6. APPENDIX for R4 (Selection of Membrane)

APPENDIX R4-1 Miscellancous Brochures of Membrane Manufacturer 6-1

APPENDIX R4-1

APPENDIX R4-1 Miscellaneous Brochures of Membrane Manufacturer

PERMASEP PRODUCTS SERVING THE WORLD

PERMASEP*

Reverse Osmosis Products

AUGUST, 1991

GENERAL GUIDE TO PRODUCTS AND PROPERTIES

A leader in reverse osmosis water desalination, Du Pont's "Permasep" products were commercialized in 1969. Since that time, they have been used in thousands of installations in dozens of countries around the world for desalination of brackish water and seawater. Over one billion gallons per day capacity (over 4 million cubic meters per day) of "Permasep" products have been purchased since commercialization, well over 20 years ago.

*Du Pont's registered trademark for its reverse osmosis products.

Start with DuPont

DUPONT

RO MEMBRANE LEADERSHIP

Today, Du Pont's Permasep®* Products are the established worldwide leader in RO desalination of brackish water and seawater with more installed capacity† than any other membrane supplier. The lead is even more dramatic in demanding seawater applications with installed capacity† more than twice the nearest competitor.

Underlying this wide acceptance of "Permasep" products is Du Pont's pioneering work more than 20 years ago to develop long-lasting membrane products and applications technology which enables qualified systems suppliers and end-users to ensure successful RO plant operations. End-users can draw upon patented and proprietary Du Pont products and technology through qualified suppliers (Licensees) of complete desalination systems using "Permasep".

WIDE ACCEPTANCE OF "PERMASEP" PRODUCTS:

Water treatment systems incorporating "Permasep" products are used in a broad spectrum of potable, industrial and specialty water desalination applications. Thousands of installations using "Permasep" products are currently operating throughout the world, producing millions of cubic meters of purified water daily. Although only a representative few are shown in this brochure, they do illustrate how

PRODUCT TYPES & USE

"Permasep" products come in two product types, according to the type of water to be treated. Product specifications for all models available in these two types appear on page three.

Seawater & High Brackish	**B-10**	A hollow fine fiber, aramid membrane permeator designed for seawater and high brackish applications where long membrane life is needed. Replacement bundles are also available.
Brackish	**B-9**	A hollow fine fiber, aramid membrane permeator designed primarily for brackish water applications where long membrane life is needed. Replacement bundles are also available.

"Permasep" products have been used to desalinate water economically, including demanding Arabian Gulf seawaters.

POTABLE APPLICATIONS

Reverse osmosis systems based on "Permasep" products are producing drinking-quality water for:

- Municipalities, cities and towns
- Island communities
- Realty developments
- Mobile home parks
- Resorts, hotels and motels
- Offshore drilling and production platforms

INDUSTRIAL APPLICATIONS

"Permasep" products are used by industrial firms to purify water for:

- Rinsing electronic components
- Boiler makeup
- Process water
- High purity water for
  - formulations
  - rinsing and cleaning metals
  - polymerization reactions

SPECIAL APPLICATIONS

Besides purifying water for municipal systems and industrial operations, our customers use "Permasep" products to desalinate water for a great variety of special end uses:

- Water-dispensing equipment
- Car washes
- Small cooling towers
- Humidifiers
- Flower growing
- Ice rinks
- Water treatment for hemodialysis
- Ice manufacture
- Fish culture
- Hydroponic gardening
- Restaurants
- Campgrounds
- Central home systems
- Yachts, ships

†1990 International Desalination Association Worldwide Desalting Plants Inventory Report No. 11

*Du Pont's registered trademark for its reverse osmosis products

PRODUCT SPECIFICATIONS FOR PERMASEP* PERMEATORS AND REPLACEMENT BUNDLES

APPLICATION	SEAWATER				BRACKISH						
PRODUCT TYPE	B-10[1,2]				B-9						
MODEL NO.	6410T	6440T	6845T	6845TR	0410	0420	0440	0840	0840R	0040	0040R
PHYSICAL CHARACTERISTICS											
MEMBRANE TYPE	ARAMID				ARAMID						
MEMBRANE CONFIGURATION	Hollow Fine Fiber				Hollow Fine Fiber						
DIAMETER, NOMINAL, cm (in)	11.7 (5)	11.7 (5)	21.6 (8)	21.6 (8)	10.2 (4)	10.2 (4)	10.2 (4)	20.3 (8)	20.3 (8)	25.4 (10)	25.4 (10)
APPROX. LENGTH[3], cm (in)	58 (23)	126 (50)	150 (59)	150 (59)[2]	43 (17)	64 (25)	119 (47)	122 (48)	89 (35)[2]	135 (53)	89 (35)[2]
APPROX. SHIPPING WEIGHT kg (lb)	10 (22)	32 (70)	122 (270)	30 (66)	7 (15)	11 (25)	23 (50)	66 (145)	34 (75)	113 (250)	53 (117)
CONNECTIONS–FEMALE NPT FEED	1/2"	1/2"	3/4"	NA	1/2"	1/2"	1/2"	3/4"	NA	1-1/2"	NA
PRODUCT	1/2"	1/2"	3/4"	NA	1/2"	1/2"	1/2"	3/4"	NA	1"	NA
BRINE	3/8"	3/8"	3/4"	NA	3/8"	3/8"	3/8"	3/4"	NA	1"	NA
SAMPLE	1/8"	1/8"	3/8"	NA	1/8"	1/8"	1/8"	3/8"	NA	3/8"	NA
OPERATING SPECIFICATIONS											
PRODUCT WATER CAPACITY m^3/day (GPD) Nominal[4]	2.46 (650)	6.81 (1800)	26.5 (7000)	26.5 (7000)	5.30 (1400)	9.08 (2400)	15.90 (4200)	60.57 (16,000)	60.57 (16,000)	94.64 (25,000)	94.64 (25,000)
RANGE	2.09/2.83 (552/747)	5.80/7.80 (1500/2100)	22.52/30.48 (5950/8050)	22.52/30.48 (5950/8050)	4.77/6.09 (1260/1540)	8.18/10.22 (2160/2640)	14.31/18.17 (3780/4620)	54.51/66.62 (14,400/17,600)	54.51/66.62 (14,400/17,600)	85.17/104.10 (22,500/27,500)	85.17/104.10 (22,500/27,500)
SALT REJECTION (%) Nominal[4]	99.2	99.2	99.2	99.2	94	94	92	92	92	92	92
MINIMUM	98.7	98.7	98.7	98.7	90	90	90	90	90	90	90
OPERATING PRESSURE RANGE KPa (psig)	(5515-8274) 800-1200				2415-2760 (350-400)						
OPERATING TEMPERATURE RANGE °C (°F)	0-40 (32-104)				0-40 (32-104)						
pH RANGE, CONTINUOUS EXPOSURE	4-9				4-11						
BRINE RATE, l/min (gpm) MAXIMUM	9.9 (2.6)	39.4 (10.4)	105.2 (27.8)	105.2 (27.8)	6.4 (1.7)	12.5 (3.3)	25.4 (6.7)	65.9 (17.4)	65.9 (17.4)	106.0 (28.0)	106.0 (28.0)
MINIMUM SEAWATER	1.1 (0.3)	5.3 (1.4)	15.9 (4.2)	15.9 (4.2)	NA	NA	NA	NA	NA	NA	NA
HIGH BRACKISH	2.3 (0.6)	8.3 (2.2)	26.5 (7.0)	26.5 (7.0)	NA	NA	NA	NA	NA	NA	NA
BRACKISH	NA	NA	NA	NA	2.3 (0.6)	4.2 (1.1)	8.3 (2.2)	26.5 (7.0)	26.5 (7.0)	43.5 (11.5)	43.5 (11.5)
STANDARD CONDITIONS											
FEED, mg/l NaCl	35,000				1,500						
PRESSURE, KPa (psig)	6895 (1000)				2760 (400)						
TEMPERATURE °C (°F)	25 (77)				25 (77)						
CONVERSION %	35				75						

*Du Pont's registered trademark for its reverse osmosis products.
NA = Not applicable

[1]Seawater and High Brackish applications
[2]All B-10 permeators are also available on special orders as "TA" models, i.e. B-10T bundles equipped with shell assemblies rated for 1000 psig
[3]Bundle length without shipping container
[4]Nominal values are for design purposes

FIELD-PROVEN COST-EFFECTIVE PERFORMANCE

World-class, performance-proven desalination technology can be found in Du Pont's unique Hollow-Fine-Fiber "Permasep" permeator and Aramid polymer membrane:

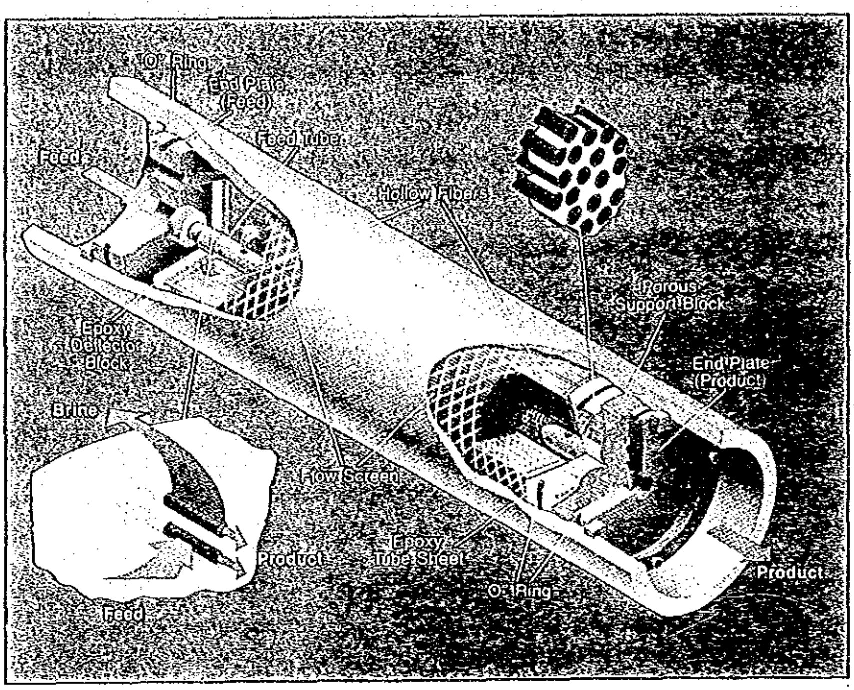
Compact and Rugged Permeator Designs

Shipped as rugged, high-quality RO devices, the self-contained membrane in each B-9 and B-10 "Permasep" permeator comes ready for "on-specification" start-up, even after years of storage. Permeators require minimum space, are easy to install in RO systems, and easy to operate and maintain. Superior quality and mechanical durability have been demonstrated through shipment and start-up in even the most remote sites. Outstanding long-term operation has been demonstrated under demanding conditions in the world's largest RO plants. And with progress to higher operating pressures in seawater desalination, more cost-effective performance is provided at higher conversions.

