรอกไซด์ (NH_4OH) หรือน้ำแอมโมเนีย)

ถ้าเป็นการอุดตันเนื่องจากตะกอนจุลินทรีย์ร่วมด้วย อาจจะต้องฆ่าเชื้อจุลินทรีย์ด้วยสารฟอร์มัลดีไฮด์ (Formaldehyde) 2.0 เปอร์เซนต์โดยน้ำหนัก ก่อนแล้วตามด้วยการล้างด้วยสารเคมีในข้อ 1-4 อย่างใดอย่างหนึ่ง

ตารางที่ 2 ปริมาณเหล็กที่ยอมให้มีได้ในน้ำที่ป้อนเข้าสู่ระบบกรองน้ำ RO ได้ ซึ่ง ต้องขึ้นอยู่กับปริมาณออกซิเจนที่ละลายน้ำและค่า pH ของน้ำ

ปริมาณความเข้มข้นออกซิเจนละลาย (มิลลิกรัมต่อลิตร)	pH	ปริมาณ Fe^{2+} ที่ยอมให้มีได้ (มิลลิกรัมต่อลิตร)
<0.5	<6.0	4
0.5-5	6.0-7.0	0.5
5-10	>7.0	0.05

ที่มา: Permasep Engineering Manual, Bulletin 503, page1, date 12/1/82

3.2.2 การล้างเมมเบรนที่อุดตันเนื่องจากตะกอนสารประกอบอลูมิเนียม

การอุดตันของโลหะออกไซด์หรือตะกอนของสารประกอบอลูมิเนียมบนเมมเบรนสามารถล้างออกได้ด้วยสารเคมีต่างๆ ดังต่อไปนี้

1. 1.0 % โดยน้ำหนัก Sodium Hydrogen sulfite ($Na_2S_2O_4$)
2. 2.0 % โดยน้ำหนักกรดมะนาว (Citric acid) โดยปรับ pH 4.0 ด้วย NH_4OH
3. 2.0 % โดยน้ำหนักกรดมะนาว (Citric acid) ผสมกับ 2.0 % โดยน้ำหนัก Sodium EDTA โดยปรับ pH ที่ 4.0 ด้วย NH_4OH
4. 1.0 % โดยน้ำหนัก Sodium Hexa meta phosphate

1. การอุดตันเนื่องจากผลึก $BaSO_4$
2. การอุดตันเนื่องจากผลึก $SrSO_4$
3. การอุดตันเนื่องจากผลึก CaF_2
4. การอุดตันเนื่องจากผลึก $CaSO_4$
5. การอุดตันเนื่องจากผลึก $CaCO_3$ หรือหินปูน
6. การอุดตันเนื่องจากผลึก SiO_2
7. การอุดตันเนื่องจากผลึก $Ca_2(PO)_4$

ตารางที่ 3 ค่า Solubility Product: K_{sp} ของเกลือที่ละลายน้ำได้น้อยบางชนิด

สารประกอบ	Solubility Product : K_{sp}
$CaSO_4$	7.10×10^{-5}
$BaSO_4$	1.07×10^{-10}
$SrSO_4$	3.44×10^{-7}
$CaCO_3$	4.96×10^{-9}
CaF_2	1.46×10^{-10}

ที่มา: Hand book of chemistry and physics, 70th edition, 1989-1990

Calculation /<u>8</u>/

Prediction of $BaSO_4$ scaling potential is performed in the same way as the previously described procedure for $CaSO_4$.

1. Calculate the ionic strength of the concentrate stream (I_c) following the procedure described in *Scaling Calculation General (Section 2.4.1)*:

$$I_c = I_f\left(\frac{1}{1-Y}\right) \qquad \text{Eq. 5}$$

2. Calculate the ion product (IP_c) for $BaSO_4$ in the concentrate stream:

$$IP_c = \left[\left({}^{m}Ba^{2+}\right)_f\left(\frac{1}{1-Y}\right)\right]\left[\left({}^{m}SO_4^{\,2-}\right)_f\left(\frac{1}{1-Y}\right)\right]$$

where:

$({}^{m}Ba^{2+})_f$ = M Ba^{2+} in feed, mol/L

$({}^{m}SO_4^{2-})_f$ = M SO_4^{2-} in feed, mol/L

3. Compare IP_c for $BaSO_4$ with the solubility product (K_{sp}) of $BaSO_4$ at the ionic strength of the concentrate stream, Figure 2.7. If $IP_c \geq K_{sp}$, $BaSO_4$ scaling can occur, and adjustment is required.

The ionic strength of the feed water is:

$$I_f = \frac{1}{2}\sum m_i z_i^2$$

where:

m_i = molal concentration of ion i (mol/kg)

z_i = ionic charge of ion i

$$m_i = \frac{c_i}{1{,}000\,MW_i}$$

where:

c_i = concentration of ion i in mg/L

MW_i = molecular weight of ion i

$$CF = \frac{1}{1-Y}$$

where the rejection is assumed to be 100%.

Calculation example of the ionic strength of the concentrate (I_c):

Feed Water Analysis

Ion	mg/L	mol/L	mol/kg
Ca^{2+}	200	5.0	$\times 10^{-3}$
Mg^{2+}	61	2.51	$\times 10^{-3}$
Na^{+}	388	16.9	$\times 10^{-3}$
HCO_3^{-}	244	4.0	$\times 10^{-3}$
SO_4^{2-}	480	5.0	$\times 10^{-3}$
Cl^{-}	635	17.9	$\times 10^{-3}$

The ionic strength I_f of the feed water is

$$I_f = \frac{1}{2}\left[4\left([Ca^{2+}]+[Mg^{2+}]+[SO_4{}^{2-}]\right)+\left([Na^{+}]+[HCO_3{}^{-}]+[Cl^{-}]\right)\right]$$

$$I_f = \frac{1}{2}\left\{4\left[(5.0+2.51+5.0)\times 10^{-3}\right]+\left[(16.9+4.0+17.9)\times 10^{-3}\right]\right\}$$

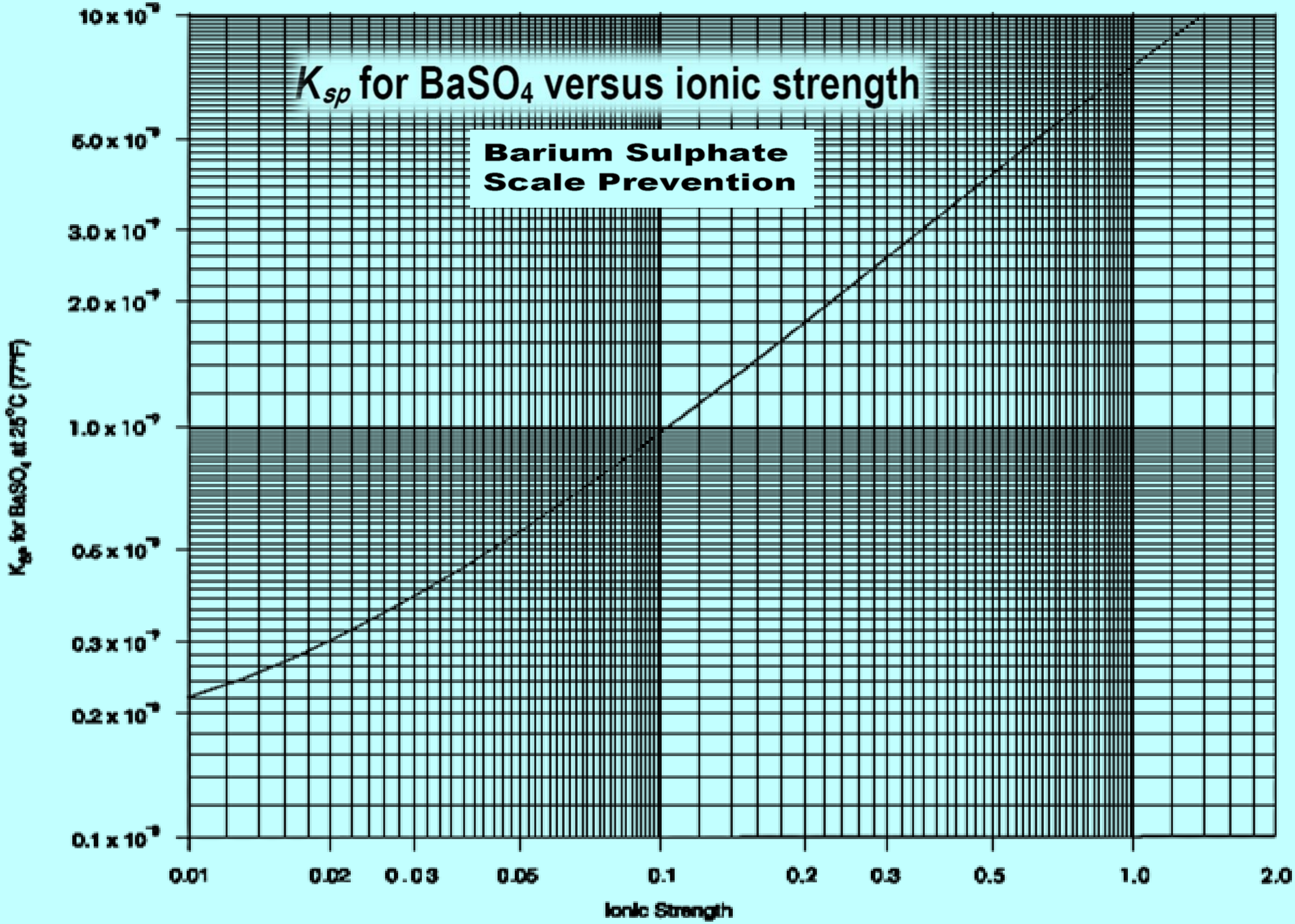
$$I_f = 0.0444$$

With a recovery of, for example, 75% ($Y = 0.75$), the ionic strength of the concentrate becomes

$$I_c = 0.0444\left(\frac{1}{1-0.75}\right)$$

$$I_c = 0.178$$

K_{sp} for $BaSO_4$ versus ionic strength



Strontium Sulphate Scale Prevention

Calculation /8/

Prediction of $SrSO_4$ scaling potential is performed in the same way as the previously described procedure for $CaSO_4$:

1. Calculate the ionic strength of the concentrate stream (I_c) following the procedure described in *Scaling Calculation General (Section 2.4.1)*:

$$I_c = I_f\left(\frac{1}{1-Y}\right) \qquad \text{Eq. 5}$$

2. Calculate the ion product (IP_c) for $SrSO_4$ in the concentrate stream:

$$IP_c = \left[\left({}^{m}Sr^{2+}\right)_f\left(\frac{1}{1-Y}\right)\right]\left[\left({}^{m}SO_4^{\,2-}\right)_f\left(\frac{1}{1-Y}\right)\right]$$

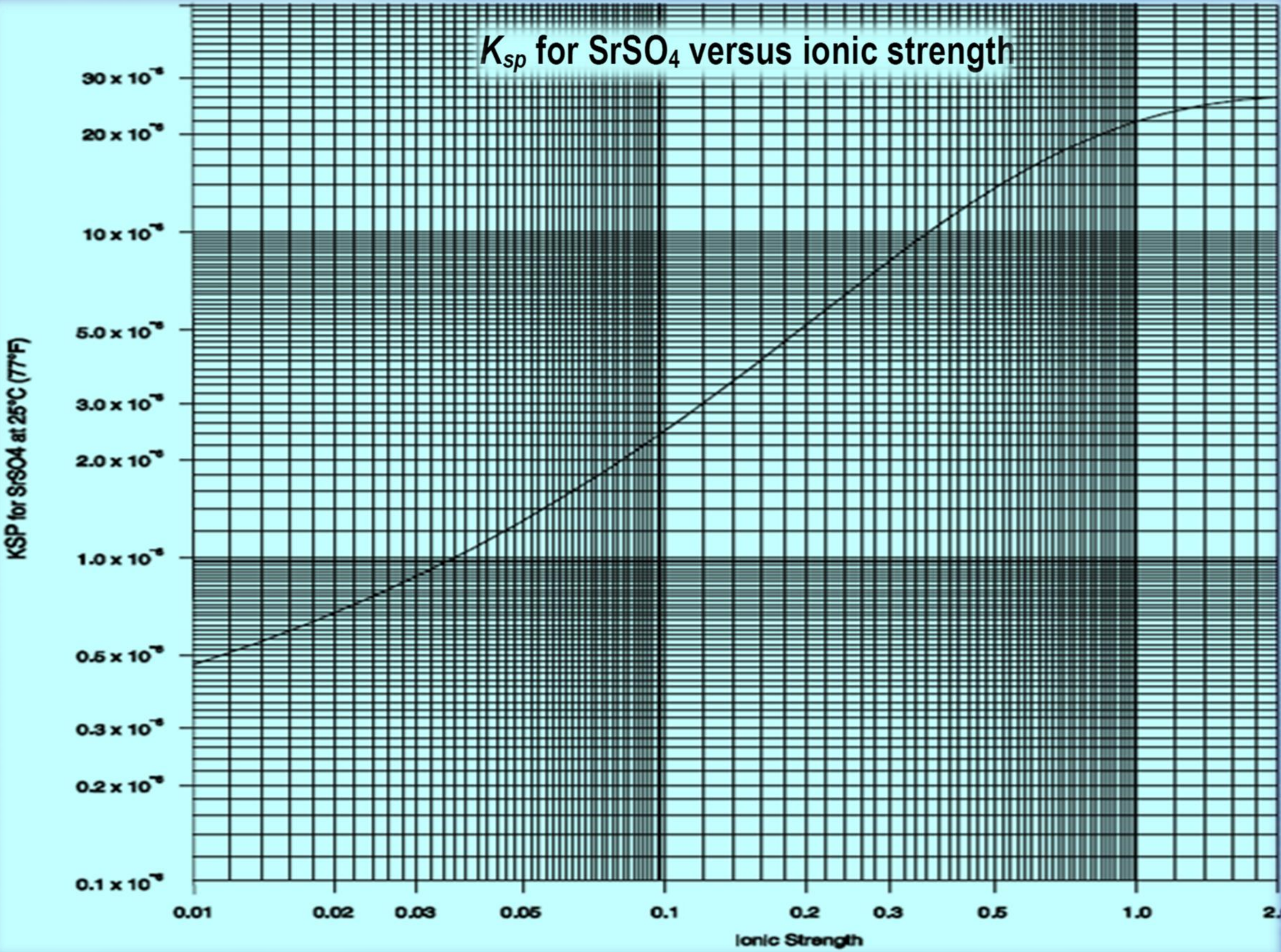
where:

$({}^{m}Sr^{2+})_f$ = M Sr^{2+} in feed, mol/L

$({}^{m}SO_4^{2-})_f$ = M SO_4^{2-} in feed, mol/L

3. Compare IP_c for $SrSO_4$ with the solubility product (K_{sp}) of $SrSO_4$ at the ionic strength of the concentrate stream, Figure 2.8. If $IP_c \geq 0.8\ K_{sp}$, $SrSO_4$ scaling can occur, and adjustment is required.

K_{sp} for $SrSO_4$ versus ionic strength



Calcium Sulphate Scale Prevention

For the determination of the calcium sulfate scaling potential, a complete feed water analysis is required.

Calculation */8/*

1. Calculate the ionic strength of the concentrate stream (I_c) following the procedure described in *Scaling Calculations General (Section 2.4.1)*:

$$I_c - I_f\left(\frac{1}{1-Y}\right) \qquad \text{Eq. 5}$$

2. Calculate the ion product (IP_c) for $CaSO_4$ in the concentrate stream:

$$IP_c = \left[\left({}^{m}Ca^{2+}\right)_f\left(\frac{1}{1-Y}\right)\right]\cdot\left[\left({}^{m}SO_4{}^{2-}\right)_f\left(\frac{1}{1-Y}\right)\right]$$

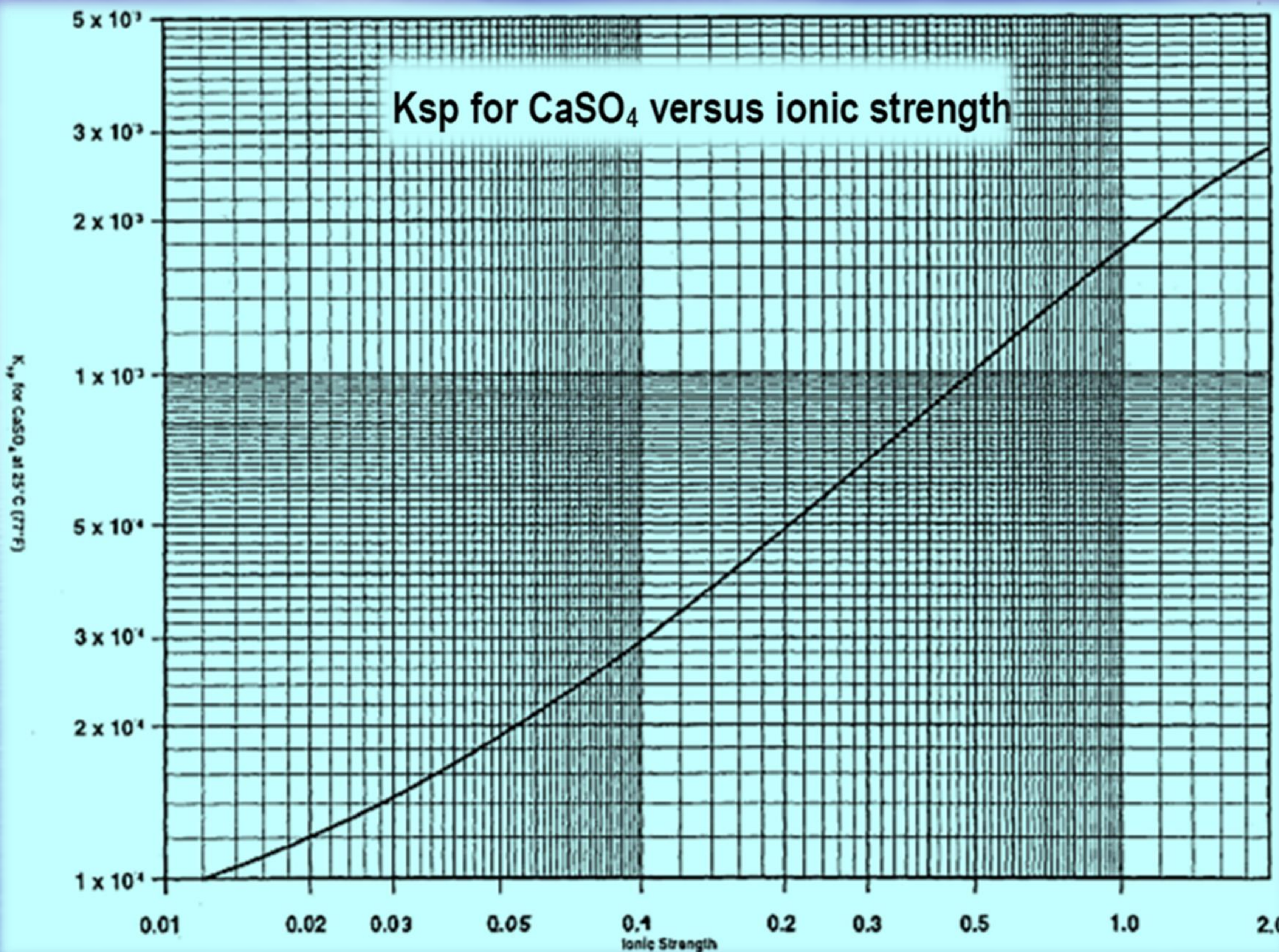
where:

