REVERSE OSMOSIS TECHNOLOGY

Applications for High-Purity-Water Production

edited by

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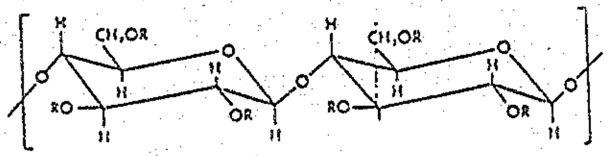
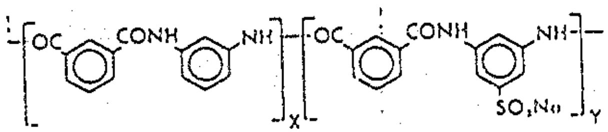
Commercial Reverse Osmosis Membranes and Modules

ANTHONY E. ALLEGREZZA, JR. *Millipore Corporation, Bedford, Massachusetts*

I. INTRODUCTION

Confronted with a process design problem requiring the purification of an aqueous feed, or the concentration of a dissolved solute, many engineers are considering reverse osmosis (RO). Where once there were a few pioneering suppliers, today's buyer of RO equipment faces an increasingly diverse array of products and equipment. This is the result of the present day acceptance of RO as a routine chemical engineering process. In the past, RO was a "promising" method of water purification, but because of its novelty and uncertain economies, RO always faced an uphill battle against older, proven technologies.

Table 4. Chemical Structure of Commercial RO Membranes

Chemical Name	Trade name	Manufacturer	Module type
Cellulose acetate[a] 		Desal	Spiral
		DuPont	Spiral
		Fluid systems	Spiral
		Koch membrane system	Tubular
		Hydranautics	Spiral
		Nitto	Tubular
		Osmonics	Spiral
		PCI	Spiral
		Stork	Tubular
		Toray	Spiral
Cellulose triacetate		Dow (FilmTec)	Hollow fiber
		Toyobo	Hollow fiber
Aromatic polyamide 	B-9	DuPont	Hollow fiber
	B-15		Spiral

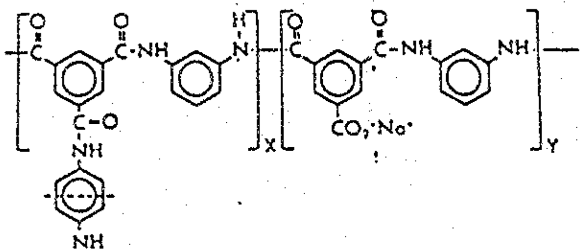
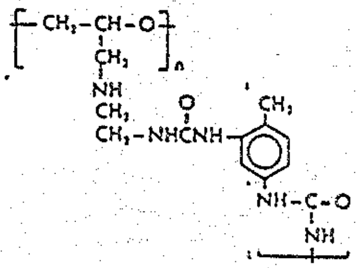
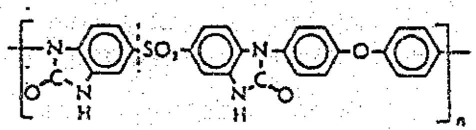
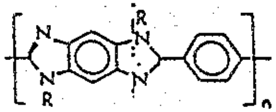
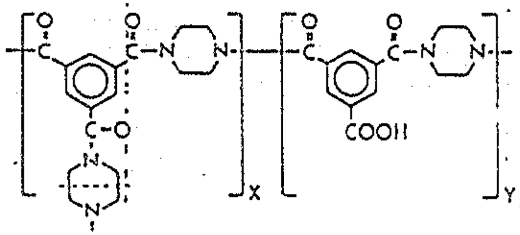
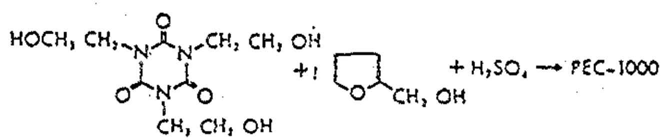
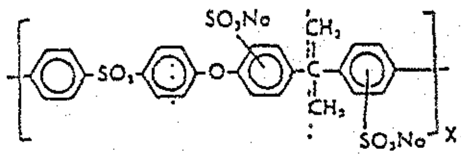
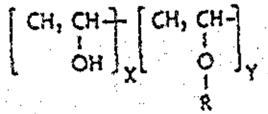
30% Terephthaloyl group replacement of isophthaloyl in above.	B-10 (seawater)	DuPont	Hollow fiber
Crosslinked aromatic polyamide 	FT-30	FilmTec	Spiral
	HR95, HR99	DDS	Plate and frame
	ZF99	PCI	Tubular
	UTc[d]	Toray	Spiral
	TFCL[d]	Fluid Systems	Spiral
Aryl-alkyl polyamide/polyurea[b] 	RC-100, PA300,	UOP	Spiral
	IFC	Hydranautics	Spiral
	SU-410	Toray	Spiral
	NTR-7197, 7199	Nitto Denko	Spiral

Table 4.1 (Continued)

Chemical name	Trade name	Manufacturer	Module type
Polybenzimidazole 	–	Teijin	Tubular
Polybenzimidazole 	–	Osmonics/Celanese	Spiral
Polyacrylonitrile (plasma treated)	–	Sumitomo	Spiral
Polypiperazineamide[c] 	NF-40	FilmTec	Spiral
	SU-210	Toray	Spiral
	Separem	DeMartini	Spiral
Polyfuran[c]	PEC-1000	Toray	Spiral

			
Sulfonated polysulfone 	Desal Plus	Desal	Spiral
	NTR 7410, 7450	Nitto	Spiral
	—	Union Carbide (Innovative membrane Systems)	Hollow fiber
Polyvinyl alcohol 	NTR 739HF, 729HF, NTR 7250 (Other monomers also used)	Nitto	Spiral

[a] Cellulose acetate membranes usually are cellulose 2.5-acetate where an average 2.5 of the three R groups on a ring are $-\underset{\underset{O}{\|}}{C}-CH_3$ (acetate) and the remainder H. In cellulose acetate, all R groups are acetate, and for cellulose diacetate, two of the three-ring R's are acetate.

[b] Various polymeric, multifunctional amines can be used. Typical structure shown. The aromatic crosslinking agent can be toluene disocyanate, isopthaloyl chloride, or similar reagents.

[c] Highly crosslinked, partially sulfonated resin results.

[d] Based on patents. Different aromatic monomers used, but similar structure results.

[e] General structure. Exact monomers used not known.

Table 5. RO Membranes by Chemical Type and Geometry

Asymmetric	Composite	Dense
	Flat sheet	
Cellulose	Aromatic polyamide	
Desal	FilmTec	
DuPont	DDS	
Fluid Systems (UOP)		
Koch Membrane	Aryl-Alkyl polyamide	
Hydranautics	Desal	
Osmonics	Fluid Systems	
Toray	Hydranautics	
	Nitto Denko	
Aromatic polyamide		
DuPont	Plasma Treated PAN	
	Sumitomo	
Polypiperazineamide		
Separem	Furan	
	Toray	

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Table 5. (Continued)

Asymmetric	Composite	Dense
	Flat sheet (continued)	
	PVA	
	Nitto Denko	
	Sulfonated polysulfone	
	Desal	
	Nitto Denko	
	Charged polymer	
	Millipore	
	Hollow fiber	
	Sulfonated polysulfone	Aromatic polyamide
	Innovative Membrane System (Union Carbide)	DuPont
		Cellulose triacetate
	Interfacial	Dow
	Bend Research	Toyobo

Tubular	
Cellulose acetate	Aromatic polyamide
Daicel	Patterson Candy Int.
Koch Membrane	Stork (unknown type)
Nitto Denko	
Patterson Candy Int.	
Stork	
PBIL	
Teijin	
Plate and frame	
Cellulose acetate	Aromatic polyamide
DDS	DDS
	Grünbeck

1992.1.22

R3 & R4

The Expanding Roster of Commercial Reverse Osmosis Membranes

Robert J. Petersen, PhD
FilmTec Corporation

TABLE 1

Classification of Commercial Reverse Osmosis Membranes by General Chemical Type

Fully Aromatic Polyamide		
duPont	Permasep B-9, B-10	hollow fine fiber
duPont	Permasep B-15	spiral
FilmTec	TW/BW/SW/HR-30	spiral
DDS	HR-95, HR-99	plate & frame
PCI	ZF-99	tubular
Culligan	developmental product	spiral
Aryl-Alkyl Polyamide/Polyurea		
UOP	RC-100 (and PA-300)	spiral
Hydranautics	CPA	spiral
Toray	SU-410	spiral
Nitto Denko	NTR-7197	spiral
Cellulose Acetate		
Numerous suppliers		all shapes
Cellulose Triacetate		
Toyobo	Hollosep	hollow fiber
FilmTec (Dow)	Dowex LP, SP	hollow fiber
Polyacrylonitrile		
Sumitomo	Solrox	tubular, spiral
Polybenzimidazolone		
Teijin	PBIL	tubular, spiral
Polypiperazineamides		
FilmTec	NF-40, NF-40HF	spiral
Nitto Denko	NTR-7250	spiral
Toray	SU-210	spiral
Sulfonated Polyfuran		
Toray	PEC-1000	spiral
Sulfonated Polysulfone		
DSI	Desal Plus	spiral
Millipore	PSRO	spiral

1992.1.22

DATA SHEET 693

FLOCON®
ANTISCALANTS

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introduction

FLOCON® 100 Antiscalant is a polymer solution which inhibits inorganic scale formation in reverse osmosis (RO) water purification systems. FLOCON 100 is especially effective against calcium carbonate, calcium sulfate, barium sulfate, and strontium sulfate scales.

Approved by all major membrane manufacturers, FLOCON 100 is the antiscalant of choice by RO systems companies around the world. Effective, economical, easy to use, and environmentally safe, FLOCON 100 is accepted for potable water use by the U.S. Environmental Protection Agency, as well as state agencies and foreign regulatory bodies.

FLOCON 100 is currently being used in a wide variety of applications ranging from potable water in municipal water plants, offshore oil platforms, condominiums, and ships at sea to ultrapure water in semiconductor plants, process water in utilities, and tertiary water recovery in sewage treatment facilities.

Installations using FLOCON 100 range in size from laboratory units up to facilities producing 15MM gallons/day. FLOCON 100 is available wherever RO units are used, from Australia to Zambesi, with Pfizer sales offices, distribution facilities, and technicians in key locations around the world.

regulatory acceptance

FLOCON 100 has been accepted for use in RO systems producing potable water by the United States Environmental Protection Agency (EPA); the United Kingdom Department of the Environment; the Testing and Research Institute of the Netherlands Waterworks KIWA Ltd.; Ministerio de Sanidad y Consumo in Spain; Statens Institutt for Folkehelse in Norway, and the Staatliche Brautechnische Pruf und Versuchsanstalt in Germany.

toxicity

FLOCON 100 has an extremely low order of acute toxicity and is only mildly irritating to the skin or eyes. It has an oral LD_{50} of > 5.0 g/kg in rats. No significant signs of toxicity occurred in rabbits during a 24-hour period in which 2.0 g/kg of undiluted material was topically applied to clipped intact skin. No significant toxic effects were noted in rats exposed to saturated vapors for one hour. Slight conjunctival irritation was produced from instillation of 0.1 ml in rabbit eyes.

FLOCON 100 did not demonstrate mutagenic activity at either the chromosomal or sub-chromosomal level.

FLOCON 100 is not a poison or corrosive material under U.S. Department of Transportation guidelines.

FLOCON 100 has been accepted by the U.S. Environmental Protection Agency for use in the preparation of potable water by reverse osmosis at dosages not to exceed 15 ppm for seawater and 20 ppm for brackish water, and is similarly approved by the U.K. Department of the Environment, KIWA, and the State of Florida.

environmental safety

Studies indicate that neither normal use nor accidental discharge of FLOCON 100 would endanger the environment. Exposure to representative freshwater and saltwater fish indicated that FLOCON 100 is not considered hazardous to aquatic animals or mammals under EPA toxicological selection criteria (Federal Register, 43, No. 49, Mar. 13, 1978, p. 10474). LC_{50} to bluegills was 1000 ppm, with no discernible effect at 680 ppm after 96 hours of static exposure. LC_{50} to sheepshead minnows was 600 ppm with no discernible effect at 360 ppm after 96 hours of static exposure.

Tests of chemical and biochemical oxygen demand indicate that FLOCON 100 is slowly biodegraded by microorganisms commonly encountered and widely distributed in the environment. Accordingly, buildup of significant concentrations is unlikely.

shipping data

FLOCON® 100 Antiscalant

Weight

- pounds per gallon, 25°C 9.75
- kilograms per liter, 25°C 1.17

Type of container and net contents

- 55-gallon (208 liters) polyethylene drums .... 500 lb (227 kg)
- 5-gallon (18.9 liters) plastic pails .... 50 lb (22.7 kg)

ICC labels required .... None

Freight description .... Chemicals, NOI

Bureau of Explosives

- description of containers .... None

precautions

Biological Fouling

Very few RO feedwaters can be classified as sterile, and biological fouling of a membrane is a possibility whenever a system is permitted to sit idle for some period of time. During operation, introduction of organisms from the antiscalant feed tank is a possibility, but since the antiscalant doses are very small, the count added from the antiscalant feed tank will in most cases be trivial. As an additional protective feature, however, FLOCON 100 contains a preservative that inhibits the formation of microorganisms in the dilution tank. Preservation is effective up to a dilution of approximately 1 part FLOCON 100 to 15 parts of RO product water. General periodic cleaning of a dosing tank is the best insurance for maintaining a feed tank that is relatively free of biological growth.

If the size of the RO system dictates a FLOCON 100 dilution greater than 1:15, the operator may wish to add some additional protection against biological growth to the feed tank. Chlorine generally is the most effective biocide, but only should be used with cellulosic membranes or the newer chlorine-resistant thin film membranes. For polyamide and traditional thin film composite polyamide membranes, sodium bisulfite at 500 to 1000 ppm added periodically has been effective in keeping the dilution tank free of biological contamination. The operator should not, under any circumstances, add quaternary ammonium biocides to solutions of FLOCON 100. These cationic products will react with anionic FLOCON 100 and reduce the availability of the FLOCON 100 in the feed stream. For questions about your system, please contact your Pfizer representative.

Use of Flocculants

Some water sources having a high level of suspended solids require the use of a flocculating agent to assist in the removal of particulates by filtration. When an RO system needs such pretreatment, it is essential to minimize the dose of the flocculant to ensure that it is removed with the silt in the filtration step. Typically, polymeric flocculants are very high in molecular weight and will foul most membranes if overdosed. The charge on these products may be positive or negative, but positively charged products seem to predominate. FLOCON 100, like all threshold scale inhibitors, is negatively charged and can interact with positively charged flocculants to form a precipitate capable of fouling a membrane. If the overdose of flocculant is recognized early and cleaning initiated without delay, the performance of the system can be restored. Contact the membrane manufacturer to determine those suitable for use in your system.

additional water treatment products

Other FLOCON Antiscalants

Pfizer Inc. has developed a line of specialty FLOCON Antiscalants to be used with problem feed waters. Contact your Pfizer representative for full details.

Flocleans

Pfizer Inc. also manufactures a family of cleaners especially formulated to restore fouled reverse osmosis membranes. Ask your Pfizer representative for the FLOCLEAN brochure.

Technical Bulletin
FILMTEC

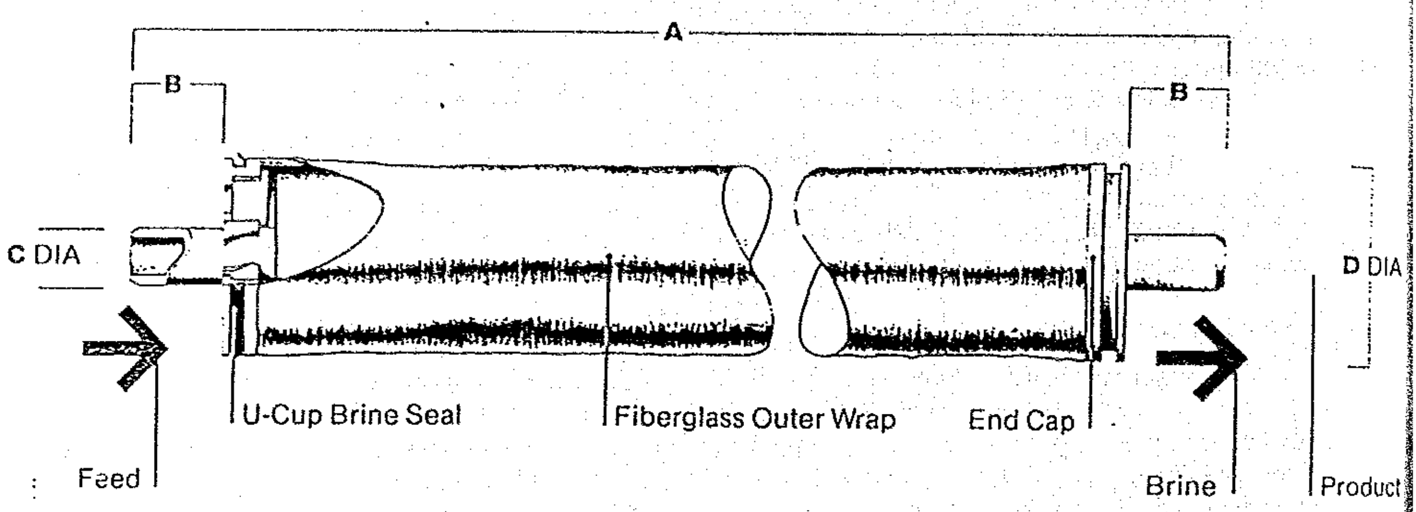
2.5" Seawater RO Element Specifications

7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
TELEFAX 612-835-4996

May 1986

	Product Water Flow Rate GPD (m³/D)	Minimum Salt Rejection Cl⁻ (%)	Average Salt Rejection Cl⁻ (%)
SW30-2514	100 (0.38)	98.6	99.1
SW30-2521	200 (0.76)	98.6	99.1
SW30-2540	500 (1.9)	98.6	99.1

1. Permeate flow and salt rejection based on the following conditions: 35000 PPM Seawater, 800 PSI (5.7 M Pa), 77°F (25°C), pH8 and recovery as indicated below. 2. Flow rates for individual elements may vary ±15%.



Operating Conditions

Membrane Type	Thin-Film Composite
Maximum Operating Pressure	1000 PSI (6.8 M Pa)
Maximum Operating Temperature	113°F (45°C)
Maximum Feed Turbidity	1 NTU
Free Chlorine Tolerance	< 0.1 PPM
pH Range:	
Continuous operation	2-11
Short-term (30 min.), cleaning	1-12
Maximum Feed Flow	6 GPM (23 LPM)
Maximum Feed Silt Density Index	SDI 5
Maximum Pressure Drop Across 40" Element	20 PSI

Single Element Recovery (Permeate Flow to Feed Flow):	Recovery	Dimensions (Inches) A	B	C	D
SW30-2514	0.035	14.0	1.1	0.75	2.4
SW30-2521	0.05	21.0	1.1	0.75	2.4
SW30-2540	0.1	40.0	1.1	0.75	2.4

3. Consult FilmTec Design Guidelines (bulletin #4004A) for multiple element applications and various feed sources. 4. Contact FilmTec Corporation, Marketing Department, before operating elements outside Design Guidelines or these specifications.

5. Element to fit 2.45 inch I.D. pressure vessel.

FILMTEC-3000A

Important Operating Information

FilmTec Corporation
A subsidiary of The Dow Chemical Company

7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
TELEFAX 612-835-4996

1. Keep elements moist at all times.
2. If operating specifications given in this Technical Bulletin are not strictly followed, the warranty will be null and void.
3. Permeate obtained from first hour of operation should be discarded.
4. Elements must be in use for at least 6 hours before formaldehyde is used as a biocide. If the elements are exposed to formaldehyde before being in use for this period of time a severe loss in flux may result.
5. To prevent bacterial growth and help maintain flux, it is recommended that elements be immersed in a solution of 20.0 percent, by weight, glycerine and 1.0 percent, by weight, sodium bisulfite whenever the system is not in use for a period longer than one week.
6. The membrane shows some resistance to short-term attack by chlorine (hypochlorite). Continuous exposure, however, may damage the membrane and should be avoided.
7. The customer is fully responsible for the effects of unapproved chemicals on FilmTec elements. Their use will void the element warranty.