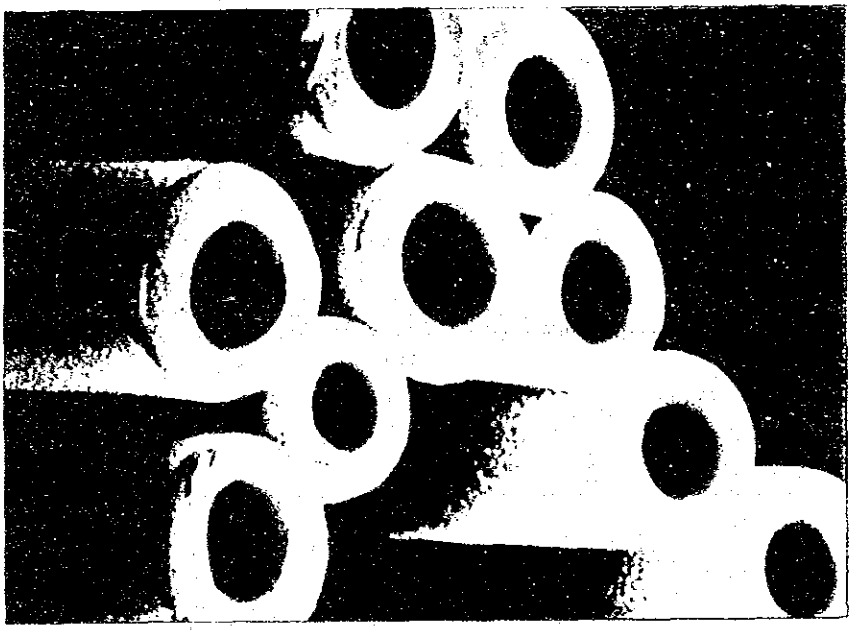
Tough Aramid Polymer Membrane

The Hollow-Fine-Fiber membranes in "Permasep" permeators are made of a tough, highly stable Aramid polymer and behave like durable, thick-walled pipes under pressure. Invented by Du Pont and commercially available for more than 20 years, these homogeneous membranes have the longest intrinsic life of any RO membrane, as demonstrated by very low replacement rates and very low cost-in-service. In seawater desalination systems, Du Pont offers additional technology to ensure consistent high salt rejection even under the most demanding high salinity and high temperature conditions of the Arabian Gulf, including surface water intakes.

*Du Pont's registered trademark for its reverse osmosis products.



B-9 and B-10 Hollow-Fine-Fiber "Permasep" Permeators



Tough Aramid Polymer Membrane (photomicrograph)

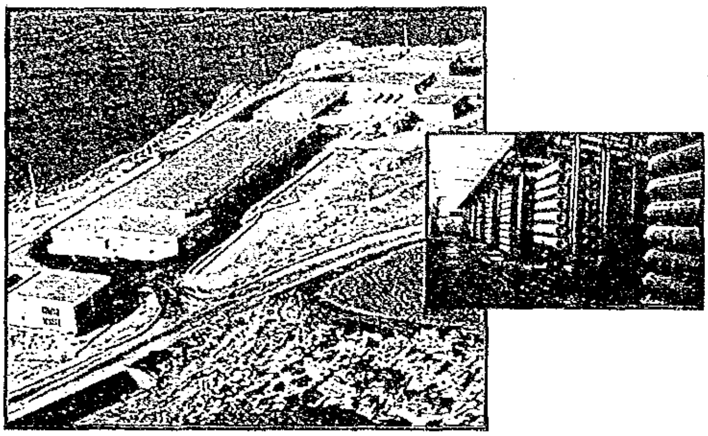
LARGE PLANT EXPERIENCE

1. This 24,000 m³/day (6.3 million GPD) seawater plant at Ghar-Lapsi, Island of Malta uses B-10 "Permasep" permeators. The total B-10 seawater desalination capacity installed on Malta is now 80,000 m³/d (21 million GPD) and provides 60% of the island's total water needs.

2. "Permasep" B-10 permeators produce 46,000 m³/day (12.2 million GPD) of fresh water at one of the world's largest RO plants at Ras Abu Jarjur, Bahrain.

3. Sarasota, Florida, U.S.A., 17,000 m³/day (4.5 million GPD) plant uses B-9 "Permasep" permeators to desalt brackish water.

4. This B-10 mobile unit, one of the largest of its kind, produces 480 m³/day (125 thousand GPD), or more, of drinking water from seawater, or lower salinity feeds.



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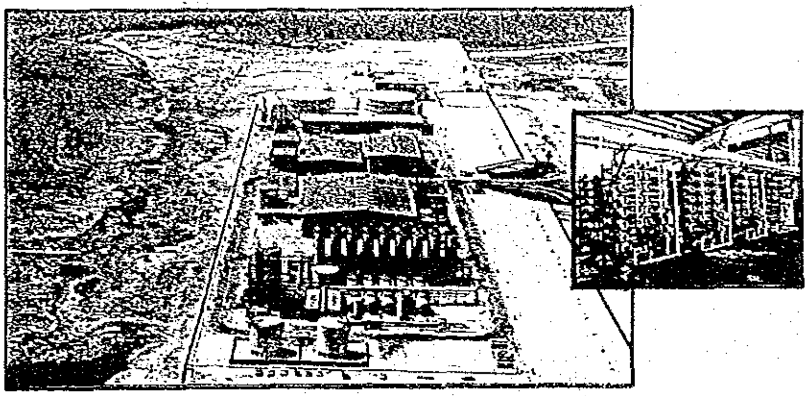

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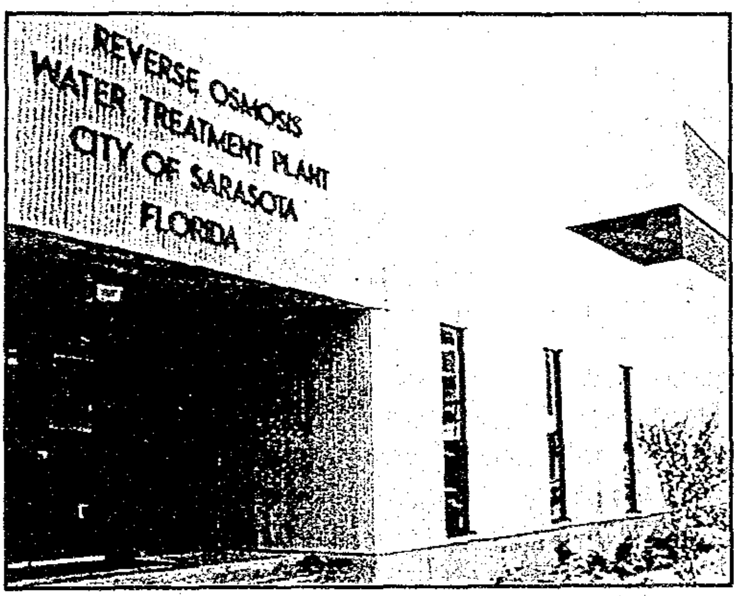

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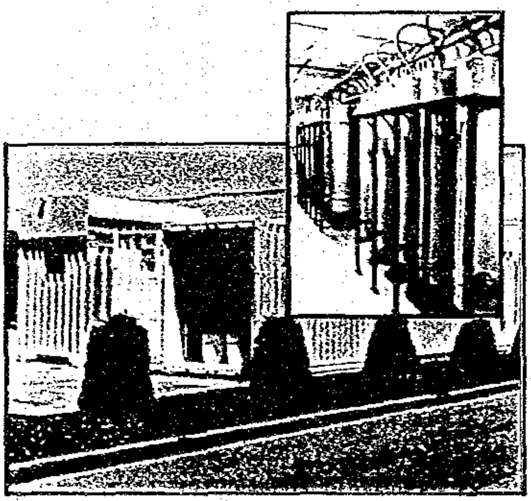

4.

