

PERMASEP

Permasep® Engineering Manual

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BULLETIN 402

B-10 "PERMASEP" PERMEATOR, FACTORS INFLUENCING PERFORMANCE

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A. INTRODUCTION

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

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

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

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

B. FLOW FACTORS

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

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

Where:

- Q_w = flow rate of water through the membrane
- K_w = membrane permeability coefficient for water
- A = membrane surface area
- τ = membrane thickness
- ΔP = hydraulic pressure differential across membrane
- $\Delta \pi$ = osmotic pressure differential across membrane

T = temperature effect

M = membrane flux decline effect

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

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

Where:

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

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

1. PRESSURE CORRECTION FACTOR—PCF

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

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

Where:

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

2. MEMBRANE FLUX RETENTION COEFFICIENT—MFRC

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

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

$$MFRC = \frac{Q_w}{Q_{w_i}} \quad (4)$$

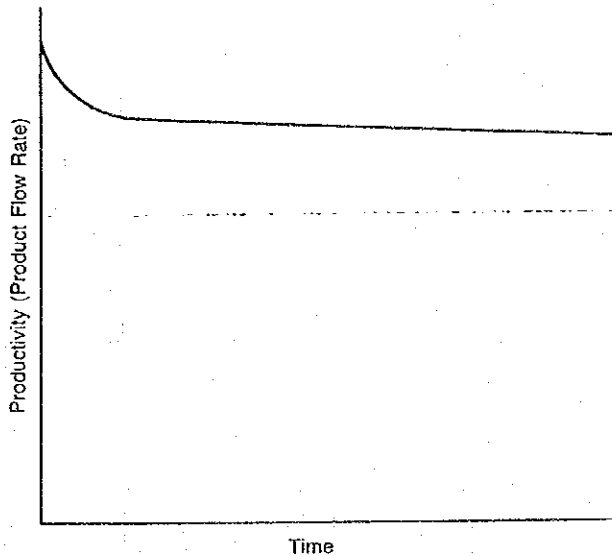
Where Q_w is the permeator flow rate at time (t) and Q_{w_i} is the permeator flow rate at initial start-up. For both Q values, all pressure and temperature terms are



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

MFRC is a log function with respect to time (see Fig. 1). The time factor, however, is not as significant

Figure 1. Permeator Productivity vs. Time



after the initial flux decline has occurred. The following relationships can be used to estimate long term permeator or system flows at various pressures and temperatures:

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

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

- For $T \leq 25$ degrees C and $P \geq 800$ psig

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

Where:

P = pressure in psig

T = temperature in degrees C

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

3. TEMPERATURE CORRECTION FACTOR—TCF

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

$$TCF = \frac{Q_{WT}}{Q_{W25}} = 1.03^{(T-25)} \quad (7)$$

Where Q_{WT} is the permeator flow rate at temperature (T), and Q_{W25} is the permeator flow rate at 25 degrees C. For both Q values, all pressure and membrane flux decline terms are the same and the only variable is temperature.

C. RO SYSTEM SALT PASSAGE

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

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

Where:

C_f = feed concentration

C_p = product concentration

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

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

The salt passage (at standard conditions, SP_0) will be different for different ions. In general, passage of monovalent ions will be greater than passage of divalent ions, and divalent ions greater than trivalent ions. Table I, Salt Passage for B-10 Permeators at Standard Test Conditions,

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

Constituent	$SP_0, \%$
Sodium, Na ⁺	1.5
Potassium, K ⁺	1.5
Calcium, Ca ⁺⁺	0.6
Magnesium, Mg ⁺⁺	0.6
Barium, Ba ⁺⁺	0.6
Iron, Fe ⁺⁺	0.6
Strontium, Sr ⁺⁺	0.6
Nitrate, NO ₃ ⁻	2.3
Chloride, Cl ⁻	1.5
Sulfate, SO ₄ ⁻	0.6
Carbonate, CO ₃ ⁼	0.6
Phosphate, PO ₄ ⁼	0.3
Silica, SiO ₂	2.3
Carbon Dioxide, CO ₂	100
Hydrogen Sulfide, H ₂ S	100

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

lists the SP_0 for constituents commonly encountered in seawater. HCO₃⁻ and F⁻ are not shown in Table I as their passage is pH dependent. The effects of pH on HCO₃⁻ and F⁻ for B-10 "Permasep" permeators are shown in Figures 3 and Figure 4 respectively.

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

$$SPCF = \frac{C_p/C_f}{C_{p0}/C_{f0}} = \frac{C_{f0}C_p}{C_fC_{p0}} \quad (10)$$