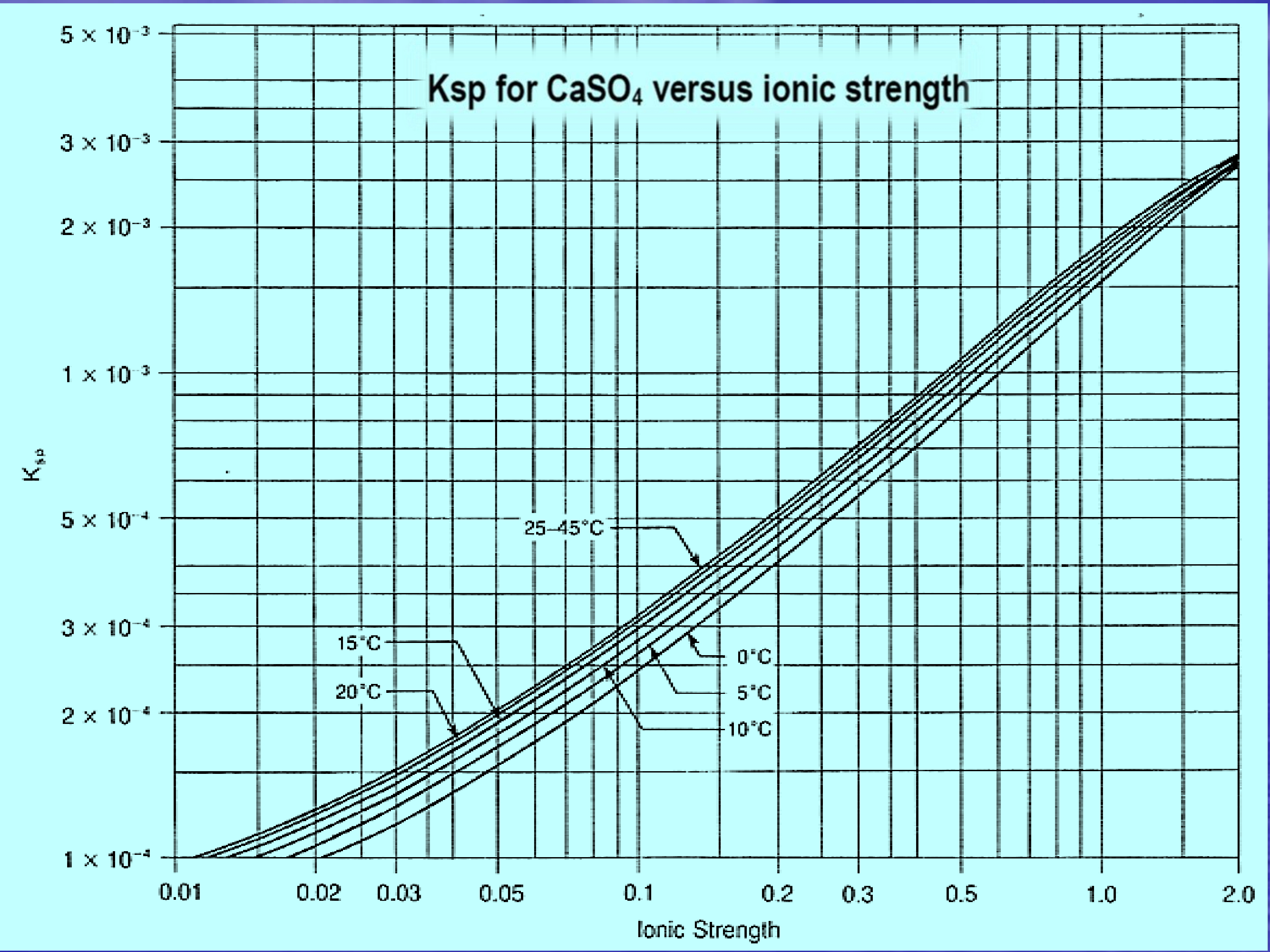
$({}^{m}Ca^{2+})_f$ = M Ca^{2+} in feed, mol/L

$({}^{m}SO_4^{2-})_f$ = M SO_4^{2-} in feed, mol/L

3. Compare IP_c for $CaSO_4$ with the solubility product (K_{sp}) of $CaSO_4$ at the ionic strength of the concentrate stream, Figure 2.6. If $IP_c \geq K_{sp}$, $CaSO_4$ scaling can occur, and adjustment is required. For a safe and conservative pretreatment design, adjustment should be made if $IP_c > 0.8\ K_{sp}$.

Ksp for $CaSO_4$ versus ionic strength




Ksp for $CaSO_4$ versus ionic strength
5×10^{-3}
3×10^{-3}
2×10^{-3}
1×10^{-3}
5×10^{-4}
3×10^{-4}
2×10^{-4}
1×10^{-4}
K_{sp}
25–45°C
15°C
20°C
0°C
5°C
10°C
0.01
0.02
0.03
0.05
0.1
0.2
0.3
0.5
1.0
2.0
Ionic Strength

ตารางที่ 4 เงื่อนไขในการเดินระบบ RO เพื่อป้องกันการอุดตันของผลึกเกลือซัลเฟตที่ค่า K_{sp} ต่าง ๆ

เกลือซัลเฟต	ผลคูณของอิออนในน้ำเกลือ (Brine) IPb	
	ไม่ใช้ Anti sealant	ใช้ Anti sealant 10 mg/L
$CaSO_4$	$< 0.8\ K_{sp}$	≤ 0.001 หรือ $1.2\ K_{sp}$
$BaSO_4$	$< 0.8\ K_{sp}$	$\leq 40\ K_{sp}$
$SrSO_4$	$< 0.8\ K_{sp}$	$\leq 8\ K_{sp}$

ที่มา: Hand book of chemistry and physics, 70^{th} edition, 1989-1990

4.1.3 การล้างเมมเบรนที่อุดตันเนื่องจากเกลือซัลเฟต

เกลือซัลเฟตที่มักพบว่ามีการอุดตันในระบบ RO เช่นเกลือ $CaSO_4$, $BaSO_4$ และ $SrSO_4$ ในระบบกรองน้ำ RO ถ้าเป็นน้ำกร่อยจะเดินระบบที่ Conversion Ratio สูงๆ ประมาณ 60-70 % เพราะจะทำให้เกิดการตกผลึกเกลือซัลเฟตดังกล่าวทั้งหมด ($CaSO_4$, $BaSO_4$ และ $SrSO_4$) ส่วนในระบบกรองน้ำทะเลผลึก $CaSO_4$ จะไม่เกิดเพราะระบบกรองน้ำทะเลเดินระบบที่ Conversion ไม่เกิน 40 % ทำให้ IP_b ของ $CaSO_4$ ไม่สูงกว่า 0.8 K_{sp} ของ $CaSO_4$

การล้างผลึก $CaSO_4$, $BaSO_4$ และ $SrSO_4$ ในกรณีที่เกิดการอุดตัน

1. สารละลาย EDTA ที่ pH 7-8
2. กรดมะนาว Citric acid 2 % โดยน้ำหนัก ปรับ pH 8 ด้วย NH_4OH

Calcium Fluoride Scale Prevention

Fluoride levels in the feed water of as low as 0.1 mg/L can create a scaling potential if the calcium concentration is high. The calculation of the scaling potential is analogous to the procedure described in *Calcium Sulfate Scale Prevention (Section 2.4.3)* for $CaSO_4$.

Calculation

1. Calculate the ionic strength of the concentrate stream (I_c) following the procedure described in *Scaling Calculation, General (Section 2.4.1)*:

$$I_c = I_f\left(\frac{1}{1-Y}\right)$$

2. Calculate the ion product (IP_c) for CaF_2 in the concentrate stream:

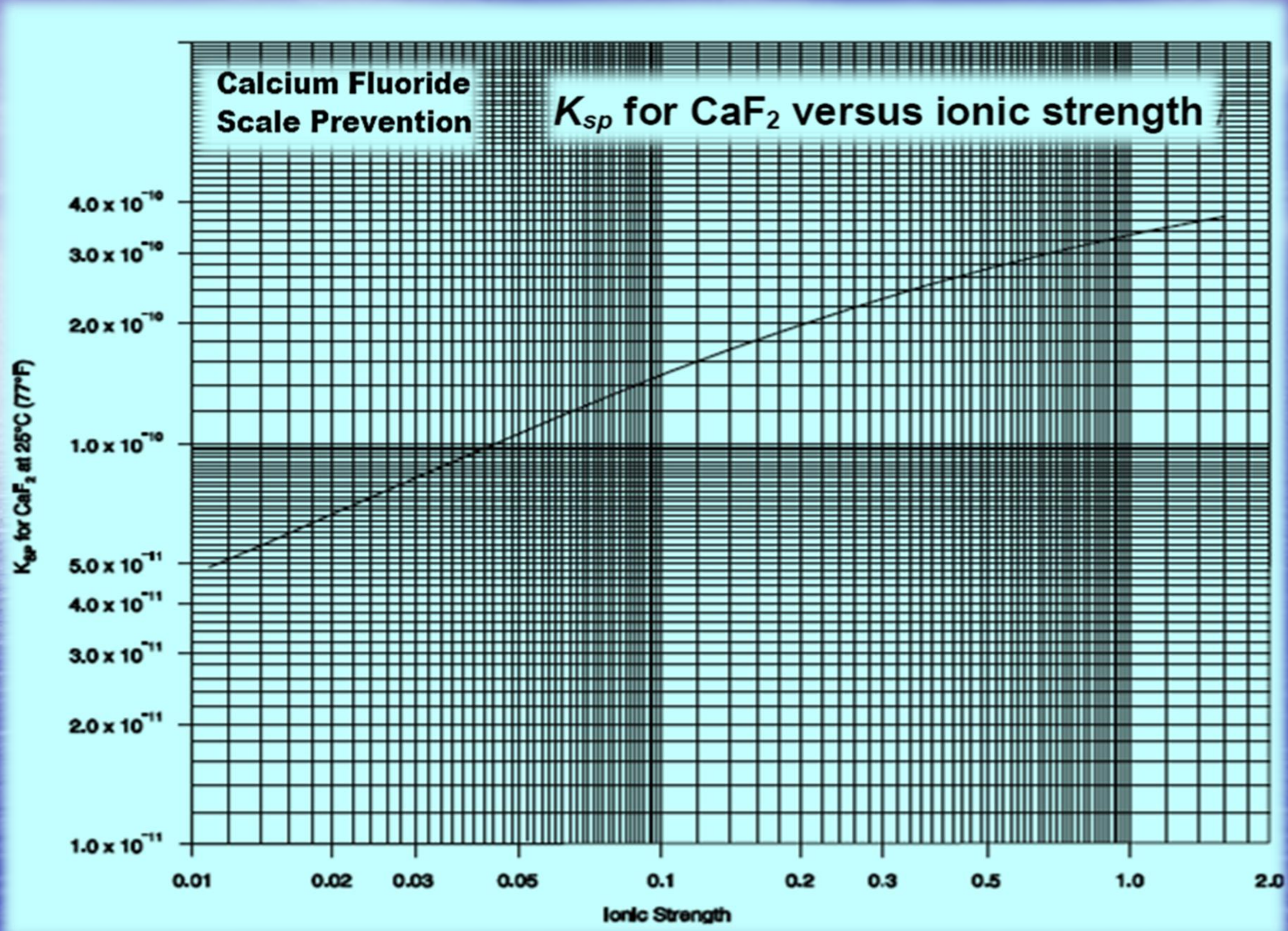
$$IP_c = \left[\left({}^{m}Ca^{2+}\right)_f\left(\frac{1}{1-Y}\right)\right]\left[\left({}^{m}F^{-}\right)_f\left(\frac{1}{1-Y}\right)\right]^2$$

where:

$({}^{m}Ca^{2+})_f$ = M Ca^{2+} in feed, mol/L

$({}^{m}F^{-})_f$ = M F^{-} in feed, mol/L

3. Compare IP_c for CaF_2 with the solubility product (K_{sp}) of CaF_2 at the ionic strength of the concentrate stream, Figure 2.9 /11/. If $IP_c \geq K_{sp}$, CaF_2 scaling can occur, and adjustment is required.



Calcium Fluoride
Scale Prevention
K_{sp} for CaF_2 versus ionic strength
K_{sp} for CaF_2 at 25°C (77°F)
4.0 x 10^{-10}
3.0 x 10^{-10}
2.0 x 10^{-10}
1.0 x 10^{-10}
5.0 x 10^{-11}
4.0 x 10^{-11}
3.0 x 10^{-11}
2.0 x 10^{-11}
1.0 x 10^{-11}
0.01
0.02
0.03
0.05
0.1
0.2
0.3
0.5
1.0
2.0
Ionic Strength

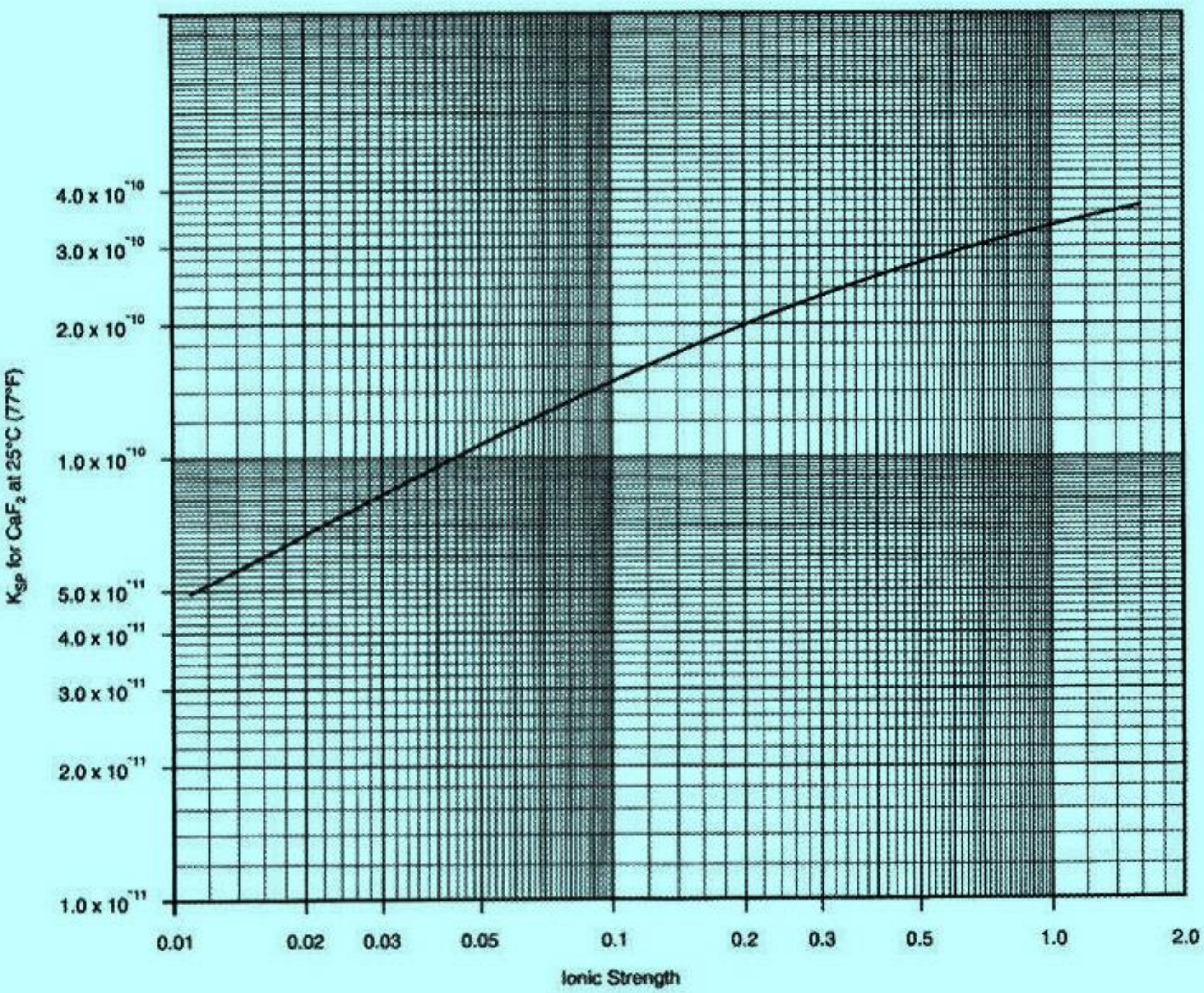


Figure 2-4 Calcium fluoride solubility product versus ionic strength

Calcium Phosphate Scale Prevention

Table 2.8 Low solubility phosphate compounds

Compound	Formula	pK_{sp}
Brushite	$CaHPO_4 \cdot 2H_2O$	6.68
Calcium phosphate	$Ca_3(PO_4)_2$	28.9
Octacalcium phosphate	$Ca_4H(PO_4)_3 \cdot 3H_2O$	46.9
Hydroxyapatite	$Ca_5(PO_4)_3OH$	57.74
Fluoroapatite	$Ca_5(PO_4)_3F$	60
Magnesium ammonium phosphate	$MgNH_4PO_4$	12.6
Aluminum phosphate	$AlPO_4$	20
Iron phosphate	$FePO_4$	15

Calcium Phosphate Scale Prevention

$SI = pH_a - pH_c$

where:

pH_a = actual pH of a feed water

pH_c = critical pH calculated by the following experimental equation:

$$pH_c = \frac{11.755 - \log(CaH) - \log(PO_4) - 2\log t}{0.65}$$

where :

CaH = Calcium hardness as ppm $CaCO_3$

PO_4 = Phosphate concentration as ppm PO_4

t = Temperature as °C

Figure 2.12 shows the effect of critical phosphate concentrations of $Ca_3(PO_4)_2$ scaling on feed calcium hardness and pH based on the equation.