WORLDWIDE OFFICES

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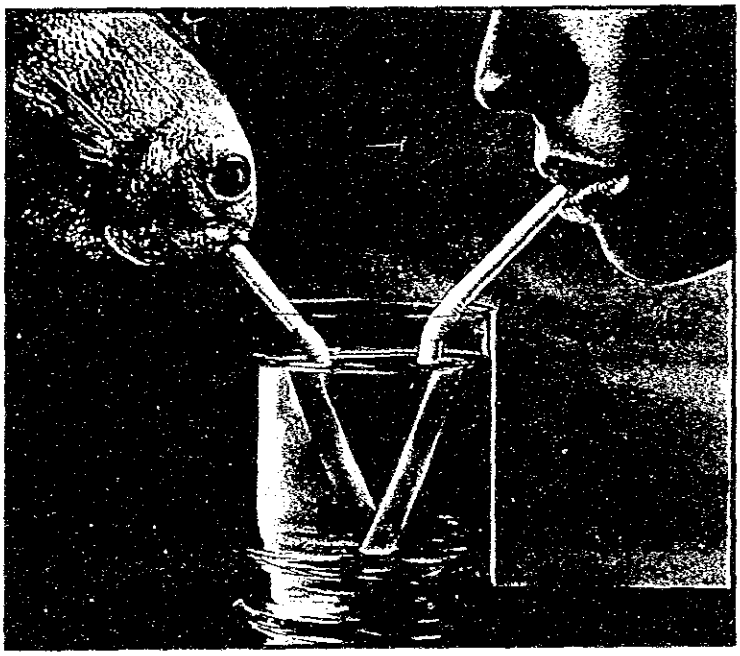
† Headquarters for Americas and Asia Pacific

†† Headquarters for Europe, Middle East and Africa

*Du Pont's registered trademark for its reverse osmosis products.



You Don't Have to be a Fish to Drink Seawater.

Start with Du Pont

DU PONT

H-19637 7/91

Printed in USA

AMH - GENERAL
Fouling

WATER SCIENCES & TECHNOLOGY ASSOCIATION, BAHRAIN
REVERSE OSMOSIS DESALINATION TECGNOLOGY
TRAINING COURSE

TROUBLE SHOOTING AND PERFORMANCE EVALUATION OF R. O. PLANT.

MARCH, 1990

T. KANNARI
SR. PROCESS ENGINEER
SASAKURA ENGINEERING
OSAKA, JAPAN

TABLE 1 COMPARISON SHEET FOR VARIOUS RO MEMBRANE(SEA WATER USE)

MANUFACTURER	DUPONT	TOYOBO	FILMTEC	UOP	TORAY
MATERIAL	POLYAMIDE	CELULOSE TRI-ACETATE	POLYAMIDE	SYNTHTIC COMPOSIT	AROMATIC POLYAMIDE
TYPE	HOLLOW FIBER	HOLLOW FIBER	SPIRAL	SPIRAL	SPIRAL
MODEL NO	B-10 6840T	HM 9255FI	SW 30 HR 8040	TFC 2021 SS	SU-810
STD. CONDITION					
PRESSURE	56 KG/CM2	55 KG/CM2	55 KG/CM2	56 KG/CM2	56 KG/CM2
NACL	35000 PPM	35000 PPM	35000 PPM	32800 PPM	35000 PPM
CONVERSION	35 %	30 %	-- %	7 %	12 %
TEMPERATURE	25 °C	25 °C	25 °C	25 °C	25 °C
CAPACITY		For 2 element	For 1 element	For 1 element	For 1 element
NOMINAL	23+15% M3/D	35 M3/D	15.14+15% M3/D	15.14+15% M3/D	16 M3/D
MINIMUM	---	32 M3/D	---	---	14 M3/D
SALT REJECTION					
NOMINAL	99.2 %	99.4 %	99.5 %	---	99.4 %
MINIMUM	98.7 %	99.2 %	99.2 %	99.2 %	99.2 %
DIMENSION		For 2 elements	For 6 elements	For 6 elements	For 6 elements
DIAMETER	226 MM	360 MM	295 MM	330 MM	316 MM
LENGTH	1499 MM	2660 MM	6392 MM	6451 MM	6267 MM
WEIGHT	102 KG	310 KG	290 KG	472 KG	477 KG
MAX. OPERATING PRESS.	84 KG/CM2	70 KG/CM2	70 KG/CM2	70 KG/CM2	70 KG/CM2
MAX. TEMPERATURE	40 °C	40 °C	45 °C	45 °C	45 °C
MAX. SDI	3	4	5	(0.52 NTU)	4
PH RANGE					
MAXIMUM	4	3	2	4	3
MINIMUM	9	8	11	11	9

R4

REVERSE OSMOSIS

PART I: CLASSIFICATION OF COMMERCIALLY AVAILABLE RO MEMBRANES

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This is the first of a two-part series on the fundamentals of reverse osmosis. The second part, dealing with system designs incorporating RO, will appear in the May/June 1986 issue of this journal.

Reverse osmosis is a separation process to remove dissolved impurities from liquids. During the past fifteen years, reverse osmosis has been used for industrial water purification both as a stand-alone process and in combination with other processes. The heart of the reverse osmosis process is the semipermeable membrane. This article will describe the reverse osmosis process and the development of membrane technology, and will compare the commercially available reverse osmosis membrane elements for brackish water (total dissolved solids less than 5,000 mg/l) applications. The term "membrane element" will be utilized throughout the paper to describe the spiral-wound membrane modules as well as hollow-fiber permeators.

History of Reverse Osmosis

Osmosis is the spontaneous passage of a liquid from a dilute to a more concentrated solution across an ideal semipermeable membrane that allows passage of the liquid but not of the dissolved solids. It is a simple dilution operation that continually occurs in nature. The word "osmosis" comes from the Greek word "osmos," meaning "to push." Obviously, reverse osmosis is a process in which the natural osmotic flow is reversed by the application of external pressure on the concentrated solution side of the membrane.

The history of osmotic phenomenon dates back more than 200 years, when it was first noted that water would diffuse through an animal bladder (membrane) into alcohol spontaneously. The interest in osmosis processes was hampered by the unreliability of animal membranes until 1864, when a synthetic selective membrane was prepared from copper ferrocyanide. Studies with this membrane linked osmotic pressure with temperature and solute concentration. This data resulted later in a mathematical relationship for osmotic pressure. Again, interest in the osmosis process declined because reliable membranes were not available.

In the 1950s, amid predictions of water scarcity, the US Department of Interior established the Office of Saline Water (OSW) to evaluate water purification methods. Reverse osmosis was attractive because of its simplicity and low energy requirements. All that was needed was a strong, reliable, economical, and selective membrane.

In 1958, Professor Reid at the University of Florida suggested seeking a suitable membrane from commercially available films. Professors Reid and Breton demonstrated that secondary cellulose acetate (CA), one of the first plastic films manufactured in this country, had the desired selectivity. However, cellulose acetate dense film had disappointingly low water transport and a very short productive life. In the early 1960s, Professors Loeb and Sourirajan, working on a similar project at the University of California, Los Angeles, enhanced the water flux of cellulose acetate membranes prepared in an asymmetric configuration, and substantially extended their usefulness by heat-treating the film and adding swelling agents to the casting formulation. This work demonstrated that the technology necessary to purify water by reverse osmosis was in hand. From this point on, the major advances have been in the development, engineering, and marketing of reverse osmosis membranes and systems.

"The heart of the reverse osmosis process is the semipermeable membrane."

The fundamental research in reverse osmosis membranes, primarily made of cellulose acetate materials, was funded heavily by the Office of Saline Water in the 1960s. Besides the academic institutions, General Atomic Division of General Dynamics (later of Gulf Oil Corporation), San Diego, was one of the primary industrial organizations involved in the development of this technology in spiral-wound configuration. The term ROGA (Reverse Osmosis General Atomic) originated from this industrial concern. The membrane development program with cellulose acetate materials continued at General Atomic throughout the 1960s and early 1970s.

The cellulose acetate membranes suffered from several significant disadvantages: susceptibility to biological attack, loss of flux due to compaction phenomena at high pressure and high temperature, damage at high operating pH, and the limitation in obtaining higher membrane fluxes while maintaining high salt rejection. The latter requirement was necessary for application of reverse osmosis in the purification of seawater. Several companies had developed membranes made of cellulose acetate blends which have improved salt rejection and greatly improved water fluxes, but the problems of chemical and biological stability still remained.

In the meantime, parallel research was being conducted with configurations other than flat films at DuPont and Dow Chemical. In 1969 DuPont, using aromatic polyamide materials, and later Dow Chemical, using cellulose triacetate materials, developed hollow-fiber membranes. The polyamide membranes were less susceptible to biological and chemical attack, but were degraded by chlorine. The development of the hollow-fiber configuration permitted a very large membrane area per unit volume, which resulted in the compactness of the reverse osmosis systems.

More funding was needed to improve the cellulose acetate membranes and to explore other materials for better chemical stability and improved performance. The Office of Saline Water was dissolved in the mid 1970s (it was replaced by the Office of Water Research and Technology), and the government funding for this research was reduced considerably. The membrane research was conducted by private industry with selective government funding. A new

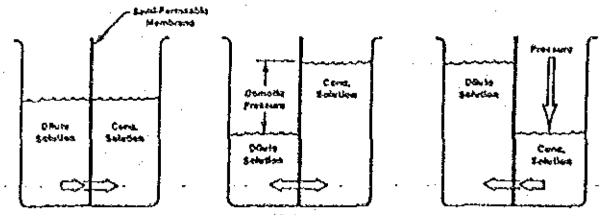

FIG. 1a Direct Osmosis — FIG. 1b Osmotic Equilibrium — FIG. 1c Reverse Osmosis

Mathematical Relationships for Osmotic Pressure

$$\pi = \frac{n}{V} RT$$

π = Osmotic Pressure, atm.