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

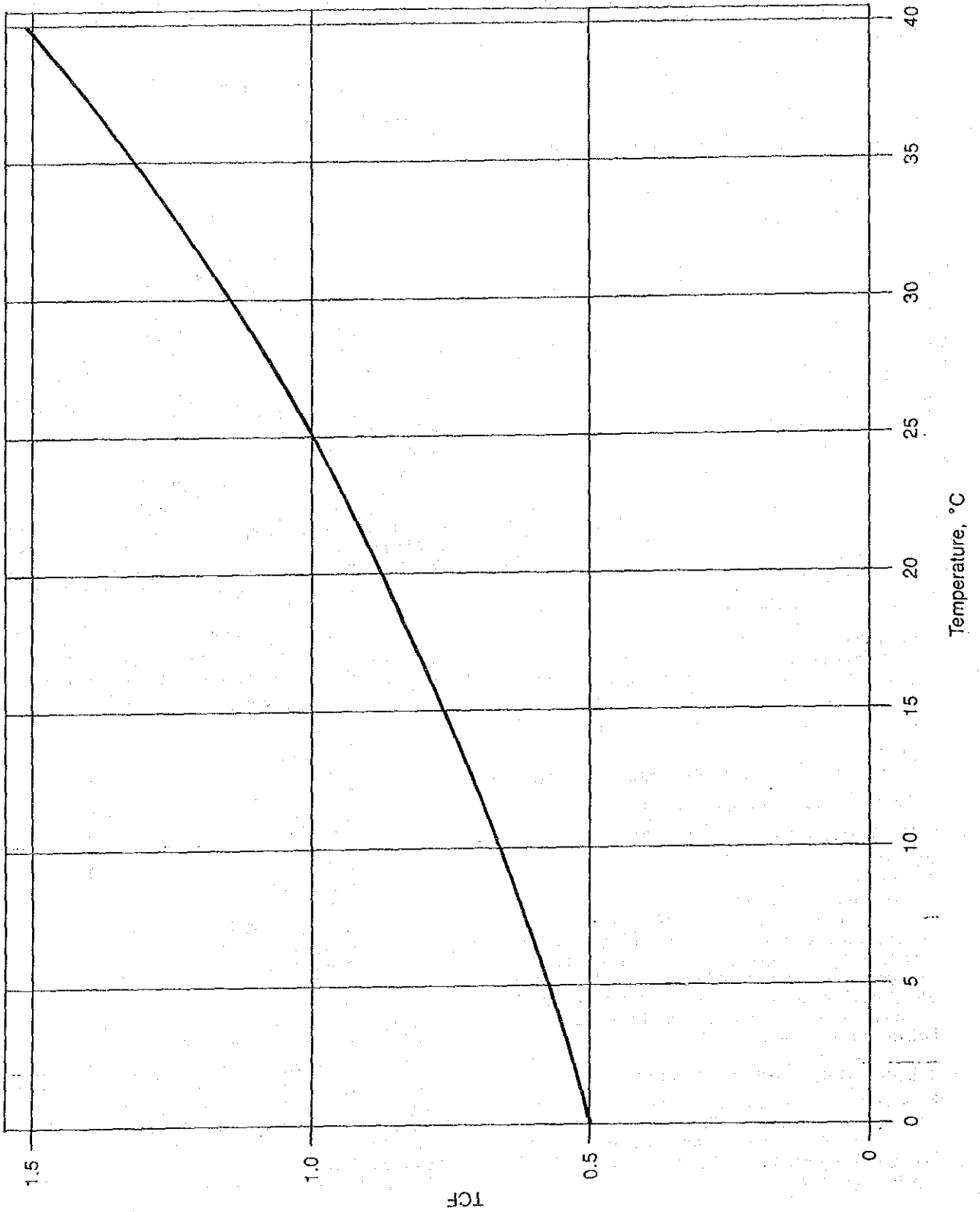


Figure 3. Effect of Feed pH on HCO₃⁻ Passage for B-10 Permeator

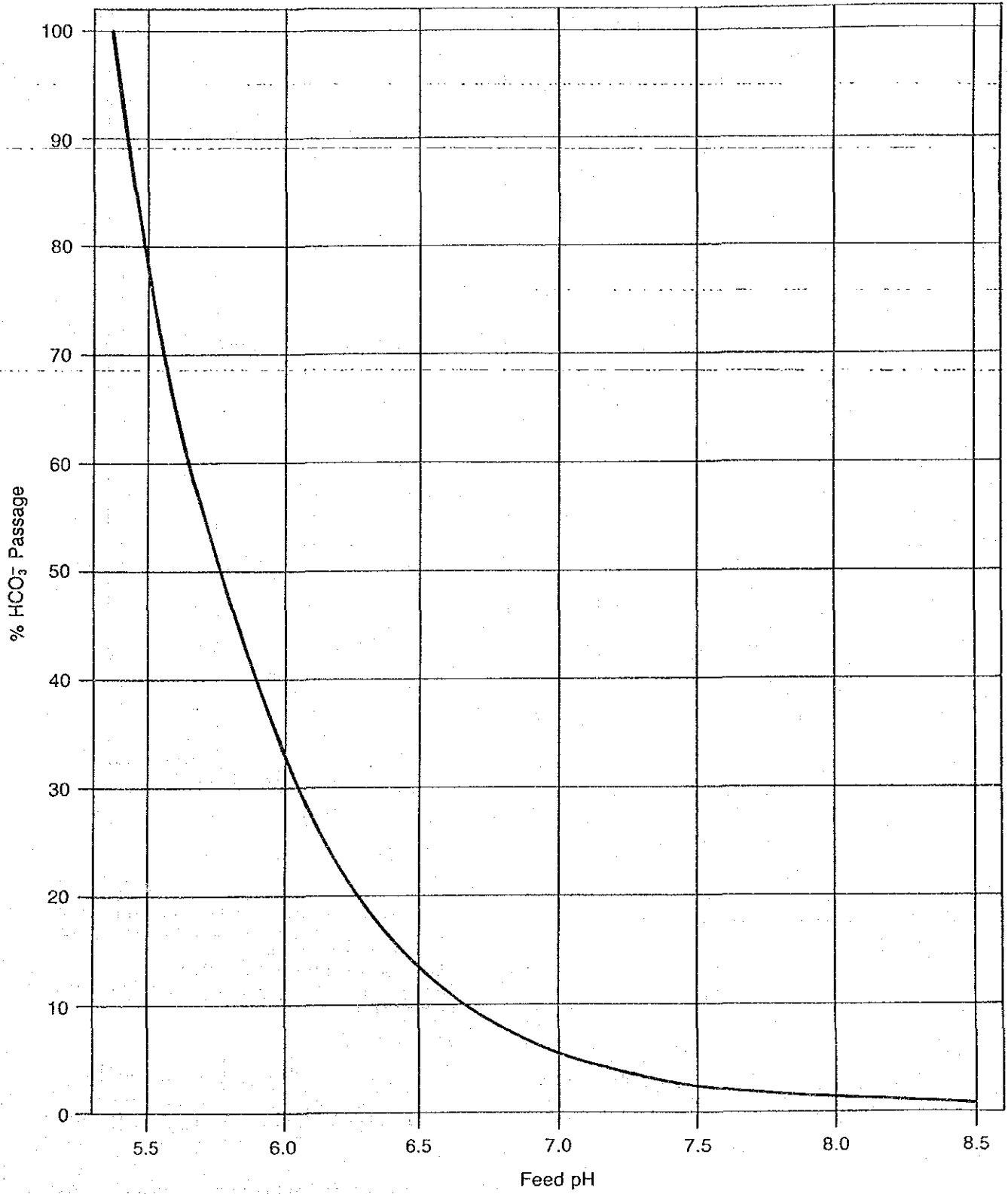
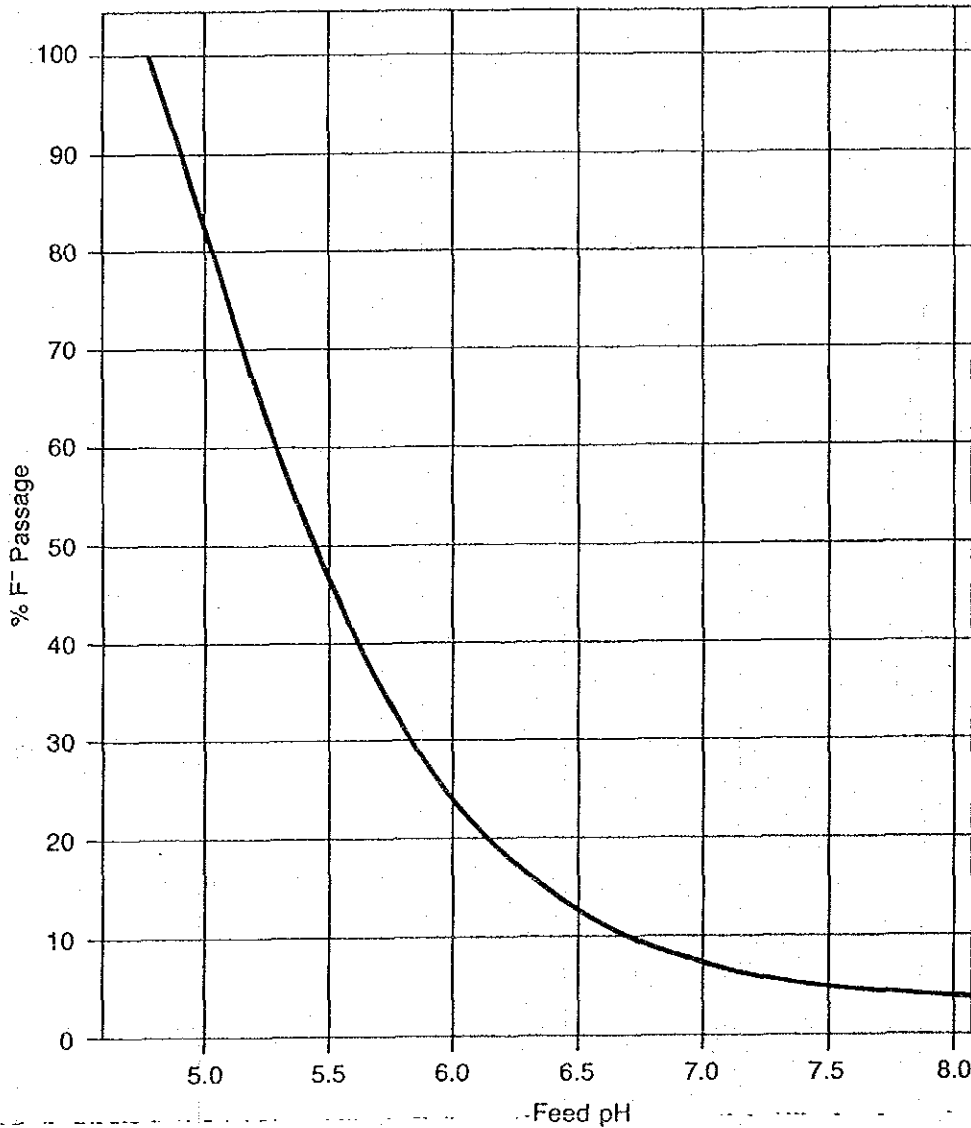