TFC® Reverse Osmosis Seawater Element Specifications

Model No.	1501	7000SS**	7020SS
Nominal diameter (in)	6	2½	2½
Design productivity* (gpd)	2,100	120	275
Design rejection* (%)	99.3	99.4	99.4
Min. rejection* (%)	99.0	99.2	99.2
Maximum pressure drop per element (psi)	10	8	10

single // stage

Model No.	1021SS	1021HF **	2021SS	2021HF
Nominal diameter (in)	4	4	8	8
Design productivity* (gpd)	1,000	1,400	4,000	6,000
Design rejection* (%)	99.4	99.0	99.4	99.0
Min. rejection* (%)	99.2	98.6	99.2	98.6
Maximum pressure drop per element (psi)	10	10	10	10

***When individual elements are tested under the following conditions:**

- 32,800 mg/L NaCl solution
- 800 psi applied pressure
- 25°C (77°F) feed temperature
- 7% recovery
- Feed pH 5.7
- 30 minutes operation prior to data collection
- Individual element productivity may vary ± 15% from design.

**Special order quantities only.

Fluid systems by UOP

10124 Old Grove Road • San Diego, CA 92131 • Telephone 619-695-3840 • TLX 188906 • Telecopier 619-695-2176

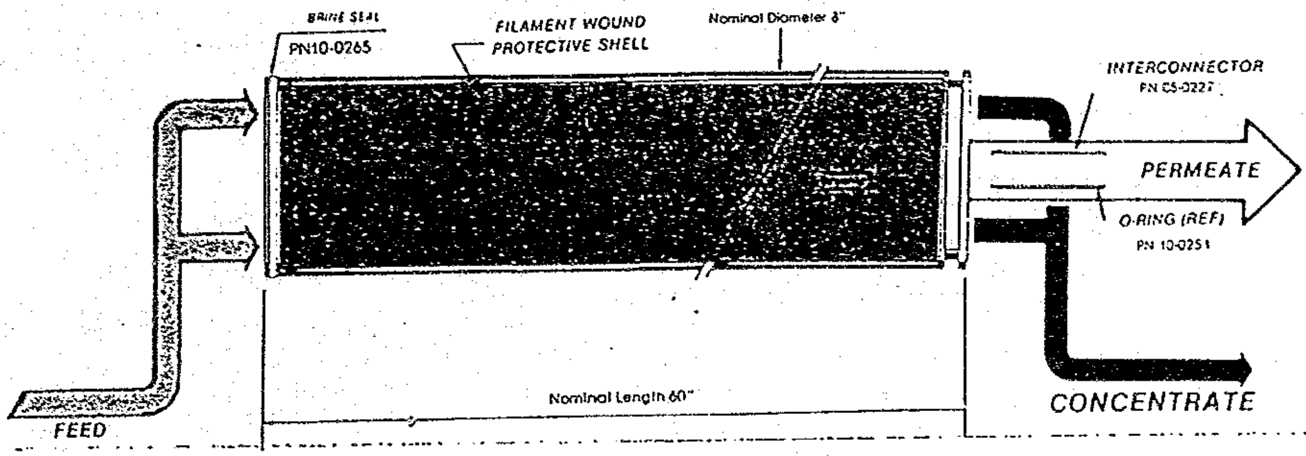
TFC® Spiral-Wound Reverse Osmosis Element
Seawater Model 2031SS MAGNUM®

PERFORMANCE SPECIFICATION

DESIGN CHLORIDE ION REJECTION	99.4%
DESIGN PERMEATE PRODUCTIVITY	6,200 U.S. gpd (23.5 m^3/d)

TEST CONDITIONS: 32,800 mg/L NaCl solution (isosmotic to ASTM seawater), 800 psi (56.3 kg/cm^2), 11% water recovery, 25°C (77°) and pH 5.7. Data are collected on each element after 30 minutes of operation at these conditions.

DRAINED WEIGHT: 58 lb (26.4 kg)



Refer to the back of this sheet for important operating and design information. This information is intended for use as a guideline. For operation outside these guidelines, please contact Fluid Systems.

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Operational and Design Information

1. The design chloride ion rejection and permeate productivity are based on average values obtained during the final acceptance testing of the elements and should be used when designing systems.

2. At the test conditions shown, the minimum chloride ion rejection is 99.2%. Individual element permeate productivities may vary ± 15% from the design value.

3. For most systems, the optimum pH is approximately 5.7 to obtain maximum rejection as well as to minimize the tendency for precipitation of sparingly soluable salts. If the operating pH is above 5.7, NaCl rejection can be estimated by the following equations:

$$\text{NaCl Rejection} = 0.994 - 0.00105\,(\text{pH} - 5.7)$$

where pH = anticipated operating pH

4. Recommended design pressure — 800 psi (56.3 kg/cm^2)
   Operation at any pressure below 1000 psi (70.3 kg/cm^2) is permissable provided the design permeate productivity per element is not exceeded and the operation is within the hydraulic limits stated in 5 and 11 below.

   Maximum operating pressure — 1000 psi (70.3 kg/cm^2)

5. Maximum pressure drop per element — 15 psi (1.05 kg/cm^2)

6. Maximum allowable feedwater turbidity — 1.0 NTU
   Experience has shown that prolonged operation on feedwater turbidities greater than 0.2 NTU generally results in prohibitively frequent cleaning requirements. Fluid Systems strongly recommends that pretreatment equipment be designed to routinely attain feedwater turbidity of less than 0.2 NTU.

7. Allowable feedwater temperature range: 1 to 45°C (34 to 113°F)
   The effects of temperature on net operating pressure and/or permeate productivity can be calculated from FSD Bulletin 0004, Temperature Effect.

8. Maximum allowable chlorine or similarly active oxidizing agents such as iodine, bromine and ozone: Zero

9. Allowable operating pH range: 4 to 11
   Allowable cleaning pH range: 3.5 to 12

10. Elements may be cleaned with cationic or nonionic surfactants. Anionic surfactants should be avoided as irreversible fouling may occur.

11. Maximum recovery rate for any presure tube in a system:

Elements/tube	one	two	three	four
Maximum (%)	19	33	40	44

Operation at greater that the maximum recovery may result in excessive boundary layer conditions or brine concentrations. Please contact Fluid Systems or your distributor for assistance.

SHEET MEMBRANE

PERFORMANCE CHARACTERISTICS[1]:

TYPE	PART NUMBER	NOMINAL[2] FLUX (gfd)	NOMINAL REJECTION	MINIMUM REJECTION
SS	10500	13	99.5	99.2
HF	10501	20	99.0	98.6
MP	10502	25	98.5	97.0
LP	10503	21	97.0	93.5
CA	10504	25	95.0	93.0

PACKAGING AND STORAGE:

TFC® sheet membrane types SS, HF, MP and LP will be rolled on a fiber core. Cellulose acetate sheet membrane (type CA) will be rolled on a PVC core. Maximum roll lengths for ease of handling and packaging is 650 linear feet. Rolls will be plastic wrapped and suitably boxed for shipment in tri-wall cardboard containers.
TFC® membrane types are shipped dry. Cellulose acetate membrane is shipped wetted with a residual 2% formaldehyde solution. Estimated shelf life of type CA is one month. Sheet membrane products:

(1) Should not be stored in direct sunlight.
(2) Should not be allowed to freeze or be exposed to temperatures in excess of 50°C (122°F) for TFC® types and 40°C (104°F) for CA.

The ideal storage temperature range is 5 to 10°C (41 to 50°F).

Note[1]: Membrane performance characteristics are determined by fabricating a spiral-wound element from the same membrane lot and testing at Fluid Systems' standard conditions:

SS/HF: 32,800 mg/L NaCl solution
800 psi (56.24 kg/cm²)
7% water recovery
25°C (77°F) and pH 5.7

MP/CA: 2,000 mg/L NaCl solution
420 psi (29.5 kg/cm²)
10% water recovery
25°C (77°F) and pH 5.7

LP: 2,000 mg/L NaCl solution
225 psi (15.8 kg/cm²)
10% water recovery
25°C (77°F) and pH 5.7

Data are collected on each element after a 30 minute equilibration period at the above conditions.

Note[2]: All membrane fluxes (gfd) listed are ±15%.

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Operational and Design Information

TFC® MEMBRANE TYPES SS, HF, MP and LP:

1. Allowable feedwater temperature range: 1 to 45°C (34 to 113°F)
   The effects of temperature on net operating pressure and permeate productivity can be calculated from FSD Bulletin, Temperature Effect.

2. Maximum allowable chlorine or similarly active oxidizing agents such as iodine, bromine and ozone: Zero

3. Allowable operating pH range: 4 to 11
   Allowable cleaning pH range: 3.5 to 12

4. These membrane types may be cleaned with cationic or nonionic surfactants. Anionic surfactants should be avoided as irreversible fouling may occur.

Note: Sodium bisulfite or similar reducing chemicals should not be used as a sterilant or storage chemical without first consulting Fluid Systems.

CELLULOSIC MEMBRANE TYPE CA:

1. Allowable feedwater temperature range: 1 to 40°C (34 to 104°F)
   The effects of temperature on net operating pressure and/or permeate productivity can be calculated from FSD Bulletin, Temperature Effect.

2. Maximum allowable continuous concentration of chlorine or similarly active oxidizing agents such as iodine, bromine and ozone: 1.0 mg/L chlorine residual or equivalent.

3. Allowable operating pH range: 3 to 7
   Allowable cleaning pH range: 3 to 8

   For most systems, a practical optimum pH is approximately 5.7. At this pH, membrane hydrolysis and the tendency of calcium carbonate to precipitate will be minimized. Above pH 6 these effects may become significant and may reduce the effective life of the membrane.

   In some instances operation outside these pH ranges is permissible. Please contact Fluid Systems or your distributor for guidance.

CLEANING INSTRUCTIONS FOR ROGA® ELEMENTS

This sheet contains two cleaning solutions used by Fluid Systems' Technical Services Department. These solutions have proven successful in most cases where fouling occurs.

NOTE: If the cleaning procedure does not restore the system production to the expected capacity or expected water quality after cleaning, please contact the Technical Services Department at Fluid Systems immediately.

Advisory: There are a number of proprietary cleaning solutions available from chemical companies. Some of these cleaning solutions have been used to clean Fluid Systems' elements and have proven effective.

Before using any cleaning solution other than those listed, contact Fluid Systems.

(Continued on Reverse Side)

Fluid systems
by UOP

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Cleaning Instructions for ROGA® Elements:

Cleaning Solution for 1 Cubic Meter of Water (264.2 Gallons)

NOTE: The water used to prepare either solution must be treated feedwater or R.O. permeate.

SOLUTION A

This solution is used to remove acid soluable substances such as metal hydroxides (iron) and calcium carbonate.

1. Citric Acid ...... 20 kg (44 pounds) or Phosphoric Acid 75% ...... 55 liters (14.7 gallons)
2. Triton X-100 .... 1 liter
3. Adjust pH to 2.5 with NH_4OH (ammonium hydroxide) after mixing chemicals.

SOLUTION B

Used where the fouling material is organic in nature.

1. Trisodium Phosphate (TSP)........................ 20 kg (44 pounds)
2. Sodium EDTA (Sodium Salt of Ethylenediaminetetra Acetic Acid)
   If powder .... 8 kg (17.5 pounds)
   If 39% solution.................................. 20 kg (44 pounds)
3. Triton X-100 .... 1 liter
4. Adjust pH with H_2SO_4 (sulfuric acid) or HCl (hydrocholoric acid) as follows after mixing chemicals with product water:

   HR Elements should be cleaned at a pH of 7.0.

   SD, S, and LP Elements should be cleaned at a pH of 8.0.

Sodium Tripolyphosphate (STPP) may be substituted in part or entirely for the TSP.

Both cleaning solutions may be used at a temperature range from ambient up to 40°C (104°F) for 45 minutes and at the recommended flow rate as indicated below. The system pressure should be the minimum required to achieve specified flow but in no case should pressure drop across any pressure tube exceed 60 psig.

Soaking elements in cleaning solutions under static conditions is sometimes useful for improving cleaning results when severe fouling has occured. SOAK TIME OF LONGER THAN 24 HOURS IS NOT RECOMMENDED.

Formaldehyde may be added to either cleaning solution to aid in disinfection or removing biological growths. Formaldehyde is available as a 37% solution (0.4 kg per liter — 3.33 pounds per gallon). It may be used as a 0.5 to 1% solution. A 0.5% solution contains 13.5 liters of 37% formaldehyde per cubic meter of water (3.6 gallons per 264.2 gallons).

MAXIMUM CLEANING FEED FLOW RATE

ROGA® Element Model	
4101	1.8 m³/hr/tube (8 gpm)
4160, 4221, 4231	2.3 m³/hr/tube (10 gpm)
8150, 8221, 8231	9.1 m³/hr/tube (40 gpm)

Pressure tubes are to be cleaned only in parallel. Where a series array of pressure tubes is used for higher recoveries, each array shall be cleaned separately.

Cleaning Instructions for TFC® Elements:

Cleaning Solution for 1 Cubic Meter of Water (264.2 Gallons)

NOTE: The water used to prepare either solution must be free of residual chlorine or other oxidizing agents. For first stage seawater applications, RO permeate is preferred, but for brackish water applications, treated feedwater can be used.

SOLUTION Y

NOTE: Cleaning solution Y may cause a temporary increase in membrane salt passage and/or water flux beyond specifications. This condition should last no longer than 24 hours.

This solution is used to remove acid soluble substances such as metal hydroxides and calcium carbonate. It should also generally be used before using SOLUTION Z.

Citric Acid .... 10 kg (22 pounds)

Adjust pH to 3.5 with NH_4OH (ammonium hydroxide) after mixing.

SOLUTION Z (CAUTION — Solution Z must NOT be used on ROGA® elements (cellulose acetate membrane).)

This solution is used to remove organic substances and microbiological slimes not acid soluble.

Borax	10 kg (22.1 pounds)
Sodium Salt of EDTA (Ethylenediaminetetracetic Acid)	
As Powder	10 kg (22.1 pounds)
As 39% Solution	25.6 kg (56.5 pounds)
Trisodium Phosphate (TSP)	10 kg (22.1 pounds)

The pH of this solution does not have to be adjusted for TFC® elements.

Both cleaning solutions may be used at a temperature range from ambient up to 40°C (104°F) for 45 minutes and at the recommended flow rate as indicated below. The system pressure should be the minimum required to achieve specified flow but in no case should the pressure drop across any vessel exceed 60 psig.

Formaldehyde may be added to either cleaning solution to aid in disinfection or removing biological growths. Formaldehyde is available as a 37% solution (0.4 kg per liter — 3.33 pounds per gallon). It may be used as a 0.5 to 1% solution. A 0.5% solution contains 13.5 liters of 37% formaldehyde per cubic meter of water (3.6 gallons per 264.2 gallons).

MAXIMUM CLEANING FEED FLOW RATES

TFC® Element Nominal Diameter	
2½"	0.7 m^3/hr/tube (3 gpm)
4"	2.3 m^3/hr/tube (10 gpm)
6"	4.6 m^3/hr/tube (20 gpm)
8"	9.1 m^3/hr/tube (40 gpm)

Pressure tubes are to be cleaned only in parallel. Where a series array of pressure tubes is used for higher recoveries, each array shall be cleaned separately

CLEANING INSTRUCTIONS FOR TFC® ELEMENTS

This sheet contains two cleaning solutions used by Fluid Systems' Technical Services Department. These solutions have proven successful in most cases where fouling occurs.

NOTE: If the cleaning procedure does not restore the system production to the expected capacity or expected water quality after cleaning, please contact the Technical Services Department at Fluid Systems immediately.

Advisory: There are a number of proprietary cleaning solutions available from chemical companies. Some of these cleaning solutions have been used to clean Fluid Systems' elements and have proven effective.

Before using any cleaning solution other than those listed, contact Fluid Systems.

(Continued on Reverse Side)

Fluid systems by UOP

10054 Old Grove Road • San Diego, CA 92131 • Telephone 619-695-3840 • TLX 188906 • Telecopier 619-695-2176

1992.1.22-36

Technical Bulletin
FILMTEC

FT30 Membrane Description

7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
TELEFAX 612-835-4996

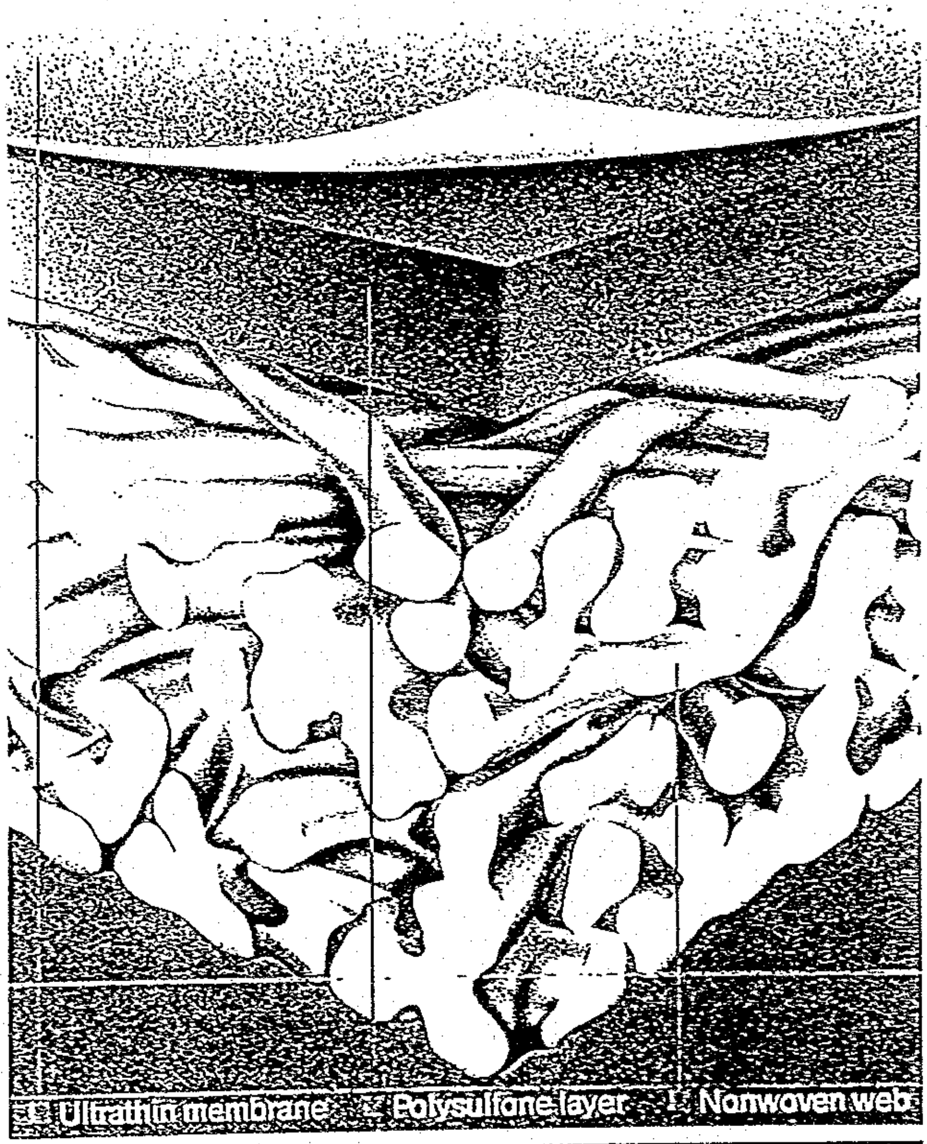
January 1988

FilmTec has developed and commercialized a thin-film composite reverse osmosis (RO) membrane that gives excellent performance for a wide variety of applications, including low-pressure tapwater use, single-pass seawater and brackish water desalination, chemical processing, and waste treatment. This membrane, designated FT30, is a significant improvement over conventional cellulose acetate types and other commercial thin-film composites in terms of flux, salt rejection, and microbiological resistance. FT30 elements can operate over a pH range of 2 to 11, are resistant to compaction, and are suitable for temperatures up to 45°C.

FilmTec spiral-wound elements of FT30 membrane have been extensively used since 1980 both in the United States and abroad. In numerous trials under actual seawater conditions, FT30 elements have provided salt rejections of better than 99 percent and fluxes of 20 gfd. On a 0.2 percent salt solution at 200 psi, rejections of 98 percent and fluxes of 22 gfd are routinely obtained.

Several long term tests have been completed. A continuous three year test operating at about 25°C and 350 psi on 3000 ppm feed did not show any membrane compaction or deterioration in salt rejection. Elements have also operated in shipboard seawater systems with normal intermittent use for over three years with no significant loss in performance.