Figure 2.12 Critical phosphate concentration under various pH at 25°C

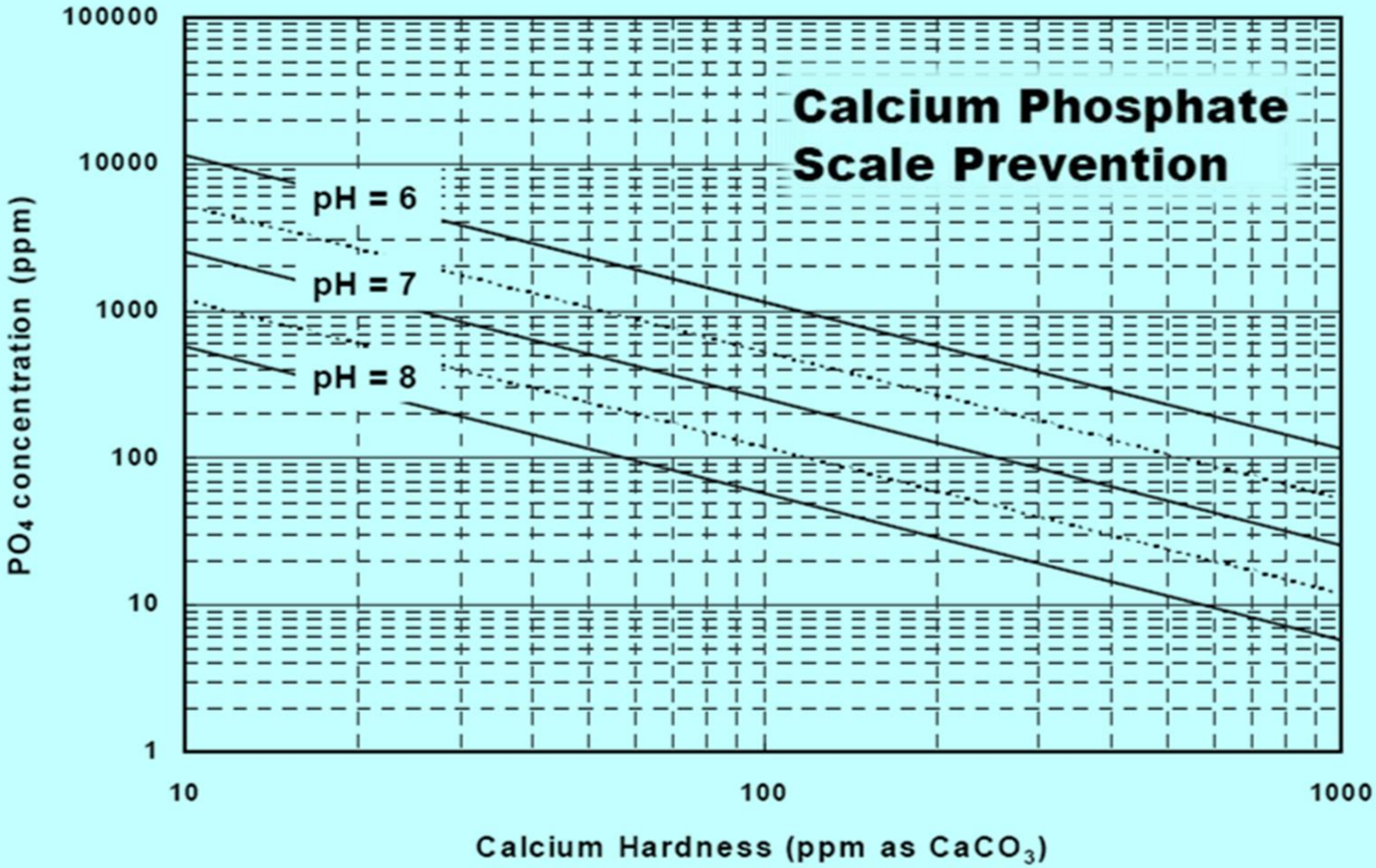


Figure 3. Effect of Feed pH on HCO_3^- Passage for B-10 Permeator

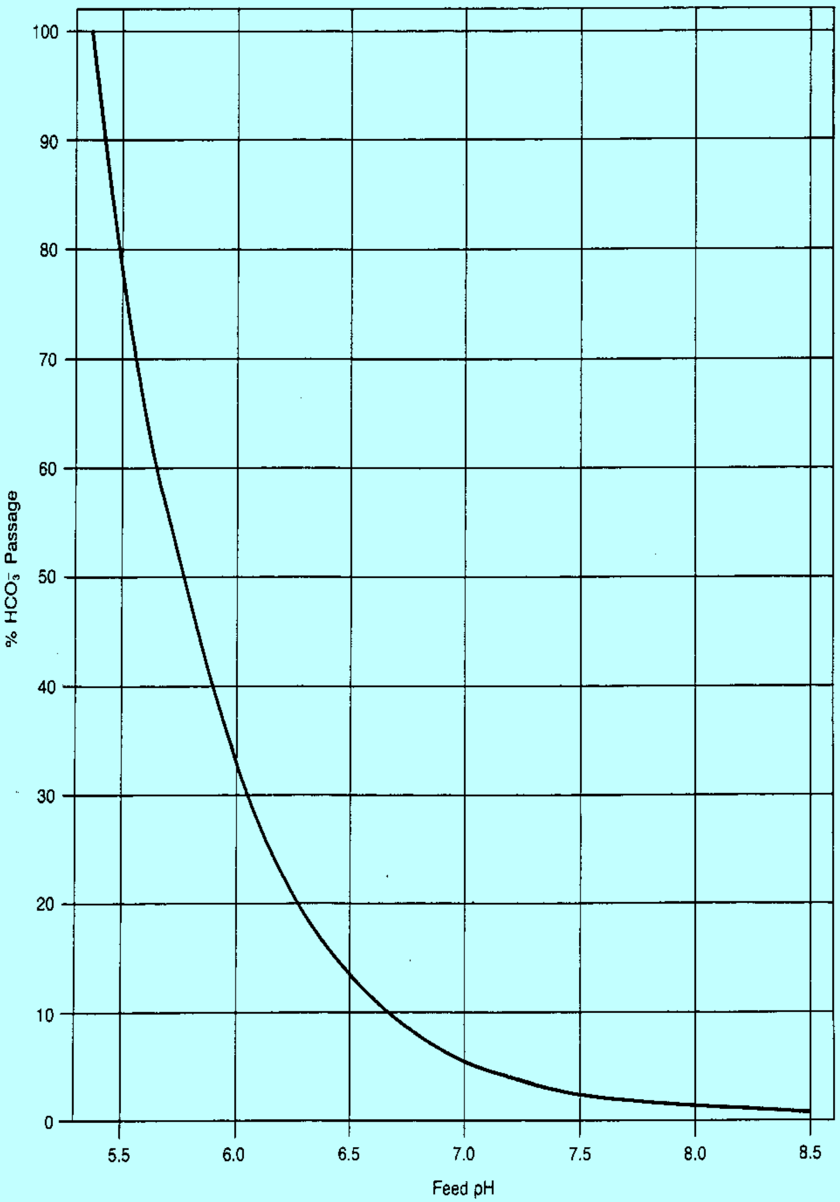
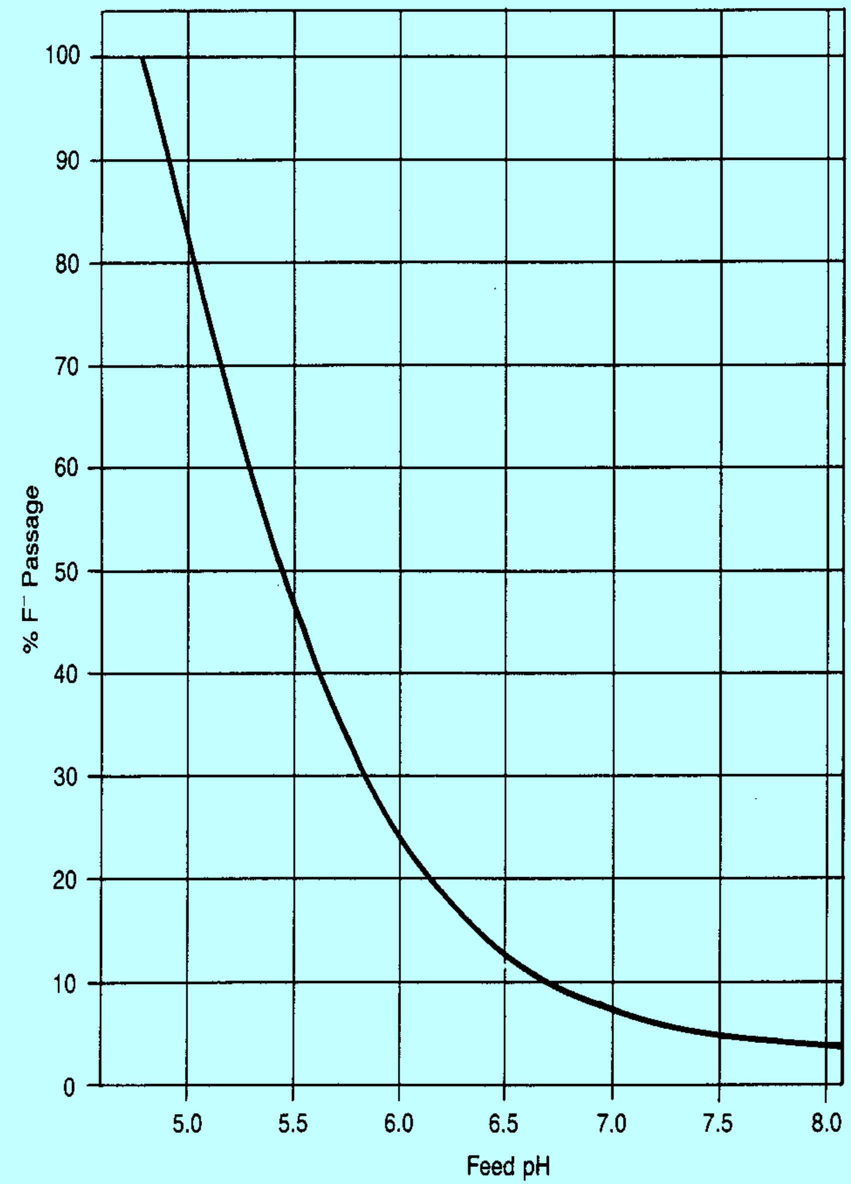


Figure 4. Effect of Feed pH on F^- Passage for B-10 Permeators



Calcium Carbonate Scale Prevention

Brackish Water

For brackish waters with TDS < 10,000 mg/L in the concentrate stream, the Langelier Saturation Index (LSI) is used to express the scaling potential for calcium carbonate /6/.

The following data are needed to calculate the LSI of the concentrate stream (LSI_c):

- Ca_f = Calcium concentration in feed as $CaCO_3$, mg/L
- TDS_f = Concentration of total dissolved solids in the feed, mg/L
- Alk_f = Alkalinity in feed as $CaCO_3$, mg/L
- pH_f = pH of the feed solution
- T = Temperature of the feed solution
- Y = Recovery of the reverse osmosis system, expressed as a decimal

Calculations

1. Calculate the calcium concentration in the concentrate stream, Ca_c, as $CaCO_3$ in mg/L:

$$Ca_c = Ca_f\left(\frac{1}{1-Y}\right) \qquad \text{Eq. 6}$$

2. Calculate the total dissolved solids in the concentrate stream, TDS_c in mg/L:

$$TDS_c = TDS_f\left(\frac{1}{1-Y}\right) \qquad \text{Eq. 7}$$

3. Calculate the alkalinity in the concentrate stream, Alk_c, as $CaCO_3$ in mg/L:

$$Alk_c = Alk_f\left(\frac{1}{1-Y}\right) \qquad \text{Eq. 8}$$

4. Calculate the free carbon dioxide content (C) in the concentrate stream by assuming that the CO_2 concentration in the concentrate is equal to the CO_2 concentration in the feed: $C_c = C_f$. The concentration of free carbon dioxide in the feed solution is obtained from Figure 2.2 as a function of the alkalinity and the pH of the feed solution.

5. Calculate the pH of the concentrate stream (pH_c) using the ratio of alkalinity Alk_c to free CO_2 in the concentrate, Figure 2.2.

6. From Figure 2.3 obtain: pCa as a function of Ca_c, pAlk as a function of Alk_c, "C" as a function of TDS_c and temperature (temperature of the concentrate is assumed equal to temperature of the feed solution).

7. Calculate pH at which the concentrate stream is saturated with $CaCO_3$ (pH_s) as follows:

$$pH_s = pCa + pAlk + "C" \qquad \text{Eq. 9}$$

8. Calculate the Langelier Saturation Index of the concentrate (LSI_c) as follows:

$$LSI_c = pH_c - pH_s \qquad \text{Eq. 10}$$

Calcium Carbonate Scale Prevention

The conditions for $CaCO_3$ scale control are:

$LSI_c < 0$	when no antiscalant is added
$LSI_c \leq 1$	when 20 mg/L sodium hexametaphosphate is in the concentrate stream
$LSI_c > 1$	possible with polymeric organic scale inhibitors. For the maximum LSI_c and required dosages, please refer to the scale inhibitor manufacturer's literature.

Table 3.6 Langelier saturation index.

LSI	Condition
3.0	Extremely severe scaling
2.0	Very severe scaling
1.0	Severe scaling
0.5	Moderate scaling
0.2	Slight scaling
0.0	Stable water (no scale)
–0.2	No scale, very slight tendency to dissolve scale

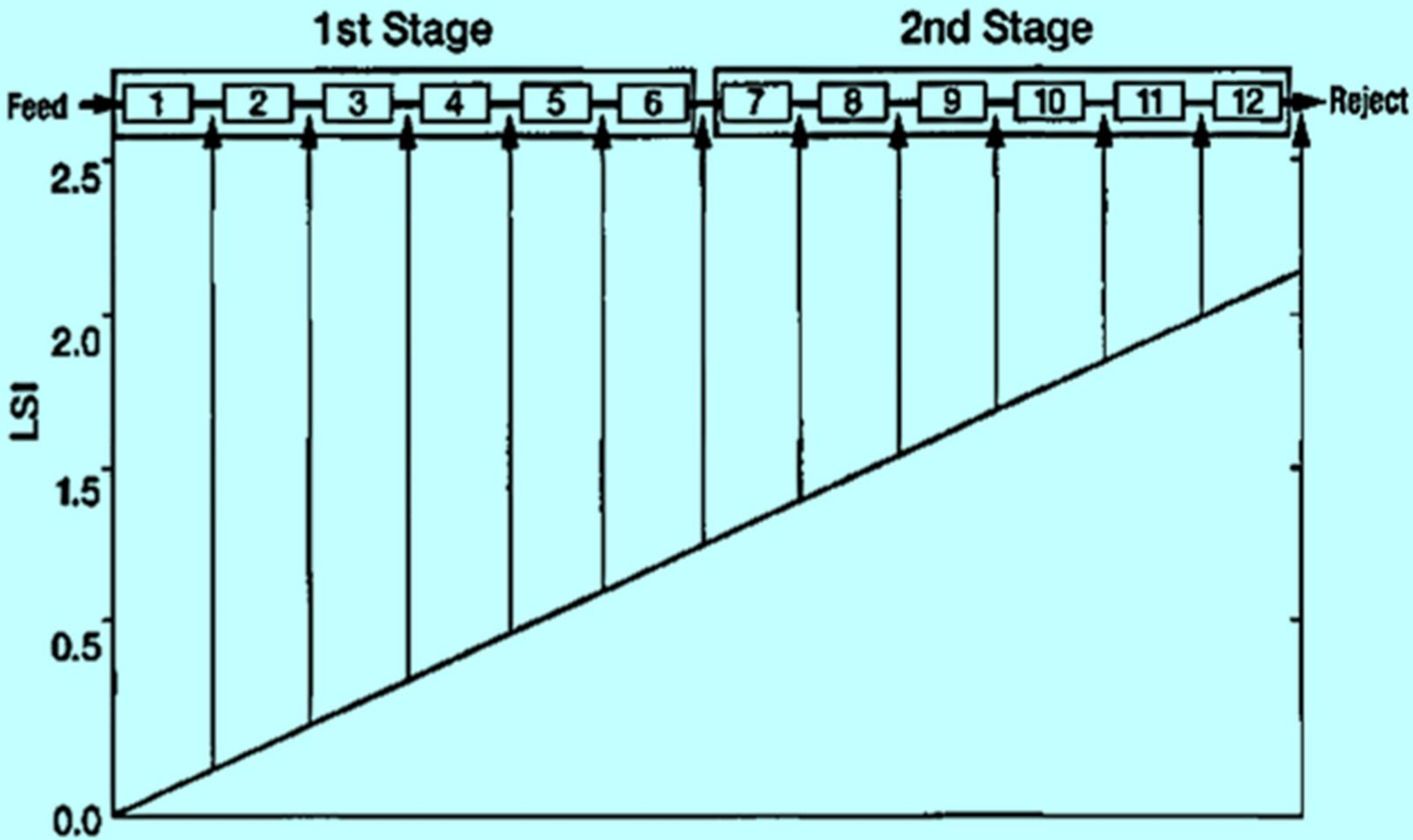
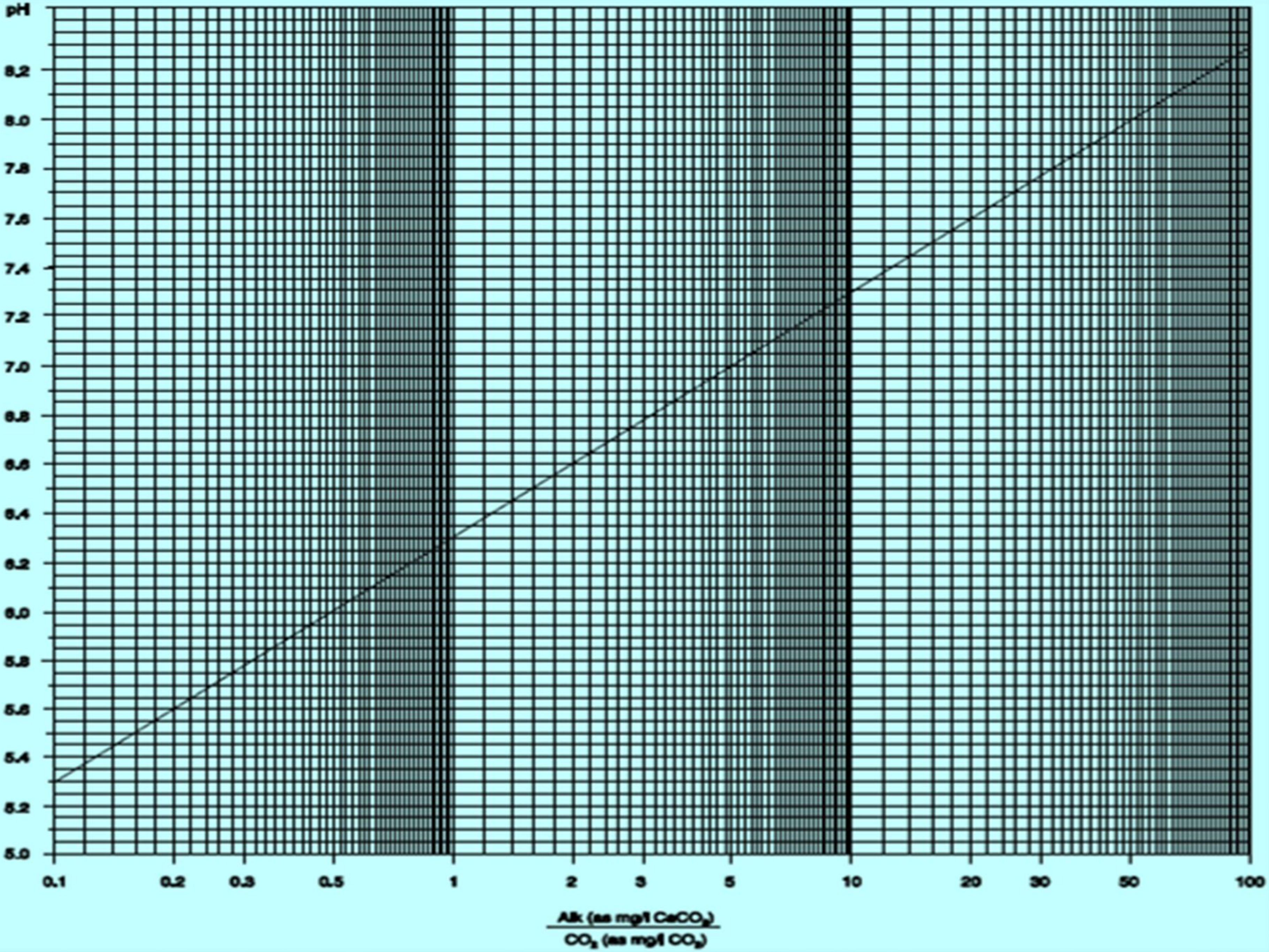
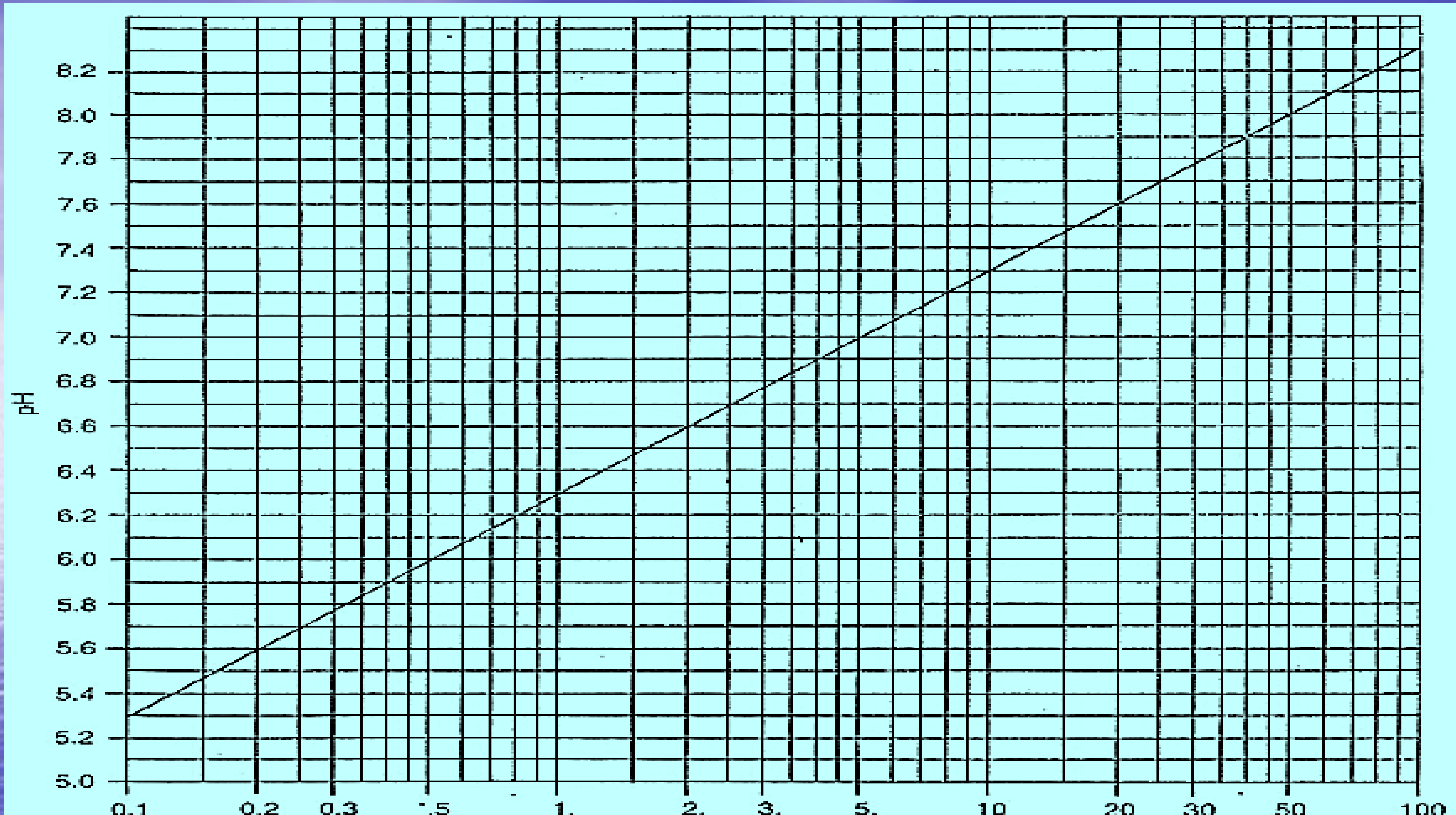
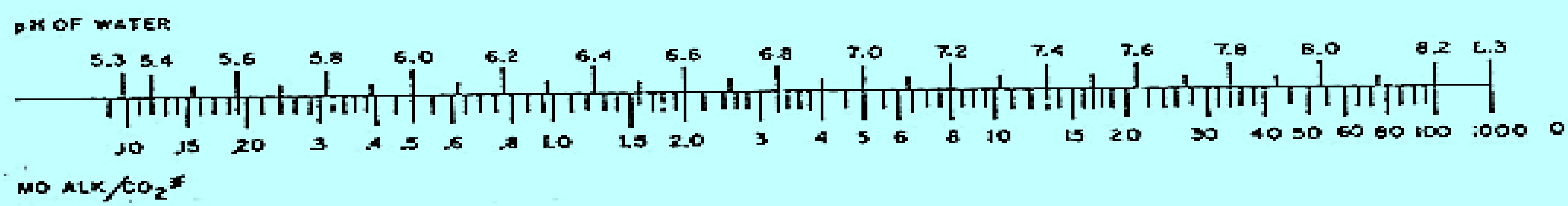