Figure 4. Effect of Feed pH on F⁻ Passage for B-10 Permeators



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

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

Where:

Q_w = flow rate of water through the membrane, which is determined from Equation 1;

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

$$Q_s = K_s \frac{A}{j} \Delta C T M \quad (12)$$

Where:

K_s = membrane permeability coefficient for salt
 A = membrane area
 τ = membrane thickness

ΔC = salt concentration differential across membrane
 $= C_{fo} - C_p \cong C_{fo}$, since C_{fo} is much larger than C_p

T = temperature effect

M = membrane flux decline effect

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

SPCF =

$$\frac{C_{fo} \left[\left(P_{fo} - \frac{\Delta P_{fo}}{2} - P_{po} \right) - (\pi_{fo} - \pi_{po}) \right]}{C_i \left[\left(P_i - \frac{\Delta P_i}{2} - P_p \right) - (\pi_s - \pi_p) \right]} \frac{C_{fo}}{C_{fo}} \quad (13)$$

Where:

C_{fo} = feed concentration at standard test conditions, 30,000 mg/l as NaCl

C_i = feed concentration at actual condition, mg/l as NaCl

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

D. PREDICTING PERFORMANCE

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

1. ESTIMATING PERMEATOR CAPACITY

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

- Use Figure 5, Conversion of Seawater TDS (mg/l) to Equivalent NaCl (mg/l), to estimate the equivalent NaCl mg/l of the given feed concentration. This equivalent NaCl concentration is used for feed concentration where required in the following graphs.
- Determine Correction Factor "A" from Figure 6, Correction Factor A for B-10.
- Determine Correction Factor "B" from Figure 7, Correction Factor B for B-10.
- Determine Correction Factor "C" from Figure 8, Correction Factor C for B-10.
- Determine Correction Factor "D" from Figure 9, Correction Factor D for B-10.

- Determine Correction Factor "E" from Figure 10, Correction Factor E for B-10.
- Determine Membrane Flux Retention Coefficient (MFRC) from Equation 5 or 6.
- After these factors have been determined, they can be applied to the following equation to solve for estimated permeator capacity:

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

Where:

Q_{pE} = estimated permeator capacity, GPD

Q_i = initial permeator capacity at standard conditions, GPD

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

Example:

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

Given:

Feedwater TDS = 34,500 mg/l ion

Feed Pressure = 6,900 kPa (1,000 psig)

Design Temperature = 25 degrees C

Maximum Temperature = 25 degrees C

Product Pressure = 69 kPa (10 psig)

Conversion = 30 percent

Initial Capacity of 8-inch B-10 = 23.8 m³/d (6,300 GPD)

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

$$Q_{pE} = (A - B - CD)E(MFRC)Q_i$$

$$= (2.74 - 0.028 - 1.265 \times 1.00) \times (1.00)(0.620)23.8$$

$$= (1.447)(1.00)(0.620)23.8$$

$$= 21.35 \text{ m}^3/\text{d} (5,641 \text{ GPD})$$

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

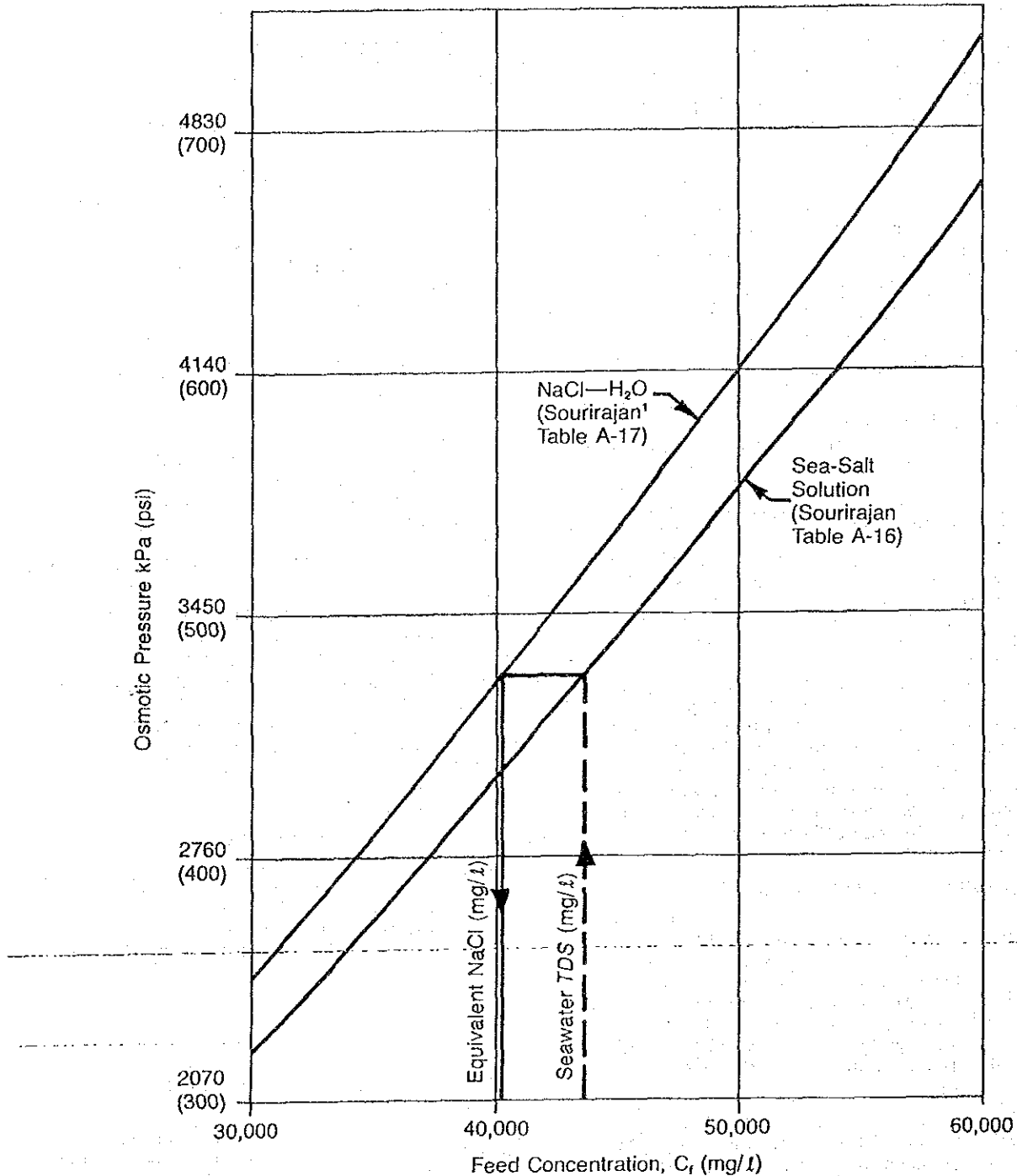
2. ESTIMATING PERMEATOR PRODUCT CONCENTRATION

A graphical approach can be used for estimating purposes only. This approach does not consider the effect of mixed ion passage, particularly HCO₃.