The FT30 membrane has been tested and approved by the U.S. Food and Drug Administration (FDA) for use in processing liquid foods and purifying water for food applications. FILMTEC FT30 is the only thin-film composite RO membrane to have received FDA approval.



FT30 Membrane Composite

Thin-Film Composite Configuration

The membrane composite consists of three layers: a polyester support web, a microporous polysulfone interlayer, and an ultrathin barrier coating on the top surface.

A schematic diagram of the membrane is shown above.

Description of the FT30 Membrane

The major structural support is provided by the nonwoven web, which has been calendered to produce a hard, smooth surface free of loose fibers. Since the polyester web is too irregular and porous to provide a proper substrate for the salt barrier layer, a microporous

FILMTEC-50048

FilmTec Corporation
A subsidiary of The Dow Chemical Company
7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
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layer of engineering plastic (Udel polysulfone) is cast onto the surface of the web. The polysulfone coating is remarkable in that it has surface pores controlled to a diameter of approximately 150 angstroms. The FT30 barrier layer, about 2000 angstroms thick, can withstand high pressures because of the support provided by the polysulfone layer. Because it is thicker than the other thin-film composites, FT30 is more resistant to mechanical stresses and chemical degradation.

Biological Protection and Disinfection

Various storage tests have been conducted at FilmTec on FT30 elements to determine biological protection procedures. The best procedure for storage is to soak the element in an aqueous solution with 20 percent by weight propylene glycol or glycerine and 1.0 percent sodium bisulfite. The propylene glycol or glycerine also prevents freeze damage. For short term storage (up to a week), only the bisulfite is needed to prevent biological growth. This treatment maintains initial membrane flux and performance.

Disinfection with chlorinating agents can be practiced within limits but is not generally recommended. The FT30 membrane is resistant to chloramine, chloramine-T, N-chloroisocyanurates to the extent that these mild agents can be used, but their disinfectant properties are not very great. Pure chlorine dioxide can be used successfully at 500 ppm concentration if the storage period is less than one week, but it is not an effective biocide for longer periods. Chlorine dioxide that is generated on site from chlorine and sodium chlorate is always contaminated with free chlorine, which attacks the membrane. The FT30 membrane is permeable to chloramine and to chlorine dioxide. Either of these will pass through the membrane resulting in a small residual disinfectant in the permeate.

The membrane has only limited resistance to free chlorine. The rate of chlorine attack is dependent on pH and salinity levels. Chlorine attack is most rapid at lower salt concentrations, occurring fastest in deionized water and slowest in seawater. Chlorine attack is slowest at neutral and acidic pH levels and fastest at alkaline pH levels. It is noteworthy, however, that short-term exposure of the membrane to chlorine does not destroy the membrane. Thus, it can be used effectively in installations where system upsets may result in temporary exposure of the membrane to free chlorine.

Alternative disinfectants that may be used are formaldehyde, hydrogen peroxide, and peracetic acid. Formaldehyde may be used after the element has been flushed out for at least six hours. Thereafter, using formaldehyde at 0.5 to 3.0 percent is feasible, but will result in a temporary flux loss. After rinse out of formaldehyde, permeate flow will return to our rated value as specified in our warranty. Hydrogen peroxide or peracetic acid can be used at concentrations up to 0.2 percent at 25°C as specified in our warranty but not at higher temperatures. Continuous exposure to hydrogen peroxide at this concentration will eventually damage the membrane.

Copper sulfate can be used to control algae growth. Iodine, quaternary germicides, and phenolic compounds should not be used as tests show that all of these agents cause flux losses.

Cleaning

Because of the FT30 membrane's combination of pH stability and temperature resistance, cleaning can be done very effectively. Both acidic and alkaline cleaners can be used at temperatures to 50°C. Acid cleaning to remove mineral scale is best done at pH 2 with phosphoric, hydrochloric, sulfamic or nitric acid. Citric acid can also be used. Alkaline cleaning to remove organic fouling is generally done with sodium hydroxide and sodium lauryl sulfate. Various combinations of agents such as sodium EDTA, sodium tripolyphosphate, and trisodium phosphate can also be used.

Generally, anionic surfactants can be used for alkaline cleaning. Cationic surfactants cause an irreversible flux loss and must be avoided. Nonionic surfactants can sometimes be used, but they must be used sparingly and thoroughly rinsed out before the membrane is pressurized. Do not use any chemical which is not approved in writing by FilmTec. Commercial laundry detergents cannot be approved because the specific chemical constituents are unknown.

See FilmTec bulletins *Cleaning Procedures* and *Biological Protection and Disinfection* for further information.

FILMTEC
Fresh Water From the Sea

Until recently, seawater desalination was a difficult and costly business. But advances made in reverse osmosis (RO) membranes have changed that. Today, the premier membrane in the desalination industry is FILMTEC* FT30. The proven spiral-wound concept coupled with the best thin-film composite membrane on the market give FILMTEC element users the highest overall cost effectiveness and reliability.

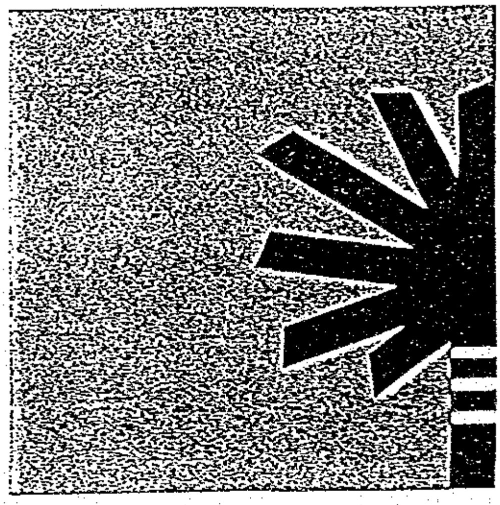
Using FILMTEC thin-film composite membranes will give you drinking water of unsurpassed quality. The low fouling potential of FILMTEC membranes and their easy cleaning capabilities mean low maintenance requirements and a long operating life. All this plus the extremely high salt rejection of FILMTEC FT30 membrane make FILMTEC elements the superior choice for your seawater RO system needs.

The graph on the reverse side shows the performance of FILMTEC elements at a seawater desalination plant in Lanzarote, Canary Islands. Data from this and other RO installations show FILMTEC FT30 membrane doing the job it is designed for: converting seawater to freshwater—reliably and efficiently.

High Performance at a Reasonable Cost. FILMTEC FT30 membrane exhibits the best combination of performance, durability and cost for seawater desalination of any membrane on the market today. FILMTEC elements provide salt rejection as high as 99.5% and fluxes as high as 15 gfd when operated at 800 to 1000 psi on seawater feed.

Complete Resistance to Bacterial Attack. FT30 completely resists attack by bacteria and their metabolic by-products. Most biological fouling can be cleaned away with appropriate cleaning chemicals to recover membrane performance.

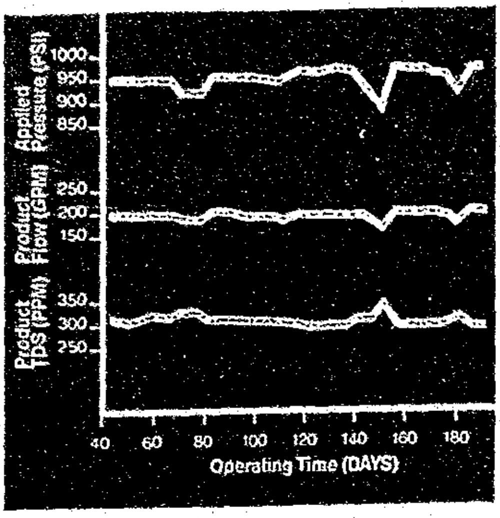
High Tolerance of pH Extremes. FT30 has an operating pH range of 2 to 11 and can be cleaned at a range of 1 to 12. This membrane toughness plus the spiral-wound configuration allow for effective membrane cleanings and long membrane life.



Whether on land or at sea, people need fresh drinking water.

Outstanding Performance History of FT30 Seawater Membrane. Years of outstanding performance in seawater applications around the world have made the FT30 membrane one of the leading membranes in the RO industry. From cruise ships to warships, from resort hotels of the Mediterranean to large plants producing potable water, FT30 provides superior performance under even the most rigorous operating conditions.

For more information about FT30 membrane and detailed specifications, contact FilmTec Corporation, 7200 Ohms Lane, Minneapolis, MN 55435 USA. Telex 290899 FILMTEC EDNA. Telephone (612) 835-5475.



FILMTEC FT30 membrane provides superior salt rejection in seawater applications under even the harshest conditions.

At the Lanzarote seawater facility in the Canary Islands, FILMTEC FT30 RO elements operate in a single stage system to produce fresh water of less than 325 ppm total dissolved solids. The chart above demonstrates the consistent performance of FT30. With proper maintenance and operation, this rate should remain steady over the projected life of the RO membrane.

November 1987

1992.1.22

FILMTEC

Technical Bulletin

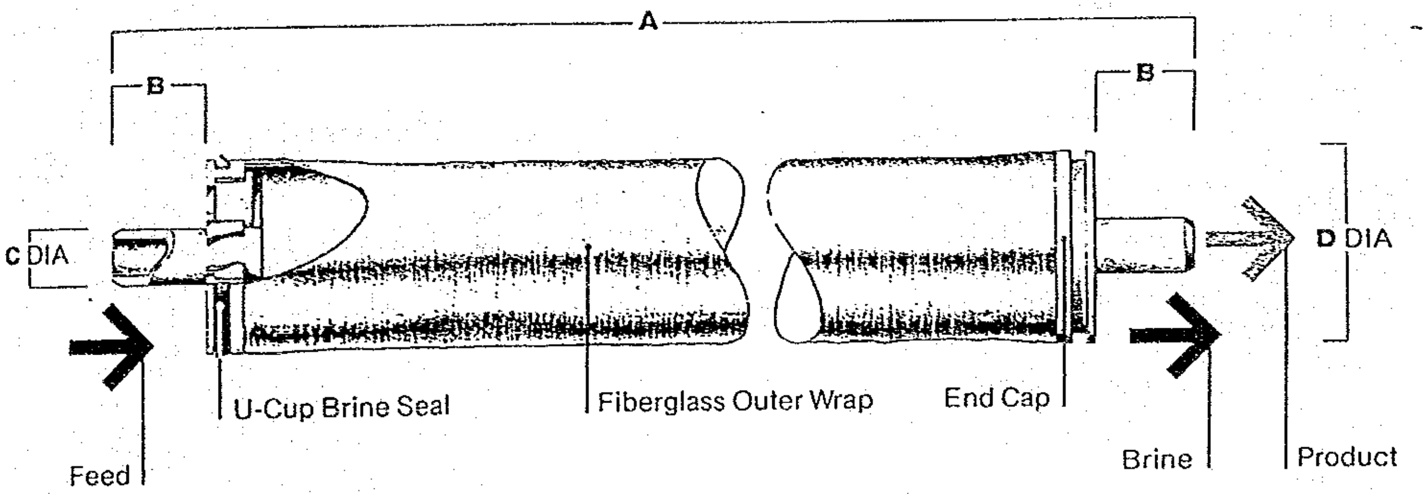
2.5" Seawater Reverse Osmosis Element Specifications

7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290699 FILMTEC EDNA
TELEFAX 612-835-4996

November 1985

	Product Water Flow Rate GPD (m^3/D)	Minimum Salt Rejection Cl⁻ (%)	Average Salt Rejection Cl⁻ (%)
SW30-2514	100 (0.38)	98.6	99.1
SW30-2521	200 (0.76)	98.6	99.1
SW30-2540	500 (1.9)	98.6	99.1

1. Permeate flow and salt rejection based on the following conditions: 35000 PPM Seawater, 800 PSI (5.7 M Pa), 77°F (25°C), pH8, and recovery as indicated below. 2. Flow rates for individual elements may vary ±15%.



Operating Conditions

Membrane Type	Thin-Film Composite
Maximum Operating Pressure	1000 PSI (6.8 M Pa)
Maximum Operating Temperature	113°F (45°C)
Maximum Feed Turbidity	1 NTU
Free Chlorine Tolerance	< 0.1 PPM
pH Range:	
Continuous operation	2-11
Short-term (30 min.), cleaning	1-12
Maximum Feed Flow	6 GPM (23 LPM)
Maximum Feed Silt Density Index	SDI 5
Maximum Pressure Drop Across 40" Element	20 PSI

Maximum Recovery (Permeate Flow to Feed Flow) on Seawater:

	Ratio	Dimensions (inches) A	B	C	D
SW30-2514	0.035	14.0	1.2	0.75	2.4
SW30-2521	0.05	21.0	1.2	0.75	2.4
SW30-2540	0.1	40.0	1.0	0.75	2.4

3. Contact FilmTec Corporation, Marketing Department, before operating elements outside these specifications.

4. Element to fit 2.5 inch I.D. pressure vessel.

FILMTEC-3000

FilmTec Corporation
7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
TELEFAX 612-835-4996

1. Keep elements moist at all times.
2. If operating specifications given in this Technical Bulletin are not strictly followed, the warranty will be null and void.
3. Permeate obtained from first hour of operation should be discarded.
4. Elements must be in use for at least 6 hours before formaldehyde is used as a biocide. If the elements are exposed to formaldehyde before being in use for this period of time a severe loss in flux may result.
5. To prevent bacterial growth and help maintain flux, it is recommended that elements be immersed in a solution of 20.0 percent, by weight, glycerine and 1.0 percent, by weight, sodium bisulfite whenever the system is not in use for a period longer than one week.
6. The membrane shows some resistance to short-term attack by chlorine (hypochlorite). Continuous exposure, however, may damage the membrane and should be avoided.
7. The customer is fully responsible for the effects of unapproved chemicals on FilmTec elements. Their use will void the element warranty.

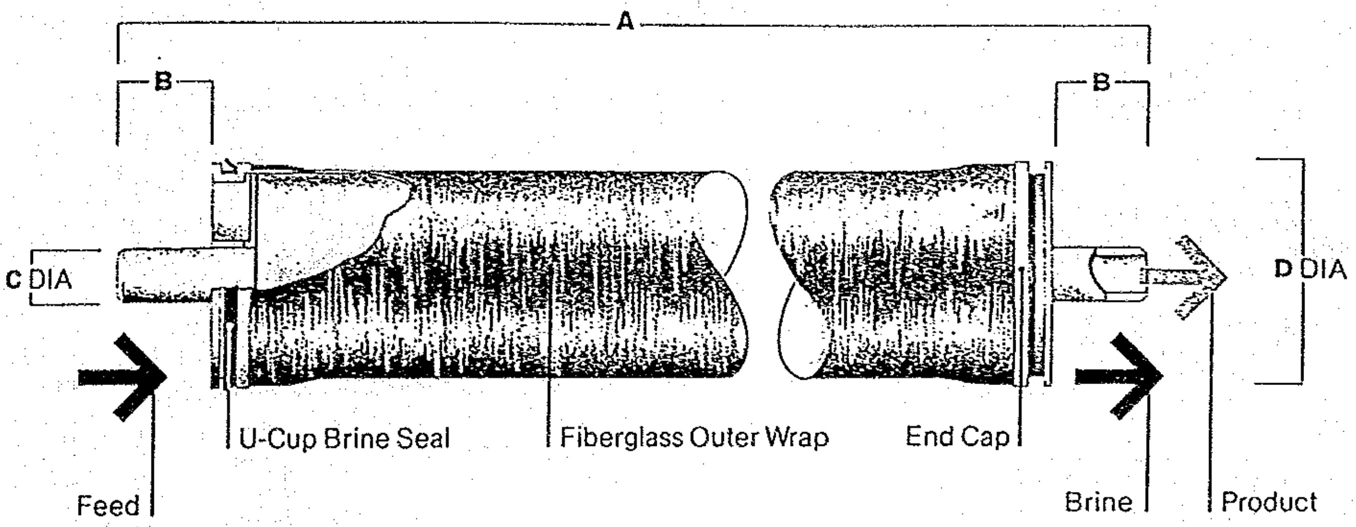
FILMTEC
Technical Bulletin
4" Seawater Reverse Osmosis Element Specifications

7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
TELEFAX 612-835-4996

January 1985

	Product Water Flow Rate GPD (m^3/D)	Minimum Salt Rejection Cl[1] (%)	Average Salt Rejection Cl[1] (%)
SW30-4014	300 (1.1)	98.6	99.1
SW30-4021	600 (2.3)	98.6	99.1
SW30-4040	1500 (5.7)	98.6	99.1

1. Permeate flow and salt rejection based on the following conditions: 35000 PPM Seawater, 800 PSI (5.7 M Pa), 77°F (25°C), pH8, and 13 GPM feed flow rate. **2.** Flow rates for individual elements may vary ±15%.



Operating Conditions

Membrane Type	Thin-Film Composite
Maximum Operating Pressure	1000 PSI (6.8 M Pa)
Maximum Operating Temperature	110°F (45°C)
Maximum Feed Turbidity	1 NTU
Free Chlorine Tolerance	< 0.1 PPM
pH Range:	
Continuous operation	2-11
Short-term (30 min.), cleaning	1-12
Maximum Feed Flow	16 GPM (60 L/M)
Maximum Feed Silt Density Index	SDI 5
Maximum Pressure Drop Across 40" Element	20 PSI

Maximum Recovery (Permeate Flow to Feed Flow) on Seawater:

	Ratio
SW30-4014	0.035
SW30-4021	0.05
SW30-4040	0.1

3. Contact FilmTec Corporation, Marketing Department, before operating elements outside these specifications.

	Dimensions (inches) A	B	C	D
SW30-4014	14.0	1.1	0.75	3.9
SW30-4021	21.0	1.1	0.75	3.9
SW30-4040	40.0	1.0	0.75	3.9

4. Element to fit 4.00 inch I.D. pressure vessel.

FILMTEC-3003

FilmTec Corporation
7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
TELEFAX 612-835-4996

1. Keep elements moist at all times.
2. If operating specifications given in this Technical Bulletin are not strictly followed, the warranty will be null and void.
3. Permeate obtained from first hour of operation should be discarded.
4. Elements must be in use for at least 6 hours before formaldehyde is used as a biocide. If the elements are exposed to formaldehyde before being in use for this period of time a severe loss in flux may result.
5. To prevent bacterial growth and help maintain flux, it is recommended that elements be immersed in a solution of 20.0 percent, by weight, glycerine and 1.0 percent, by weight, sodium bisulfite whenever the system is not in use for a period longer than one week.
6. The membrane shows some resistance to short-term attack by chlorine (hypochlorite). Continuous exposure, however, may damage the membrane and should be avoided.
7. The customer is fully responsible for the effects of unapproved chemicals on FilmTec elements. Their use will void the element warranty.

FILMTEC

Technical Bulletin

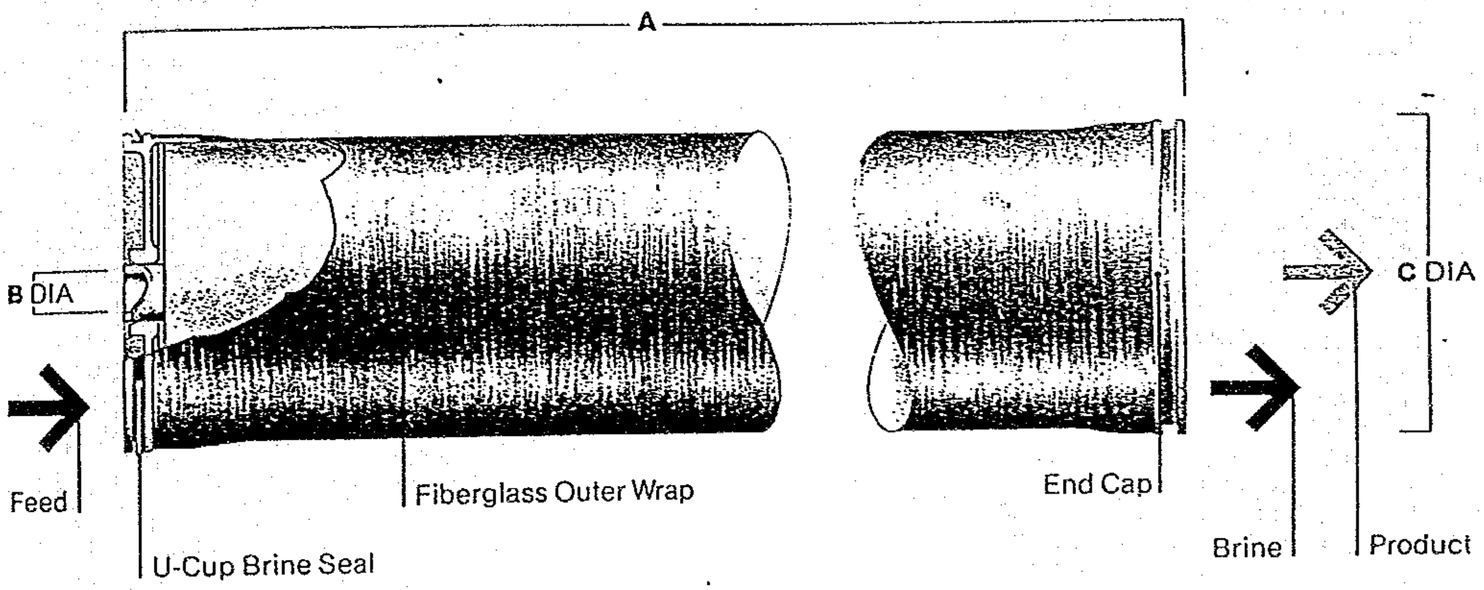
8" Seawater Reverse Osmosis Element Specifications

7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
TELEFAX 612-835-4996

November 1985

	Product Water Flow Rate GPD (m^3/D)	Minimum Salt Rejection Cl⁻ (%)	Average Salt Rejection Cl⁻ (%)
SW30-8040	6000 (23)	98.6	99.1

1. Permeate flow and salt rejection based on the following conditions: 35000 PPM Seawater, 800 PSI (5.7 M Pa), 77°F (25°C), pH8 and recovery as indicated below. 2. Flow rates for individual elements may vary ±15%.