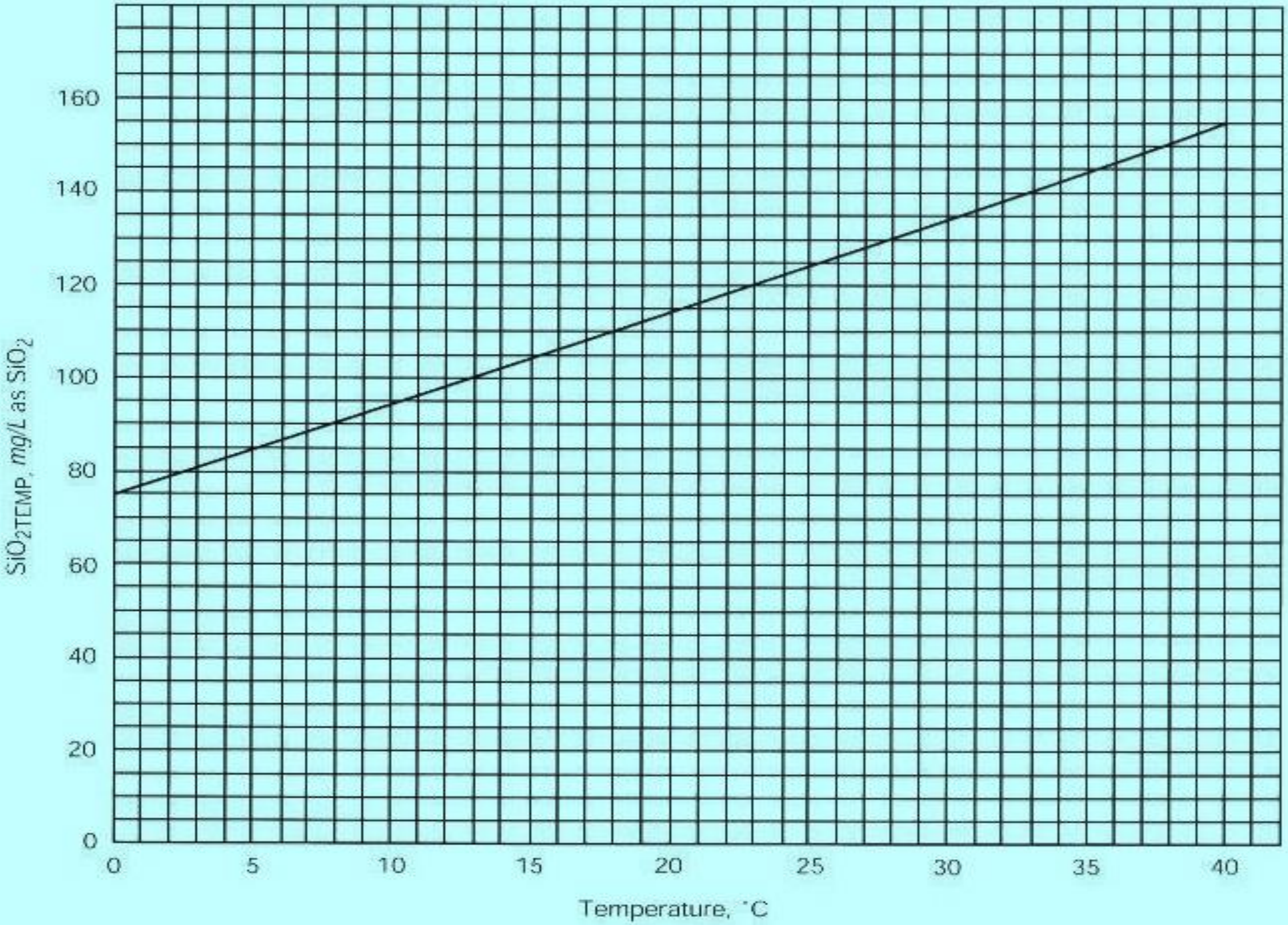
Figure 5.5 Langeleir Saturation Index (LSI) as a function of module position and recovery for a two-stage, 75%-recovery RO system. Assumes feed water conditions: 200 ppm calcium, 150 ppm bicarbonate, and pH = 7.0.


pH
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
0.1
0.2
0.3
0.5
1
2
3
5
10
20
30
50
100
Alk (as mg/l $CaCO_3$)
CO_2 (as mg/l CO_2)





*RATIO $\dfrac{\text{METHYL ORANGE ALKALINITY (EXPRESSED AS mg/litre } CaCO_3\text{)}}{\text{FREE CARBON DIOXIDE (EXPRESSED AS mg/litre } CO_2\text{)}}$



Effect of temperature on theoretical SiO_2 solubility, pH 7.7

Calcium Carbonate Scale Prevention

Seawater

For high-salinity brackish waters with TDS > 10,000 mg/L in the concentrate stream and for seawaters, the Stiff & Davis Stability Index (S&DSI) is used to express the scaling potential for calcium carbonate. The data needed to calculate the S&DSI of the concentrate stream are the same as the data needed to calculate the LSI. Additionally, the molal concentrations of all ions in the feed solution are required, at least of all major ions (i.e., Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, SO_4^{2-}, and Cl^{-}).

Calculations /7/

1. Calculate the calcium concentration in the concentrate stream, Ca_c, as $CaCO_3$ in mg/L:

$$Ca_c = Ca_f \frac{1}{1-Y} \qquad \text{Eq. 6}$$

2. Calculate the alkalinity in the concentrate stream, Alk_c, as $CaCO_3$ in mg/L:

$$Alk_c = Alk_f \frac{1}{1-Y} \qquad \text{Eq. 8}$$

3. Calculate the ionic strength of the feed stream (I_f):

$$I_f = \frac{1}{2}\sum m_i z_i^2 \qquad \text{Eq. 3}$$

4. Calculate the ionic strength of the concentrate stream (I_c):

$$I_c = I_f\left(\frac{1}{1-Y}\right) \qquad \text{Eq. 5}$$

5. From Figure 2.4, obtain pCa as a function of Ca_c and pAlk as a function of Alk_c. From Figure 2.5, obtain "K" as a function of concentrate ionic strength and feed temperature.

6. Calculate the pH at which the concentrate stream is saturated with $CaCO_3$ (pH_s) as follows:

   $$pH_s = pCa + pAlk + "K"$$

7. Calculate the free carbon dioxide content (C) in the concentrate stream by assuming that the CO_2 concentration in the concentrate is equal to the CO_2 concentration in the feed: $C_c = C_f$. The concentration of free carbon dioxide in the feed solution is obtained from Figure 2.2 as a function of the alkalinity and the pH of the feed solution.

8. Calculate the pH of the concentrate stream (pH_c) using the ratio of alkalinity (from Eq. 8) to free CO_2 in the concentrate (from Step 7), Figure 2.2.

9. Calculate the Stiff and Davis Stability Index of the concentrate ($S\&DSI_c$) as follows:

   $$S\&DSI_c = pH_c - pH_s$$

Calcium Carbonate Scale Prevention

For an assumed pH (pH_{acid}), obtained from addition of acid to the feed solution, obtain the ratio of Alk_{acid}/C_{acid} from Figure 2.3. From this ratio, Alk_f, and C_f, calculate the mg/L of acid used (x). For example, for H_2SO_4 addition (100%):

$$\frac{\mathrm{Alk}_{\mathrm{acid}}}{\mathrm{C}_{\mathrm{acid}}} = \frac{\mathrm{Alk}_f - 1.02x}{\mathrm{C}_f + 0.90x} \qquad \text{Eq. 11}$$

Calculate the total alkalinity of the acidified feed water (Alk_{acid}) and the CO_2 content in the acidified feed water (C_{acid}) as follows:

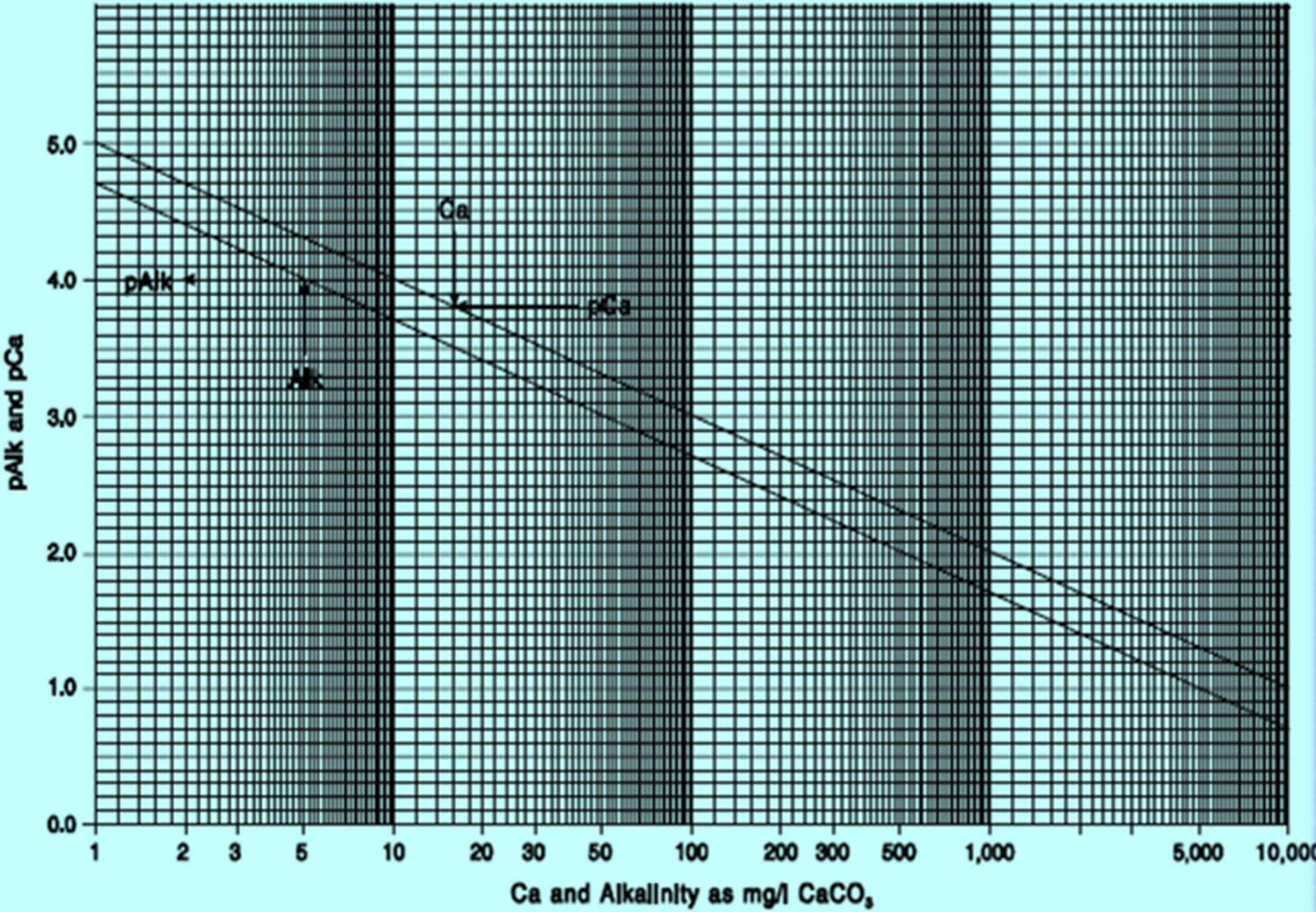
$$\mathrm{Alk}_{\mathrm{acid}} = \mathrm{Alk}_f - 1.02x \qquad \text{Eq. 12}$$

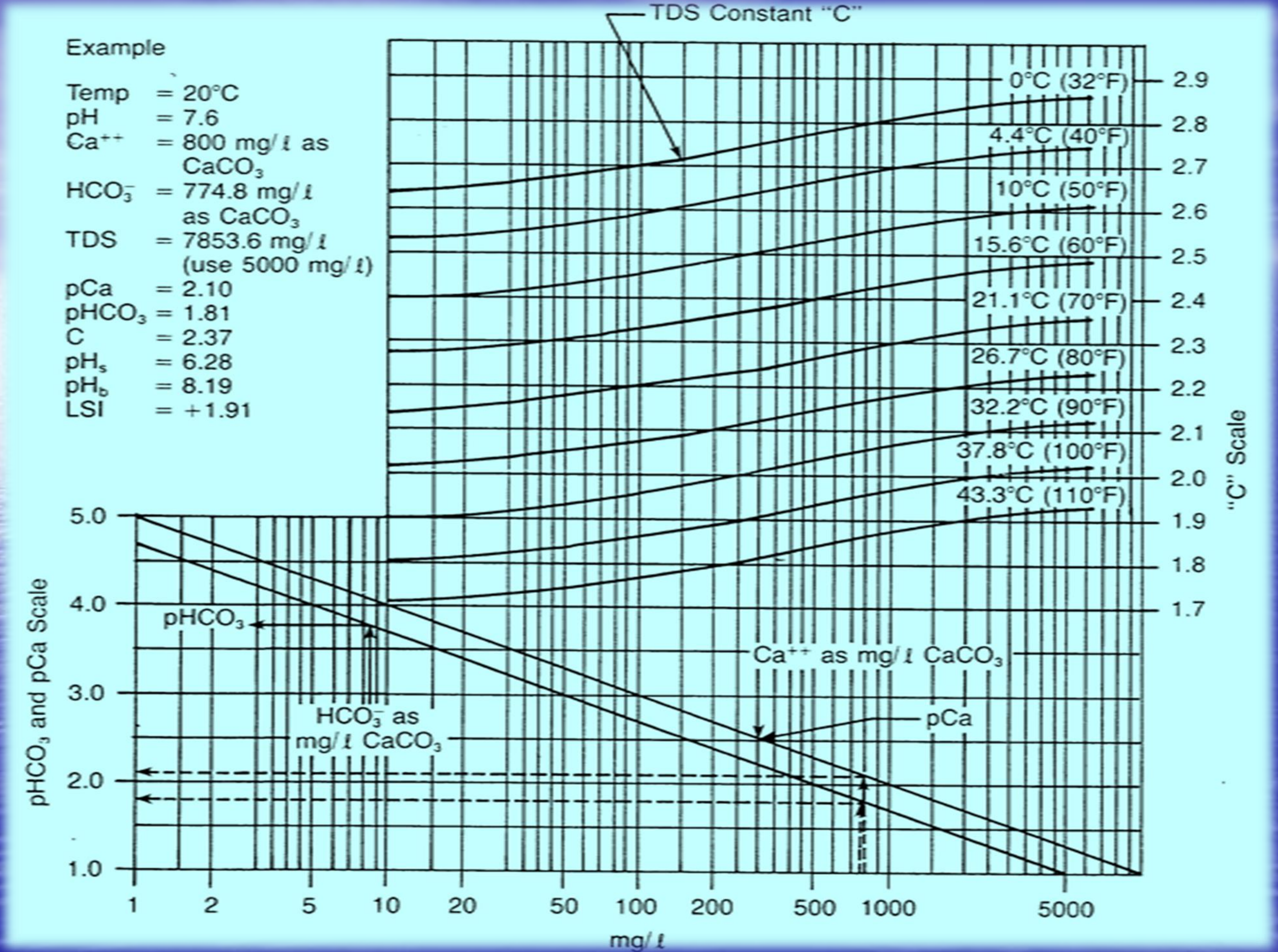
$$\mathrm{C}_{\mathrm{acid}} = \mathrm{C}_f + 0.90x \qquad \text{Eq. 13}$$

Using Alk_{acid} and C_{acid} for the new pH, calculate the LSI_c.
If HCl (100%) is used for acidification, Eq. 11 is:

$$\frac{\mathrm{Alk}_{\mathrm{acid}}}{\mathrm{C}_{\mathrm{acid}}} = \frac{\mathrm{Alk}_f - 1.37y}{\mathrm{C}_f + 1.21y} \qquad \text{Eq. 14}$$

where:
y = HCl (100%), mg/L


5.0
4.0
3.0
2.0
1.0
0.0
pAlk and pCa
pAlk
Alk
Ca
pCa
1
2
3
5
10
20
30
50
100
200
300
500
1,000
5,000
10,000
Ca and Alkalinity as mg/l $CaCO_3$



Example
Temp = 20°C
pH = 7.6
Ca++ = 800 mg/ℓ as CaCO3
HCO3- = 774.8 mg/ℓ as CaCO3
TDS = 7853.6 mg/ℓ (use 5000 mg/ℓ)
pCa = 2.10
pHCO3 = 1.81
C = 2.37
pHs = 6.28
pHb = 8.19
LSI = +1.91
TDS Constant "C"
0°C (32°F)
4.4°C (40°F)
10°C (50°F)
15.6°C (60°F)
21.1°C (70°F)
26.7°C (80°F)
32.2°C (90°F)
37.8°C (100°F)
43.3°C (110°F)
"C" Scale
pHCO3 and pCa Scale
pHCO3
HCO3- as mg/ℓ CaCO3
Ca++ as mg/ℓ CaCO3
pCa
mg/ℓ

4.3.4 การล้างเมมเบรนที่อุดตันเนื่องจากตะกรันแคลเซียมคาร์บอเนต

การล้างเมมเบรนที่อุดตันเนื่องจากตะกรันแคลเซียมคาร์บอเนต $CaCO_3$ ในระบบกรองน้ำ RO สามารถล้างได้ด้วยกรดต่างๆ ดังนี้

1. ล้างด้วยกรดไฮโดรคลอริก (HCl) 1% ที่ pH = 2
2. ล้างด้วยกรดมะนาว Citric acid เข้มข้น 2% โดยน้ำหนัก ปรับ pH = 4 ด้วย NH_4OH

Silica Scale Prevention

The scaling potential of soluble silica (silicic acid) in the absence of trivalent metal cations can be calculated as follows. The calculation requires the following data for the feed solution (after acid addition, if acid is used for control of calcium carbonate):

- SiO_2 concentration
- Temperature
- pH
- Total alkalinity

Calculation */16/*

1. The SiO_2 concentration in the concentrate stream is calculated from the SiO_2 concentration in the feed solution and the recovery of the reverse osmosis system:

$$SiO_{2c} = SiO_{2f}\left(\frac{1}{1-Y}\right)$$

where:
SiO_{2c} = silica concentration in concentrate as SiO_2, mg/L
SiO_{2f} = silica concentration in feed as SiO_2, mg/L
Y = recovery of the reverse osmosis system, expressed as a decimal

2. Calculate the pH of the concentrate stream from the pH of the feed stream using the procedure given in *Calcium Carbonate Scale Prevention (Section 2.4.2)*.