$\frac{n}{V}$ = Ionic Concentration, moles/liter

R = Proportionality Constant, 0.083, $\frac{\text{atm. liter}}{\text{moles °K}}$

T = Temperature, °K

Figure 1. Basics of reverse osmosis process.

class of membranes emerged from this research, the thin-film composites (TFC). This type of membrane offers several advantages over asymmetric membranes, such as the ability to individually optimize each layer of membrane for performance characteristics, the ability to utilize noncellulosic, nonbiodegradable compositions, the capability to achieve resistance to pH extremes, and the development of membrane-compositions serviceable at high pressures and temperatures. The composites provide high fluxes at moderate operating pressures, show good salt rejection, and have good chemical stability. Only one important problem remains to be solved: in common with all other noncellulosic membranes, the composites' resistance to chlorine in the feedwater is slight or modest at best.

Theory of Reverse Osmosis

Direct osmosis is depicted in Figure 1(a). Two solutions of different concentrations are separated by a semipermeable membrane in a container. Due to the difference in chemical concentration of the two solutions, the pure water will pass through the membrane from the dilute solution to the concentrated solution side. Figure 1(b) shows the osmotic equilibrium condition. In the osmotic equilibrium condition, equal amounts of water are passing to each side. The difference in the height of two solutions is the osmotic pressure difference between these particular solutions. The application of hydraulic pressure in Figure 1(c) offsets osmotic pressure and provides the driving force for reverse osmosis.

The osmotic pressure is proportional to the amount of dissolved substances in the solution and to the temperature of the solution. The osmotic pressure is completely independent of the membrane. The mathematical relationship for osmotic pressure can be expressed as shown in Figure 1. A precise determination of the osmotic pressure for most applications is usually unnecessary, as the pressure applied in reverse osmosis is usually many times the osmotic pressure. As as rule of thumb, the osmotic pressure can be estimated at 1 psig per 100 ppm of dissolved solids.

Two parameters are utilized for characterizing the performance of a reverse osmosis membrane: water flux (expressed as gal/day/membrane area) and salt rejection (expressed as a percentage of feed salinity). The water flux

TABLE A
Relative Performance of Cellulose Acetate and Thin-Film Composite Membranes

	CA	*TFC*
Temperature, °F	33-90	33-120
pH	4-6.5	2-12
Salt rejection	Good	Better
Organics rejection	Fair	Good
Biological stability	Fair	Good
Chlorine stability	Fair	Poor
Water flux	Good	Better

through a particular membrane is determined by its physical characteristics, properties of the solution being purified, and the applied pressure. For a given membrane and a feed solution, the flux simply becomes a function of the pressure differential across the membrane. Flux is also affected by feed temperature. Water permeability of the membrane increases about 1½% per °F Salt rejection is the ratio of solute rejected by a membrane to the solute in the feed. The ability of a membrane to reject salts is a function of membrane's permeability coefficient, and the difference between the salt concentration in the feed and the permeate. For a given membrane, the salt passage is independent of pressure.

The mechanism by which reverse osmosis occurs across a semipermeable membrane has been studied extensively. The transport of water across a membrane may be through pores physically present (sieve model) or by diffusion from one bonding site to another within the membrane (solution-diffusion model). Dissolved ions that do not hydrogen bond cannot enter into attachments with bonding sites and are left to concentrate on the membrane surface. Both the chemical and physical nature of a membrane determine its inherent ability to transport water and reject salts.

Membrane Configurations

The commercial development of reverse osmosis has closely paralleled improvements in membrane technology and membrane element design. There are three major membrane types on the market today: cellulose acetate, aromatic polyamides, and thin-film composites, as shown in Figure 2.

Cellulose acetate, with an established technology in casting films, has good selectivity, good availability of raw materials, and relatively low cost. Reverse osmosis membranes are cast from di-acetate or triacetate formulations. With increasing acetyl content, salt rejection improves and water flux declines. When cast as RO membranes, the cellulose acetate film is about 4 mils thick. *It* is *asymmetric:* that is, the film has a thin dense layer above a thick porous layer. The thin layer is the salt-rejecting surface, while the thick porous layer acts as a support layer (Figure 2a). These membranes have performed well during the past 15 years. The CA membranes are susceptible to biological attack, and have limited chemical and physical stability.

The second category of membrane, aromatic polyamide, was pioneered by DuPont. The membrane was spun in the unique form of a hollow, hairlike fiber with an outer diameter of about 85 microns and an inside diameter of about 42 microns. The fibers are assembled into a bundle, sealed at the ends, and installed in a pressure housing. This fiber became the cornerstone of DuPont's hollow fine fiber permeators. This fiber has an asymmetric structure (Figure 2b). The polyamide membrane has relatively better stability

Classification of RO Membranes

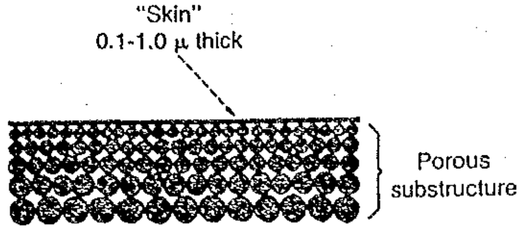

Figure 2a. Asymmetric membrane has a thin, dense skin and a porous substructure.

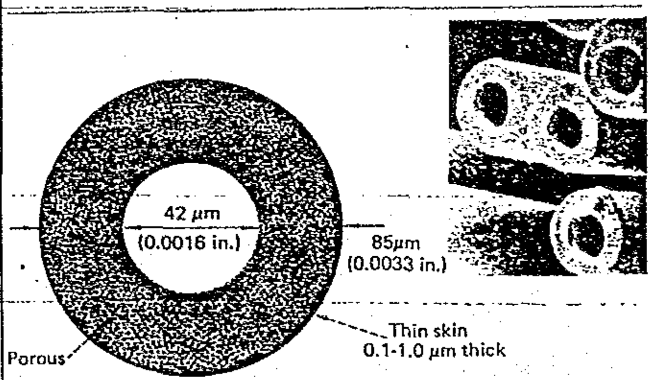

Figure 2b. Hollow fibers are formed from Aramid membrane.
Figures 2a-b excerpted by special permission from CHEMICAL ENGINEERING (June, 1984). Copyright© (1984), by McGraw-Hill, Inc., New York, NY 10020

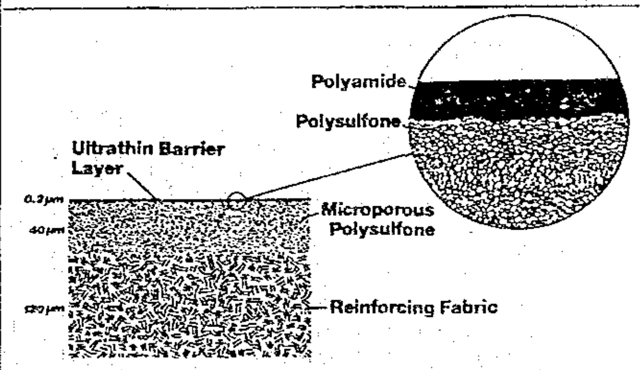

Figure 2c. Schematic cross-section of thin-film composite RO membrane. Source: FilmTec Corporation, Minneapolis, MN.

to chemical and biological attack compared to cellulose acetate, but is degraded by chlorine.

The third and most recent category of membranes, developed during the late 1970s and early 1980, is classified as thin-film composites. The major difference between the thin-film composite and the asymmetric membrane is that a microporous layer of polysulfone has been substituted for the porous cellulose acetate sublayer and an ultrathin barrier or rejecting layer (0.2 microns) of a polymer (polyurea, polyamide) has been formed on the surface of the microporous polysulfone by an *in situ* interfacial polymerization technique (Figure 2c). The major differences between various thin-film composite membranes on the market today are the thickness and composition of the barrier layer. These membranes offer excellent chemical and biological stability, while operating at modest pressures.(See Table A).

These three types of membranes have been incorporated in two predominant types of reverse osmosis devices: spiral

TABLE B

Membrane Element Manufacturers

Manufacturer	*Element type/material*
Desalination Systems, Inc. Escondido, CA	Cellulose acetate, Desal-1,2,3 Spiral wound Seawater, brackish water
DuPont Permasep Products Wilmington, DE	Polyamide, Cellulose acetate Hollow fine fiber, spiral wound Seawater, brackish water
FilmTec Corporation Minneapolis, MN (Div. of Dow Chemical)	FT-30, Cellulose triacetate Spiral wound-TFC, hollow fiber Seawater, brackish water
Hydranautics, Inc. Santa Barbara, CA (Div. of Rohm & Haas)	Cellulose acetate, Polyamide Spiral-wound Seawater, brackish water
Osmonics, Inc. Minnetonka, MN	Cellulose acetate, Polyamide Spiral wound Seawater, brackish water
Toray Industries (America), Inc New York, NY	Cellulose acetate, Polyether Spiral wound Seawater, brackish water
Millipore Corporation Bedford, MA	Product literature not available
Toyobo Membrane Division Japan	Cellulose acetate, Hollow fiber
Nitto Denko America, NY Santa Clara, CA	Product literature not available

wound and hollow fiber. The spiral-wound element was developed by ROGA systems in the mid 1960s under the sponsorship of OSW. The spiral-wound configuration consists of two layers of membranes separated by a woven fabric. The edges of the membrane are sealed on three sides and the fourth, open end is attached to a perforated central collection tube. A sheet of plastic netting, which separates membrane layers during assembly and promotes turbulence in the feed stream, is placed adjacent to the membrane. The membrane laminate is wrapped around the central tube to form a spiral configuration. The spiral-wound elements have high packing density and low manufacturing costs, and can be cleaned with relative ease.

The hollow-fiber design, developed by DuPont in 1969, offers extremely high packing density for membranes, resulting in compact systems. This concept was later used by Dow Chemical, using cellulose triacetate material. The hollow-fiber design, however, is more prone to fouling and is difficult to clean. There are applications for each type of membrane and membrane element based on the characteristics of feedwater. The trend will be to utilize the latest thin-film composite membranes, preferably in a spiral-wound configuration, for most industrial applications.