Operating Conditions

Membrane Type	Thin-Film Composite
Maximum Operating Pressure	1000 PSI (6.8 M Pa)
Maximum Operating Temperature	110°F (45°C)
Maximum Feed Turbidity	1 NTU
Free Chlorine Tolerance	< 0.1 PPM
pH Range:	
Continuous operation	2-11
Short-term (30 min.), cleaning	1-12
Maximum Feed Flow	64 GPM (240 l/M)
Maximum Feed Silt Density Index	SDI 5
Maximum Pressure Drop Across 40" Element	20 PSI

Maximum Recovery (Permeate Flow to Feed Flow) on Seawater:

	Ratio
SW30-8040	0.10

3. Contact FilmTec Corporation, Marketing Department, before operating elements outside these specifications.

Dimensions (inches)

A	B	C
40.0	1.125	7.9

4. Element to fit 8.0 inch I.D. pressure vessel.

FILMTEC-3002

Important Operating Information

FilmTec Corporation
7200 Ohms Lane
Minneapolis, MN 55435 USA
Telephone 612-835-5475
TELEX 290899 FILMTEC EDNA
TELEFAX 612-835-4996

1. Keep elements moist at all times.
2. If operating specifications given in this Technical Bulletin are not strictly followed, the warranty will be null and void.
3. Permeate obtained from first hour of operation should be discarded.
4. Elements must be in use for at least 6 hours before formaldehyde is used as a biocide. If the elements are exposed to formaldehyde before being in use for this period of time a severe loss in flux may result.
5. To prevent bacterial growth and help maintain flux, it is recommended that elements be immersed in a solution of 20.0 percent, by weight, glycerine and 1.0 percent, by weight, sodium bisulfite whenever the system is not in use for a period longer than one week.
6. The membrane shows some resistance to short-term attack by chlorine (hypochlorite). Continuous exposure, however, may damage the membrane and should be avoided.
7. The customer is fully responsible for the effects of unapproved chemicals on FilmTec elements. Their use will void the element warranty.

1992.1.22

TFC® Reverse Osmosis MAGNUM® Element Specifications

Low Pressure | 1.5m Magnum | TFCL

Model No.	4031 LP	4031 MP	TFCL-HP	8031 LP	8921 L
Nominal diameter (in)	4	4	8	8	8
Design productivity * (gpd)	2,750	3,000		11,000	7500
Design rejection * (%)	97.0	98.5		97.0	97.5
Min. rejection * (%)	95.0	97.0	≥ 99	95.0	97
Maximum pressure drop per element (psi)	15	15		15	"

Low Pr | Mod P | high P (400 psi) | Low Pres (200 psi)

single stage | High Flow

Model No.	8031 MP	2031 SS	2031 HF
Nominal diameter (in)	8	8	8
Design productivity * (gpd)	12,500	6,200	9,200
Design rejection * (%)	98.5	99.4	99.0
Min. rejection * (%)	97.0	99.2	98.6
Maximum pressure drop per element (psi)	15	15	15

Seawater | High Flux

*When individual elements are tested under the following conditions:

- 30 minutes operation prior to data collection
- Individual element productivity may vary ± 15% from design

For LP and MP ELEMENTS:
- Feed pH 5.7
- 16% water recovery
- 2,000 mg/L NaCl solution
- 420 psi applied pressure for MP
  225 psi applied pressure for LP

For SS and HF ELEMENTS:
- Feed pH 5.7
- 11% water recovery
- 32,800 mg/L NaCl solution
- 800 psi applied pressure

(*) Tolerate Chlorine 1000 hrs @ 1 ppm

WHAT IS THE ADVANTAGE of MAGNUM (1.5m) over conventional element of the same width?

Fluid systems by UOP

10124 Old Grove Road • San Diego, CA 92131 • Telephone 619-695-3840 • TLX 188906 • Telecopier 619-695-2176

(*) Chlorine can be removed using Activated carbon

TFC® Reverse Osmosis Seawater Element Specifications

Model No.	1501	7000SS**	7020SS
Nominal diameter (in)	6	2½	2½
Design productivity* (gpd)	2,100	120	275
Design rejection* (%)	99.3	99.4	99.4
Min. rejection* (%)	99.0	99.2	99.2
Maximum pressure drop per element (psi)	10	8	10

Model No.	1021SS	1021HF**	2021SS	2021HF
Nominal diameter (in)	4	4	8	8
Design productivity* (gpd)	1,000	1,400	4,000	6,000
Design rejection* (%)	99.4	99.0	99.4	99.0
Min. rejection* (%)	99.2	98.6	99.2	98.6
Maximum pressure drop per element (psi)	10	10	10	10

***When individual elements are tested under the following conditions:**

- 32,800 mg/L NaCl solution
- 800 psi applied pressure
- 25°C (77°F) feed temperature
- 7% recovery
- Feed pH 5.7
- 30 minutes operation prior to data collection
- Individual element productivity may vary ± 15% from design.

**Special order quantities only.

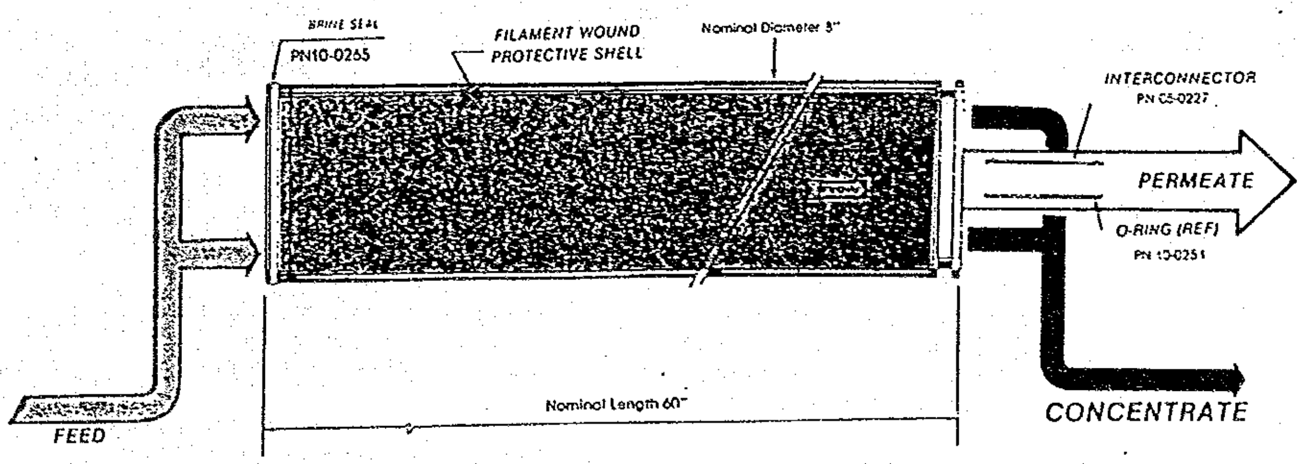
TFC® Spiral-Wound Reverse Osmosis Element
Seawater Model 2031 SS MAGNUM®

PERFORMANCE SPECIFICATION

DESIGN CHLORIDE ION REJECTION	99.4%
DESIGN PERMEATE PRODUCTIVITY	6,200 U.S. gpd (23.5 m^3/d)

TEST CONDITIONS: 32,800 mg/L NaCl solution (isosmotic to ASTM seawater), 800 psi (56.3 kg/cm^2), 11% water recovery, 25°C (77°) and pH 5.7. Data are collected on each element after 30 minutes of operation at these conditions.

DRAINED WEIGHT: 58 lb (26.4 kg)



Refer to the back of this sheet for important operating and design information. This information is intended for use as a guideline. For operation outside these guidelines, please contact Fluid Systems.

Fluid systems by UOP

10124 Old Grove Road • San Diego, CA 92131 • Telephone 619-695-3840 • TLX 188906 • Telecopier 619-695-2176

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6-51

Operational and Design Information

1. The design chloride ion rejection and permeate productivity are based on average values obtained during the final acceptance testing of the elements and should be used when designing systems.

2. At the test conditions shown, the minimum chloride ion rejection is 99.2%. Individual element permeate productivities may vary ± 15% from the design value.

3. For most systems, the optimum pH is approximately 5.7 to obtain maximum rejection as well as to minimize the tendency for precipitation of sparingly soluable salts. If the operating pH is above 5.7, NaCl rejection can be estimated by the following equations:

   NaCl Rejection = 0.994 – 0.00105 (pH – 5.7)

   where pH = anticipated operating pH

4. Recommended design pressure — 800 psi (56.3 kg/cm^2)
   Operation at any pressure below 1000 psi (70.3 kg/cm^2) is permissable provided the design permeate productivity per element is not exceeded and the operation is within the hydraulic limits stated in 5 and 11 below.

   Maximum operating pressure — 1000 psi (70.3 kg/cm^2)

5. Maximum pressure drop per element — 15 psi (1.05 kg/cm^2)

6. Maximum allowable feedwater turbidity — 1.0 NTU
   Experience has shown that prolonged operation on feedwater turbidities greater than 0.2 NTU generally results in prohibitively frequent cleaning requirements. Fluid Systems strongly recommends that pretreatment equipment be designed to routinely attain feedwater turbidity of less than 0.2 NTU.

7. Allowable feedwater temperature range: 1 to 45°C (34 to 113°F)
   The effects of temperature on net operating pressure and/or permeate productivity can be calculated from FSD Bulletin 0004, Temperature Effect.

8. Maximum allowable chlorine or similarly active oxidizing agents such as iodine, bromine and ozone: Zero

9. Allowable operating pH range: 4 to 11
   Allowable cleaning pH range: 3.5 to 12

10. Elements may be cleaned with cationic or nonionic surfactants. Anionic surfactants should be avoided as irreversible fouling may occur.

11. Maximum recovery rate for any presure tube in a system:

Elements/tube	one	two	three	four
Maximum (%)	19	33	40	44

   Operation at greater that the maximum recovery may result in excessive boundary layer conditions or brine concentrations. Please contact Fluid Systems or your distributor for assistance.

SHEET MEMBRANE

PERFORMANCE CHARACTERISTICS[1]:

TYPE	PART NUMBER	NOMINAL[2] FLUX (gfd)	NOMINAL REJECTION	MINIMUM REJECTION
SS	10500	13	99.5	99.2
HF	10501	20	99.0	98.6
MP	10502	25	98.5	97.0
LP	10503	21	97.0	93.5
CA	10504	25	95.0	93.0

PACKAGING AND STORAGE:

TFC® sheet membrane types SS, HF, MP and LP will be rolled on a fiber core. Cellulose acetate sheet membrane (type CA) will be rolled on a PVC core. Maximum roll lengths for ease of handling and packaging is 650 linear feet. Rolls will be plastic wrapped and suitably boxed for shipment in tri-wall cardboard containers. TFC® membrane types are shipped dry. Cellulose acetate membrane is shipped wetted with a residual 2% formaldehyde solution. Estimated shelf life of type CA is one month. Sheet membrane products:

(1) Should not be stored in direct sunlight.
(2) Should not be allowed to freeze or be exposed to temperatures in excess of 50°C (122°F) for TFC® types and 40°C (104°F) for CA.

The ideal storage temperature range is 5 to 10°C (41 to 50°F).

Note[1]: Membrane performance characteristics are determined by fabricating a spiral-wound element from the same membrane lot and testing at Fluid Systems' standard conditions:

SS/HF: 32,800 mg/L NaCl solution
800 psi (56.24 kg/cm²)
7% water recovery
25°C (77°F) and pH 5.7

MP/CA: 2,000 mg/L NaCl solution
420 psi (29.5 kg/cm²)
10% water recovery
25°C (77°F) and pH 5.7

LP: 2,000 mg/L NaCl solution
225 psi (15.8 kg/cm²)
10% water recovery
25°C (77°F) and pH 5.7

Data are collected on each element after a 30 minute equilibration period at the above conditions.

Note[2]: All membrane fluxes (gfd) listed are ±15%.

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Operational and Design Information

TFC® MEMBRANE TYPES SS, HF, MP and LP:

1. Allowable feedwater temperature range: 1 to 45°C (34 to 113°F)
   The effects of temperature on net operating pressure and permeate productivity can be calculated from FSD Bulletin, Temperature Effect.

2. Maximum allowable chlorine or similarly active oxidizing agents such as iodine, bromine and ozone: Zero

3. Allowable operating pH range: 4 to 11
   Allowable cleaning pH range: 3.5 to 12

4. These membrane types may be cleaned with cationic or nonionic surfactants. Anionic surfactants should be avoided as irreversible fouling may occur.

Note: Sodium bisulfite or similar reducing chemicals should not be used as a sterilant or storage chemical without first consulting Fluid Systems.

CELLULOSIC MEMBRANE TYPE CA:

1. Allowable feedwater temperature range: 1 to 40°C (34 to 104°F)
   The effects of temperature on net operating pressure and/or permeate productivity can be calculated from FSD Bulletin, Temperature Effect.

2. Maximum allowable continuous concentration of chlorine or similarly active oxidizing agents such as iodine, bromine and ozone: 1.0 mg/L chlorine residual or equivalent.

3. Allowable operating pH range: 3 to 7
   Allowable cleaning pH range: 3 to 8

   For most systems, a practical optimum pH is approximately 5.7. At this pH, membrane hydrolysis and the tendency of calcium carbonate to precipitate will be minimized. Above pH 6 these effects may become significant and may reduce the effective life of the membrane.

   In some instances operation outside these pH ranges is permissible. Please contact Fluid Systems or your distributor for guidance.

CLEANING INSTRUCTIONS FOR TFC® ELEMENTS

This sheet contains two cleaning solutions used by Fluid Systems' Technical Services Department. These solutions have proven successful in most cases where fouling occurs.

NOTE: If the cleaning procedure does not restore the system production to the expected capacity or expected water quality after cleaning, please contact the Technical Services Department at Fluid Systems immediately.

Advisory: There are a number of proprietary cleaning solutions available from chemical companies. Some of these cleaning solutions have been used to clean Fluid Systems' elements and have proven effective.

Before using any cleaning solution other than those listed, contact Fluid Systems.

(Continued on Reverse Side)

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Cleaning Instructions for TFC® Elements:

Cleaning Solution for 1 Cubic Meter of Water (264.2 Gallons)

NOTE: The water used to prepare either solution must be free of residual chlorine or other oxidizing agents. For first stage seawater applications, RO permeate is preferred, but for brackish water applications, treated feedwater can be used.

SOLUTION Y

NOTE: Cleaning solution Y may cause a temporary increase in membrane salt passage and/or water flux beyond specifications. This condition should last no longer than 24 hours.

This solution is used to remove acid soluble substances such as metal hydroxides and calcium carbonate. It should also generally be used before using SOLUTION Z.

Citric Acid .... 10 kg (22 pounds)

Adjust pH to 3.5 with NH_4OH (ammonium hydroxide) after mixing.

SOLUTION Z (CAUTION — Solution Z must NOT be used on ROGA® elements (cellulose acetate membrane).)

This solution is used to remove organic substances and microbiological slimes not acid soluble.

Borax .... 10 kg (22.1 pounds)
Sodium Salt of EDTA (Ethylenediaminetetracetic Acid)
As Powder .... 10 kg (22.1 pounds)
As 39% Solution .... 25.6 kg (56.5 pounds)
Trisodium Phosphate (TSP) .... 10 kg (22.1 pounds)

The pH of this solution does not have to be adjusted for TFC® elements.

Both cleaning solutions may be used at a temperature range from ambient up to 40°C (104°F) for 45 minutes and at the recommended flow rate as indicated below. The system pressure should be the minimum required to achieve specified flow but in no case should the pressure drop across any vessel exceed 60 psig.

Formaldehyde may be added to either cleaning solution to aid in disinfection or removing biological growths. Formaldehyde is available as a 37% solution (0.4 kg per liter — 3.33 pounds per gallon). It may be used as a 0.5 to 1% solution. A 0.5% solution contains 13.5 liters of 37% formaldehyde per cubic meter of water (3.6 gallons per 264.2 gallons).

MAXIMUM CLEANING FEED FLOW RATES

TFC® Element Nominal Diameter

2½" .... 0.7 m^3/hr/tube (3 gpm)
4" .... 2.3 m^3/hr/tube (10 gpm)
6" .... 4.6 m^3/hr/tube (20 gpm)
8" .... 9.1 m^3/hr/tube (40 gpm)

Pressure tubes are to be cleaned only in parallel. Where a series array of pressure tubes is used for higher recoveries, each array shall be cleaned separately.

CLEANING INSTRUCTIONS FOR ROGA® ELEMENTS

This sheet contains two cleaning solutions used by Fluid Systems' Technical Services Department. These solutions have proven successful in most cases where fouling occurs.

> NOTE: If the cleaning procedure does not restore the system production to the expected capacity or expected water quality after cleaning, please contact the Technical Services Department of Fluid Systems immediately.

Advisory: There are a number of proprietary cleaning solutions available from chemical companies. Some of these cleaning solutions have been used to clean Fluid Systems' elements and have proven effective.

Before using any cleaning solution other than those listed, contact Fluid Systems.

(Continued on Reverse Side)

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Cleaning Instructions for ROGA® Elements:

Cleaning Solution for 1 Cubic Meter of Water (264.2 Gallons)

NOTE: The water used to prepare either solution must be treated feedwater or R.O. permeate.

SOLUTION A

This solution is used to remove acid soluable substances such as metal hydroxides (iron) and calcium carbonate.

1. Citric Acid ...... 20 kg (44 pounds) **or** Phosphoric Acid 75% ...... 55 liters (14.7 gallons)
2. Triton X-100 .... 1 liter
3. Adjust pH to 2.5 with NH_4OH (ammonium hydroxide) after mixing chemicals.

SOLUTION B

Used where the fouling material is organic in nature.

1. Trisodium Phosphate (TSP)... 20 kg (44 pounds)
2. Sodium EDTA (Sodium Salt of Ethylenediaminetetra Acetic Acid)
   If powder .... 8 kg (17.5 pounds)
   If 39% solution.. 20 kg (44 pounds)
3. Triton X-100 .... 1 liter
4. Adjust pH with H_2SO_4 (sulfuric acid) or HCl (hydrocholoric acid) as follows after mixing chemicals with product water:

   HR Elements should be cleaned at a pH of 7.0.
   SD, S, and LP Elements should be cleaned at a pH of 8.0.

Sodium Tripolyphosphate (STPP) may be substituted in part or entirely for the TSP.

Both cleaning solutions may be used at a temperature range from ambient up to 40°C (104°F) for 45 minutes and at the recommended flow rate as indicated below. The system pressure should be the minimum required to achieve specified flow but in no case should pressure drop across any pressure tube exceed 60 psig.

Soaking elements in cleaning solutions under static conditions is sometimes useful for improving cleaning results when severe fouling has occured. SOAK TIME OF LONGER THAN 24 HOURS IS NOT RECOMMENDED.

Formaldehyde may be added to either cleaning solution to aid in disinfection or removing biological growths. Formaldehyde is available as a 37% solution (0.4 kg per liter — 3.33 pounds per gallon). It may be used as a 0.5 to 1% solution. A 0.5% solution contains 13.5 liters of 37% formaldehyde per cubic meter of water (3.6 gallons per 264.2 gallons).