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

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

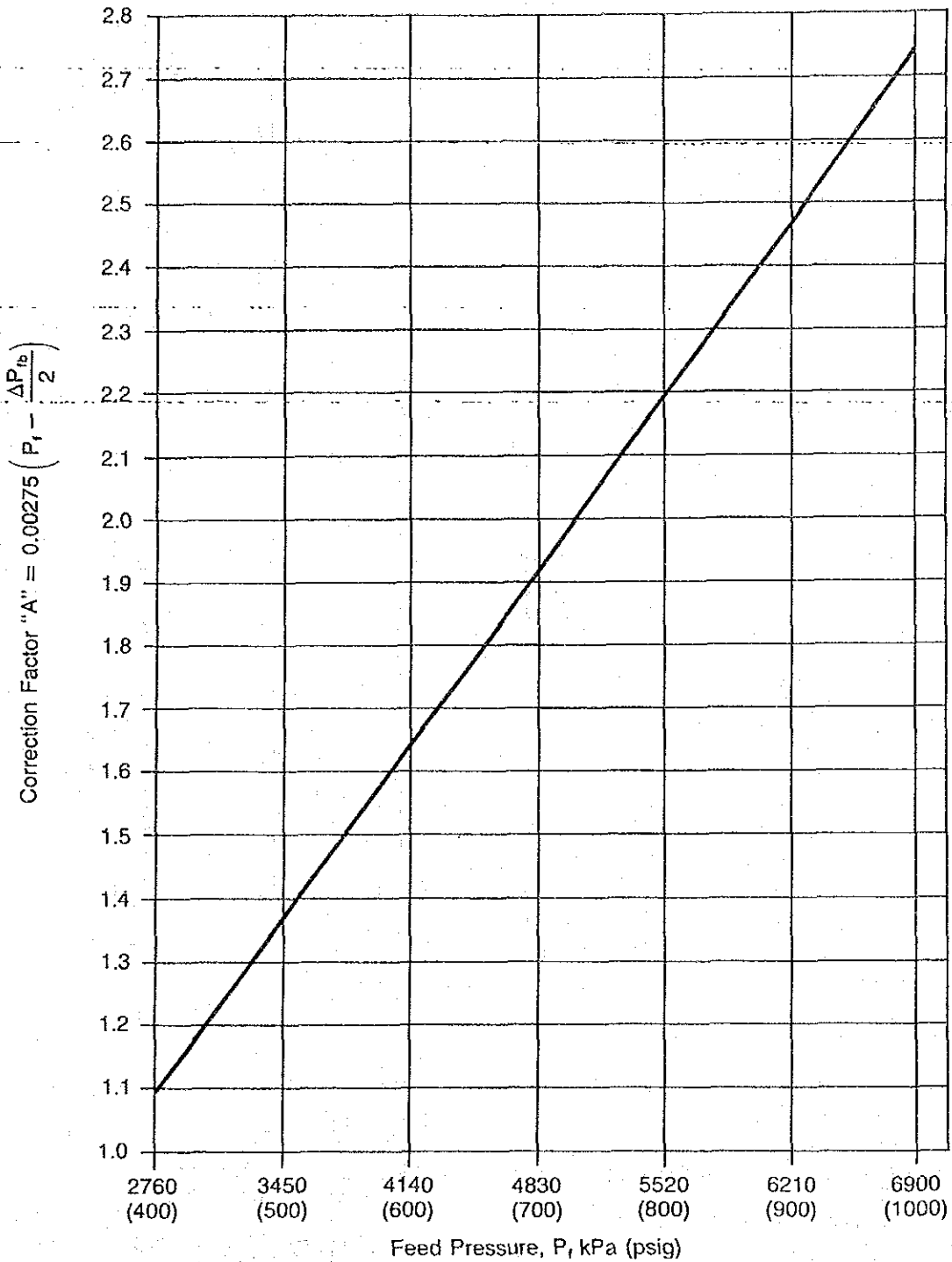
Figure 5. Conversion of Seawater TDS (mg/l) to Equivalent NaCl (mg/l)



- Determine SPCF "F" from Figure 11, Salt Passage Correction Factor F for B-10.
- Determine SPCF "G" from Figure 12, Salt Passage Correction Factor G for B-10.
- Determine SPCF "H" from Figure 13, Salt Passage Correction Factor H for B-10.
- Determine SPCF "I" from Figure 14, Salt Passage Correction Factor I for B-10.

- Determine SPCF "J" from Figure 15, Salt Passage Correction Factor J for B-10.
- Determine SPCF "K" from Figure 16, Salt Passage Correction Factor K for B-10.
- After these factors have been determined apply Equation 15 to solve Estimated Salt Passage Correction Factor ($SPCF_E$).

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



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

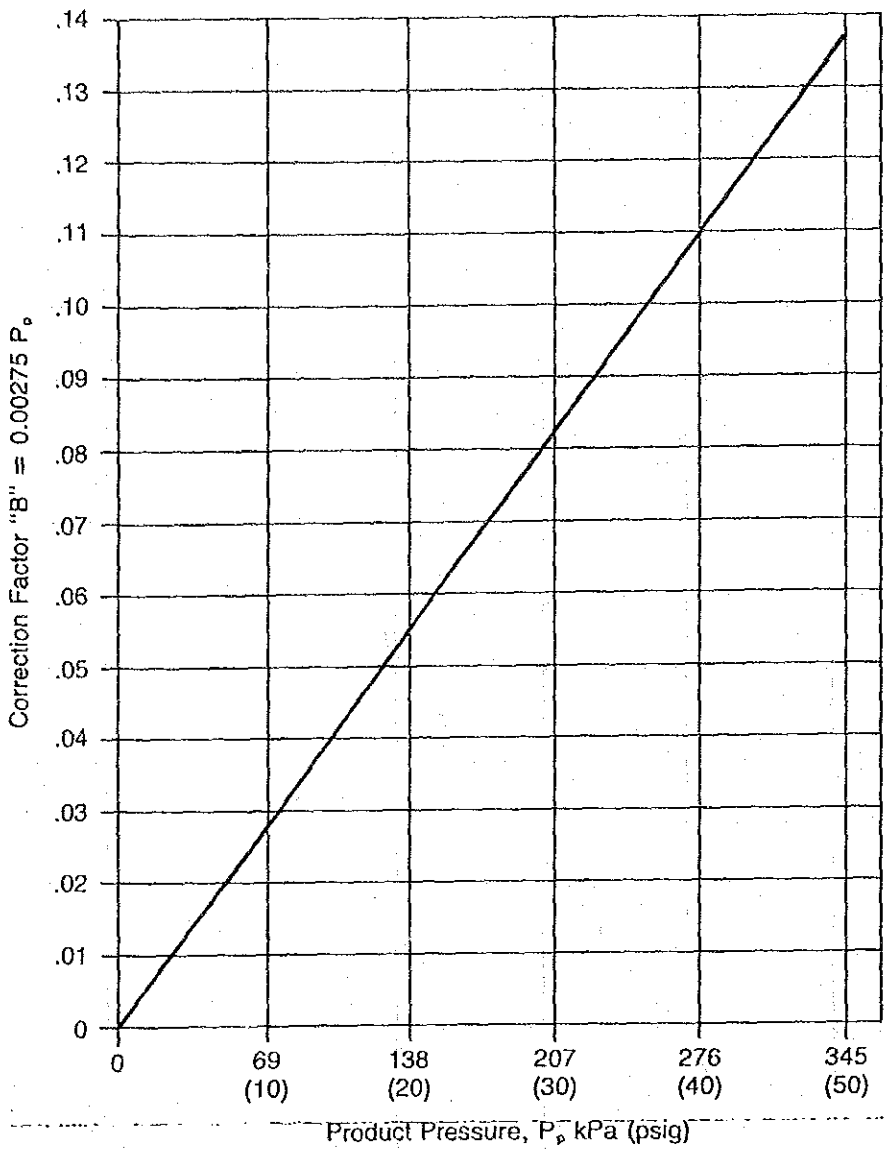
• Determine estimated product water TDS using Equation 16.