Membrane Element Manufacturers

The reverse osmosis membrane elements have been commercially available since 1969. The spiral-wound and hollow-fiber configurations are primarily used for industrial applications. Starting with the pioneering companies such as ROGA Systems, DuPont, and Dow Chemical, the membrane manufacturing industry has expanded in recent years,

TABLE C

Membrane Element Specification Criteria

A. Test conditions	
Water quality	2000 ppm NaCl-spiral wound 1500 ppm NaCl-Aramid hollow fiber
Water temperature	25°C (77°F)
Water recovery/element	10-15% spiral wound 50-75% hollow fiber
Applied pressure	225 psig thin-film composite 400psig hollow fiber 425 psig cellulose acetate
B. Performance specifications	
Water productivity	Initial average, minimum End-of-life values
Salt rejection	Initial average, minimum End-of-life values
C. Operating conditions	
Maximum operating pressure	600 psig—TFC, CA 400 psig—HFF
Maximum operating temperature	110°F—TFC 104°F—HFF,CA
Feedwater turbidity	1.0 NTU 3-5 SDI
Free-chlorine tolerance	0-5-1.0 ppm—CA <0.1 ppm—TFC/HFF
Feedwater pH	4.0-6.5—CA 2.0-11.0—TFC 4.0-11.0—HFF

TABLE D

RO Membrane Elements—CA, Polyamide

Manufacturer	*Size*	*Model No.*	*Productivity* Gal/day	*Salt rejection* %
Desalination Systems, Inc.	4"×40"	C4040FF	2100	96
	4"×40"	C4040DF	1400	98
	8"×40"	C8040FF	8000	96
	8"×40"	C8040DF	5400	98
Fluid Systems Division of UOP	4"×40"	4221SD	2000	95
	4"×40"	4221HR	1600	98
	4"×60"	4231SD Magnum	3250	95.
	4"×60"	4231HR Magnum	2650	98
	8"×40"	8221SD	8000	95
	8"×40"	8221HR	6300	98
	8"×60"	8231SD Magnum	13000	95.
	8"×60"	8231HR Magnum	10500	98
DuPont (C-1)	4"×40"	4440	2100	96
	4"×40"	4441	1700	98
	8"×40"	4840	8600	96
	8"×40"	4841	7000	98
DuPont (B-9)	4"×47"	0440	4200	90
	8"×48"	0840	16000	90
Hydranautics	4"×40"	4040-MSY-CAB1	2000	95
	4"×40"	4040-MSY-CAB2	1600	98
	8"×40"	8040-MSY-CAB1	8500	95
	8"×40"	8040-MSY-CAB2	6800	98
Toray	4"×40"	SC-2100	2320	95
	4"×40"	SC-6100	1400	98
	8"×40"	SC-2200	9280	95
	8"×40"	SC-6200	5840	98

offering a wide selection of element types and materials. The major manufacturers of membrane elements are listed in Table B.

Beginning with the acquisition of ROGA Systems by Universal Oil Products in 1976, the membrane industry has attracted other large chemical companies during the past couple of years (Ajax by DuPont, FilmTec by Dow Chemical, and Hydranautics by Rohm & Haas). This consolidation will help to provide the necessary research expenditures for continued developments in membrane technology.

Membrane Element Specification Criteria

The performance of a membrane element is characterized by its water productivity and salt rejection values for a given feedwater condition. All manufacturers provide this performance data in a similar format. The spiral-wound elements have been standardized in diameters of 4, 8, and 12 inches, with an overall length of 40 inches. Fluid Systems/UOP is also offering spiral-wound elements in 60-inch lengths, which are classified as Magnums. The hollow-fiber elements (bundles) have similar sizes without the outer shells.

The important considerations in the membrane element specification are outlined in Table C. All membrane elements are tested for performance using a standard sodium chloride solution. A standard solution provides a common basis for comparison. In actual applications, the feedwater quality is translated into osmotic pressure, which in turn is utilized to calculate the net driving force. Feedwater temperature directly affects the productivity of a membrane element. The performance is usually specified for 77°F and a correction factor is applied at other temperatures using data provided by each manufacturer. The water recovery per element is an important consideration to ensure that an adequate feed/brine flowrate is maintained at the membrane surface, in order to minimize the effect of concentration polarization (which is the ratio of solute concentration at the membrane surface relative to that in the bulk of solution). As reverse osmosis occurs, the water permeates through the membrane, leaving the salts on the surface. This salt layer at the membrane surface is minimized by maintaining turbulent flow conditions. All manufacturers generally specify the minimum recommended brine flowrate and water recovery. The water productivity of a membrane element is a direct function of the net applied pressure. Net pressure is calculated by subtracting the osmotic pressure, hydraulic pressure loss, and permeate pressure from the applied pressure. For TFC membrane elements, the 225 psig applied pressure translates to 200 psig net pressure. (The values for CA elements are 425 psig and 400 psig, respectively.)

The performance specification is characterized by salt rejection and water productivity for a single element and for a batch of elements. These values are experimentally determined for each type of membrane element. Initial value is the productivity for the first 24 hours. By continuing the testing for a given time period, a flux decline slope can be determined for computing the end-of-life performance. The initial and end-of-life values are then used as a criteria for the reverse osmosis plant design. The average values represent the expected performance for a given batch of membrane elements. The operating conditions represent the application limits of a membrane element. Maximum feedwater temperature, flow, and pressure limits are related to the physical integrity of the membrane, while the feedwater pH and chlorine tolerance are related to the chemical stability of the membrane. Feedwater turbidity, a measure of the suspended solids level in a feedwater source, is related to the membrane fouling over a period of time.

Specifications of Membrane Elements

The reverse osmosis membrane industry has made significant improvements in the design and quality of RO elements during the past few years. The cellulose acetate blend membranes have been optimized for a net applied pressure of 400 psig. The thin-film composite membranes provide similar or enhanced performance for a net pressure of 200 psig, thus cutting the power consumption in half. The industry has standardized product specifications in both these categories.

The specifications of elements utilizing asymmetric membranes are summarized in Table D. Standard specifications for spiral-wound elements are based on operation with a feed of 2,000 ppm sodium chloride solution at 420 psig operating pressure, 77°F water temperature, and 10% recovery per module. DuPont hollow-fiber recovery rate is 75% with a feed quality of 1,500 ppm NaCl. All elements are 40 inches long (except the hollow fiber and Magnum) and are physically interchangeable with appropriate adapters. Refer to individual element specifications for more details (references 6, 7, 9, 10, 11). Table E lists the cross-comparison of spiral-wound elements. The key parameter here is the net pressure of 400 psig for spiral-wound elements. The test water quality varies from 1,000 ppm to 2,000 ppm NaCl.

The specifications of thin-film composite membrane elements are summarized in Table F. Standard specifications are based on operation with a feed of 2,000 ppm NaCl

TABLE E
RO Elements Cross-Reference Chart
Asymmetric Membranes

Membrane type	*Manufacturers and model numbers* Hydranautics	Toray	FSD/UOP	DSI	DuPont C-1
Standard	4040-MSY-CAB1	SC-2100	4221SD	C4040FF	4440
rejection (95%-96%)	8040-MSY-CAB1	SC-2200	8221SD	C8040FF	4840
High	4040-MSY-CAB2	SC-6100	4221HR	C4040DF	4441
Rejection (97%-98%)	8040-MSY-CAB2	SC-6200	8221HR	C8040DF	4841

solution, 225 psig applied pressure (270 psig for Hydranautics), 77°F water temperature, and a minimum of 10% recovery per module. All elements are physically interchangeable with appropriate adapters. Refer to individual element specifications for more details (references 7-11).

Due to the high water flux of TFC elements, the pretreatment requirements for the RO feedwater need careful evaluation in order to minimize membrane fouling. Again, the key parameter is 200 psig net pressure.

Field replacement of elements should be carefully evaluated for productivity, salt rejection, element cost, and element performance history. These tables are to be used as guidelines only. The element performance history is an especially important consideration for the application of a specific TFC element.

One new permeator, not covered in the above comparison, has been available for a few years for low pressure (250 psig) brackish water applications. Dow Chemical developed this permeator in cellulose triacetate hollow-fiber membrane configuration. This low pressure permeator will reduce energy consumption by about 40% and will effectively compete with the TFC elements.

TABLE F
RO Membrane Elements
Thin-Film Composites

Manufacturer	Size	Model no.	*Standard specifications* Productivity Gal/day	Salt rejection %
DSI	4"×40"	S4040JF	1800	98
	8"×40"	S8040JF	7500	98
DuPont (asymmetric)	4"×40"	3440L	2000	96
	8"×40"	3840L	8300	96
FilmTec	4"×40"	BW30-4040	1800	98
	8"×40"	BW30-8040	7500	98
FSD/UOP	4"×40"	4021LP	1800	96
	8"×40"	8021LP	7000	96
Hydranautics	4"×40"	4040-MSY-IFC1	1600	97.5
	8"×40"	8040-MSY-IFC1	6300	97.5

TABLE G
RO Membranes Cross-Reference Chart
Thin-Film Composites

Membrane type	*Manufacturers and model numbers* FilmTec	DSI	Hydranautics	FSD/UOP	DuPont B-15
4" dia.	BW30-4040	S4040JF	4040-MSY-IFC1	4021LP	3440L
4" dia.	BW30-8040	S8040JF	8040-MSY-IFC1	8021LP	3840L

Conclusions

There are three types of membrane elements commercially available today: low pressure operation, 200 to 250 psig; medium pressure operation, 300 to 350 psig; and standard pressure operation, 400 to 450 psig. Hollow-fiber permeators are primarily used on well water supply installations or when the pretreatment system has been properly designed and operated. Spiral-wound elements find wide application in all types of water sources, as they are relatively easy to clean. The TFC and other low pressure elements will find greater use in the coming years because of the lower total cost and better performance. The future of reverse osmosis and other separation membranes is extremely promising. The membrane development program is already entering the fourth generation, offering membranes for brackish water applications for transmembrane pressures of about 100 psig.