MAXIMUM CLEANING FEED FLOW RATE

ROGA® Element Model	
~~4101~~	1.8 m³/hr/tube (8 gpm)
4160, 4221, 4231	2.3 m³/hr/tube (10 gpm)
8150, 8221, 8231	9.1 m³/hr/tube (40 gpm)

Pressure tubes are to be cleaned only in parallel. Where a series array of pressure tubes is used for higher recoveries, each array shall be cleaned separately.

Temperature Effect

ROGA® and TFC® Spiral Wound Reverse Osmosis Elements

To estimate the effect of temperature alone (constant net pressure*) on the permeate flow rate of an element or group of elements, the following equation may be used:

$$T_{cor.} = \frac{Q_{25}}{Q_T} = e^x$$

where: $T_{cor.}$ = Temperature Correction Factor
Q_{25} = the permeate flow rate at 25°C (77°F)
Q_T = the permeate flow rate at temperature T
e = 2.71828....

$$x = U\left(\frac{1}{T+273} - \frac{1}{298}\right)$$

T = the temperature in degrees Celsius (°C)
U = a constant which depends on the element being used
For ROGA® Models 4101, 4160S, 4160HR, 8150S and 8150HR: U = 2158

For ROGA® Models 4221SD, 4221HR, 4231SD MAGNUM, 4231HR MAGNUM, 8221SD, 8221HR, 8231SD MAGNUM, 8231HR MAGNUM: U = 2732

For all TFC® Models: U = 3470

To estimate Q_{25}, the permeate flow rate at 25°C (77°F), mutliply Q_T, the observed permeate flow rate, by $T_{cor.}$

To estimate the net pressure* at temperature T°C required to obtain the same permeate flow rate that would be obtained at 25°C, multiply the net pressure* by $T_{cor.}$

To estimate Q_T, the permeate flow rate at T°C, divide Q_{25}, the permeate flow rate at 25°C, by $T_{cor.}$

For your convenience, a tabulation of $T_{cor.}$ values for different element types at various temperatures is provided on the back of this sheet.

*Net pressure is defined as the pressure remaining after the differential osmotic pressure, permeate pressure and any brine channel and manifolding losses have been subtracted from the applied pressure.

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Values of $T_{cor.}$ for ROGA® and TFC® Elements

Temperature °C	°F	ROGA® Models 4101, 4160S, 4160HR	ROGA® Models 8150S, 8150HR	ROGA® Models 4221SD&HR, 8221SD&HR (including MAGNUMS)	All TFC® Models
1	33.8	1.886	1.886	2.232	2.773
2	35.6	1.832	1.832	2.153	2.648
3	37.4	1.781	1.781	2.077	2.530
4	39.2	1.732	1.732	2.004	2.418
5	41	1.684	1.684	1.934	2.311
6	42.8	1.637	1.637	1.867	2.210
7	44.6	1.593	1.593	1.803	2.114
8	46.4	1.550	1.550	1.741	2.023
9	48.2	1.508	1.508	1.682	1.936
10	50	1.468	1.468	1.626	1.854
11	51.8	1.429	1.429	1.571	1.775
12	53.6	1.391	1.391	1.520	1.701
13	55.4	1.355	1.355	1.470	1.630
14	57.2	1.320	1.320	1.421	1.563
15	59	1.286	1.286	1.375	1.498
16	60.8	1.253	1.253	1.330	1.437
17	62.6	1.221	1.221	1.288	1.379
18	64.4	1.190	1.190	1.247	1.323
19	66.2	1.160	1.160	1.207	1.270
20	68	1.132	1.132	1.170	1.220
21	69.8	1.104	1.104	1.133	1.172
22	71.6	1.076	1.076	1.098	1.126
23	73.4	1.050	1.050	1.064	1.082
24	75.2	1.025	1.025	1.031	1.040
25	77	1.000	1.000	1.000	1.000
26	78.8	0.976	0.976	0.970	0.962
27	80.6	0.953	0.953	0.941	0.925
28	82.4	0.930	0.930	0.913	0.890
29	84.2	0.909	0.909	0.886	0.857
30	86	0.887	0.887	0.860	0.825
31	87.8	N/A	0.867	0.835	0.795
32	89.6	N/A	0.847	0.810	0.765
33	91.4	N/A	0.828	0.787	0.738
34	93.2	N/A	0.809	0.764	0.711
35	95	N/A	0.790	0.743	0.685
36	96.8	N/A	0.773	0.722	0.661
37	98.6	N/A	0.756	0.701	0.637
38	100.4	N/A	0.739	0.682	0.615
39	102.2	N/A	0.723	0.663	0.593
40	104	N/A	0.707	0.645	0.572
41	105.8	N/A	N/A	N/A	0.552
42	107.6	N/A	N/A	N/A	0.533
43	109.4	N/A	N/A	N/A	0.515
44	111.2	N/A	N/A	N/A	0.498
45	113	N/A	N/A	N/A	0.481
46	114.8	N/A	N/A	N/A	0.465
47	116.6	N/A	N/A	N/A	0.449
48	118.4	N/A	N/A	N/A	0.434
49	120.2	N/A	N/A	N/A	0.420
50	122	N/A	N/A	N/A	0.406

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PEM
Permasep® Engineering Manual

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Du Pont Company / Polymer Products Dept. / Permasep* Products / Wilmington, DE 19898

BULLETIN 401

THE B-10 "PERMASEP" PERMEATOR

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A. INTRODUCTION

The Du Pont B-10 "Permasep" permeator was commercialized in 1974. It was designed to desalt seawater and highly brackish water. The B-10 was the first reverse osmosis (RO) permeator capable of producing potable water from typical seawater (35,000 mg/ℓ *TDS*) in a single pass.

By the end of 1981, over 500 seawater RO plants using "Permasep" B-10 permeators were either operational or under construction. These plants represent a capacity close to 50,000 m^3/d (13 million U.S. GPD).

B. PERMEATOR CHARACTERISTICS

Each B-10 permeator is rated for performance under the following 'standard' test conditions:

- Feed solution — 30,000 ppm NaCl
- Feed pressure — 5,520 kPa (800 psig)
- Feed temperature — 25 degrees C
- Conversion — 30 percent

Four-inch diameter permeators are produced in two standard sizes with initial nominal flows of 0.95 m^3/d (250 GPD) and 6.0 m^3/d (1,600 GPD). Eight-inch diameter permeator models nominally produce 23.8 m^3/d (6,300 GPD). All B-10 permeators reject at least 98.5 percent of all dissolved salts at standard conditions. Other product specifications are given in the product bulletins included in this section.

Like the B-9 permeators, Du Pont's B-10 "Permasep" permeators use hollow fine fiber membrane made from "aramid" polymer. Though only about as thick as a human hair, the fibers are engineered to withstand the high external pressures required for seawater desalting. The fiber is called "asymmetric" because it has a very dense skin on the outside, supported by a porous structure of the same chemical composition. Aramid fibers are chemically stable, can tolerate a broad range of pH conditions, and are impervious to biological attack.

Primarily used for seawater desalting applications, B-10 "Permasep" permeators are also used for desalting higher *TDS* brackish waters. Brackish water is often described as having total dissolved solids *(TDS)* less than 10,000 mg/ℓ. Above 10,000 mg/ℓ, water is categorized as either high-brackish water or seawater. The specific composition of high-brackish water can vary widely. However, the ion ratios of seawater are generally consistent, although the salinity *(TDS)* will vary.

The high osmotic pressure of very brackish water and seawater requires a much higher driving force for reverse osmosis permeators. Operating pressures of 5,520 to 6,900 kPa (800 to 1,000 psig) are now typical for efficient seawater reverse osmosis permeators such as the B-10 "Permasep" permeator. Nominal seawater *TDS* level is quoted at 35,000 mg/ℓ with ion ratios similar to those in Table I. Actually, seawater can have *TDS* levels far below and far above 35,000 mg/ℓ. For this discussion, we shall define seawater as being water with a *TDS* above 25,000 mg/ℓ but also having ion ratios as indicated in Table I. (In the Arabian Gulf, the *TDS* may exceed 50,000 mg/ℓ).

TABLE I
SEAWATER *TDS* LEVELS

Ion	Concentration— mg/ℓ (ppm)	Percent of Total Salt
Cl^-	18,980	55.04
Br^-	65	0.19
$SO_4^=$	2,649	7.68
HCO_3^-	140	0.41
F^-	1	0.00
H_3BO_3	26	0.07
Mg^{++}	1,272	3.69
Ca^{++}	400	1.16
Sr^{++}	13	0.04
K^+	380	1.10
Na^{++}	10,556	30.61
Total	34,482	99.99

The B-10 "Permasep" permeator is particularly well suited to operate as part of a desalination system for high *TDS* feedwaters. Metal components are not in contact with water, minimizing corrosion problems. There are no moving parts within the permeator that can fail. Since RO is an ambient temperature process, safety problems and mechanical stress on the system are less than for high temperature operations such as distillation. Desalting with RO does not require the energy-intensive phase changes of distillation, reducing the cost of operating RO systems.

C. PERMEATOR OPERATION

The general construction and flow pattern in a B-10 "Permasep" permeator resembles a shell and tube heat exchanger. Figures 1 and 2 illustrate B-10 permeator construction. Millions of hollow fibers are oriented in parallel and fixed in epoxy at both ends. This gives the bundle mechanical stability. The fibers at one end of the bundle

Figure 1. The B-10 Permeator

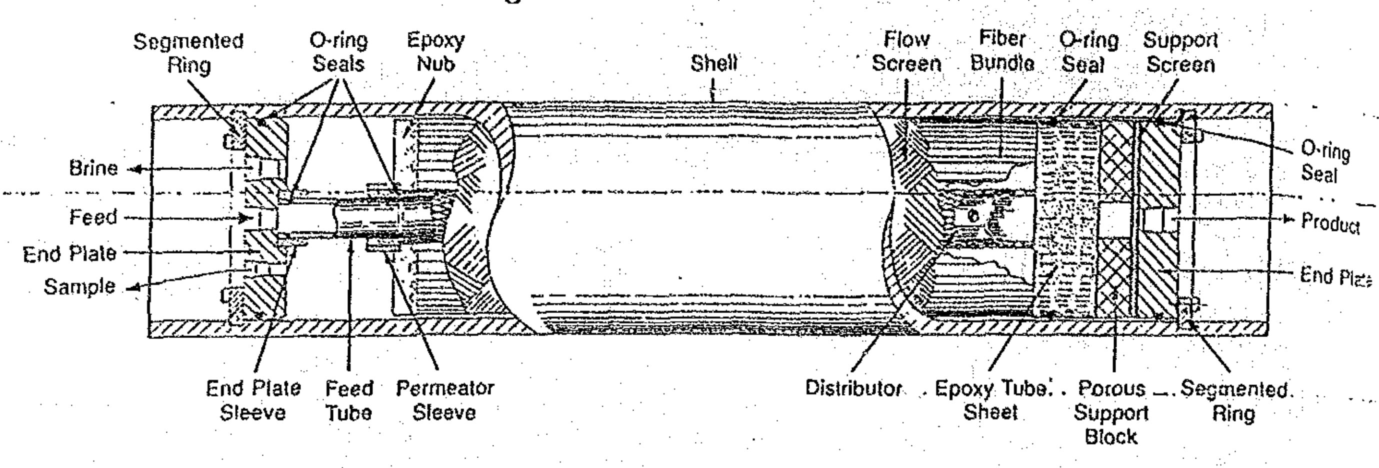


Figure 2. Illustration of Hollow Fiber RO Process

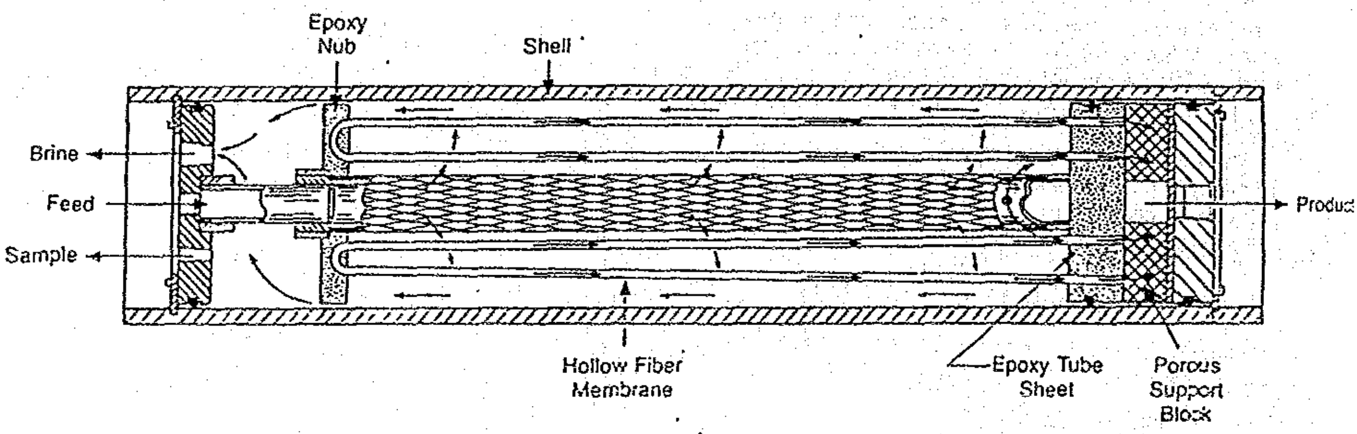
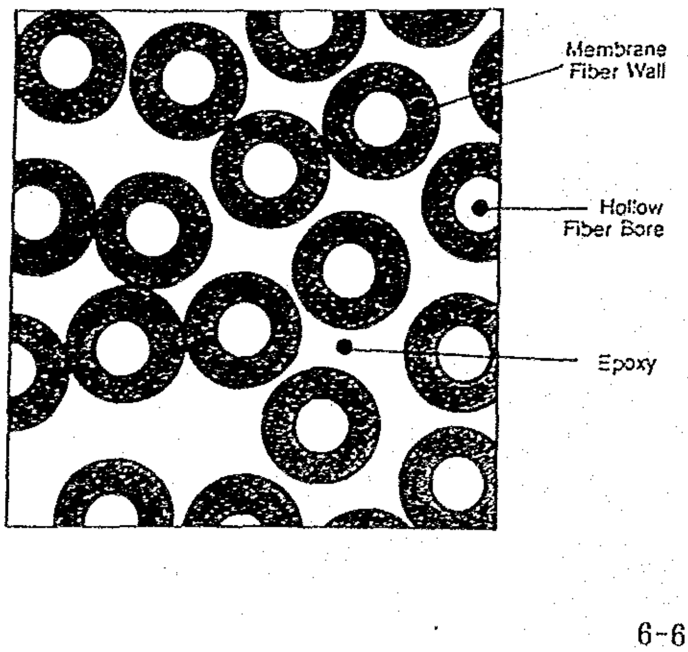


Figure 3. Illustration at Tube Sheet Faces



are precisely cut so that product water can be discharged from the bore of the fibers. This is called the tube sheet end of the bundle. Figure 3 is an illustration of the surface of the tube sheet showing the open fibers fixed in epoxy.

Under pressure, feedwater is fed into a central distributor tube where it is forced out radially through the bundle of fibers. As pressurized feedwater contacts the outside of the fibers, permeate is forced to the center of each hollow fiber. The permeate moves along the hollow bore to the face of the tube sheet and out of the permeator. The brine is forced to the other end of the bundle and out of the permeator. O-ring seals prevent mixing of the feed, brine and product.

The operating pressure needed in a seawater reverse osmosis system is determined by the feedwater *TDS* level. As a rough approximation, each 1,000 mg/ℓ of total dissolved solids in seawater contributes about 69 kPa (10 psig) of osmotic pressure. Therefore, the osmotic pressure of a 35,000 mg/ℓ seawater is about 2,400 kPa (350 psig). The osmotic pressure inside the permeator increases rapidly as permeation occurs and the brine becomes concentrated. A conversion of 50 percent will double the concentration of the brine, resulting in an average osmotic pressure in the feed/brine mixture that is 1.5 times greater than that in the feed. With nominal seawater at 35,000 mg/ℓ *TDS* and 50 percent conversion, the average osmotic pressure in the brine would be about 3,600 kPa (525 psig). Therefore, a B-10 seawater device must operate at much higher pressure than a brackish water permeator to be effective. The typical pressures required for seawater RO systems range from 5,520 kPa (800 psig) to 6,900 kPa (1,000 psig) allowing conversions from 15 to 40 percent. For comparison, RO for a 2,000 mg/ℓ brackish water requires an operating pressure of only 2,760 kPa (400 psig) and permits conversion up to 90 percent.

The major design differences between the Permasep* B-10 permeator and the B-9 brackish water permeator are:

- The permeator shell wall and other external hardware are thicker and stronger.
- The wall thickness of the hollow fiber aramid membrane is increased to withstand the higher hydraulic pressures used to overcome the high osmotic pressure of seawater (i.e., 95μ outside diameter and 42μ inside diameter).
- The fiber microstructure is modified to reject a higher percentage of salts in the more concentrated feedwater.

D. MEMBRANE LIFE

With over 500 plants operating around the world, B-10 "Permasep" permeators have been exposed to a variety of feedwaters and operating conditions. Although it is impossible to determine the permeator performance history in every case, data from land-based plants demonstrate that the B-10 "Permasep" permeator will have an average life greater than five years. Table II shows the experience at some of the older and larger B-10 "Permasep" permeator installations.

TABLE II
PERMEATOR LIFE
"PERMASEP" PERMEATOR RO SYSTEMS

System	Size m³/day (GPD × 1,000)	Feed *TDS*	Start-up Date	Permeators* Installed	Replacements** No.	Replacements** %/Year
Florida Keys Florida, USA	11,350 (3,000)	38,000	Dec. '80	525	6	1
CADAFE I Venezuela	3,785 (1,000)	38,000	Apr. '80	250	15	3
United Building Factories Bahrain	2,271 (600)	10,500	Jan. '77	198	66	11
Ras Al Khaimah UAE	568 (150)	42,000	Dec. '77	50	2	1

*8-inch B-10 permeators, except for United Building Factories, which uses 4-inch B-10 permeators.
**Bulletin 405 discusses membrane replacement cost in greater detail.

*Reg. U.S. Pat. & Tm. Off. for Du Pont's Permeators.

PEM Permasep® Engineering Manual

Du Pont Company / Polymer Products Dept. / Permasep* Products / Wilmington, DE 19898

BULLETIN 402

B-10 "PERMASEP" PERMEATOR, FACTORS INFLUENCING PERFORMANCE

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A. INTRODUCTION

"Permasep" B-10 permeators are rated for salt passage and initial capacity using the following standard test conditions (Standard test conditions are not to be assumed as recommended operating conditions for a single permeator. Refer to the specification bulletin for the minimum brine flow rate for the permeator model that will be used.):

Feed solution	30,000 mg/ℓ NaCl
Feed pressure	5,520 kPa (800 psig)
Feed temperature	25 degrees C (77 degrees F)
Conversion	30 percent

Factors such as feed pressure, feed concentration, feed temperature, conversion, product pressure and time will influence the capacity and salt passage of a permeator.

This bulletin describes the factors that must be considered in order to predict actual permeator performance in a specific application.

B. FLOW FACTORS

The effect of the specific site variables on capacity is determined from Equation 1 which is an approximation of water flow through a semipermeable membrane:

$$Q_w = K_w \frac{A}{\tau}(\Delta P - \Delta\pi)TM \quad (1)$$

Where:
Q_w = flow rate of water through the membrane
K_w = membrane permeability coefficient for water
A = membrane surface area
τ = membrane thickness
ΔP = hydraulic pressure differential across membrane
$\Delta\pi$ = osmotic pressure differential across membrane
T = temperature effect
M = membrane flux decline effect

When designing a plant using "Permasep" permeators, it is necessary to account for these variables, correcting permeator capacity from standard test conditions. This is done by calculating three correction factors which adjust for pressure/concentration/conversion, temperature, and time as shown in Equation 2.

$$Q_p = (PCF)(TCF)(MFRC)Q_i \quad (2)$$

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

The correction factors are calculated from the ratio of the permeator flow rate at actual operating conditions, to the flow rate at standard test conditions. Detailed derivations of these correction factors is beyond the scope of this manual, but each is described below in greater detail.