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

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

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

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



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

- From Figure 5
 34,500 mg/l ion = 31,500 mg/l NaCl
- From Figure 11, "F" = 0.95
- From Figure 12, "G" = 2.70
- From Figure 13, "H" = 0.027
- From Figure 14, "I" = 1.23

- From Figure 15, "J" = 1.05
- From Figure 16, "K" = 1.00

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

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

$$C_{pE} = 0.015 (SPCF_E) TDS_i$$

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

REFERENCE

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

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

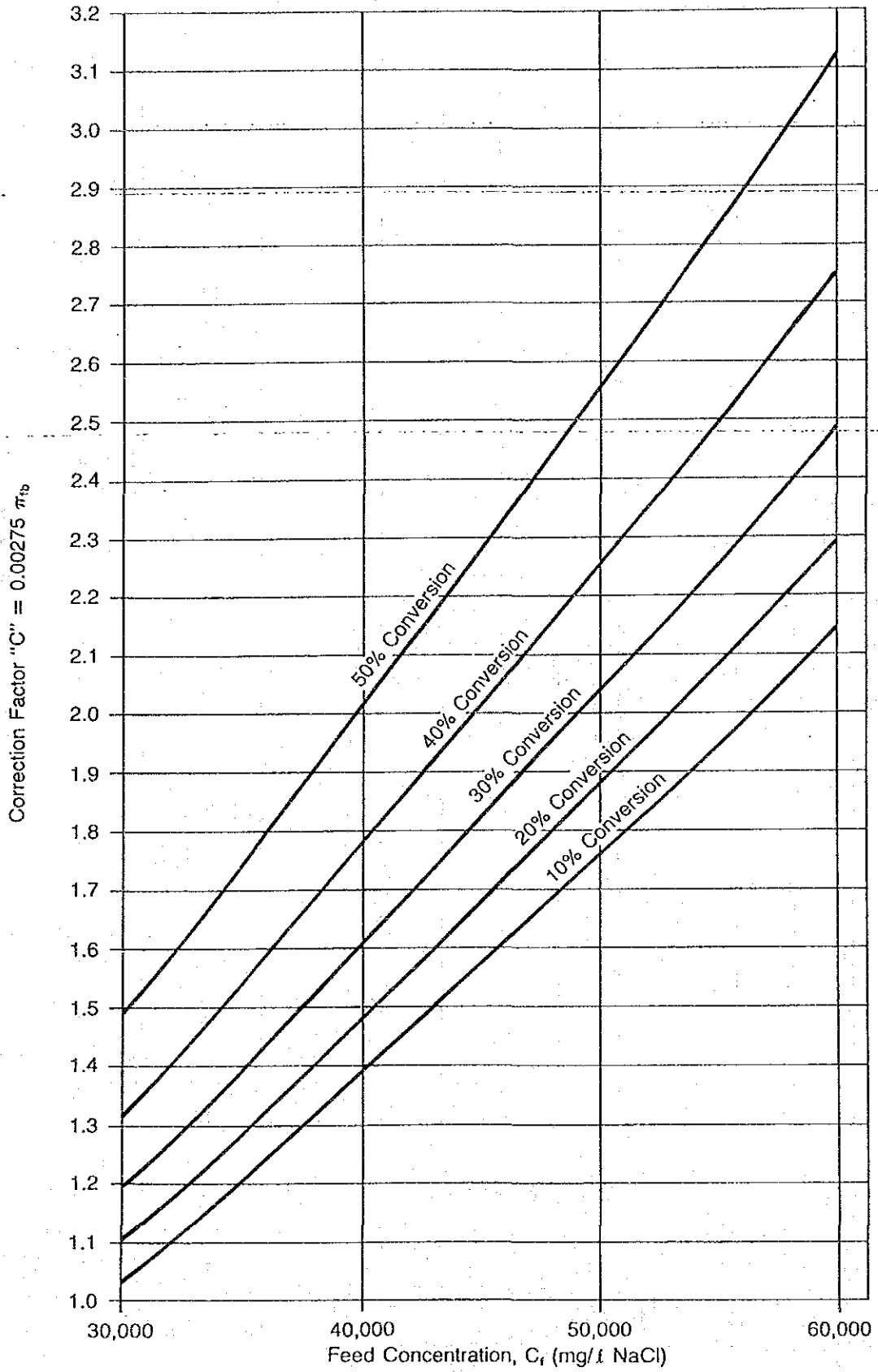


Figure 9. Correction Factor "D" for B-10

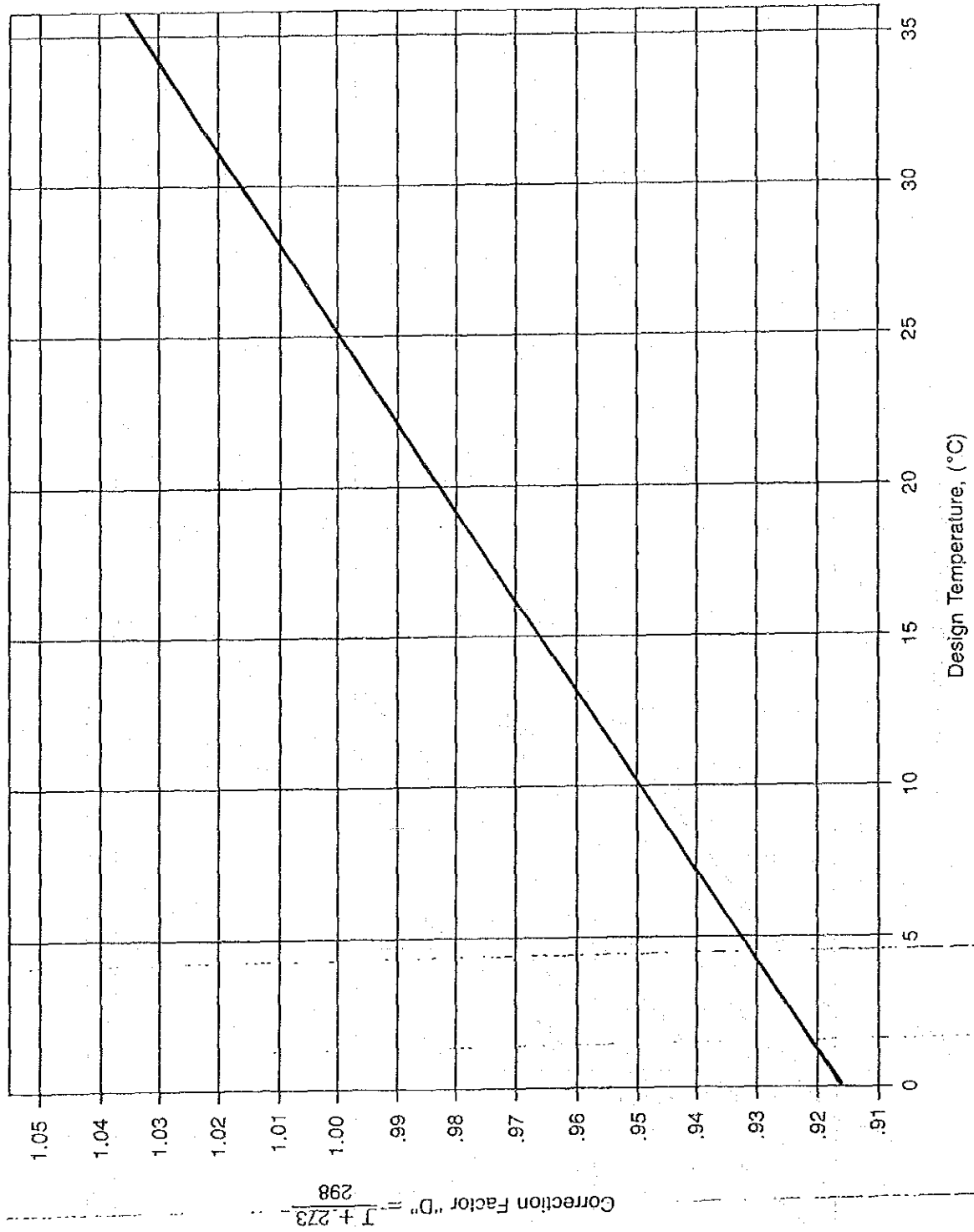


Figure 10. Correction Factor "E" for B-10

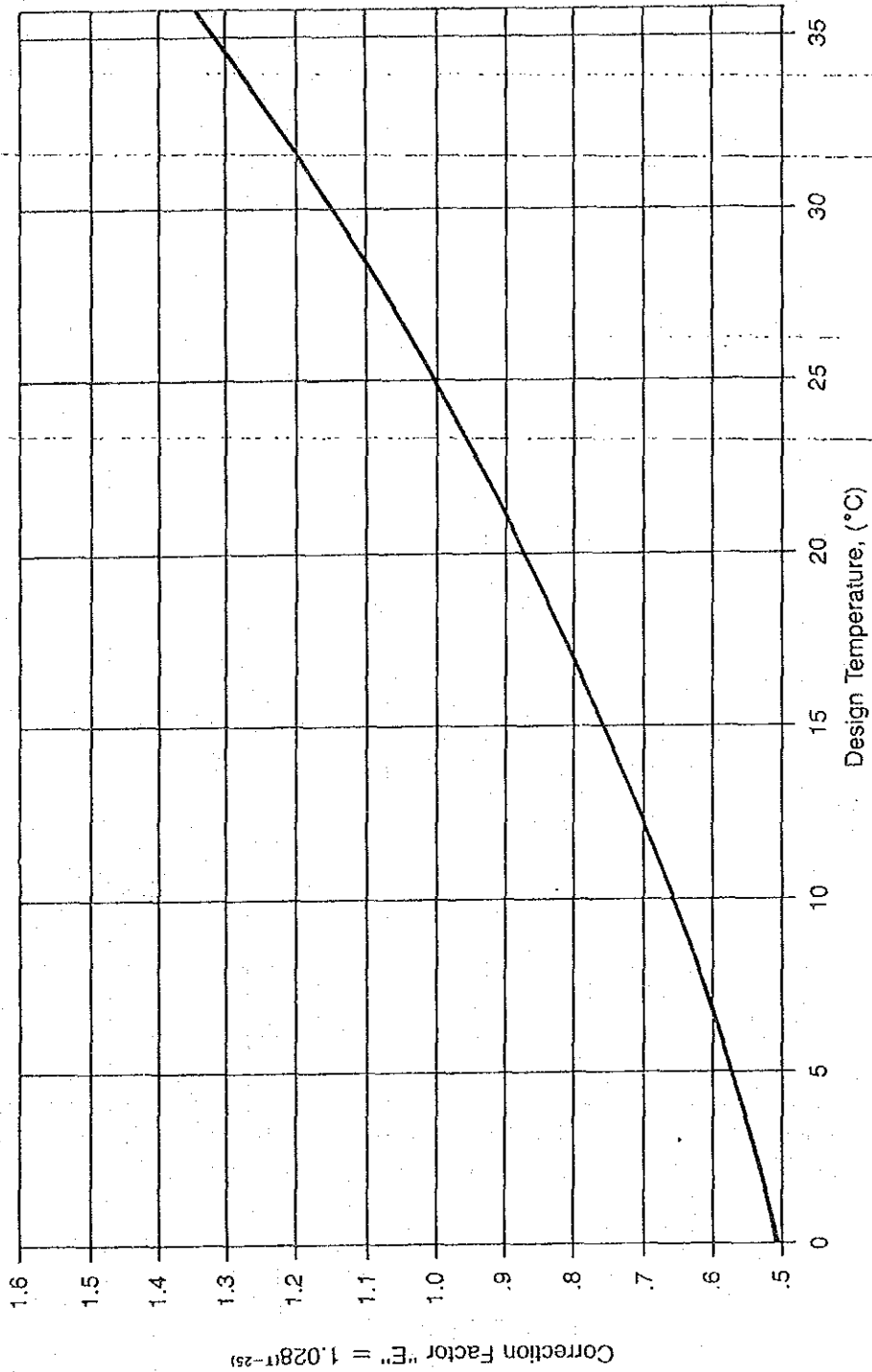


Figure 11. Salt Passage Correction Factor "F" for B-10

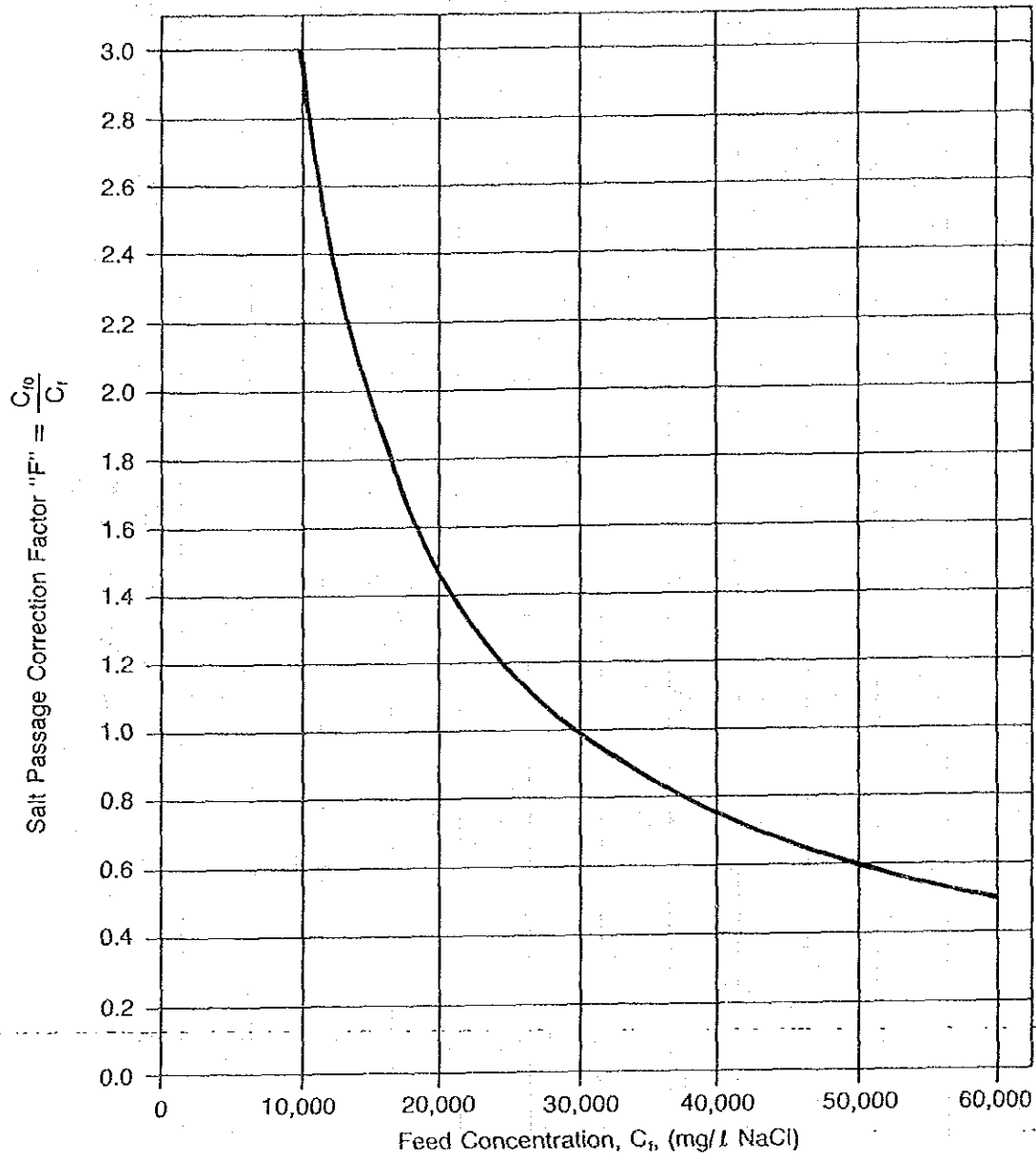