 Form No. 609-02022-1004

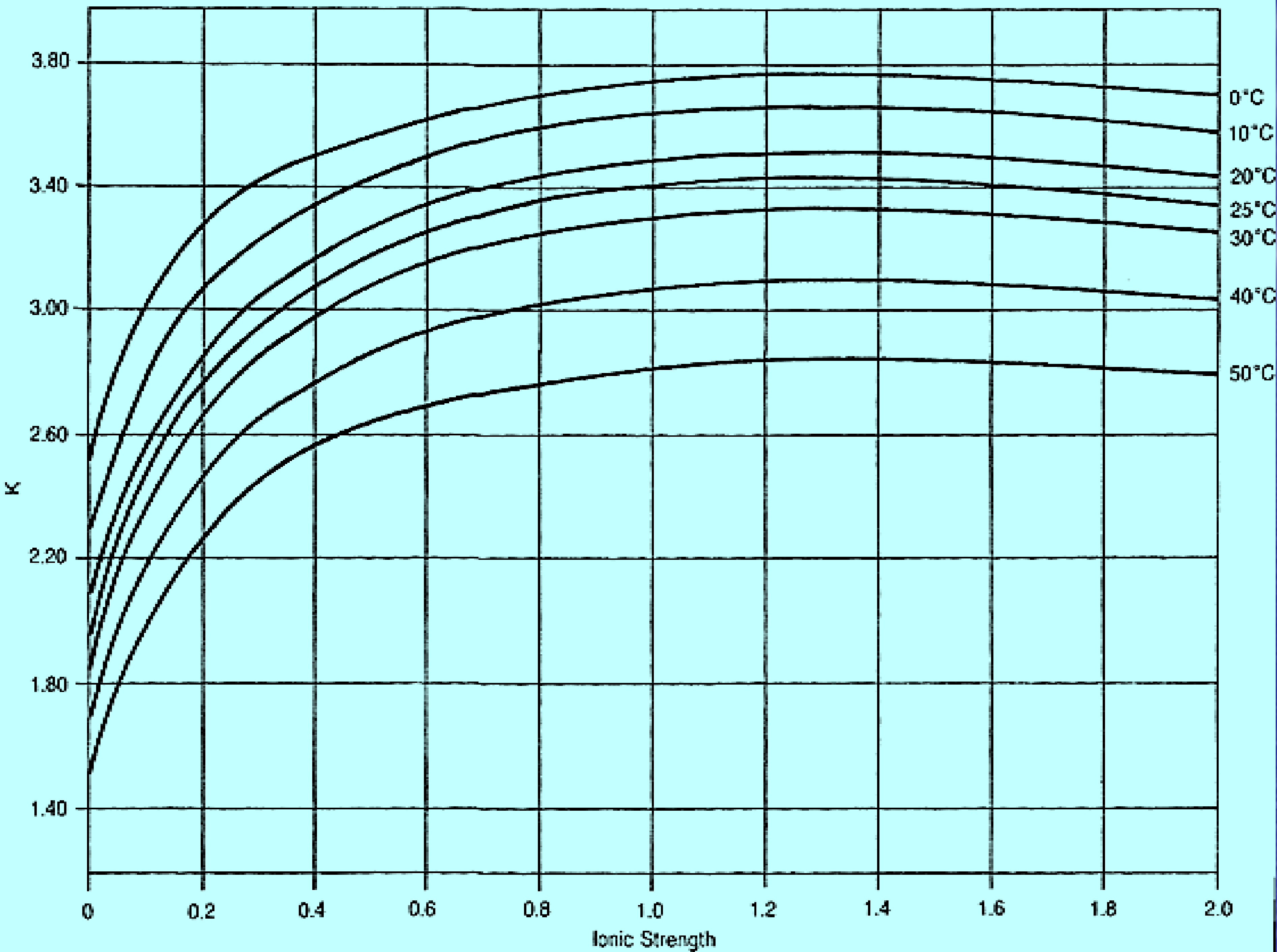
Silica Scale Prevention (cont.)

3. From Figure 2.10, obtain the solubility of SiO_2 as a function of temperature (SiO_2 temperature). The temperature of the concentrate is assumed equal to the temperature of feed solution. If the temperature of the water is known to vary, use the minimum temperature for calculations.

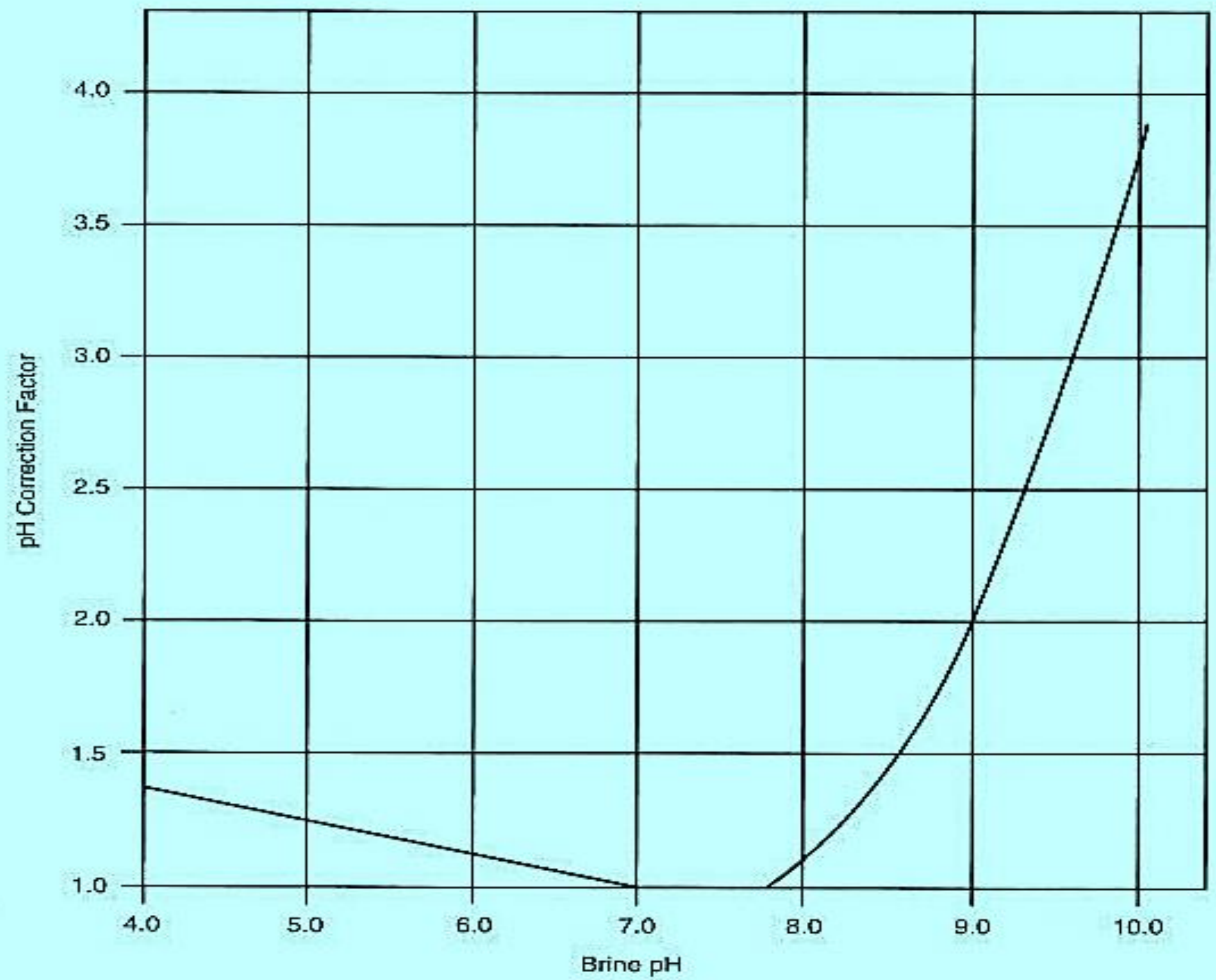
4. From Figure 2.11, obtain the pH correction factor for the concentrate pH calculated in Step 2.

5. Calculate the solubility of SiO_2 corrected for pH (SiO_{2corr}) by multiplying the solubility of SiO_2 obtained in Step 3 by the pH correction factor obtained in Step 4.

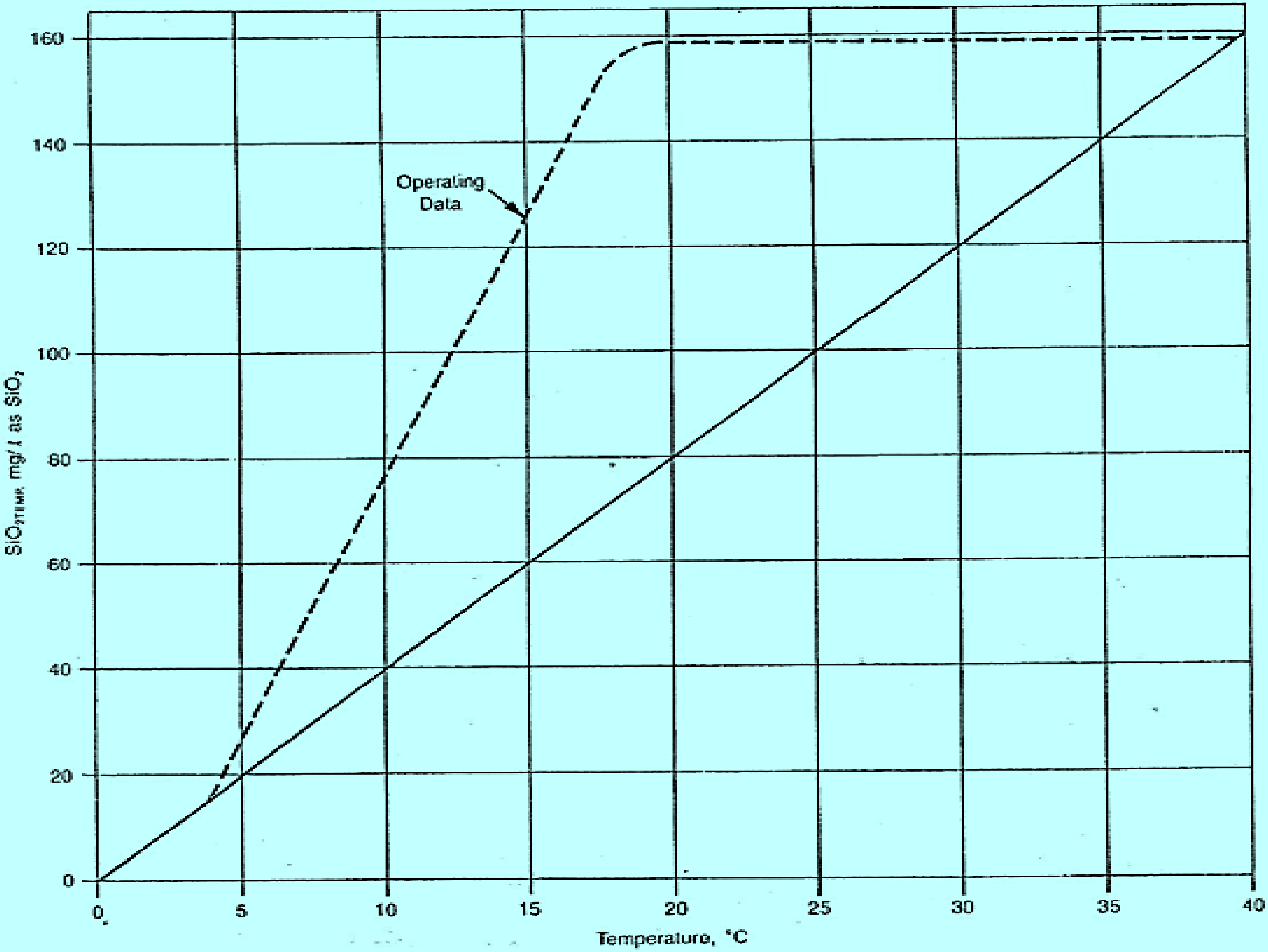
6. Compare the silica concentration in the concentrate (SiO_{2c}) obtained in Step 1 with the silica solubility (SiO_{2corr}) obtained in Step 5. Once a reverse osmosis system is operating, the scaling potential of SiO_2 can be directly calculated from the analysis of the concentrate stream and compared with the projected scaling potential calculated above. If SiO_{2c} is greater than SiO_{2corr}, silica scaling can occur and adjustment is required.



3.80
3.40
3.00
2.60
2.20
1.80
1.40
K
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Ionic Strength
0°C
10°C
20°C
25°C
30°C
40°C
50°C



SiO_2 pH correction factors


Operating Data
Temperature, °C
0
5
10
15
20
25
30
35
40
160
140
120
100
40
20

5.2 การล้างเมมเบรนที่อุดตันเนื่องจากสารอินทรีย์

การล้างเมมเบรนที่อุดตันเนื่องจากสารอินทรีย์ มีวิธีการล้างได้หลายวิธีดังต่อไปนี้

1. ล้างด้วยโซดาไฟ NaOH pH 11.0 เพราะโซดาไฟจะทำปฏิกริยากับไขมันและกรดอินทรีย์ กลายเป็นเกลือที่ละลายน้ำได้
2. ล้างด้วยกลุ่มสารซักฟอก (Detergent) ที่มีฟอสเฟต แต่ต้องไม่มีสารฟอกขาวจำพวกออกซิไดซิงเอเจนต์ผสมอยู่ เพราะจะทำให้เมมเบรนเสียหาย อาจผสมโซดาไฟ NaOH ปรับ pH อยู่ที่ 11.0 ร่วมด้วยได้
3. ถ้ามีการอุดตันเนื่องจากจุลินทรีย์ร่วมด้วยอาจต้องใช้ 0.25-2 % ฟอร์มัลดีไฮด์ (Formaldehyde) ล้าง แล้วล้างด้วยน้ำสะอาด

ตารางที่ 6 อายุการคงสภาพของสารละลายโซเดียมไบซัลไฟต์

ความเข้มข้นของสารโซเดียมไบซัลไฟต์ Sodium Bisulfite Solution ($NaHSO_3$) Weight %	อายุการคงสภาพของสารละลาย Sodium Bisulfite Maximum Solution Life
2	3 วัน
10	1 สัปดาห์
20	1 เดือน
30	6 เดือน

ที่มา: Permasep Engineering Manual, Bulletin 505, page 1, date 12/1/82

6.4 การล้างเมมเบรนที่อุดตันเนื่องจากจุลินทรีย์

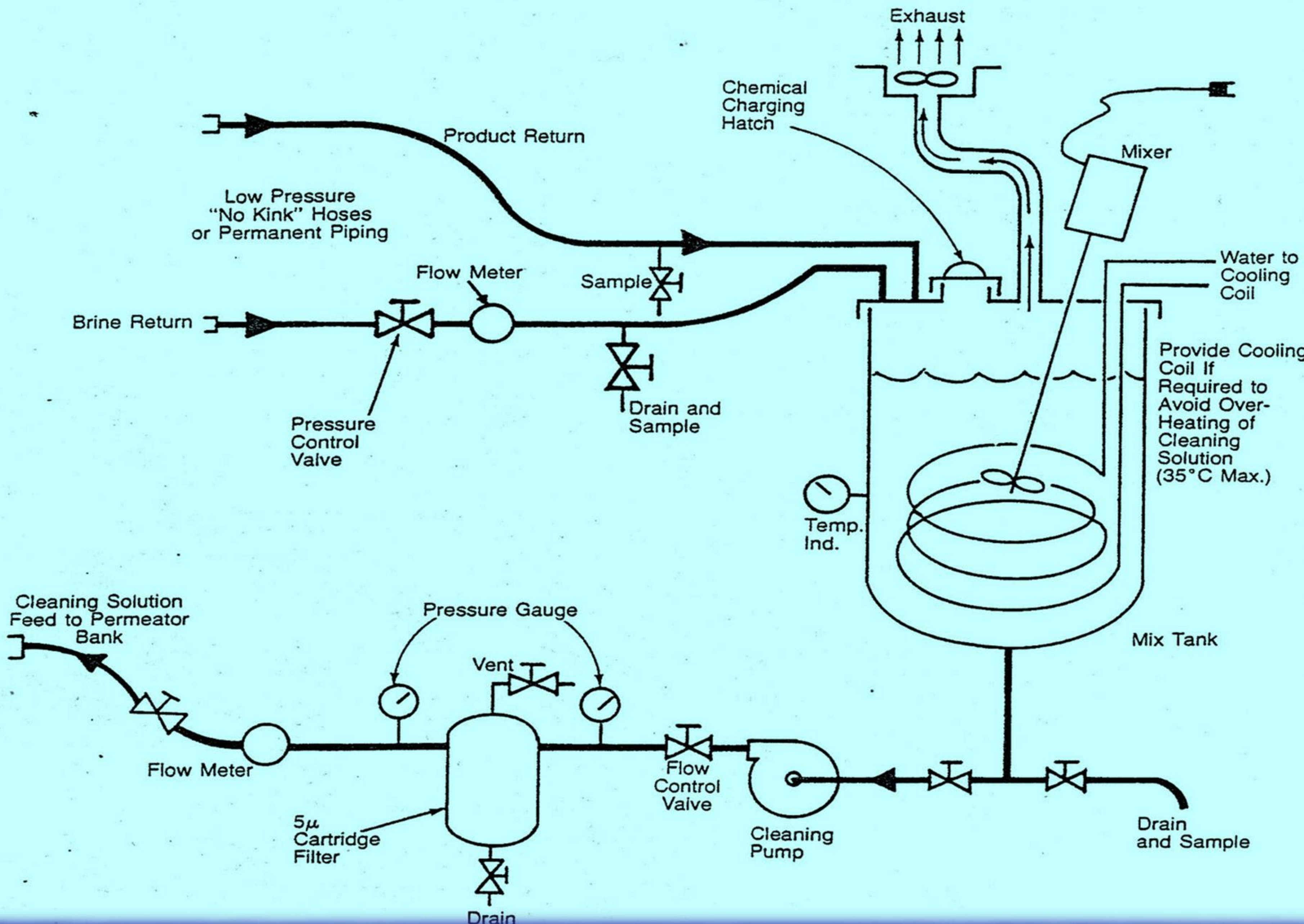
การล้างเมมเบรนที่อุดตันด้วยจุลินทรีย์ใช้วิธีการฆ่าเชื้อจุลินทรีย์ด้วย 2% โดยน้ำหนัก Formaldehyde แล้วล้างด้วยสารซักฟอก 0.25 %โดยน้ำหนัก (ต้องไม่มีสารฟอกขาว) นอกจากนี้การฆ่าเชื้อจุลินทรีย์อาจใช้โซเดียมเมตาไบซัลไฟด์ 1.0%โดยน้ำหนัก ก็ได้ แต่ต้องเติม 18 % กลีเซอรีน (Glycerine) เพื่อยับยั้งการเจริญเติบโตของจุลินทรีย์

TABLE I
CHEMICAL CLEANING AGENTS

Chemicals	Foulants						
	$CaCO_3$	$CaSO_4$ $BaSO_4$ $SrSO_4$ CaF_2	SiO_2	Metal Oxides	Inorganic Colloids	Biological Matter	Organics
Hydrochloric Acid[1] (HCl)(pH 4.0)	X				X		
2.0 wt. % Citric Acid + NH_4OH (pH 4.0)	X			X	X		
5 wt. % Nutek NT-600	X						
2 wt. % Citric Acid + NH_4OH (pH 8)		X					
1.5 wt. % Na_2EDTA[3] + NaOH (pH 7–8) or 1.5 wt. % Na_4EDTA + HCl (pH 7–8)		X					
1.0 wt. % Na Hydrosulfite ($Na_2S_2O_4$)		X		X			
NaOH (pH 11.0)[2]			X		X		X
2.0 wt. % Citric Acid + 2.0 wt. % Na_2EDTA + NH_4OH (pH 4.0)	X			X			
0.5 wt. % "Biz"[4] (with phosphate) + NaOH (pH 11.0)			X		X		X
1 wt. % Drewsperse 738					X		
1 wt. % NaHMP				X	X		X
1/4–2 wt. % Formaldehyde followed by 0.25 wt. % "Biz" (with phosphate)						X	

1. A lower pH may be more effective. If pH is <4.0 the low pH Guideline must be followed.
2. A higher pH may be more effective. If pH is >11.0 the high pH Guideline must be followed.
3. EDTA is ethylenediaminetetracetic acid.
4. "Biz" is a detergent sold by Procter and Gamble, U.S.A.