1. PRESSURE CORRECTION FACTOR—*PCF*

The pressure correction factor *(PCF)* incorporates the pressure terms affecting capacity. These terms include feed pressure, bundle pressure drop, product pressure and osmotic pressure. Osmotic pressure is calculated from feed concentration and conversion. The *PCF* for B-10 permeators is calculated using Equation 3.

$$PCF = 0.00275\left(P_f - \frac{\Delta P_{fb}}{2} - P_p - \pi_{fb}\right) \quad (3)$$

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

2. MEMBRANE FLUX RETENTION COEFFICIENT—*MFRC*

All RO membranes compact over their operating life resulting in reduced flow capacity. This phenomenon is known as membrane flux decline. The rate of decline increases with increased pressure and/or temperature; the greater the pressure and temperature, the greater the rate of decline.

The effect of pressure, temperature and time on membrane flux decline is expressed as a membrane flux retention coefficient *(MFRC)*. *MFRC* is defined as:

$$MFRC = \frac{Q_{wt}}{Q_{wi}} \quad (4)$$

Where Q_{wt} is the permeator flow rate at time *(t)* and Q_{wi} is the permeator flow rate at initial start-up. For both *Q* values, all pressure and temperature terms are

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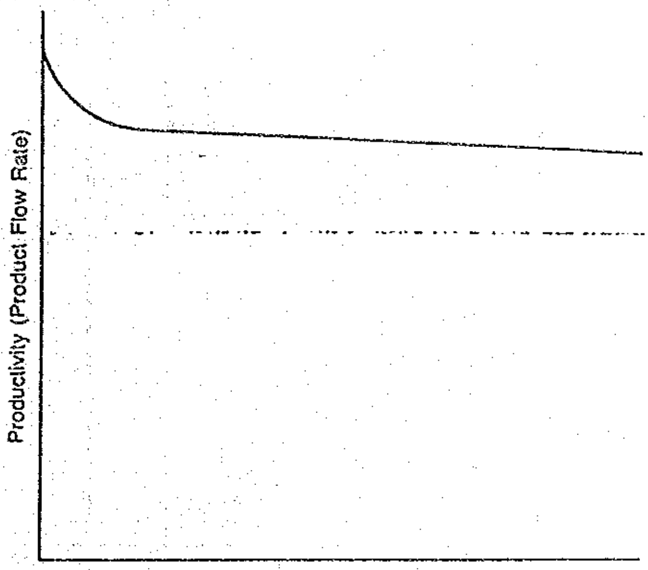
the same and the only variable is time related flux decline. The *MFRC* value expresses the amount of flow (flux) retained by a permeator relative to its initial flow rate when only flux decline effects are considered. Thus, an $MFRC = 0.800$ means the permeator has retained 80 percent of its original flow.

MFRC is a log function with respect to time (see Fig. 1). The time factor, however, is not as significant after the initial flux decline has occurred. The following relationships can be used to estimate long term permeator or system flows at various pressures and temperatures:

Figure 1. Permeator Productivity vs. Time



- For $T > 25$ degrees C and $P \geqslant 800$ psig

$$MFRC_{3-5\ years} = (1.5 \times 10^{-5}P - 0.0428)T - 0.00127P + 2.595 \quad (5)$$

- For $T \leqslant 25$ degrees C and $P \geqslant 800$ psig

$$MFRC_{3-5\ years} = 1.017^{-(1.079)^T(P)^{3.209}(10)^{-8}} \quad (6)$$

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

The difference in *MFRC*, and consequently permeator and system flow, between the third and fifth year of continuous operation is less than two percent. RO systems are normally designed to produce a specific amount of permeate at the end of a finite period (such as five years), so the expected flux decline is included in the design.

3. TEMPERATURE CORRECTION FACTOR—*TCF*

Instantaneous capacity of the permeator is affected by the feedwater temperature. The temperature correction factor *(TCF)* is defined by Equation 7 and shown in Figure 2. The Temperature Correction Factor *(TCF)* for a B-10 permeator is:

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

Where Q_{wT} is the permeator flow rate at temperature *(T)*, and Q_{w25} is the permeator flow rate at 25 degrees C. For both *Q* values, all pressure and membrane flux decline terms are the same and the only variable is temperature.

C. RO SYSTEM SALT PASSAGE

Salt passage *(SP)* and product concentration (C_p) at any condition are interrelated as shown by Equation 8.

$$SP = \frac{C_p}{C_f} \quad (8)$$

Where:
C_f = feed concentration
C_p = product concentration

Factors such as the ionic constituents in the water and their concentration, feed pressure and conversion will influence *SP* and C_p. When these factors are set equal to the standard test conditions (5,520 kPa, 25 degrees C, 30 percent conversion and 30,000 mg/ℓ NaCl), the B-10 permeator will have a salt passage (SP_0) of less than 1.5 percent. However, for permeators operated at conditions other than the standard conditions, a new *SP* must be determined (Equation 9) using a salt passage correction factor *(SPCF)*.

$$SP = (SP_0)(SPCF) \quad (9)$$

The salt passage (at standard conditions, SP_0) will be different for different ions. In general, passage of monovalent ions will be greater than passage of divalent ions, and divalent ions greater than trivalent ions. Table I, Salt Passage for B-10 Permeators at Standard Test Conditions, lists the SP_0 for constituents commonly encountered in seawater. HCO_3^- and F^- are not shown in Table I as their passage is pH dependent. The effects of pH on HCO_3^- and F^- for B-10 "Permasep" permeators are shown in Figures 3 and Figure 4 respectively.

TABLE I
SALT PASSAGE FOR B-10 PERMEATORS AT STANDARD TEST CONDITIONS*

Constituent	SP_0, %
Sodium, Na^+	1.5
Potassium, K^+	1.5
Calcium, Ca^{++}	0.6
Magnesium, Mg^{++}	0.6
Barium, Ba^{++}	0.6
Iron, Fe^{++}	0.6
Strontium, Sr^{++}	0.6
Nitrate, NO_3^-	2.3
Chloride, Cl^-	1.5
Sulfate, $SO_4^=$	0.6
Carbonate, $CO_3^=$	0.6
Phosphate, $PO_4^{\equiv}$	0.3
Silica, SiO_2	2.3
Carbon Dioxide, CO_2	100
Hydrogen Sulfide, H_2S	100

*5515 kPa (800 psig), 25°C (77°F), 30% conversion, and osmotic pressure equivalent to 30,000 mg/ℓ NaCl.

Using Equations 8 and 9 the *SPCF* can be rewritten as:

$$SPCF = \frac{C_p/C_f}{C_{po}/C_{fo}} = \frac{C_{fo}C_p}{C_fC_{po}} \quad (10)$$

Figure 2. Temperature Correction Factor (TCF) for B-10 Permeator

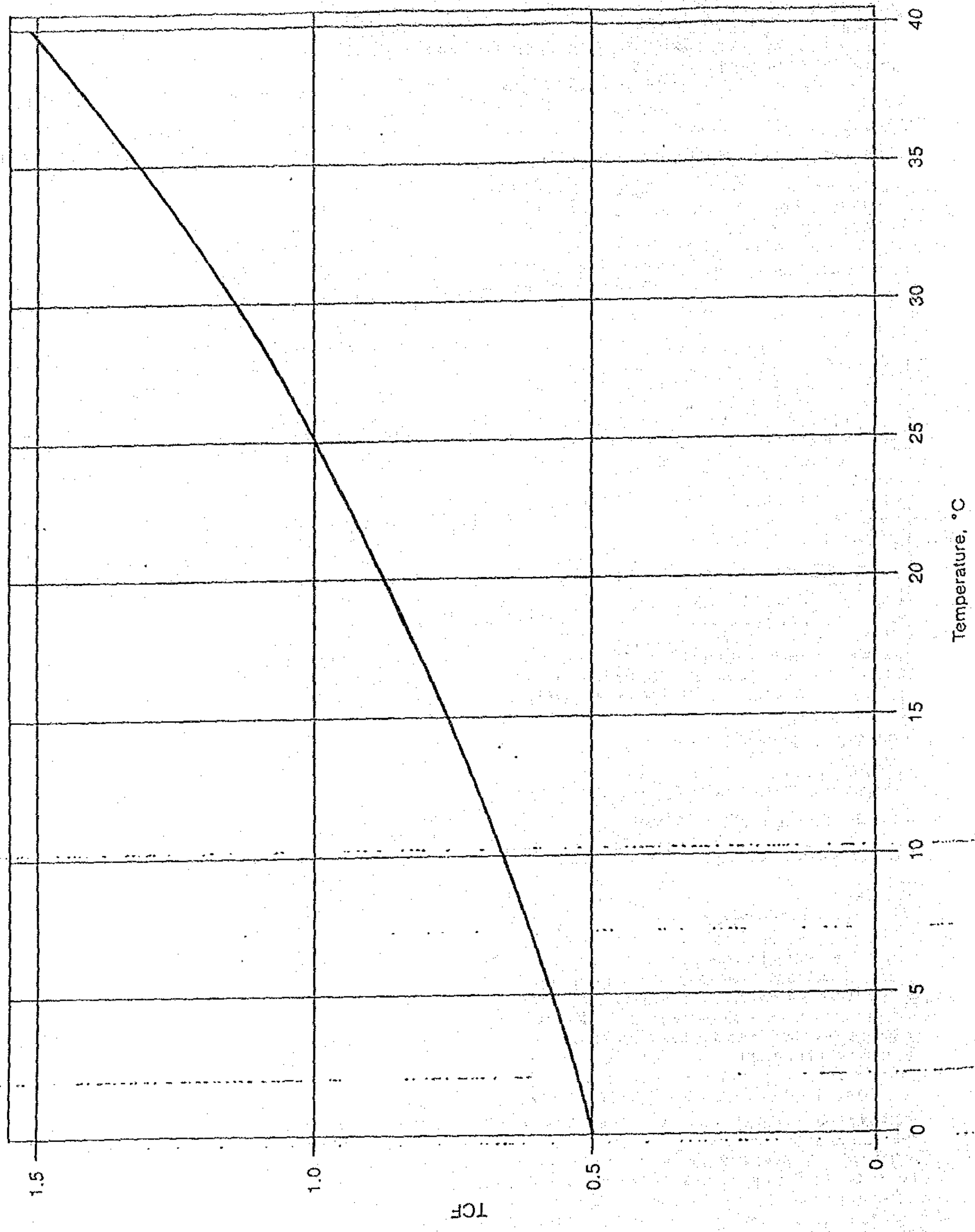


Figure 3. Effect of Feed pH on HCO_3^- Passage for B-10 Permeator

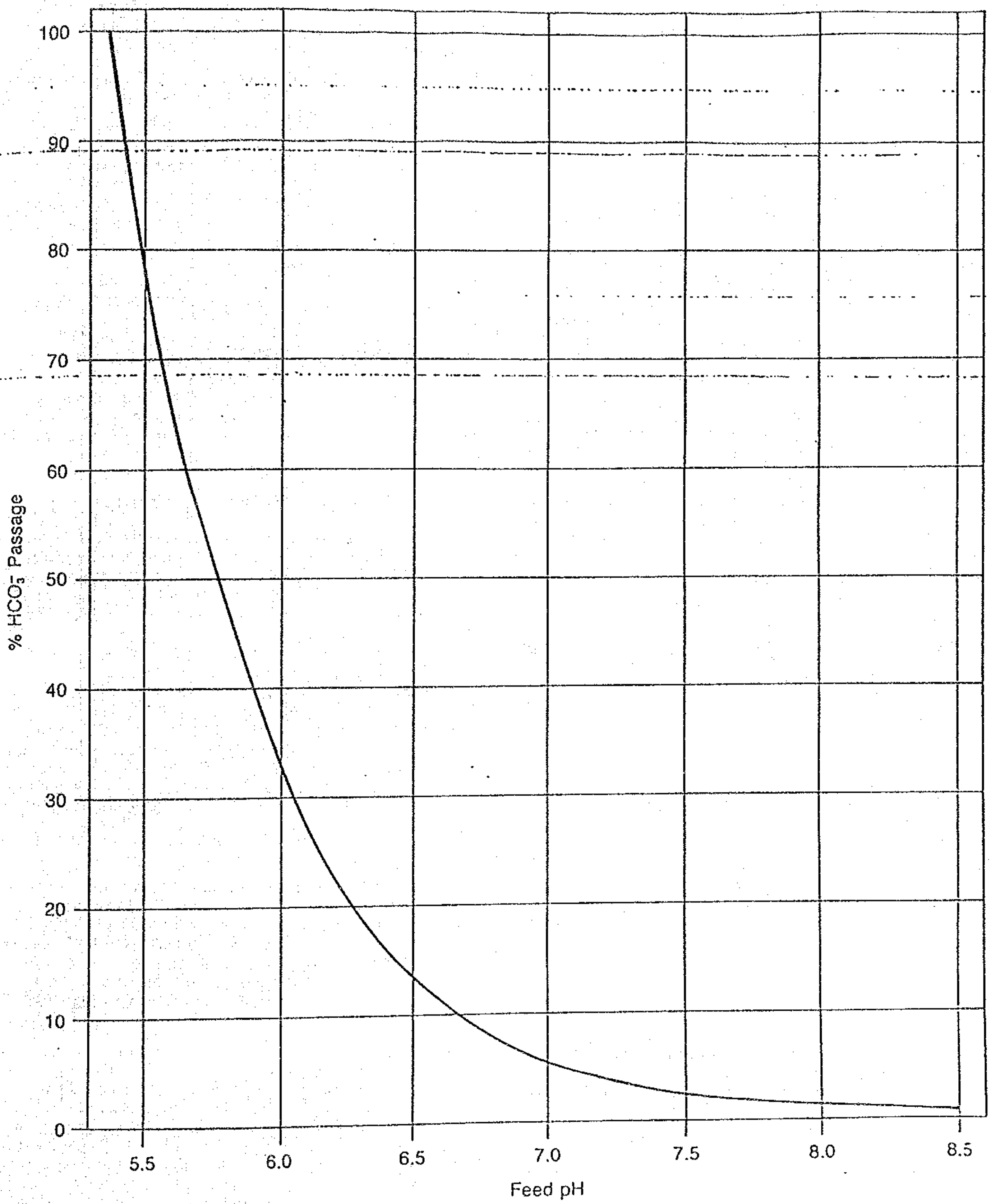
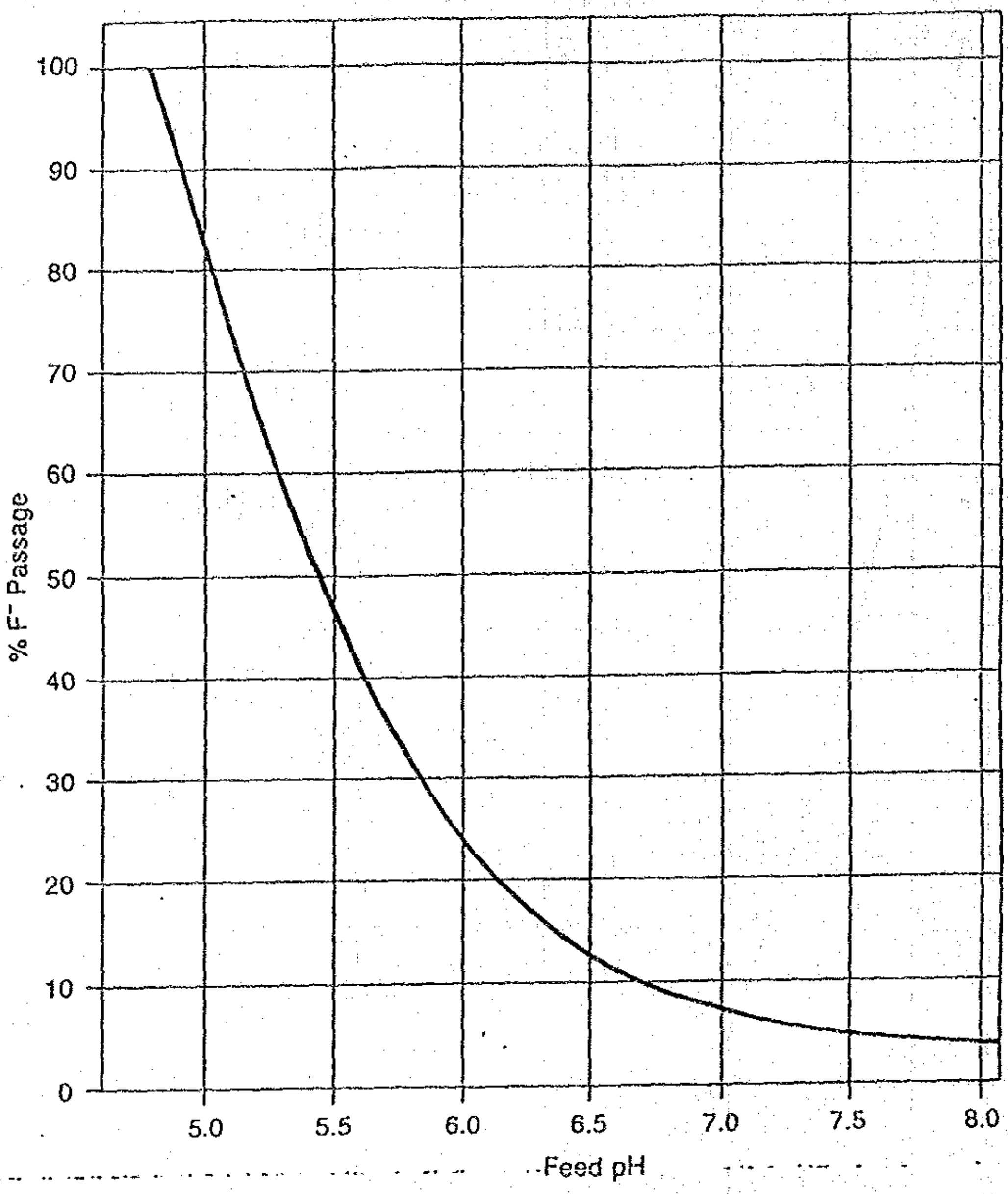


Figure 4. Effect of Feed pH on F^- Passage for B-10 Permeators



The salt concentration in the product stream is defined by Equation 11:

$$C_p = \frac{Q_s}{Q_w} \qquad (11)$$

Where:
Q_w = flow rate of water through the membrane, which is determined from Equation 1,
Q_s = flow rate of salt through the membrane, which is determined from Equation 12:

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

Where:
K_s = membrane permeability coefficient for salt
A = membrane area
τ = membrane thickness
ΔC = salt concentration differential across membrane $= C_{fb} - C_p \cong C_{fb}$, since C_{fb} is much larger than C_p
T = temperature effect
M = membrane flux decline effect

The *SPCF* for a particular situation can be determined from Equation 13.

$$SPCF = \frac{\dfrac{C_{fo}}{C_f}\left[\left(P_{fo} - \dfrac{\Delta P_{fbo}}{2} - P_{po}\right) - \left(\pi_{fbo} - \pi_{po}\right)\right]}{\left[\left(P_f - \dfrac{\Delta P_{fb}}{2} - P_p\right) - \left(\pi_{fb} - \pi_p\right)\right]} \frac{C_{fb}}{C_{fbo}} \qquad (13)$$

Where:
C_{fo} = feed concentration at standard test conditions, 30,000 mg/ℓ as NaCl
C_f = feed concentration at actual condition, mg/ℓ as NaCl

P_{fo} = feed pressure at standard test conditions, 5,520 kPa (800 psig)
P_f = feed pressure at actual conditions, kPa (psig)
$\frac{\Delta P_{fbo}}{2}$ = one-half permeator bundle pressure drop at standard test conditions, 20.7 kPa (3 psi)
$\frac{\Delta P_{fb}}{2}$ = one-half permeator bundle pressure drop at actual condition, kPa (psi)
P_{po} = product pressure at standard test condition, 0 kPa
P_p = product pressure at actual condition kPa (psig)
π_{fbo} = osmotic pressure of feed-brine stream at standard test conditions, 2,992 kPa (433.7 psi)
π_{fb} = osmotic pressure of feed-brine stream at actual condition, kPa (psi)
π_{po} = osmotic pressure of product at standard conditions, 31.0 kPa (4.5 psi)
π_p = osmotic pressure of product at actual conditions, which is approximated as 0.01 times the osmotic pressure of the feed stream, kPa (psi)
C_{fbo} = average feed-brine concentration at standard test conditions, 36,429 mg/ℓ as NaCl
C_{fb} = average feed-brine concentration at actual conditions, mg/ℓ as NaCl

D. PREDICTING PERFORMANCE

Du Pont and suppliers of Permasep* RO systems (Licensees) have developed computer programs to predict product water quality and quantity as well as the number of permeators required for specific plant designs. Other guidelines concerning solubility limits for sparingly soluble salts, flow balancing requirements, minimum and maximum brine flow rates, and temperature/pressure limits must also be considered. Even though these guidelines are discussed in this manual, **the information contained in the "Permasep® Engineering Manual" is not intended to permit specific independent system design or performance determinations.** Specific questions concerning RO performance for a particular application should be referred to a qualified "Permasep" Licensee (Bulletin 101).