Acknowledgments

The author is grateful to Dr. Bill Benzinger, Mr. Greg Montgomery, and Mr. Bill Norton, all of Culligan International, for their review and comments on this manuscript. The author also acknowledges the assistance of Mrs. Joan Connor in the preparation of this manuscript.

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REVERSE OSMOSIS TECHNOLOGY

Applications for High-Purity-Water Production

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R4 & R3

2

Commercial Reverse Osmosis Membranes and Modules

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

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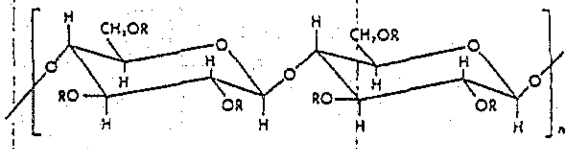
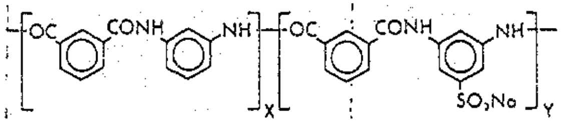
I. INTRODUCTION

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

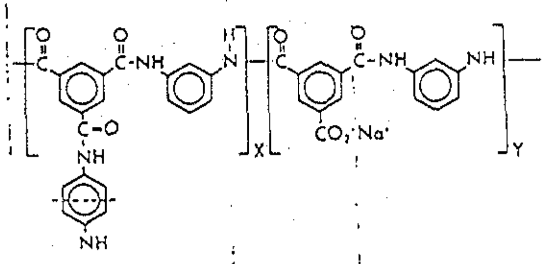
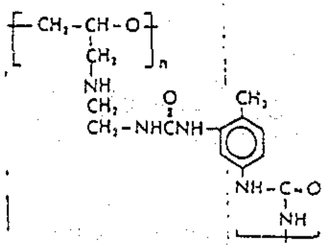
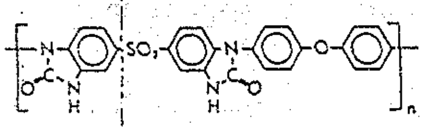
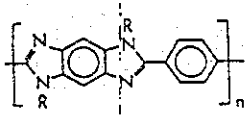
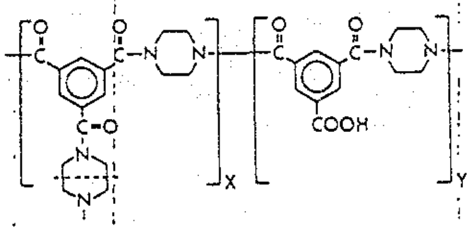
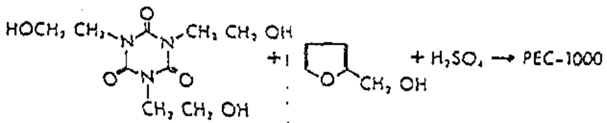
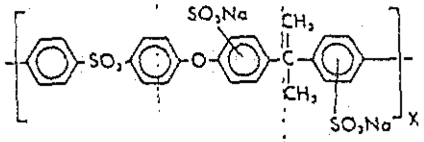
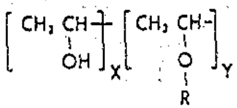
30% Terephthaloyl group replacement of isophthaloyl in above	B-10 (seawater)	DuPont	Hollow fiber
Crosslinked aromatic polyamide	FT-30	FilmTec	Spiral
	HR95, HR99	DDS	Plate and frame
	ZF99	PCI	Tubular
	UTc[d]	Toray	Spiral
	TFCL[d]	Fluid Systems	Spiral
Aryl-alkyl polyamide/polyurea[b]	RC-100, PA300,	UOP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

Table 4. (Continued)

Chemical name	Trade name	Manufacturer	Module type
Polybenzimidazole 	–	Teijin	Tubular
Polybenzimidazole 	–	Osmonics/Celanese	Spiral
Polyacrylonitrile (plasma treated)	–	Sumitomo	Spiral
Polypiperazineamide[e] 	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	

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

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

![Pfizer]

CHEMICAL DIVISION

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®

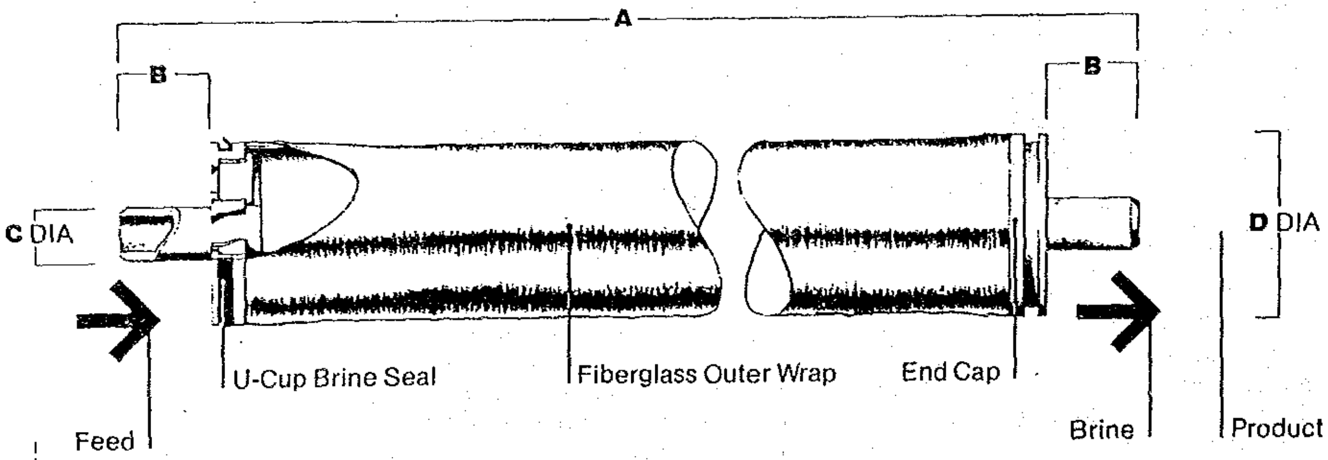
2.5" Seawater RO Element Specifications

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

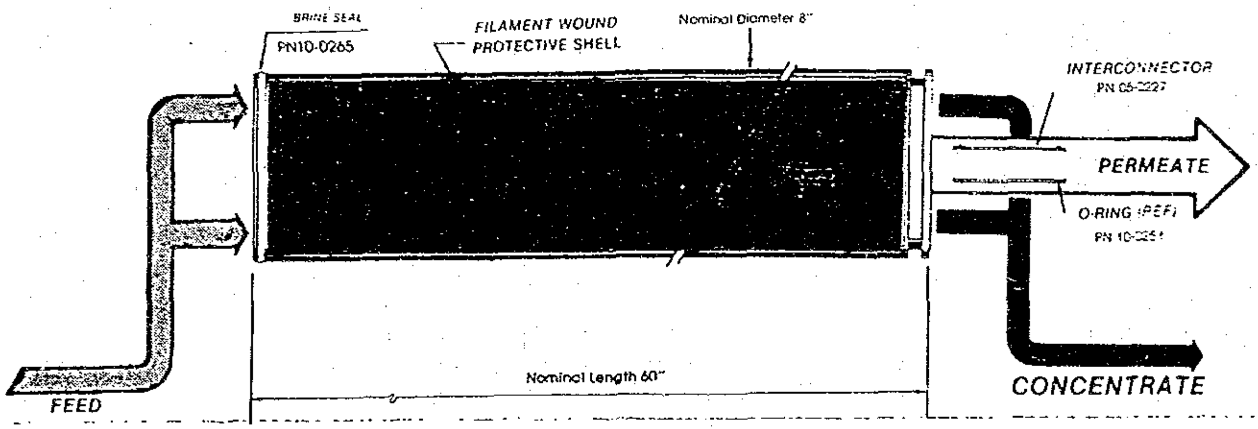
TFC® Spiral-Wound Reverse Osmosis Element
Seawater Model 2031 SS MAGNUM®

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.