Figure 1. Equipment for Cleaning, Sterilization and Posttreatment



Hydranautics Design Limits.

Saturation Limits for Sparingly Soluble Salts in the Concentrate:

Salt	Saturation %
$CaSO_4$	230
$SrSO_4$	800
$BaSO_4$	6000
SiO_2	100

Limits of Saturation Indices:

Condition*	LSI Value
LSI and SDSI without scale inhibitor	≤ -0.2
LSI & SDSI with SHMP	≤ 0.5
LSI & SDSI with organic scale inhibitor	≤ 1.8

* Langelier and Stiff & Davis Saturation Indices

Table 3.5 Generally-accepted water quality guidelines to minimize RO membrane scaling.

Species	Measure	Value
Silica (Soluble)	ppm	200*
Barium, Strontium	ppm	< 0.05
Calcium	LSI	< 0**

* In RO reject stream

** Can go up to 2.0 – 2.5 with appropriate antiscalant

Table 7.1 Generally-accepted water quality guidelines for RO influent and concentrate waters.

Species	Units	Guideline Value/Range
Colloids	SDI (unit-less)	< 5*
Suspended Solids	NTU	< 1
Calcium Carbonate	LSI	< 0**†
Metals: iron, manganese, aluminum	ppm	< 0.05
Barium, Strontium	ppm	< 0.05
Hydrogen Sulfide	ppm	< 0.1
Microbes	CFU/ml	< 1,000†
Silica (soluble)	ppm	140 – 200*†
Organics (TOC)	ppm	< 3
Color	APHA	< 3
Chemical Oxygen Demand (COD)	ppm	< 10
pH—CA Membranes	pH units	4 – 6
pH—PA Membranes	pH units	2 – 12†††
Chlorine, free—CA Membranes	ppm	< 1
Chlorine, free—PA Membranes	ppm	< 0.02
Temperature—CA Membranes	°C	< 30
Temperature—PA Membranes	°C	< 45

* Silt density index (see Chapter 3.8)

** Can be up to 2.0 – 2.5 depending of the type of antiscalant used

Table 8.1 Mechanical RO pretreatment techniques and species that these techniques address.

Mechanical Pretreatment	Species Addressed
Clarification	Suspended solids, Colloids, Organics, Color, SDI
Multimedia Filtration	Turbidity, Suspended solids down to 2 – 10 microns, SDI
High-Efficiency Filtration	Suspended solids down to 0.25 microns
Carbon Filters	Total organic carbon, Chlorine
Iron Filters	Iron, Manganese, Hydrogen sulfide
Sodium Softeners	Hardness, Soluble iron
UV Radiation	Organics, Microbes
Membrane	Microbes, Algae, Color

Table 3.2 General rejection capabilities of most polyamide composite membranes at room temperature.

Species	Rejection (%)
Sodium	92 – 98
Calcium	93 – 99+
Magnesium	93 – 98
Potassium	92 – 96
Iron	96 – 98
Manganese	96 – 98
Aluminum	96 – 98
Ammonium*	80 – 90
Copper	96 – 99
Nickel	96 – 99
Zinc	96 – 98
Silver	93 – 96
Mercury	94 – 97
Hardness	93 – 99
Chloride	92 – 98
Bicarbonate	96 – 99
Sulfate	96 – 99+
Fluoride	92 – 95
Silicate	92 – 95
Phosphate	96 – 98
Bromide	90 – 95
Borate	30 – 50
Chromate	85 – 95
Cyanide	90 – 99+

* below pH 7.8. Above this pH, ammonia exists as a gas that is not rejected by RO membranes.

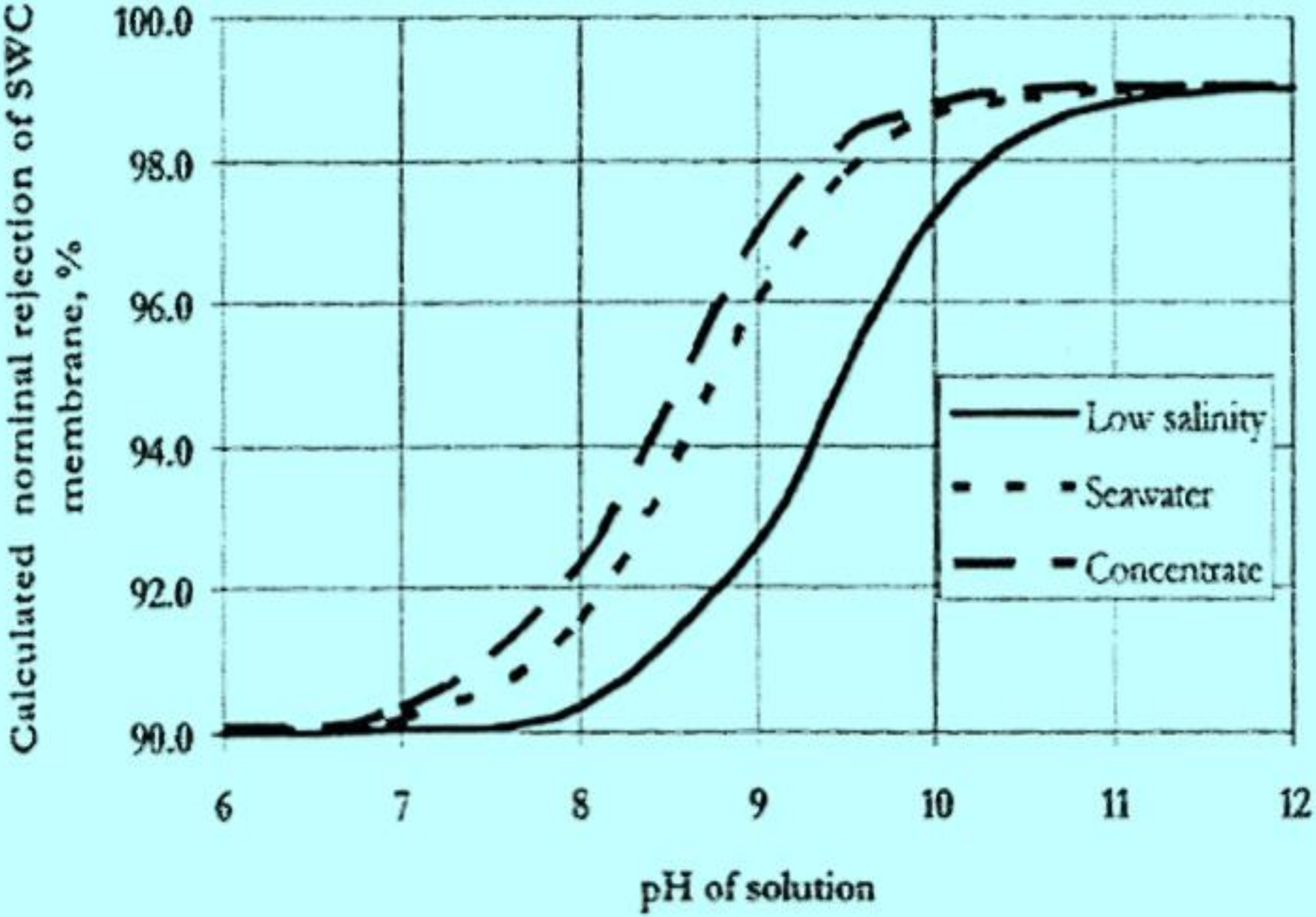


FIG. Calculated rejection of boron species vs. feed water pH and salinity at 25°C.

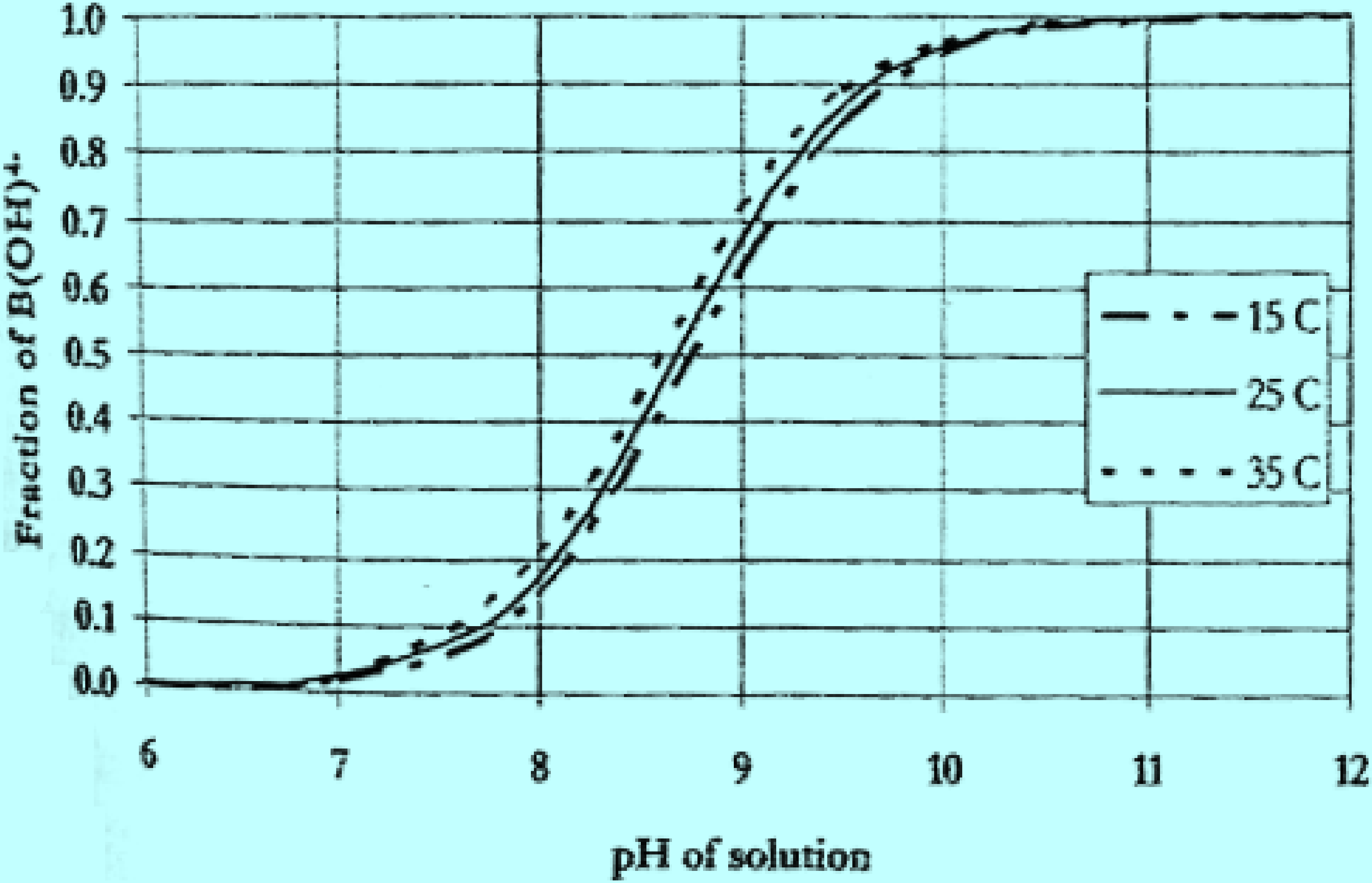


FIG. Distribution of boron species in seawater vs. feed water pH and temperature

Quantity of sulfuric acid required to maintain concentrate pH below the threshold value of saturation index of calcium phosphate.

Recovery rate, %	75	80	85
Required concentrate pH	7.0	6.7	6.3
Required feed pH	6.2	5.9	5.5
Dosing rate of H_2SO_4, ppm (100%)	173	219	260
Contribution to product water cost, $/m^3 at sulfuric acid cost of $500/t	0.087	0.109	0.130

Ksp or concentrations limit of scale forming compounds common to RO.

Compound	Formula	Ksp or concentration limit, (ppm)
Calcium sulfate	$CaSO_4$	2.5×10^{-5}
Barium Sulfate	$BaSO_4$	2.0×10^{-10}
Tricalcium Phosphate	$Ca_3(PO_4)_2$	2.8×10^{-30}
Calcium Phosphate Dihydrate	$CaHPO_4 \times 2H_2O$	2.2×10^{-7}
Calcium Carbonate	$CaCO_3$	LSI < 0, S&DSI < 0
Reactive Silica	H_4SiO_4	(120–160 ppm)

$$2CO_2 + Ca(OH)_2 = Ca(HCO_3)_2$$

$$CO_2 + CaCO_3 + H_2O = Ca(HCO_3)_2$$

$$CO_2 + NaOH = NaHCO_3$$

$$CO_2 + Na_2CO_3 + H_2O = 2NaHCO_3$$

Concentration changes per unit of CO_2 neutralized. (gram/gram or lb/lb).

Reagent	Usage	Compound formed	Hardness increase	Alkalinity increase	TDS increase, ppm
$Ca(OH)_2$	0.84	$Ca(HCO_3)_2$	1.13	1.13	1.84
$CaCO_3$	2.27	$Ca(HCO_3)_2$	2.27	2.27	3.27
NaOH	0.91	$NaHCO_3$	0.0	1.13	1.91
$Na2CO_3$	2.40	$NaHCO_3$	0.0	2.27	3.40

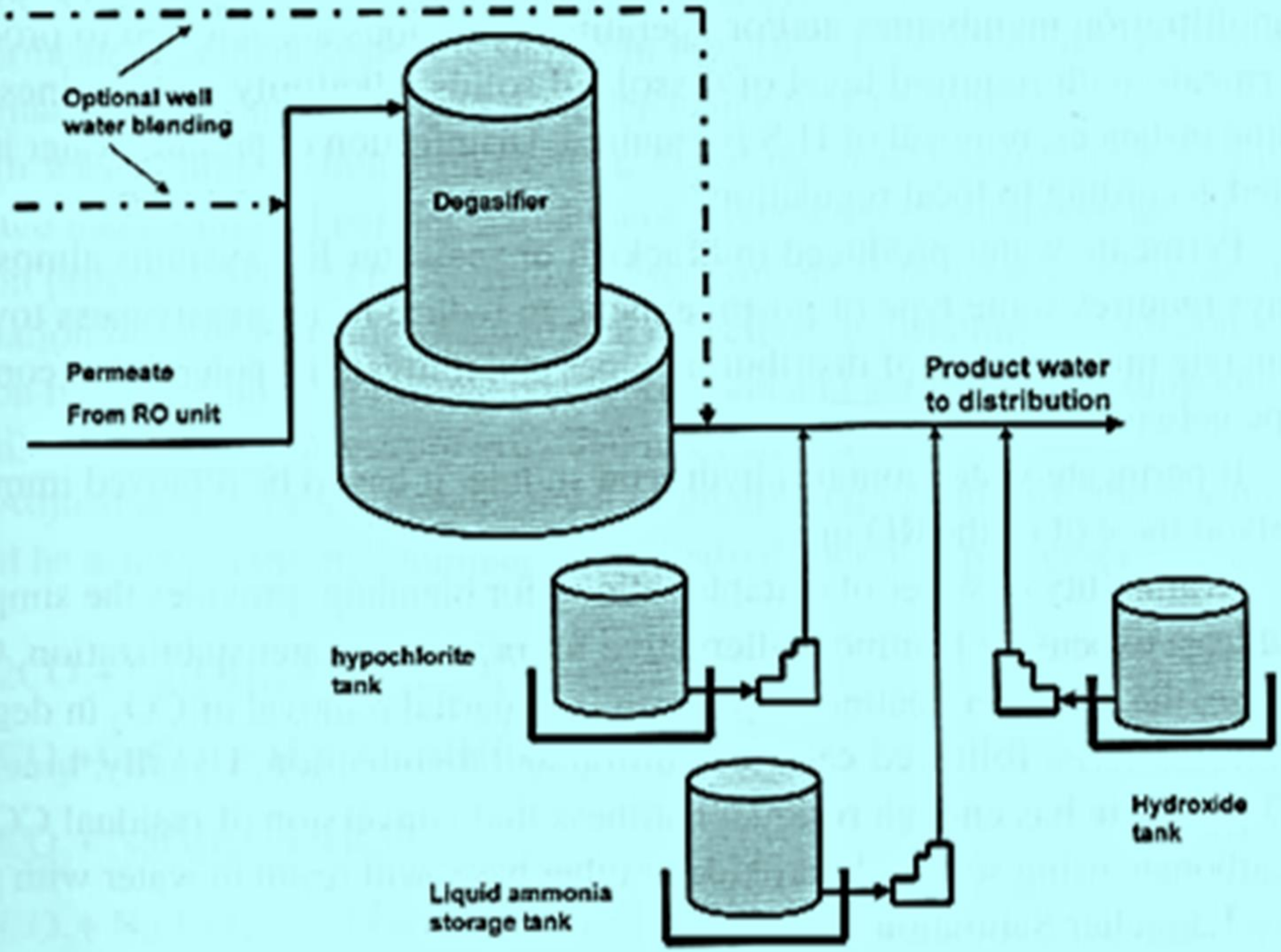


FIG. 16.15 Schematic diagram of treatment of permeate from brackish RO or wastewater reclamation unit.