1. ESTIMATING PERMEATOR CAPACITY

A graphical and tabular approach is provided below for estimating purposes only. This approach does not consider all of the variables that are included in a specific design proposal and does not consider staging or brine flow rate specifications. This method may only be used for seawater applications. It is based on the premise that although the salinity of seawater varies, the relative ratios of the major ions remain nearly constant.

- Use Figure 5, Conversion of Seawater *TDS* (mg/ℓ) to Equivalent NaCl (mg/ℓ), to estimate the equivalent NaCl mg/ℓ of the given feed concentration. This equivalent NaCl concentration is used for feed concentration where required in the following graphs.
- Determine Correction Factor "A" from Figure 6, Correction Factor *A* for B-10.
- Determine Correction Factor "B" from Figure 7, Correction Factor *B* for B-10.
- Determine Correction Factor "C" from Figure 8, Correction Factor *C* for B-10.
- Determine Correction Factor "D" from Figure 9, Correction Factor *D* for B-10.
- Determine Correction Factor "E" from Figure 10, Correction Factor *E* for B-10.
- Determine Membrane Flux Retention Coefficient *(MFRC)* from Equation 5 or 6.
- After these factors have been determined, they can be applied to the following equation to solve for estimated permeator capacity:

$$Q_{pE} = [A - B - CD](E)(MFRC)Q_i \quad (14)$$

Where:
Q_{pE} = estimated permeator capacity, GPD
Q_i = initial permeator capacity at standard conditions, GPD

The number of permeators required to obtain the overall plant capacity (Q_{pO}) is calculated by dividing Q_{pO} by Q_{pE}.

Example:
Estimate the number of permeators required for an 8-inch B-10 seawater system producing 378.5 m³/d (100,000 GPD) at the end of three years.

Given:
Feedwater *TDS* = 34,500 mg/ℓ ion
Feed Pressure = 6,900 kPa (1,000 psig)
Design Temperature = 25 degrees C
Maximum Temperature = 25 degrees C
Product Pressure = 69 kPa (10 psig)
Conversion = 30 percent
Initial Capacity of 8-inch B-10 = 23.8 m³/d (6,300 GPD)

- From Figure 5
  34,500 mg/ℓ *TDS* = 31,500 mg/ℓ NaCl
- From Figure 6, "A" = 2.74 at 1,000 psig
- From Figure 7, "B" = 0.028 at 10 psig
- From Figure 8, "C" = 1.265 at 31,500 mg/ℓ NaCl and 30 percent Y
- From Figure 9, "D" = 1.00 at 25 degrees C
- From Figure 10, "E" = 1.00 at 25 degrees C
- From Equation 6, *MFRC* = 0.620 at 6,900 kPa (1,000 psig), 25 degrees C and 3 years
- From Equation 14:

$$\begin{aligned} Q_{pE} &= (A - B - CD)E(MFRC)Q_i \\ &= (2.74 - 0.028 - 1.265 \times 1.00) \times (1.00)(0.620)23.8 \\ &= (1.447)(1.00)(0.620)23.8 \\ &= 21.35\text{m}^3/\text{d} \ (5{,}641 \text{ GPD}) \end{aligned}$$

- Number of 6840 B-10 permeators $= \frac{378.5 \text{ m}^3/\text{d}}{21.35 \text{ m}^3/\text{d}}$ = 17.7, say 18 permeators.

2. ESTIMATING PERMEATOR PRODUCT CONCENTRATION

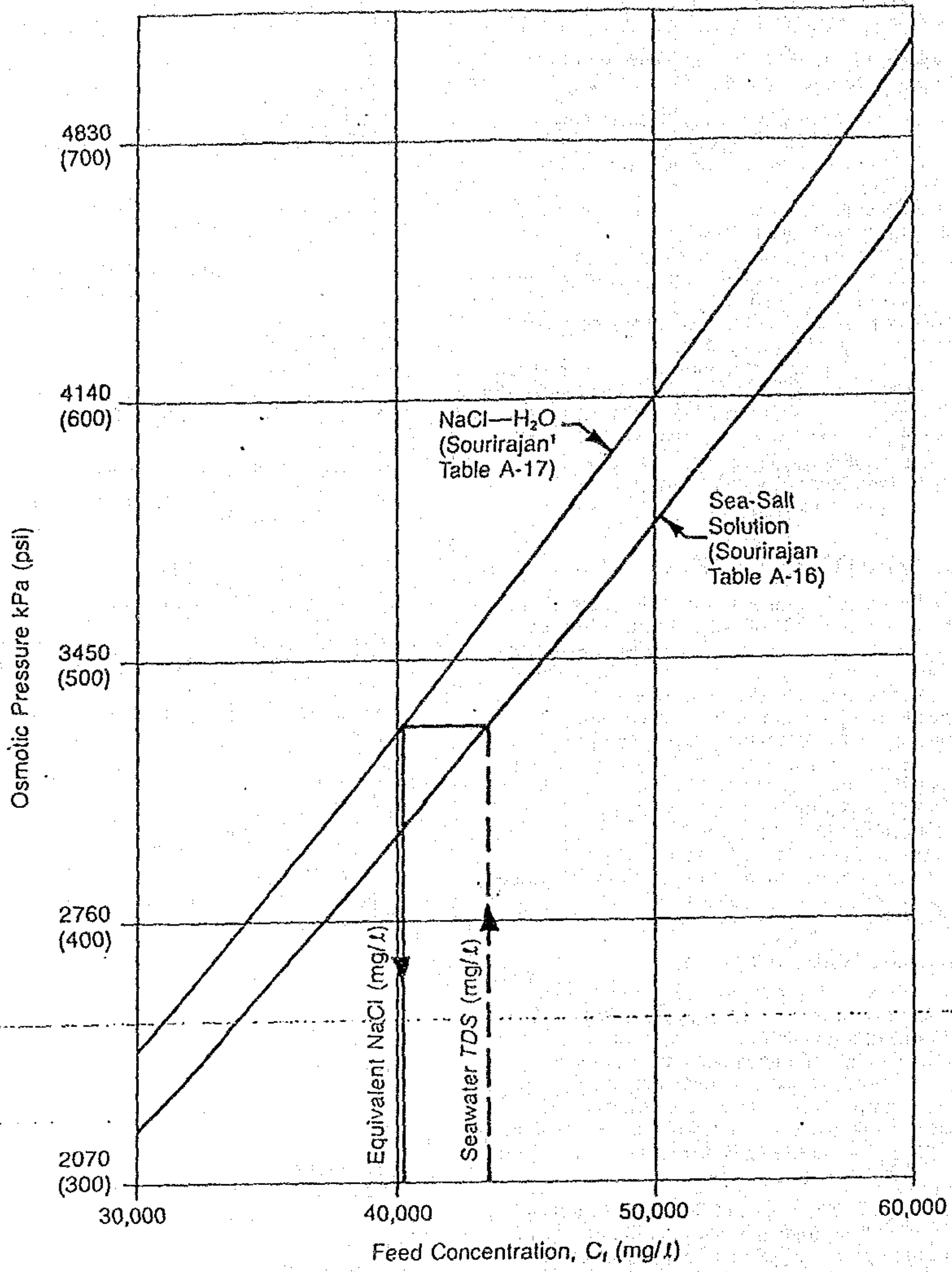
A graphical approach can be used for estimating purposes only. This approach does not consider the effect of mixed ion passage, particularly HCO_3^-.

This method may be used only for seawater. It is based on the premise that although the salinity of seawater varies, the relative ratios of the major ions remain nearly constant.

- Use Figure 5, Conversion of Seawater *TDS* (mg/ℓ) to Equivalent NaCl (mg/ℓ), to estimate the equivalent NaCl mg/ℓ of the given feed concentration. This equivalent NaCl concentration is used for feed concentration where required in the following graphs.

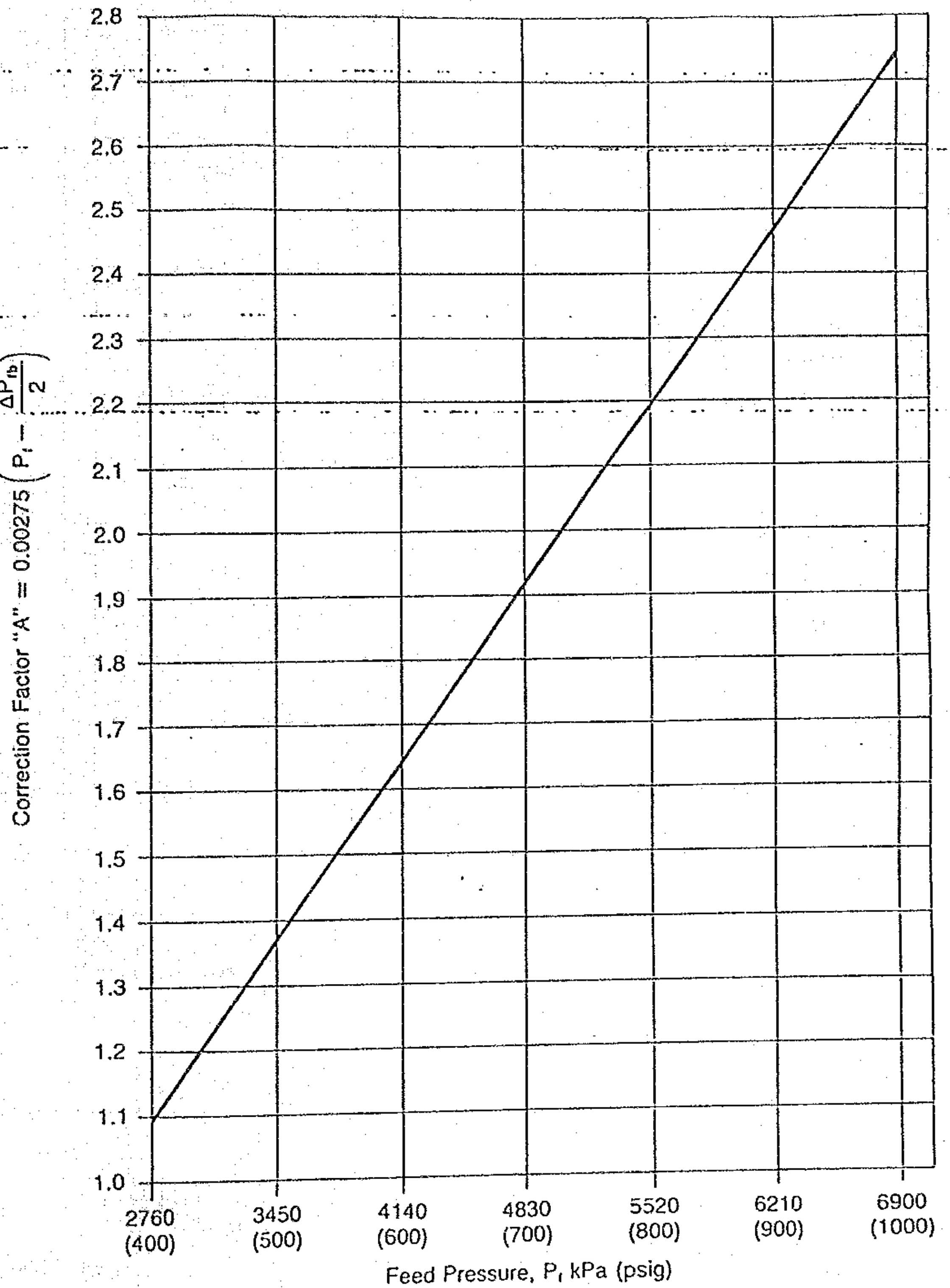
*Reg. U.S. Pat. & Tm. Off. for Du Pont's Permeators.

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



- Determine SPCF "F" from Figure 11, Salt Passage Correction Factor *F* for B-10.
- Determine SPCF "G" from Figure 12, Salt Passage Correction Factor *G* for B-10.
- Determine SPCF "H" from Figure 13, Salt Passage Correction Factor *H* for B-10.
- Determine SPCF "I" from Figure 14, Salt Passage Correction Factor *I* for B-10.
- Determine SPCF "J" from Figure 15, Salt Passage Correction Factor *J* for B-10.
- Determine SPCF "K" from Figure 16, Salt Passage Correction Factor *K* for B-10.
- After these factors have been determined apply Equation 15 to solve Estimated Salt Passage Correction Factor *($SPCF_E$)*.

Figure 6. Correction Factor "A" for B-10



$$SPCF_E = \frac{F}{[G - H - (I)(K)]}(J)(K) \qquad (15)$$

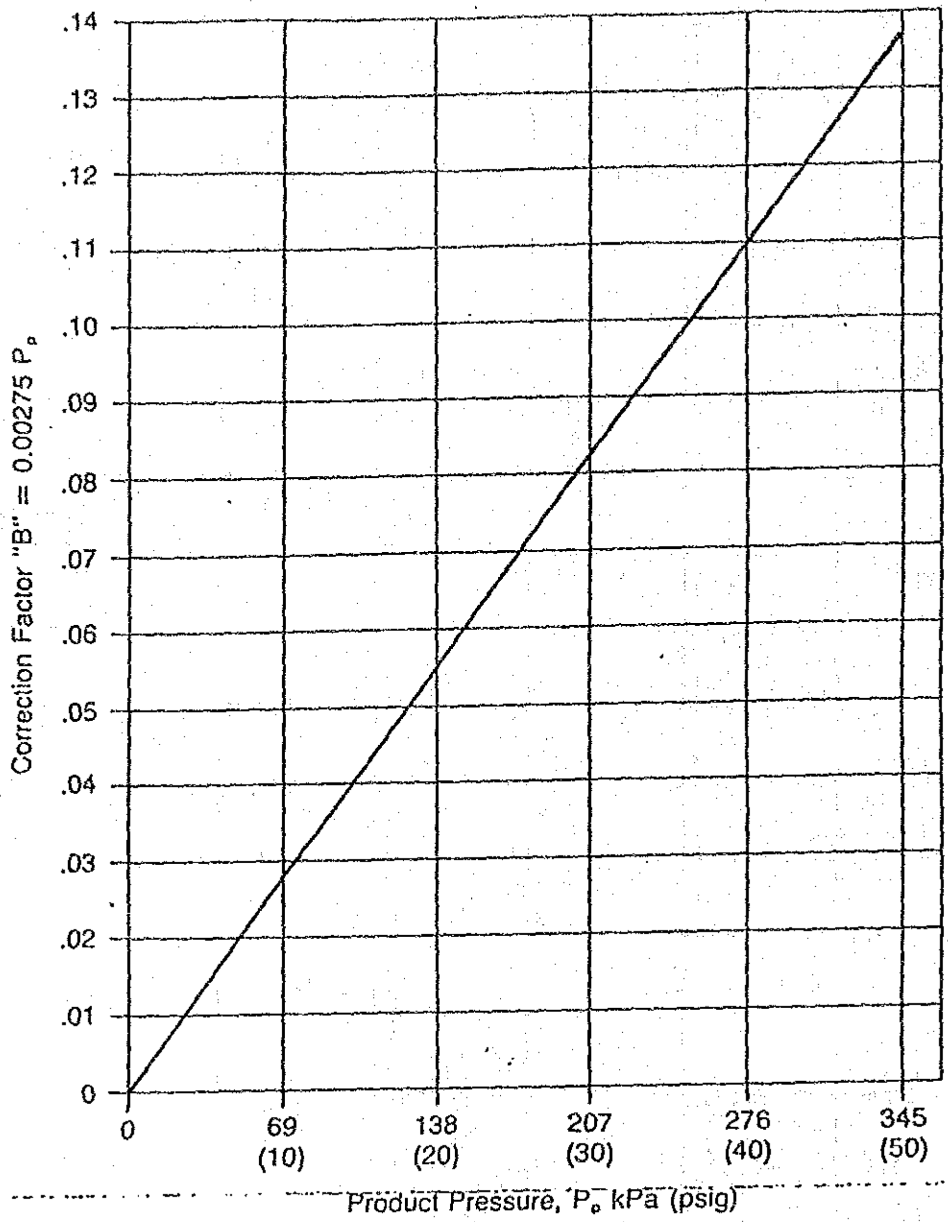
- Determine estimated product water *TDS* using Equation 16.

$$C_{pE} = 0.015(SPCF_E)TDS_f \qquad (16)$$

Where:
C_{pE} = estimated product water, mg/ℓ as ion
TDS_f = feedwater *TDS*, mg/ℓ as ion

Example:
Feedwater *TDS* = 34,500 mg/ℓ ion
Feed Pressure = 6,900 kPa (1,000 psig)

Figure 7. Correction Factor "B" for B-10



Minimum (design) Temperature = 25 degrees C (77 degrees F)
Maximum Temperature = 25 degrees C (77 degrees F)
Product Pressure = 10 psig
Conversion = 30 percent

- From Figure 5

  34,500 mg/ℓ ion = 31,500 mg/ℓ NaCl

- From Figure 11, "F" = 0.95
- From Figure 12, "G" = 2.70
- From Figure 13, "H" = 0.027
- From Figure 14, "I" = 1.23
- From Figure 15, "J" = 1.05
- From Figure 16, "K" = 1.00
- $$SPCF_E = \frac{F}{[G - H - (I)(K)]}(J)(K)$$