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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/cm^2)
7% water recovery
25°C (77°F) and pH 5.7

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

LP: 2,000 mg/L NaCl solution
225 psi (15.8 kg/cm^2)
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)

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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 m³/hr/tube (3 gpm)
4" . . . . 2.3 m³/hr/tube (10 gpm)
6" . . . . 4.6 m³/hr/tube (20 gpm)
8" . . . . 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

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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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

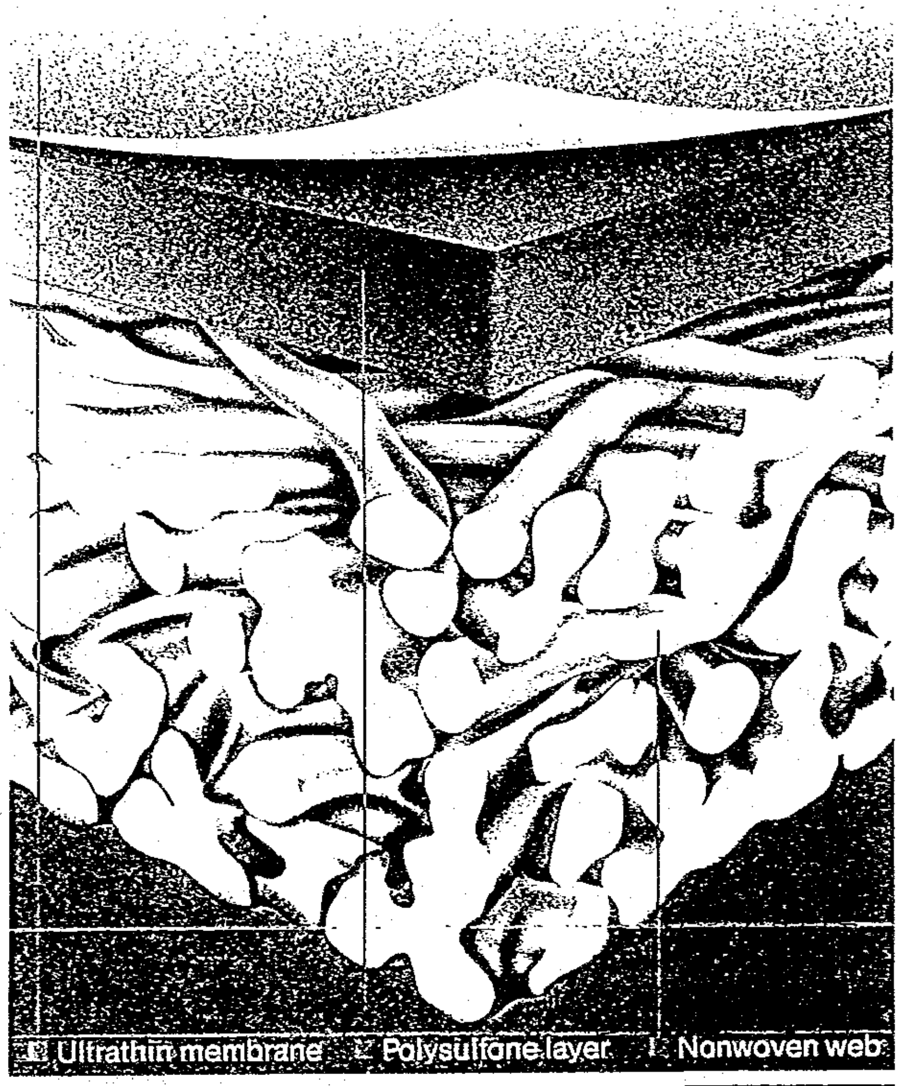
January 1988

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-50043

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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.

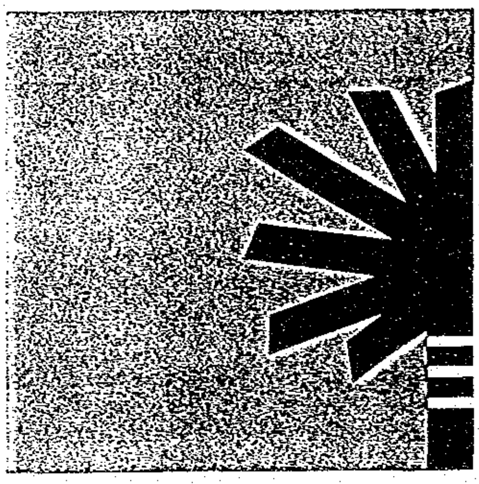
Using FILMTEC thin-film composite membranes will give you drinking water of unsurpassed quality. The low fouling potential of FILMTEC membranes and their easy cleaning capabilities mean low maintenance requirements and a long operating life. All this plus the extremely high salt rejection of FILMTEC 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.

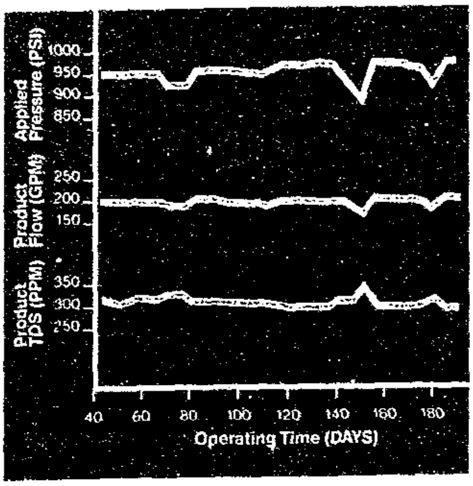
High Tolerance of pH Extremes. FT30 has an operating pH range of 2 to 11 and can be cleaned at a range of 1 to 12. This membrane toughness plus the spiral-wound configuration allow for effective membrane cleanings and long membrane life.



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.

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

November 1985

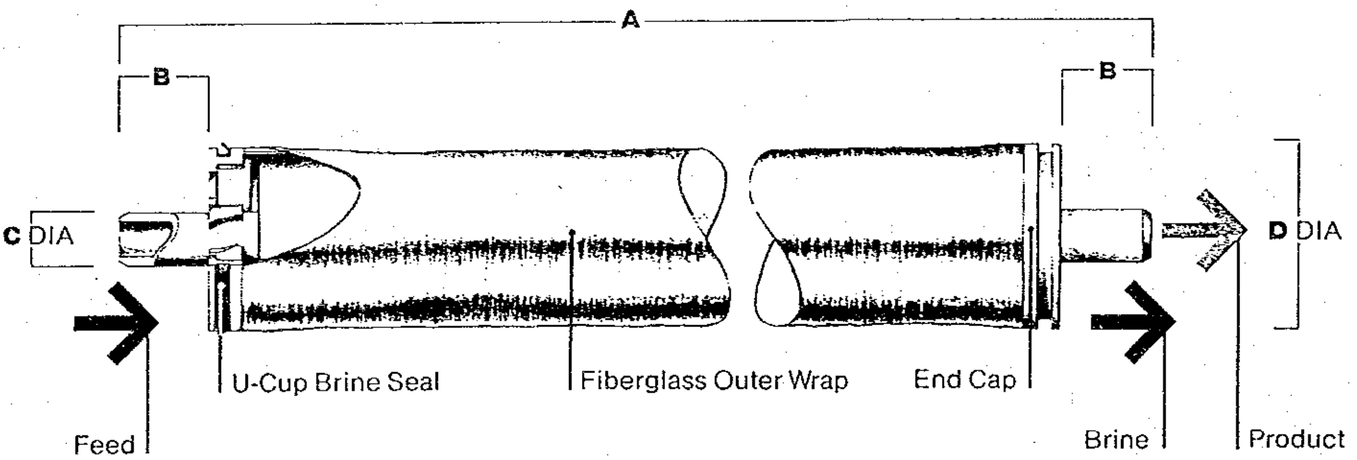
FILMTEC®

Technical Bulletin

2.5" Seawater Reverse Osmosis Element Specifications

	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

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

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.

FILMTEC

Technical Bulletin

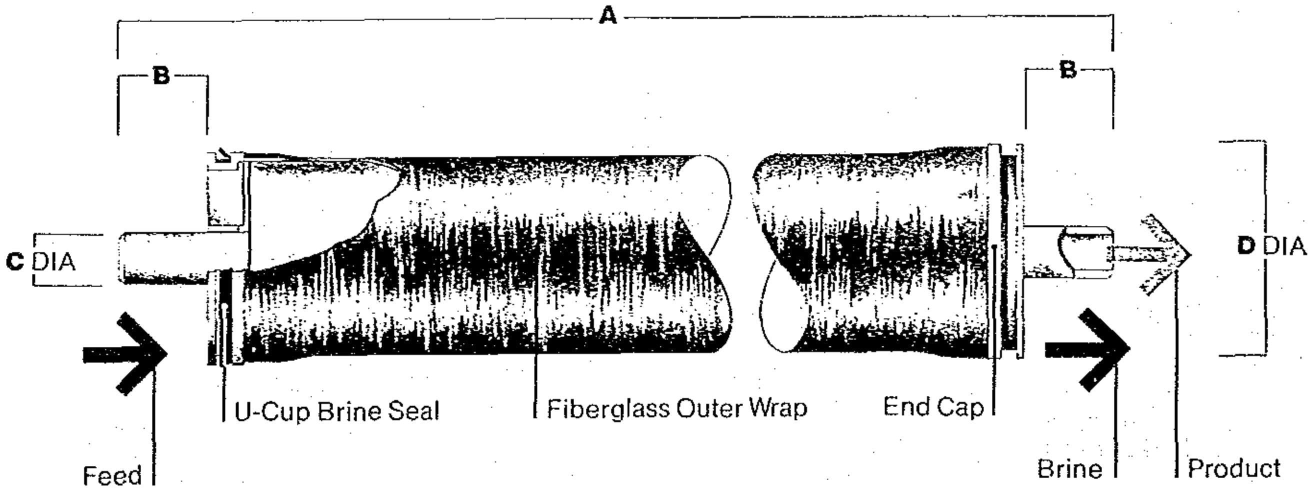
4" Seawater Reverse Osmosis Element Specifications

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^- (%)	Average Salt Rejection Cl^- (%)
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	Dimensions (inches) A	B	C	D
SW30-4014	0.035	14.0	1.1	0.75	3.9
SW30-4021	0.05	21.0	1.1	0.75	3.9
SW30-4040	0.1	40.0	1.0	0.75	3.9

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

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

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.