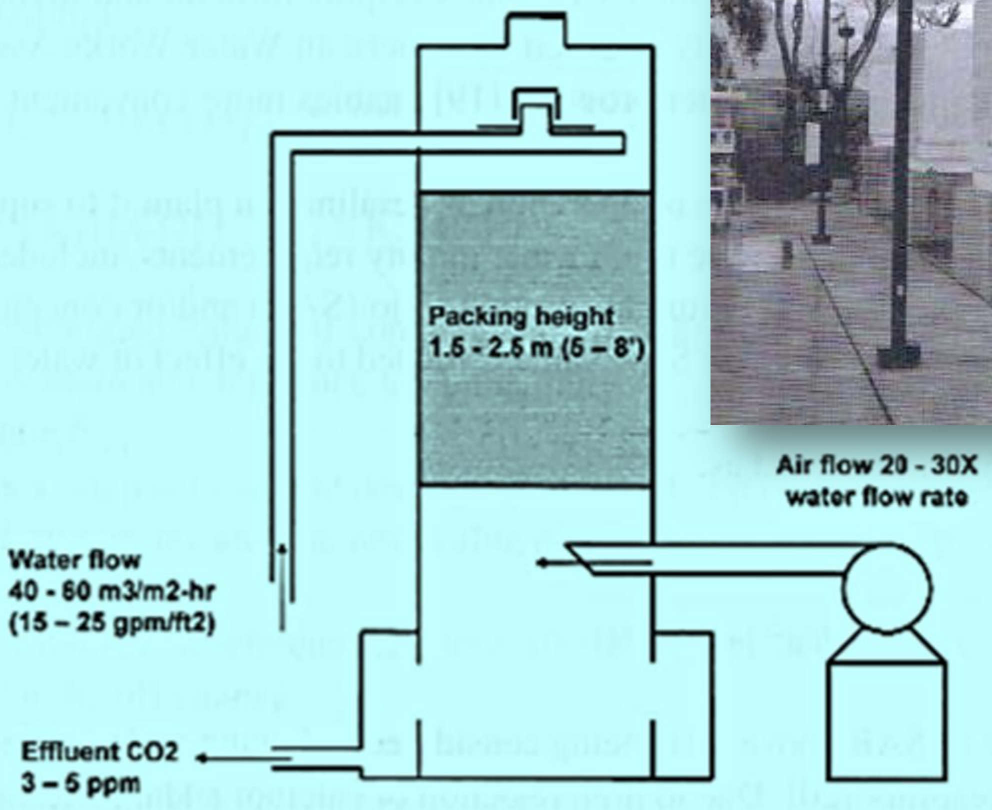
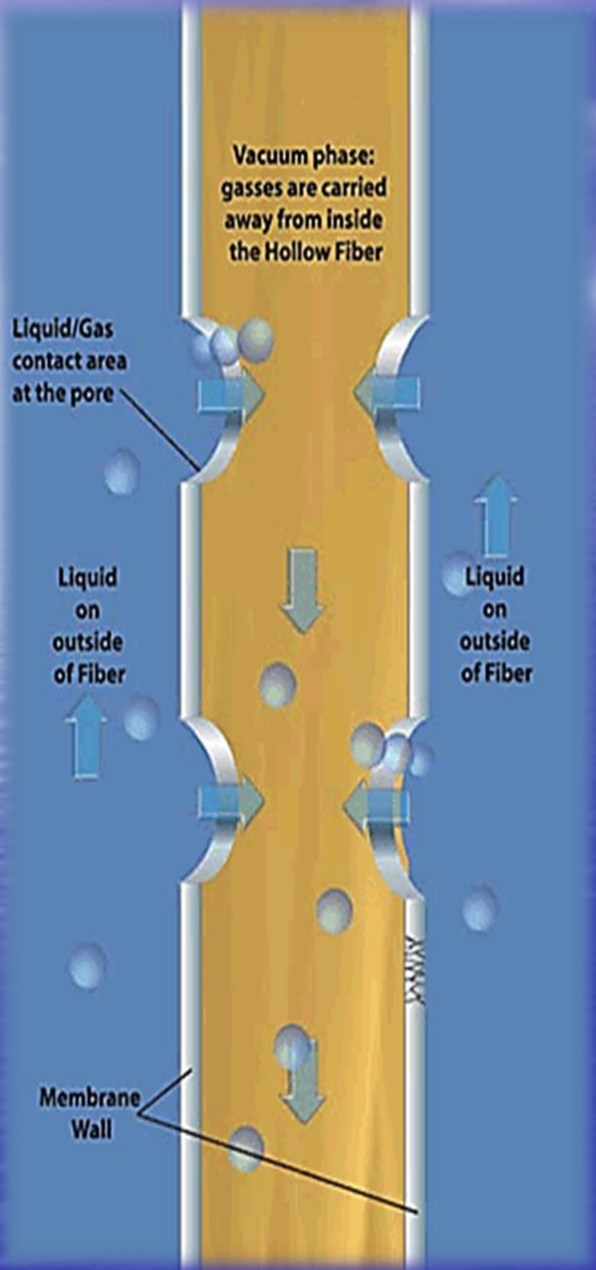
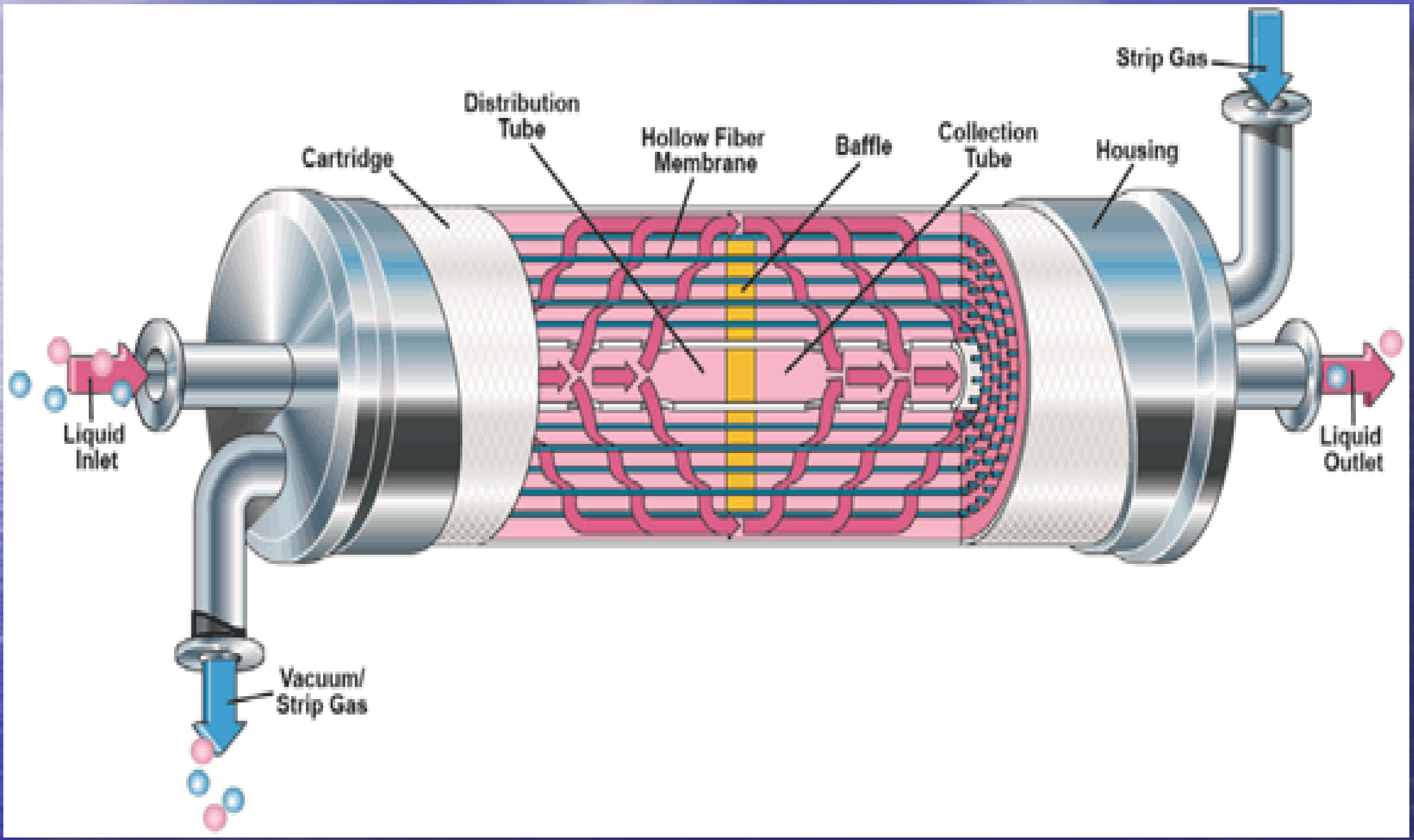
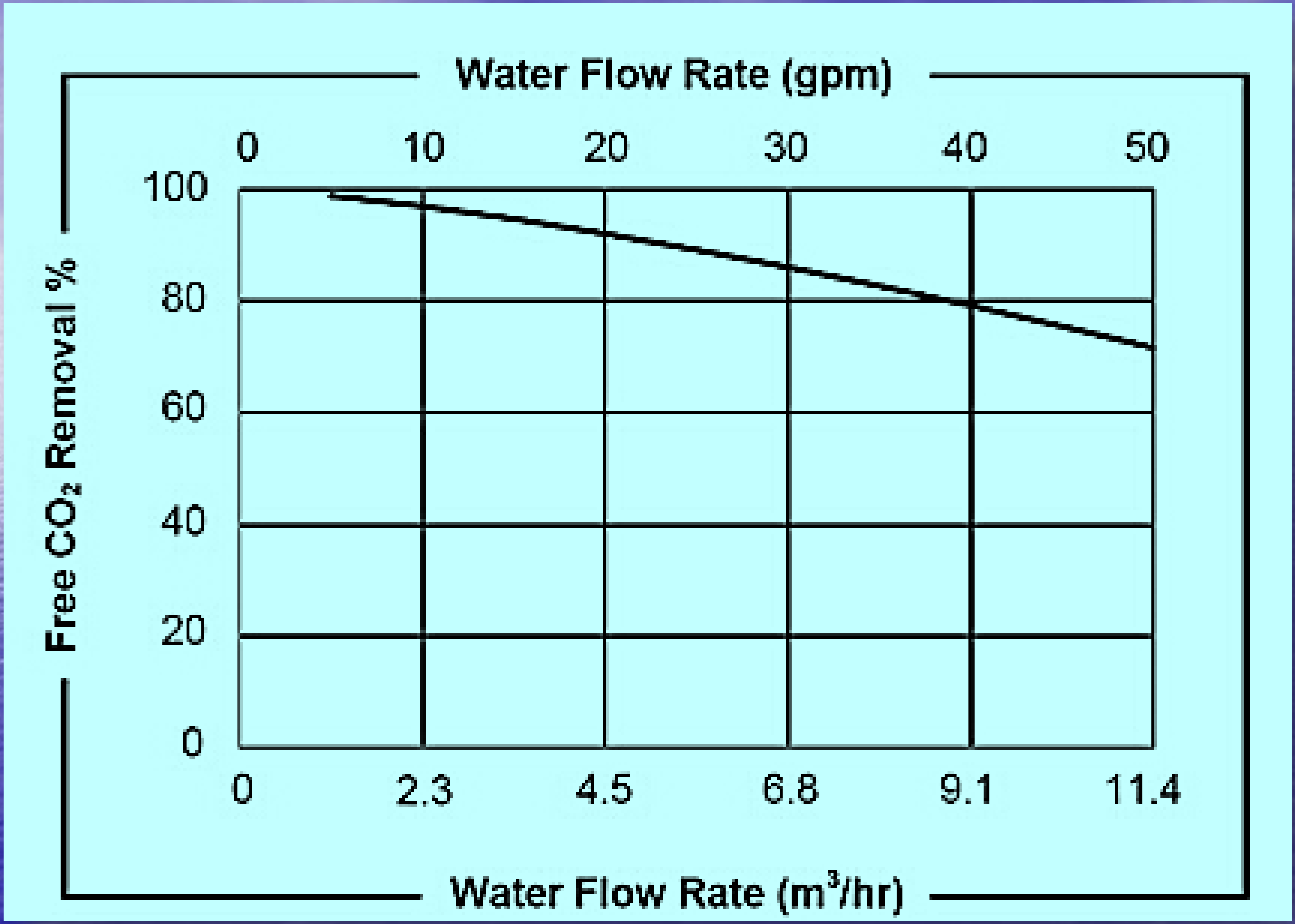


FIG. 16.16 Schematic diagram forced air degasifier for CO_2 removal.

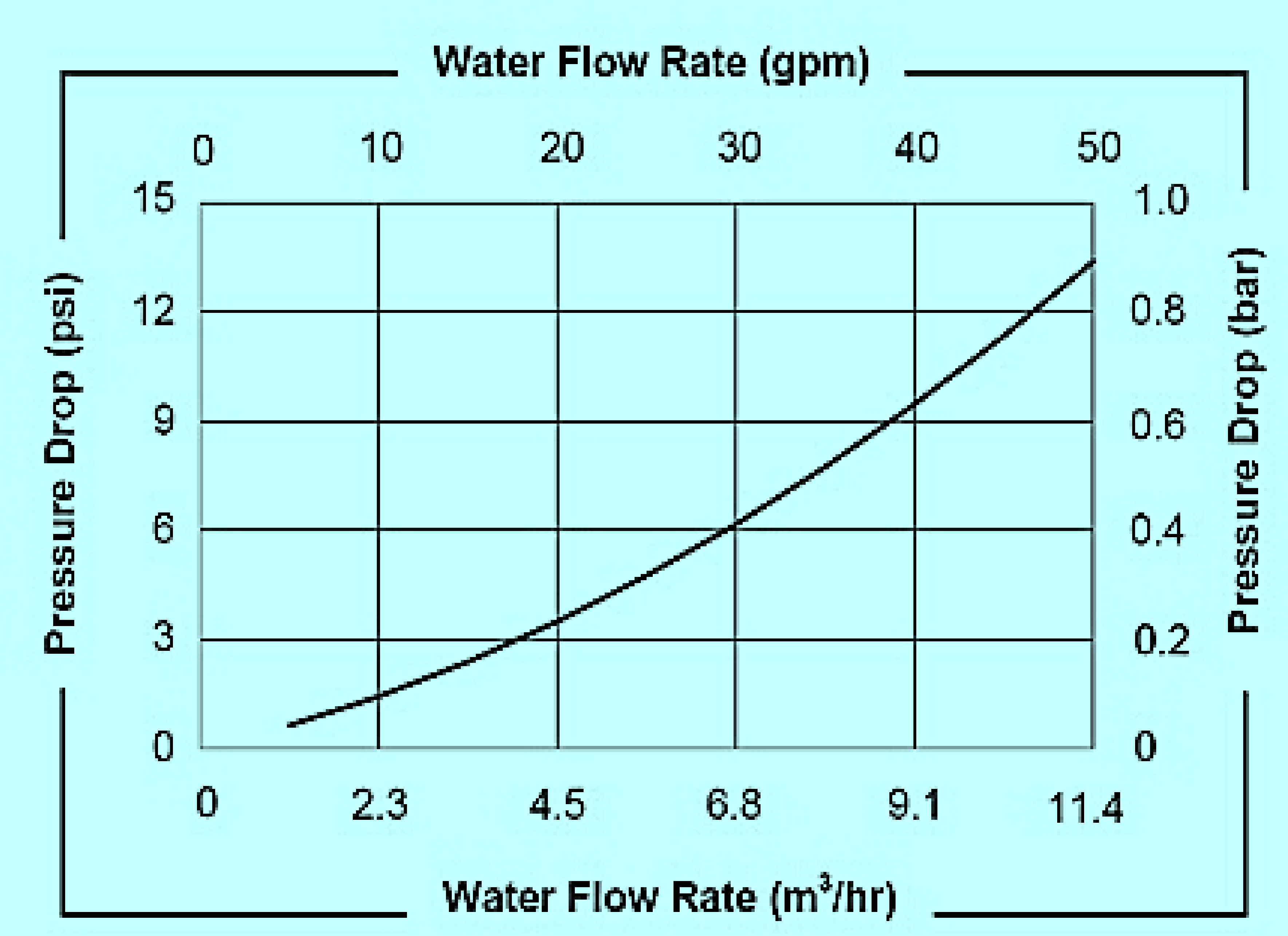

Vacuum phase: gasses are carried away from inside the Hollow Fiber
Liquid/Gas contact area at the pore
Liquid on outside of Fiber
Liquid on outside of Fiber
Membrane Wall


MEMBRANE TREATMENT SYSTEM


Strip Gas
Distribution Tube
Hollow Fiber Membrane
Baffle
Collection Tube
Cartridge
Housing
Liquid Inlet
Liquid Outlet
Vacuum/ Strip Gas



Water Flow Rate (gpm)
0
10
20
30
40
50
100
80
60
40
20
0
Free CO_2 Removal %
0
2.3
4.5
6.8
9.1
11.4
Water Flow Rate (m^3/hr)



Water Flow Rate (gpm)
0
10
20
30
40
50
15
12
9
6
3
0
1.0
0.8
0.6
0.4
0.2
0
Pressure Drop (psi)
Pressure Drop (bar)
0
2.3
4.5
6.8
9.1
11.4
Water Flow Rate (m³/hr)

$$SP_y = SP_0 \times (1 + SPI)^{*}Y \qquad (15.33)$$

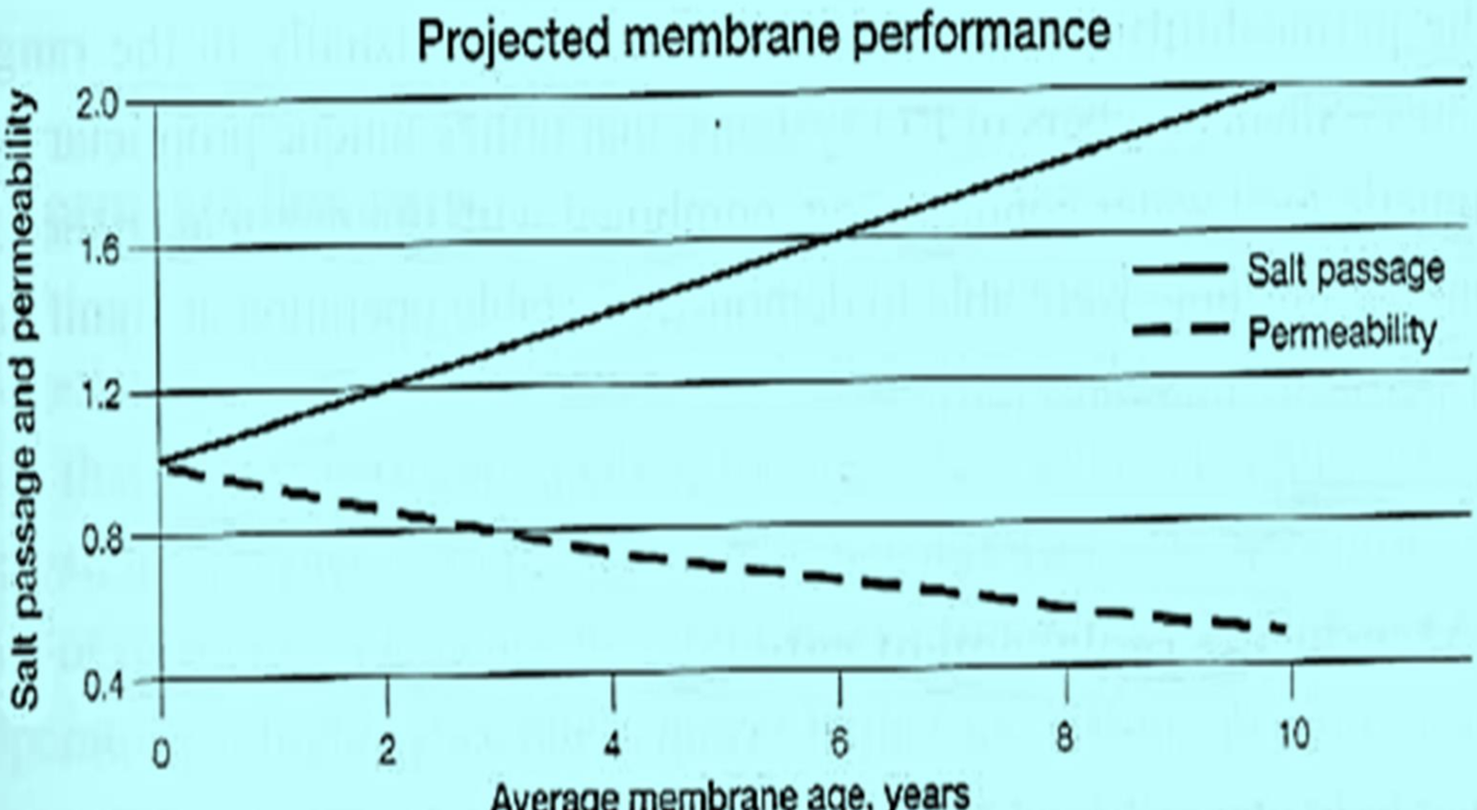


FIG. 15.6 Projected changes of salt passage and water permeability over time.