$$SPCF_E = \frac{0.95(1.05)(1.00)}{[2.70 - 0.027 - (1.23)(1.00)]} = 0.691$$

- $C_{pE} = 0.015\ (SPCF_E)TDS_f$

$C_{pE} = 0.015(0.691)(34,500) = 358$ mg/ℓ as ion

REFERENCE

1. Sourirajan, S., *Reverse Osmosis*, Academic Press, New York, 1970.

Figure 8. Correction Factor "C" for B-10

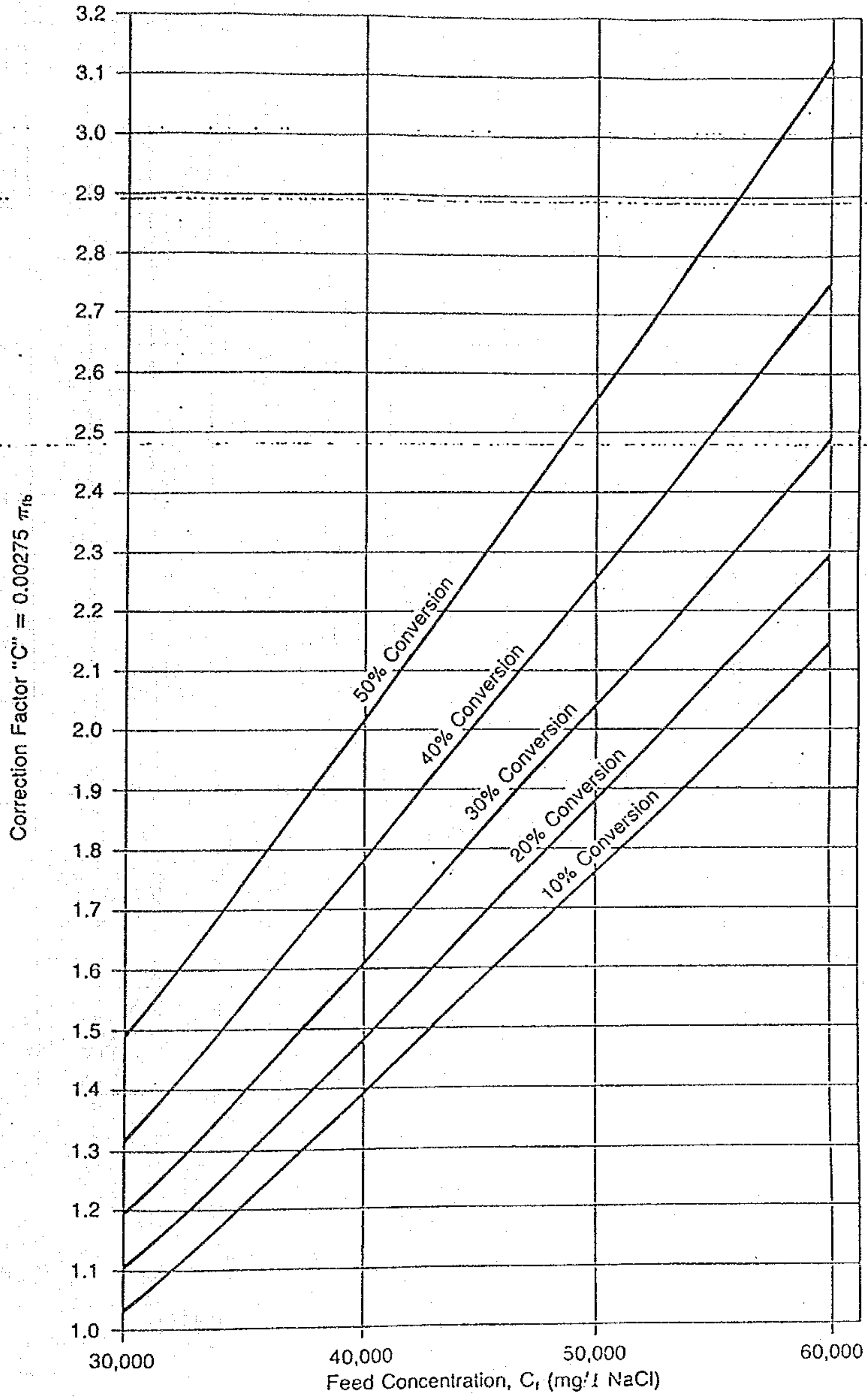


Figure 9. Correction Factor "D" for B-10

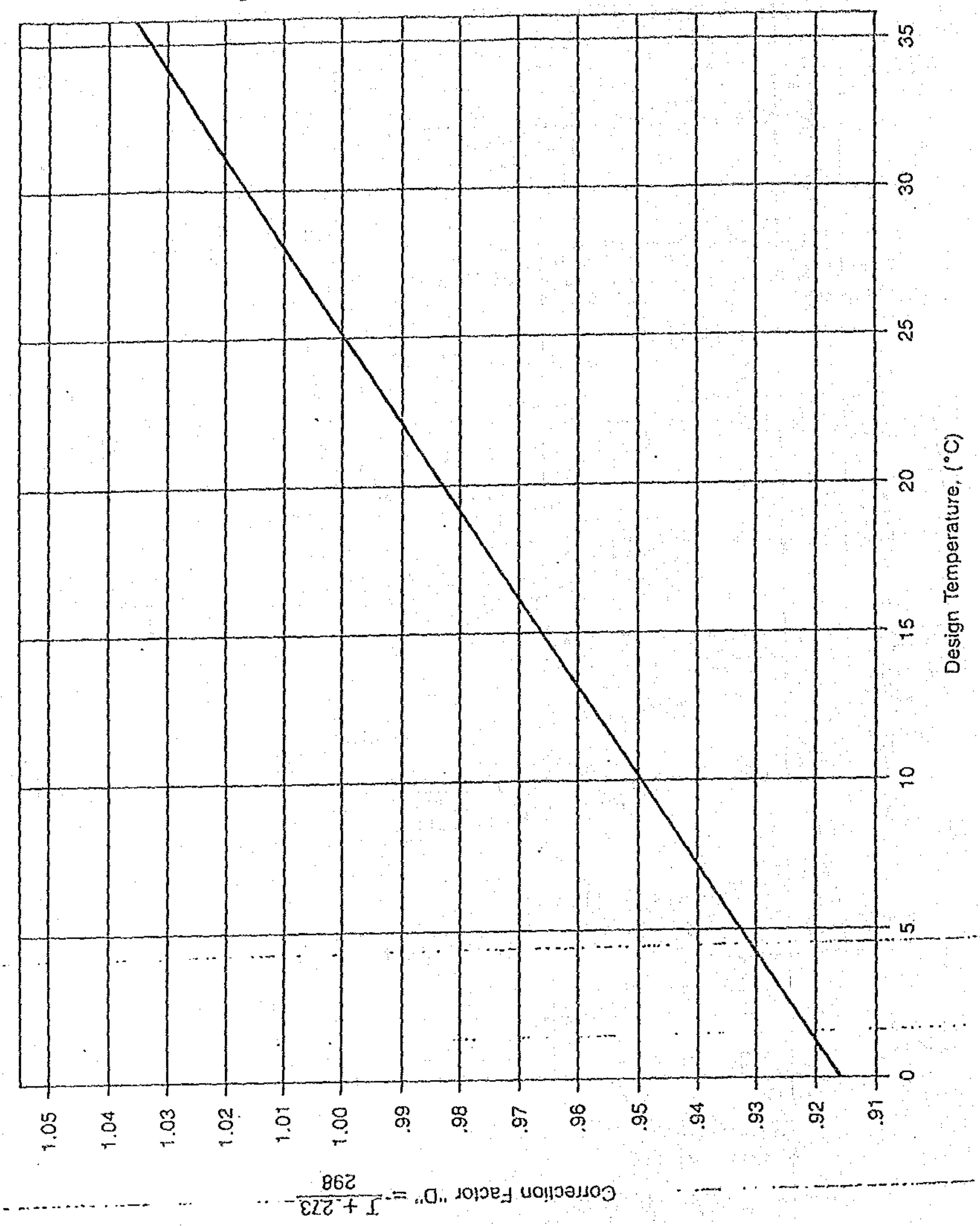


Figure 10. Correction Factor "E" for B-10

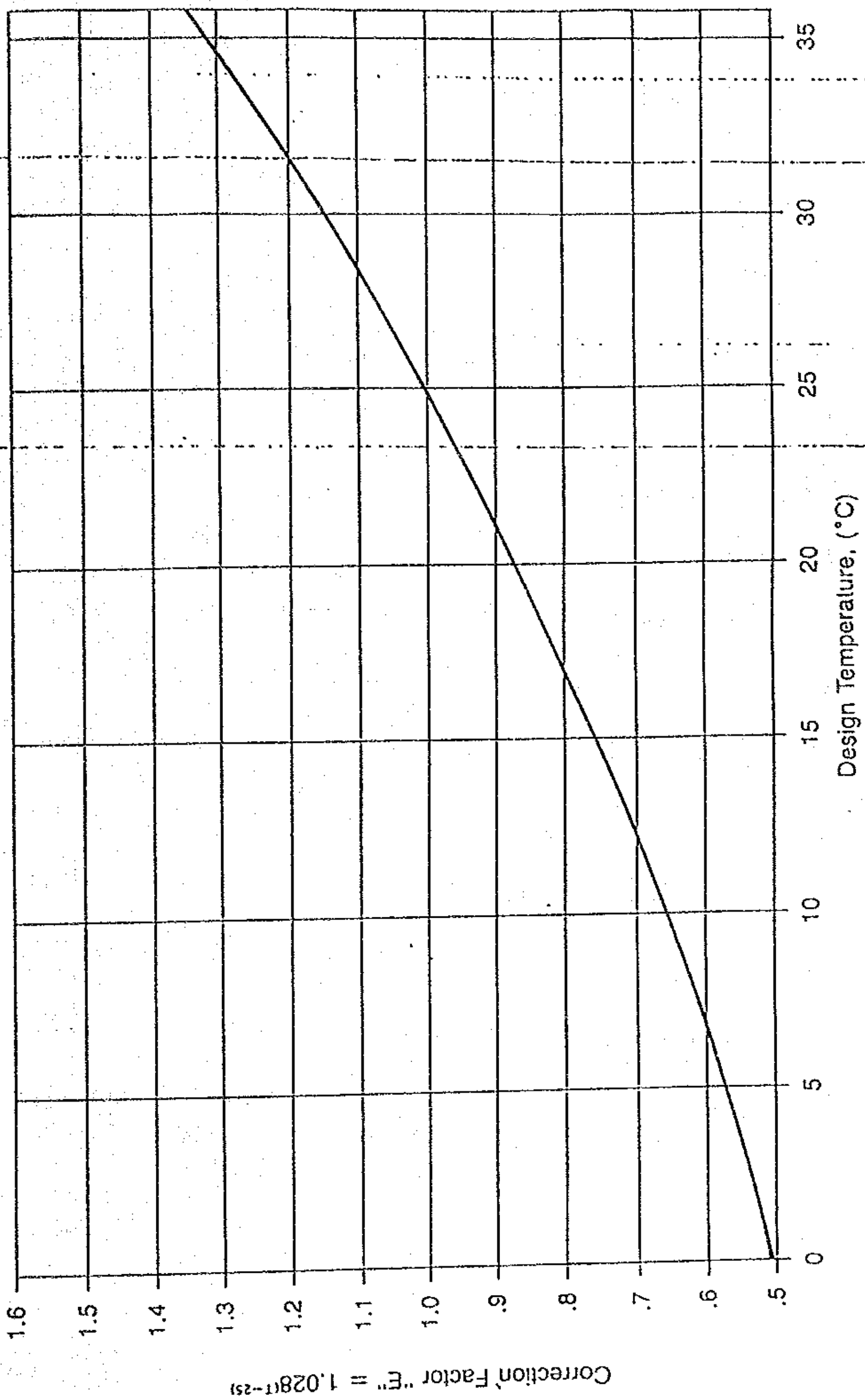


Figure 11. Salt Passage Correction Factor "F" for B-10

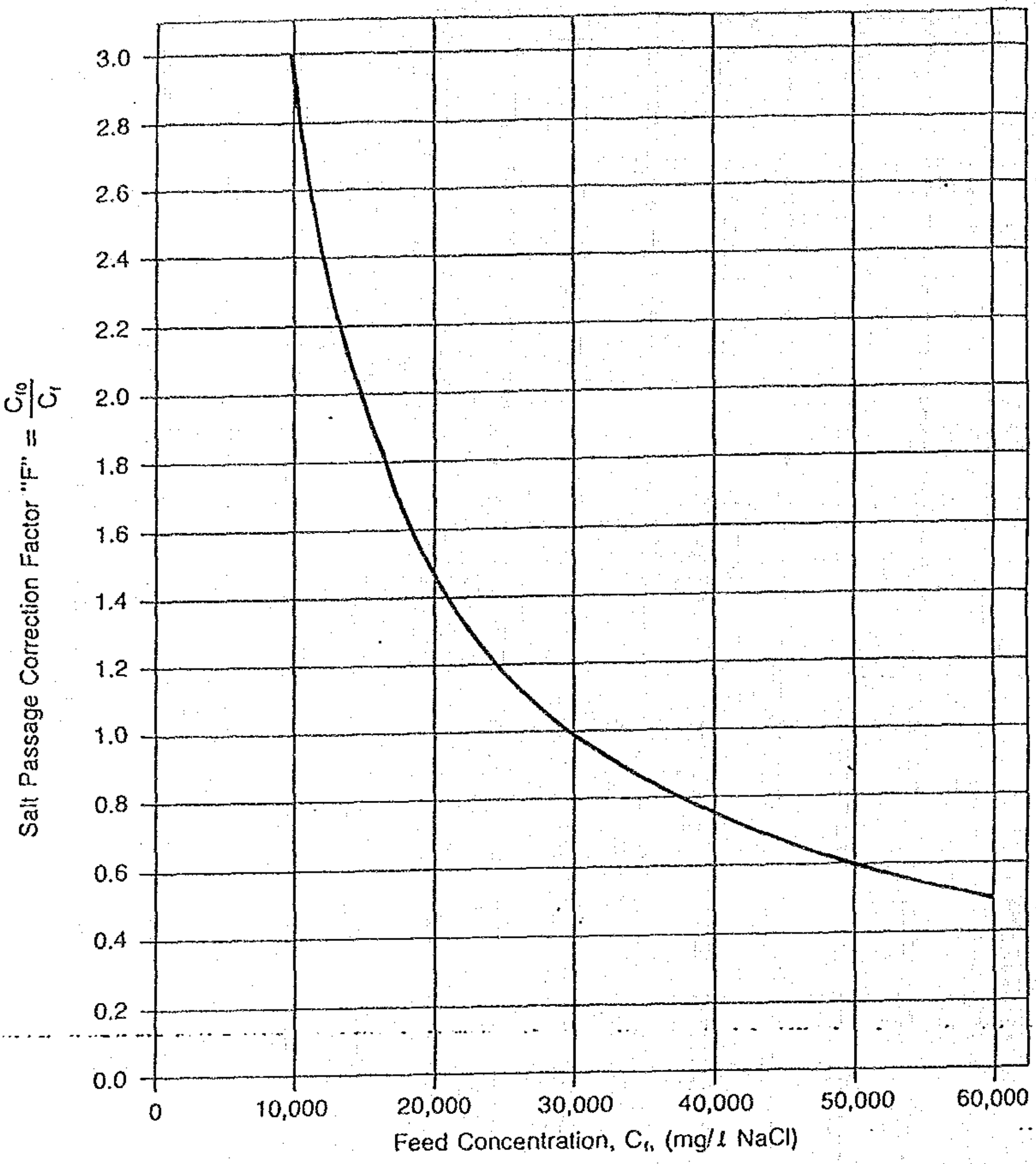


Figure 12. Salt Passage Correction Factor "G" for B-10

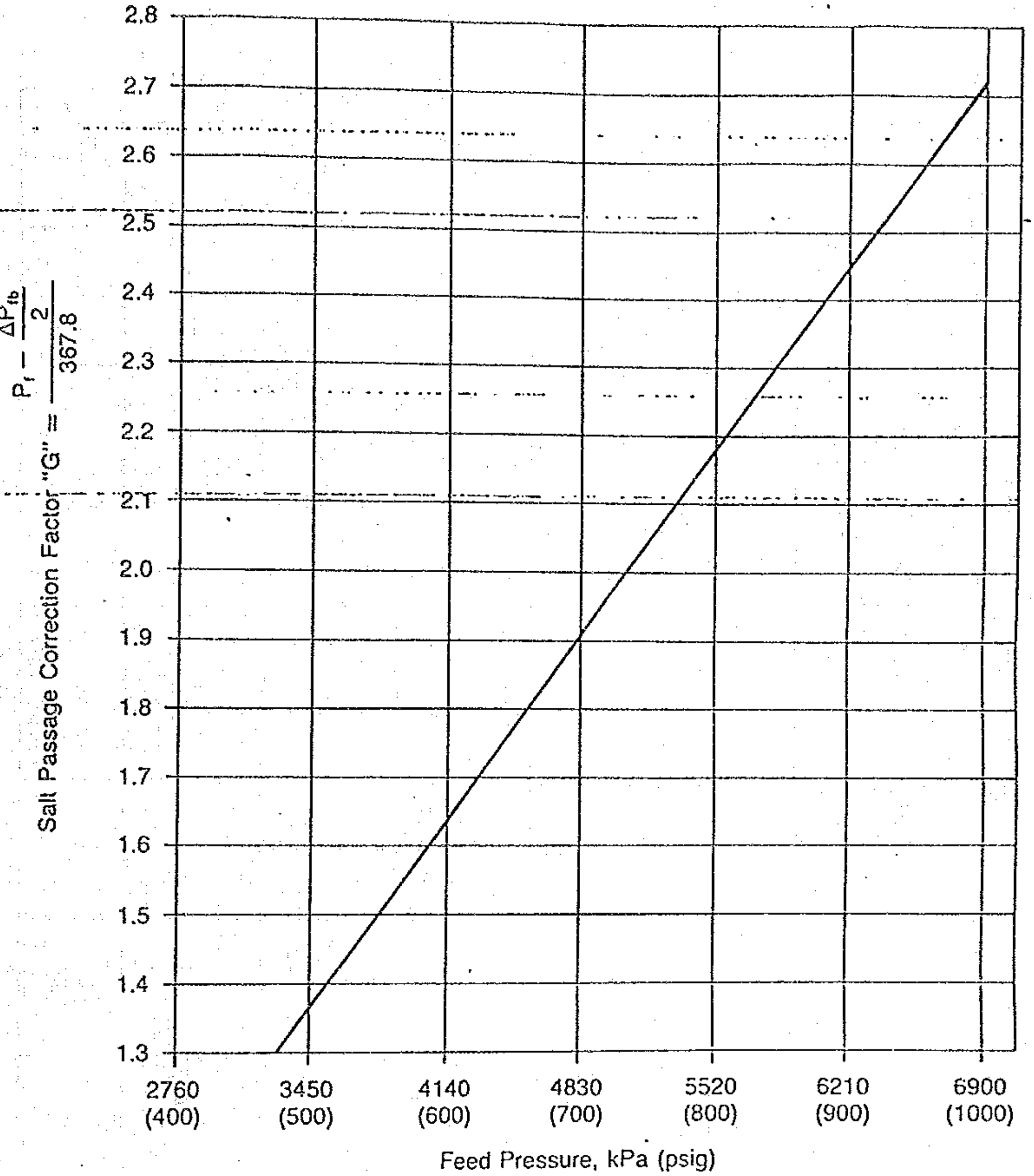


Figure 13. Salt Passage Correction Factor "H" for B-10

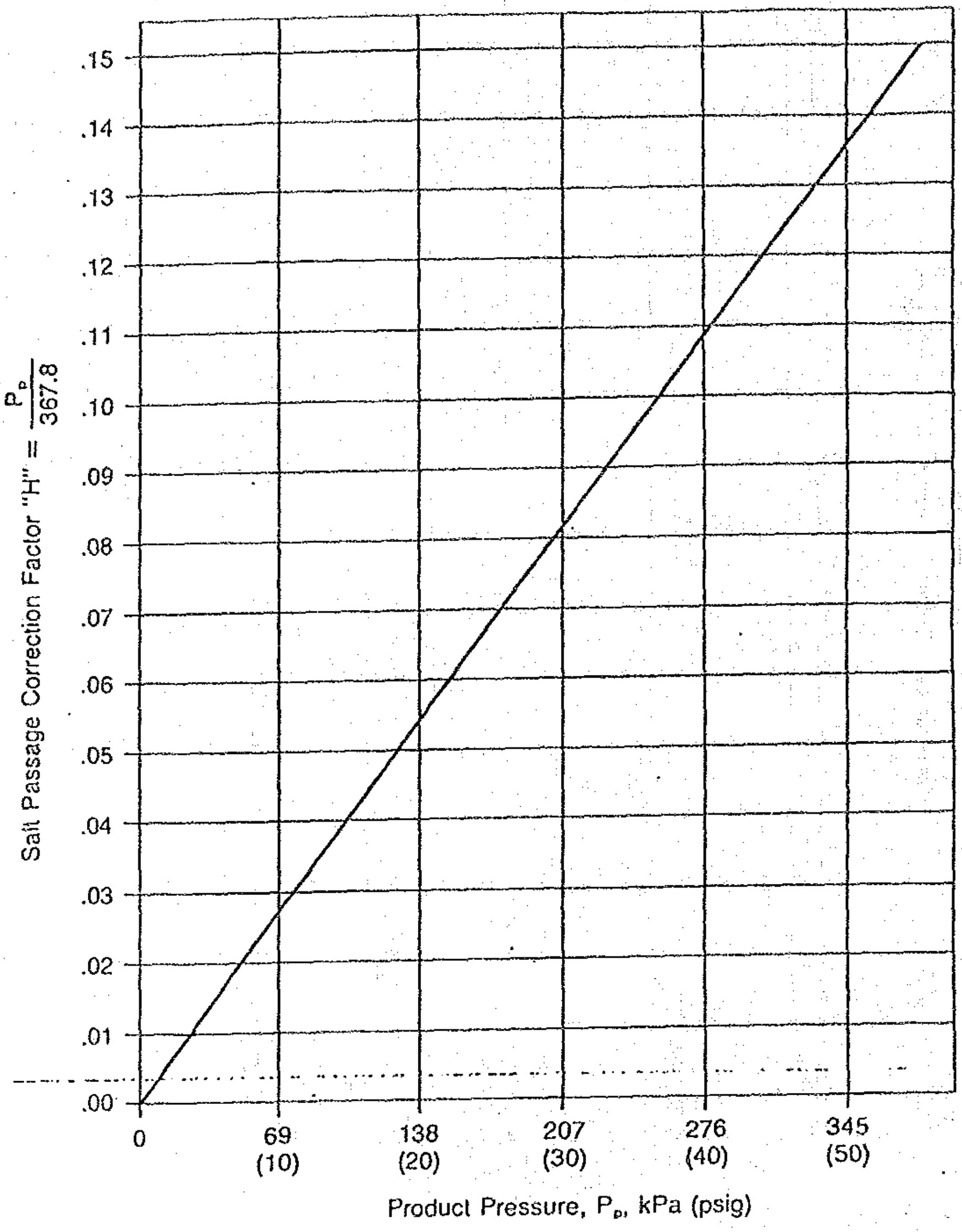


Figure 14. Salt Passage Correction Factor "I" for B-10