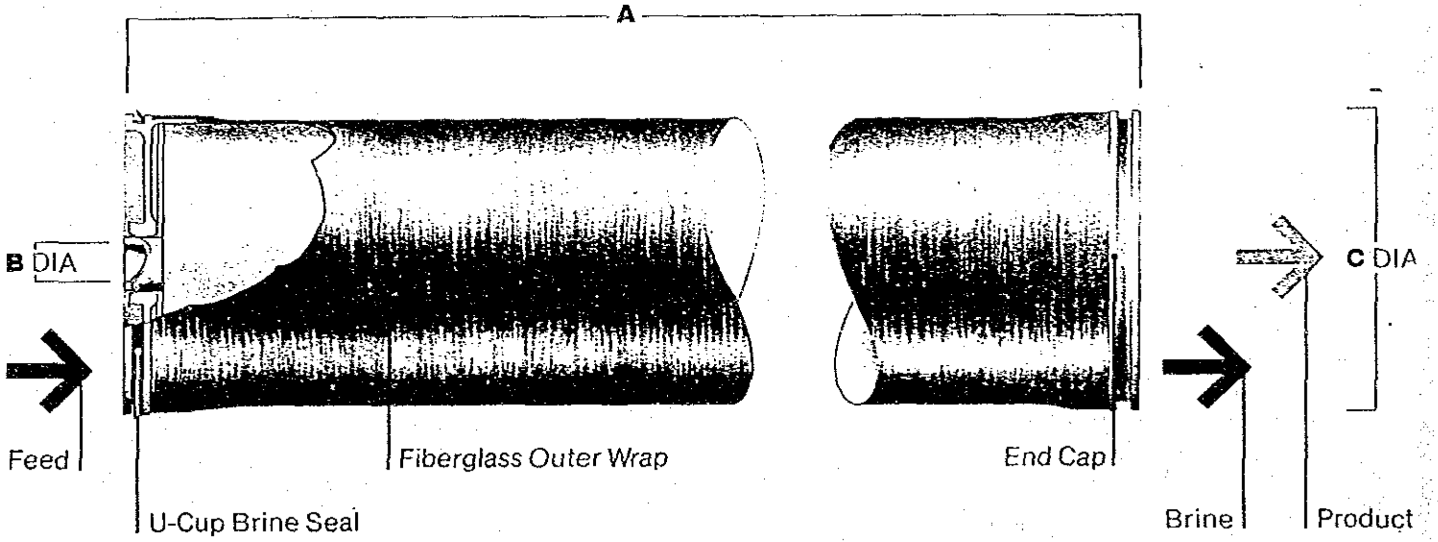
FILMTEC
Technical Bulletin
8" Seawater Reverse Osmosis Element Specifications

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	Dimensions (inches) A	B	C
SW30-8040	0.10	40.0	1.125	7.9

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

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.

TFC® Reverse Osmosis MAGNUM® Element Specifications

Low Pressure | 1.5m magnum | TFCL

Model No.	4031 LP	4031 MP	TFCL-HP	8031 LP	TFCL 8821 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	Med P	high P (400 psi)		Low Pres (200 psi)

Model No.	8031 MP	2031 SS	2031 HF
		single stage	High Flow
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?

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 (*) Cl2 can be removed using Activated carbon

10/86

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.

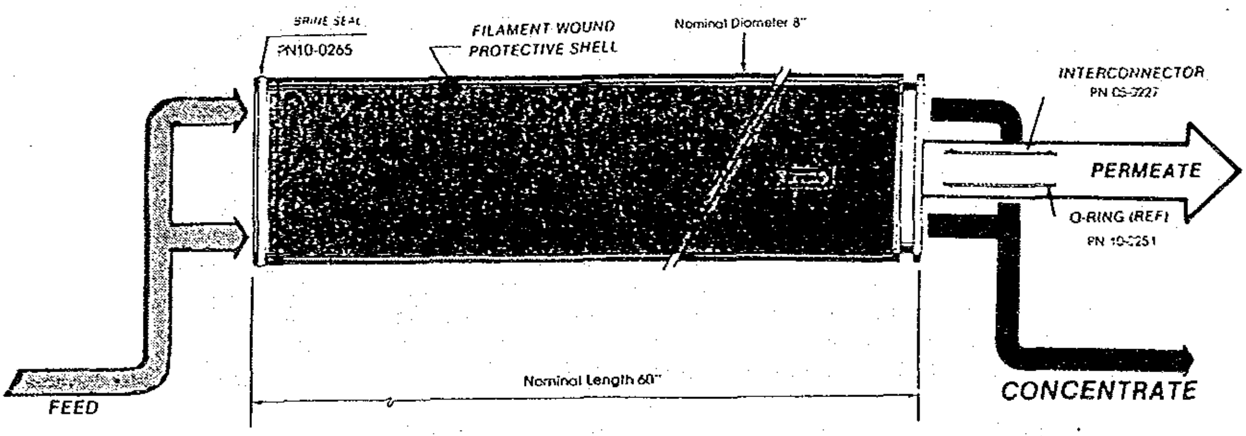
TFC® Spiral-Wound Reverse Osmosis Element
Seawater Model 2031SS MAGNUM®

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/cm^2)
7% water recovery
25°C (77°F) and pH 5.7

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

LP: 2,000 mg/L NaCl solution
225 psi (15.8 kg/cm^2)
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 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.

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.

Fluid systems by UOP

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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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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

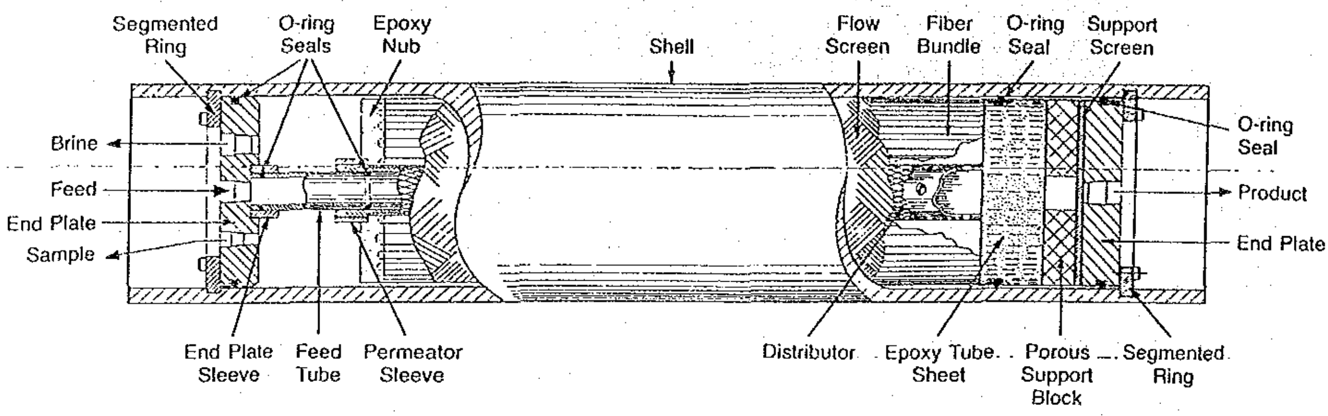


Figure 2. Illustration of Hollow Fiber RO Process

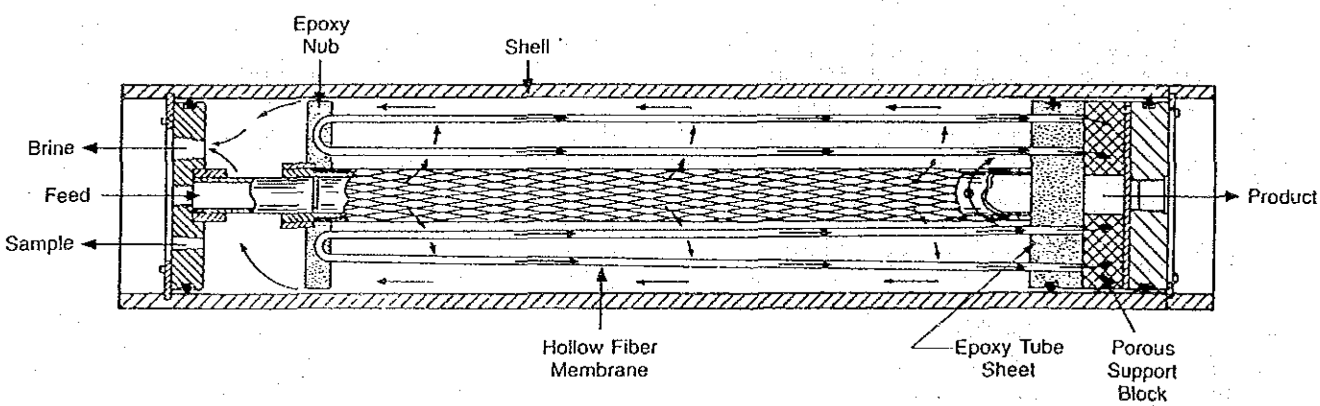
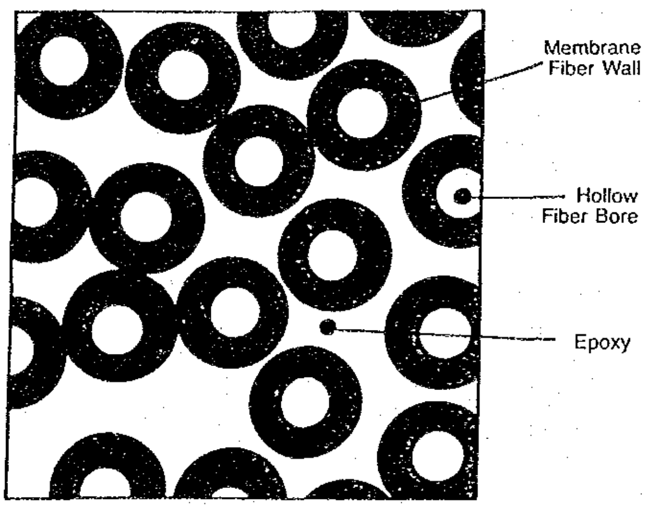


Figure 3. Illustration at Tube Sheet Faces



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 m^3/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.