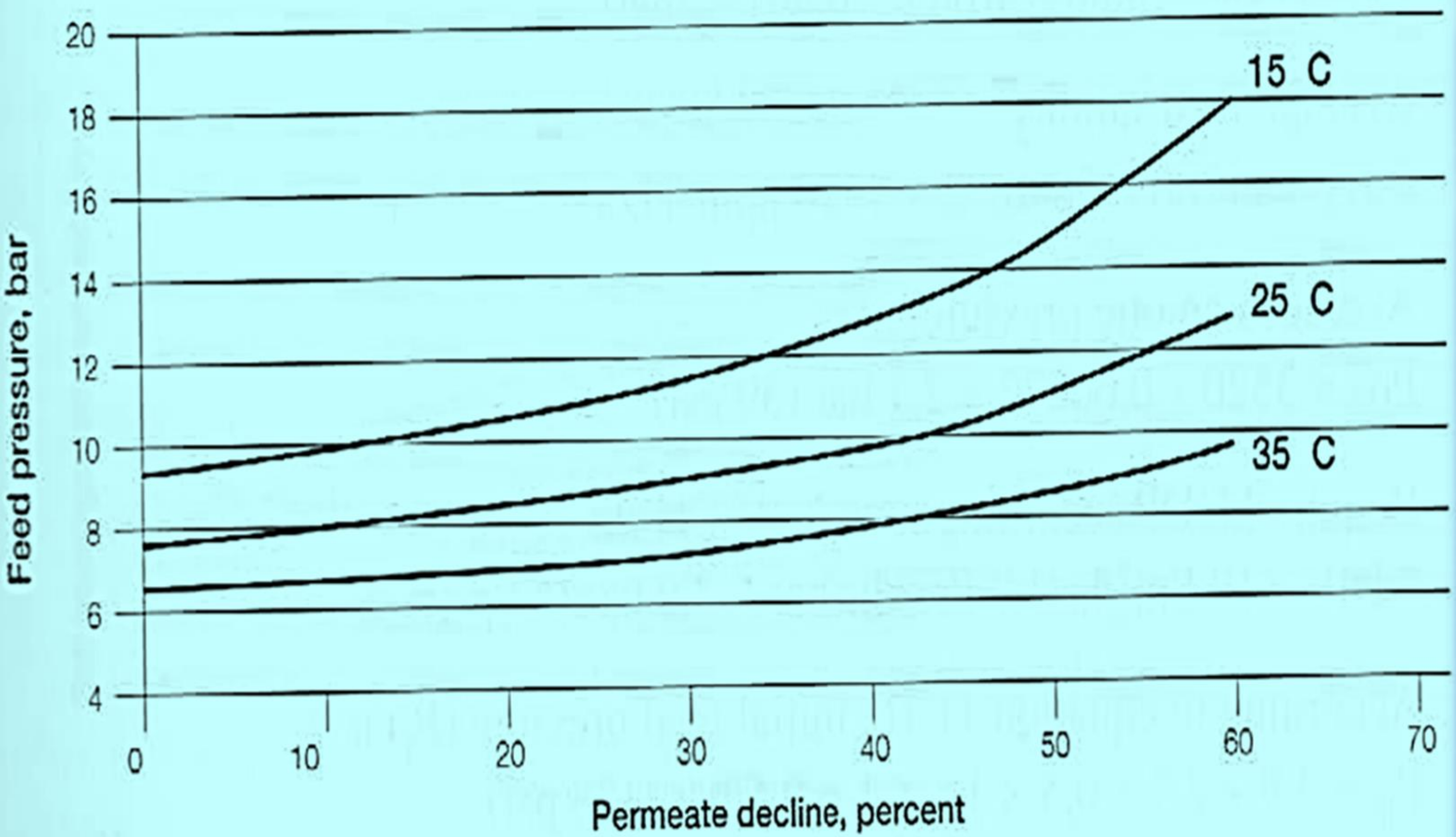


FIG. 15.7 Feed water pressure as function of fouling rate. Feed salinity 1000 ppm TDS, recovery rate 85% and permeate flux 19 $l/m^2/hr$.

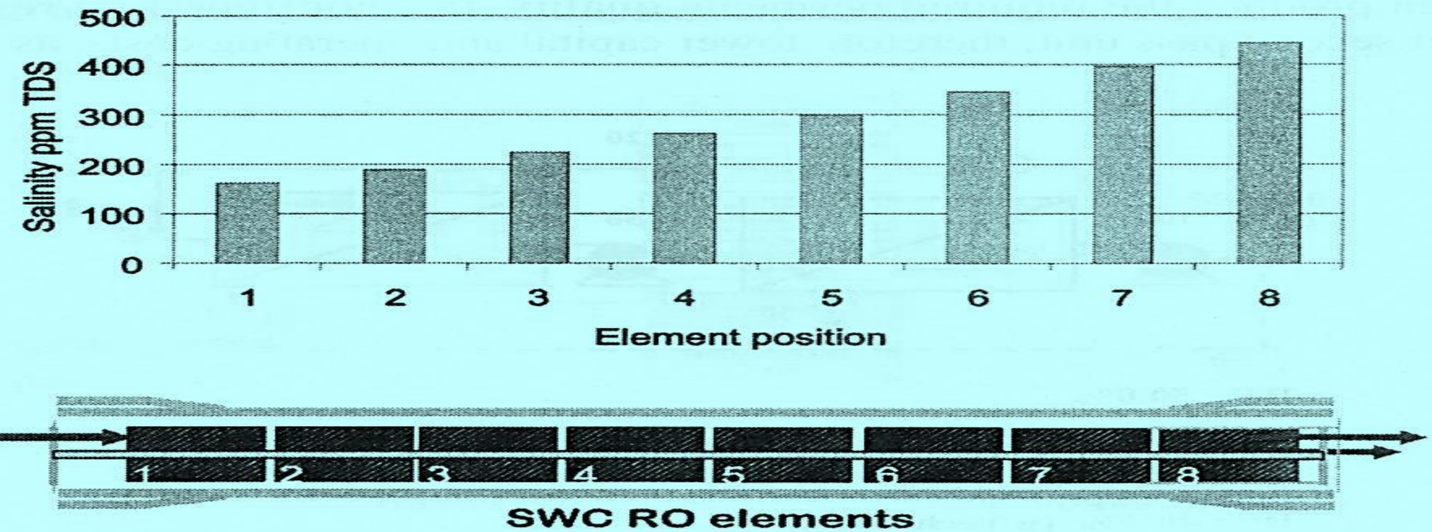


FIG. 5.9 Combined permeate salinity vs. element position in a pressure vessel.

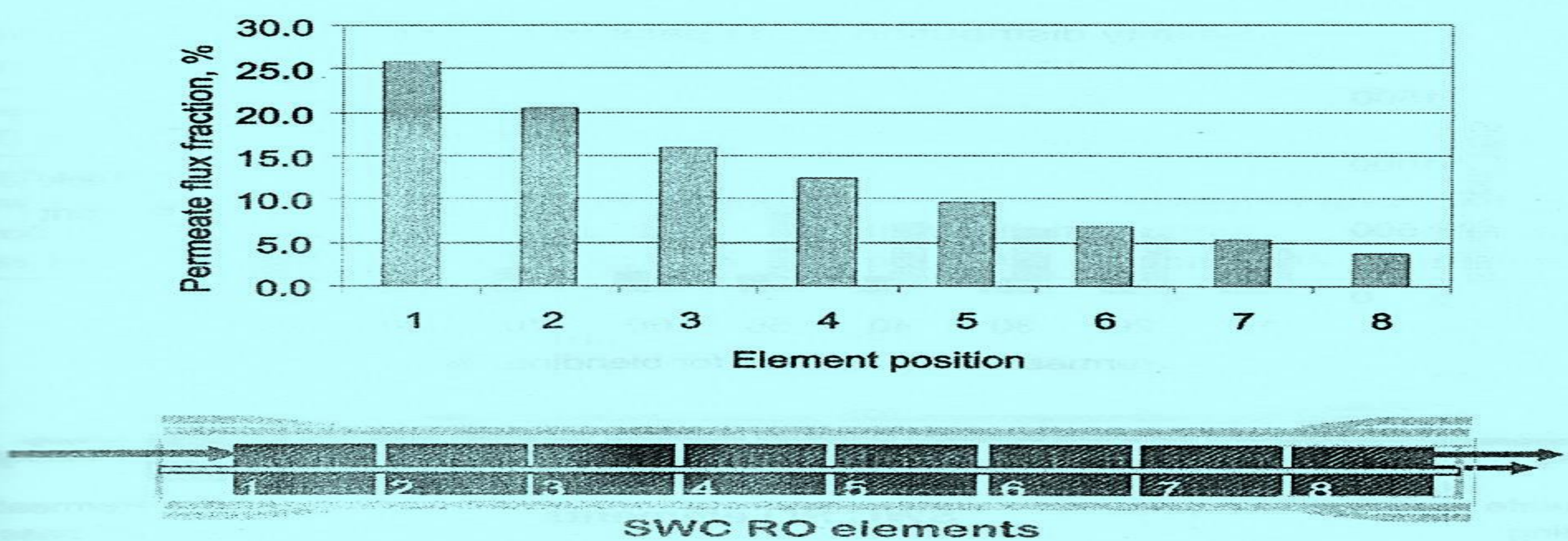
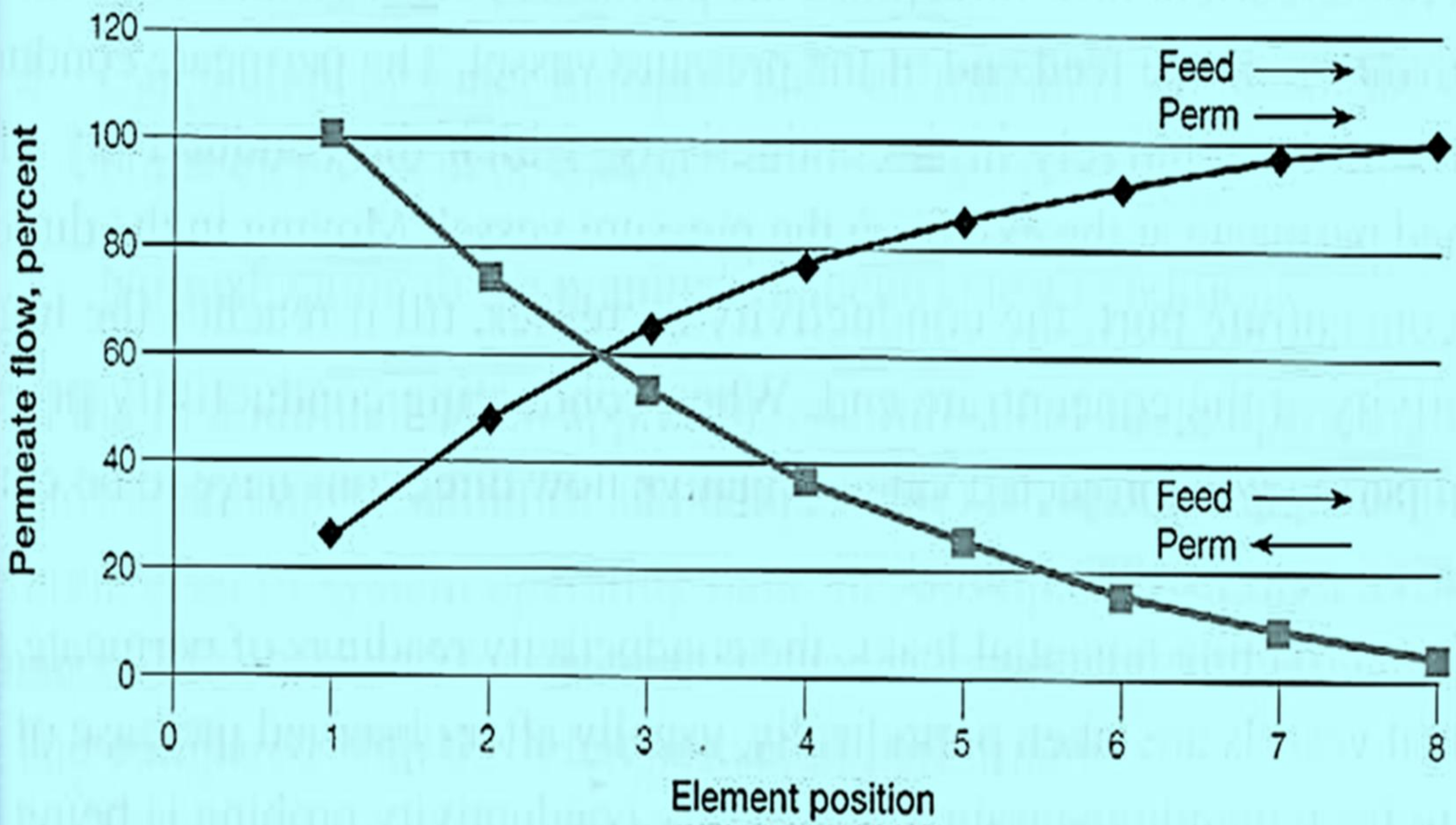
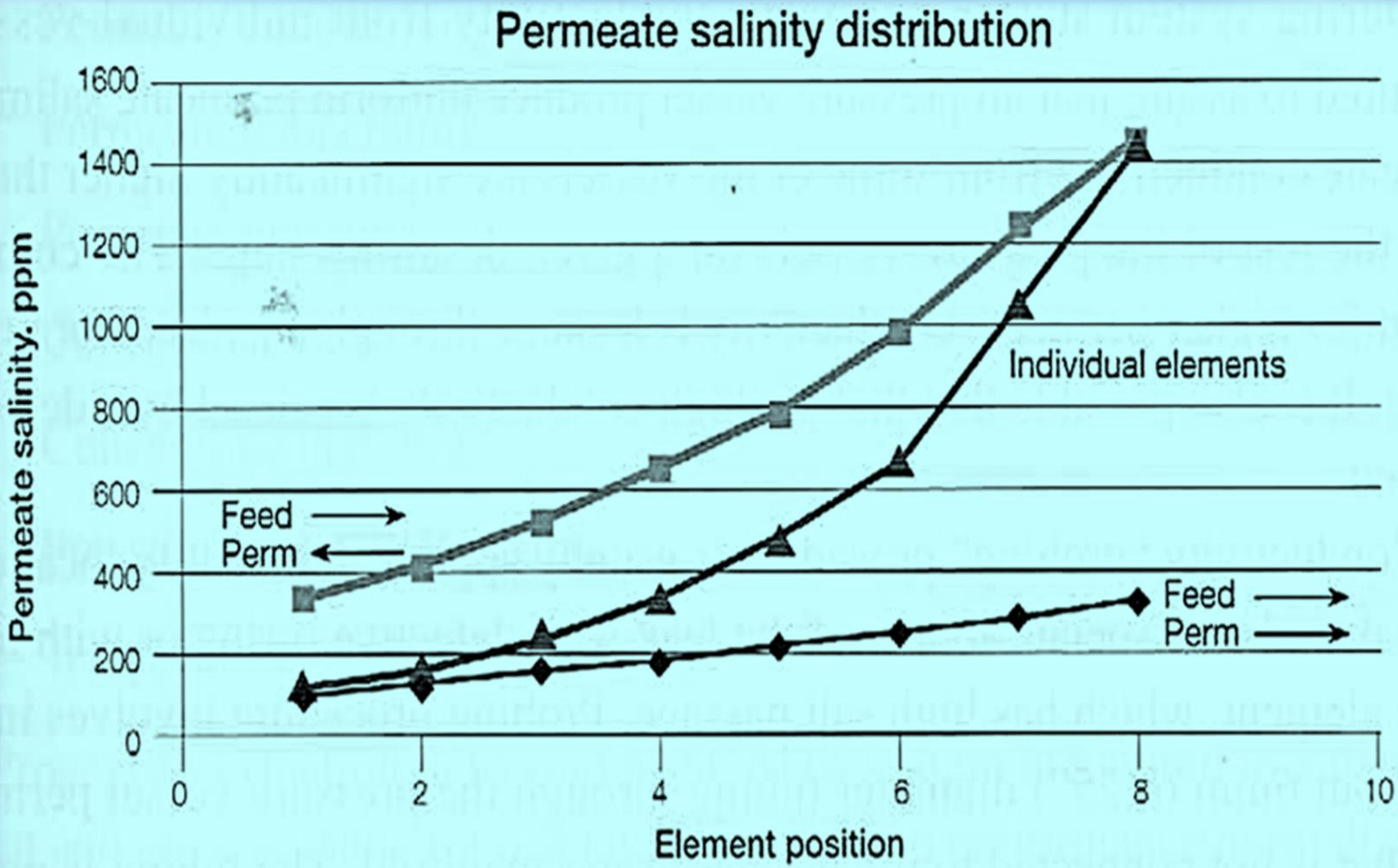


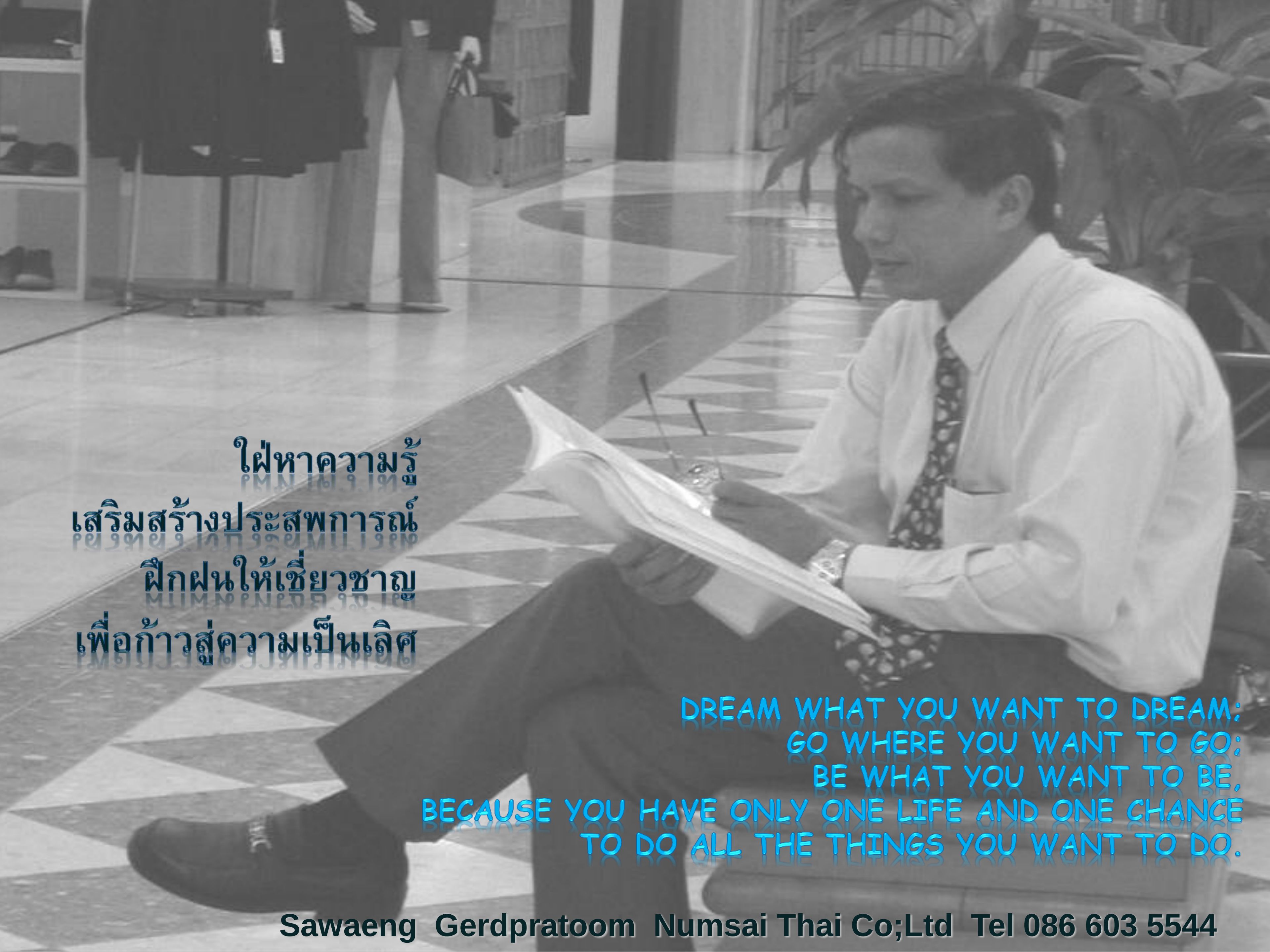
FIG. 5.10 Flux distribution from individual elements vs. element position in a pressure vessel.



17.2 Cumulative permeate flow in pressure vessel as a function of relative flow directions.



17.3 Cumulative conductivity profile in pressure vessel as a function of relative flow directions.



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เสริมสร้างประสพการณ์
ฝึกฝนให้เชี่ยวชาญ
เพื่อก้าวสู่ความเป็นเลิศ
DREAM WHAT YOU WANT TO DREAM;
GO WHERE YOU WANT TO GO;
BE WHAT YOU WANT TO BE,
BECAUSE YOU HAVE ONLY ONE LIFE AND ONE CHANCE
TO DO ALL THE THINGS YOU WANT TO DO.
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