Figure 12. Salt Passage Correction Factor "G" for B-10

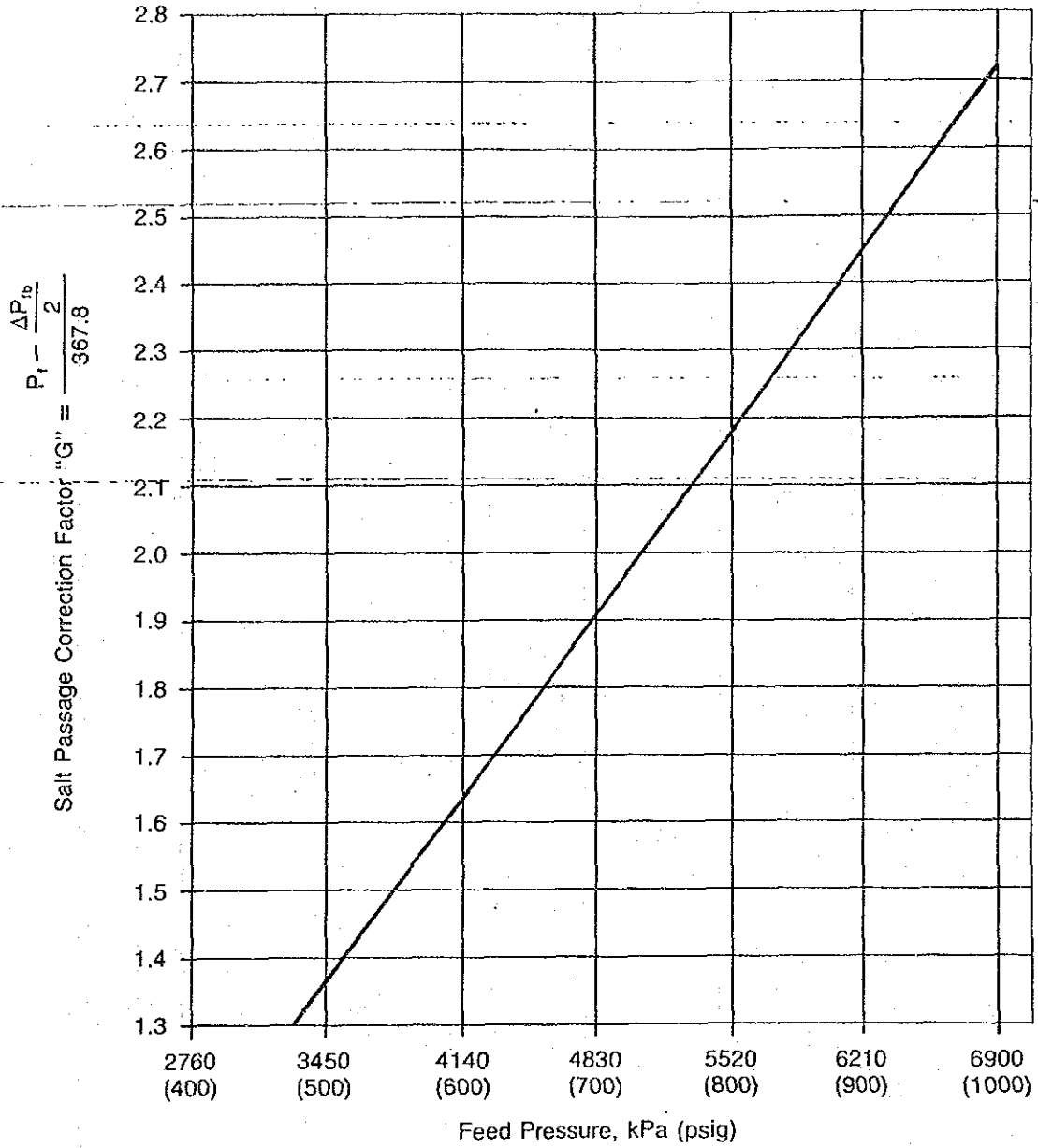


Figure 13. Salt Passage Correction Factor "H" for B-10

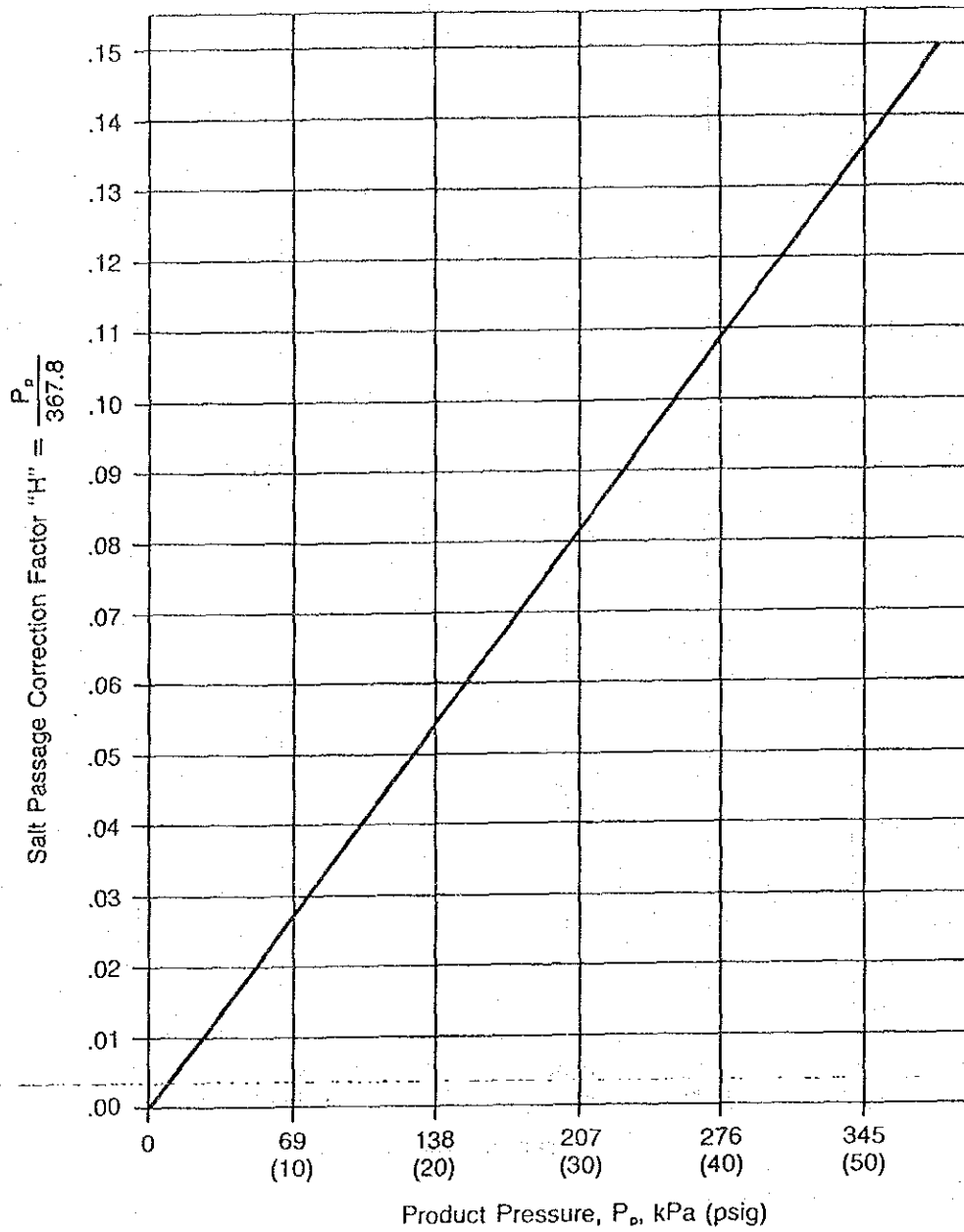


Figure 14. Salt Passage Correction Factor "I" for B-10

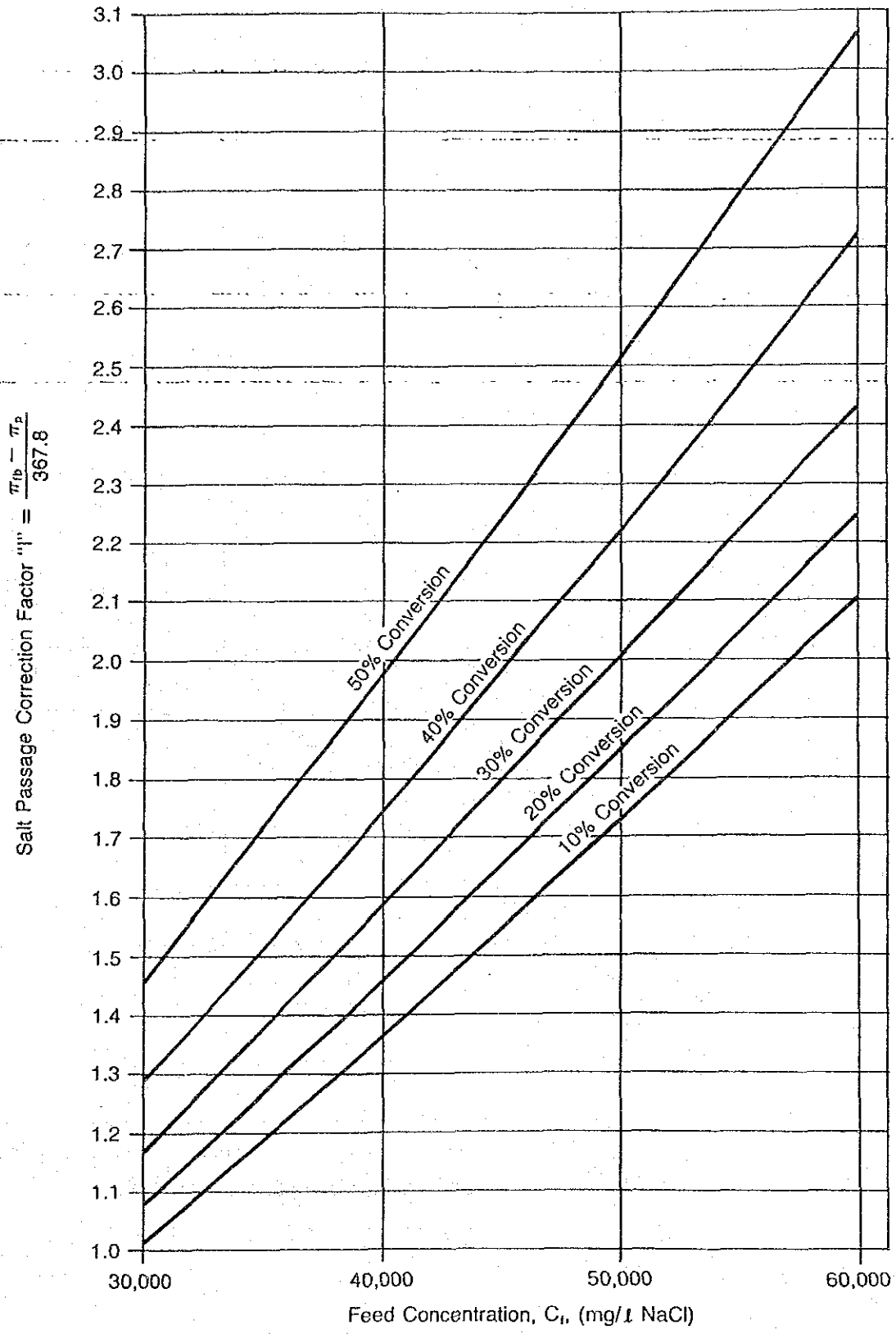


Figure 15. Salt Passage Correction Factor "J" for B-10

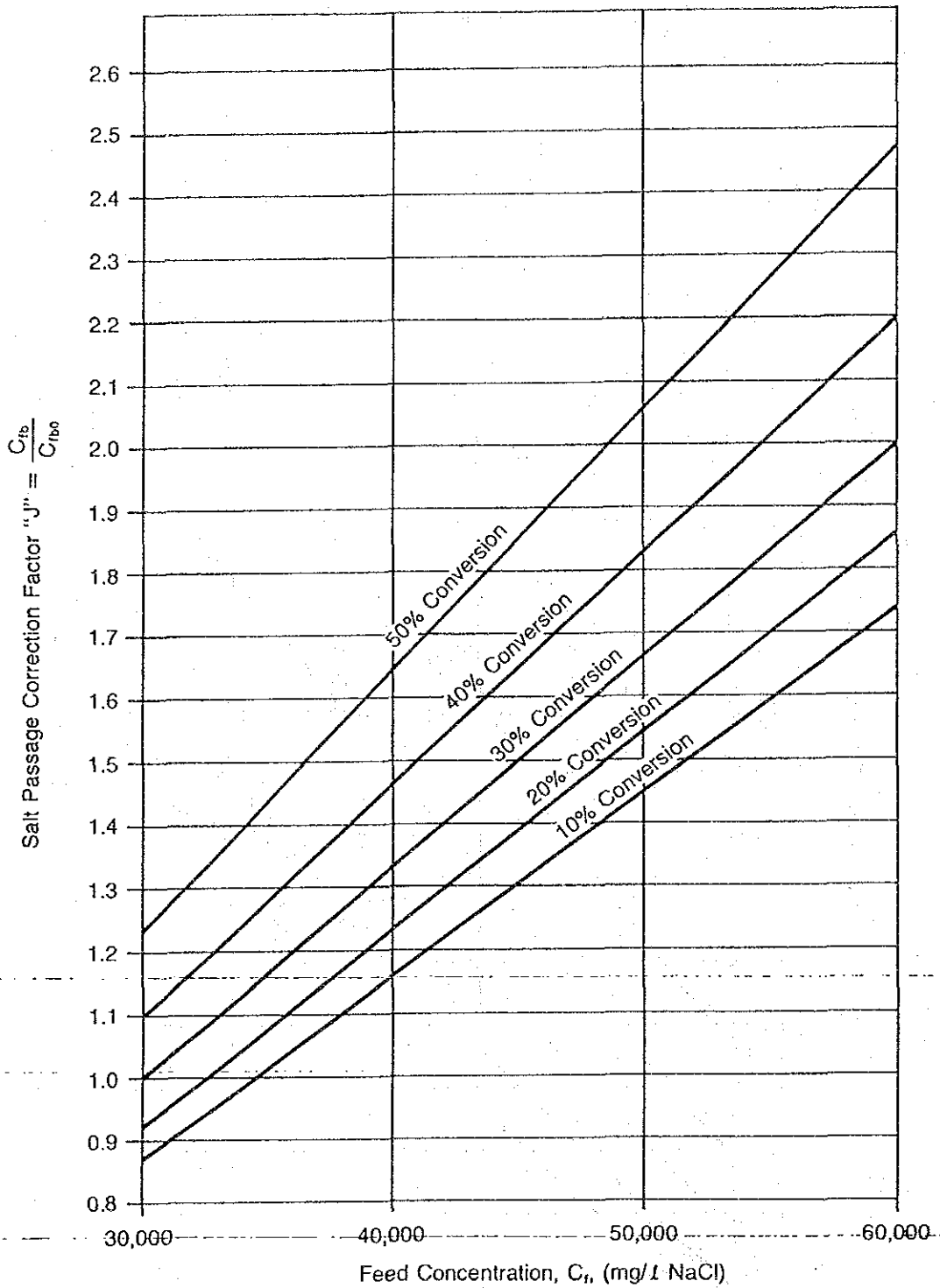
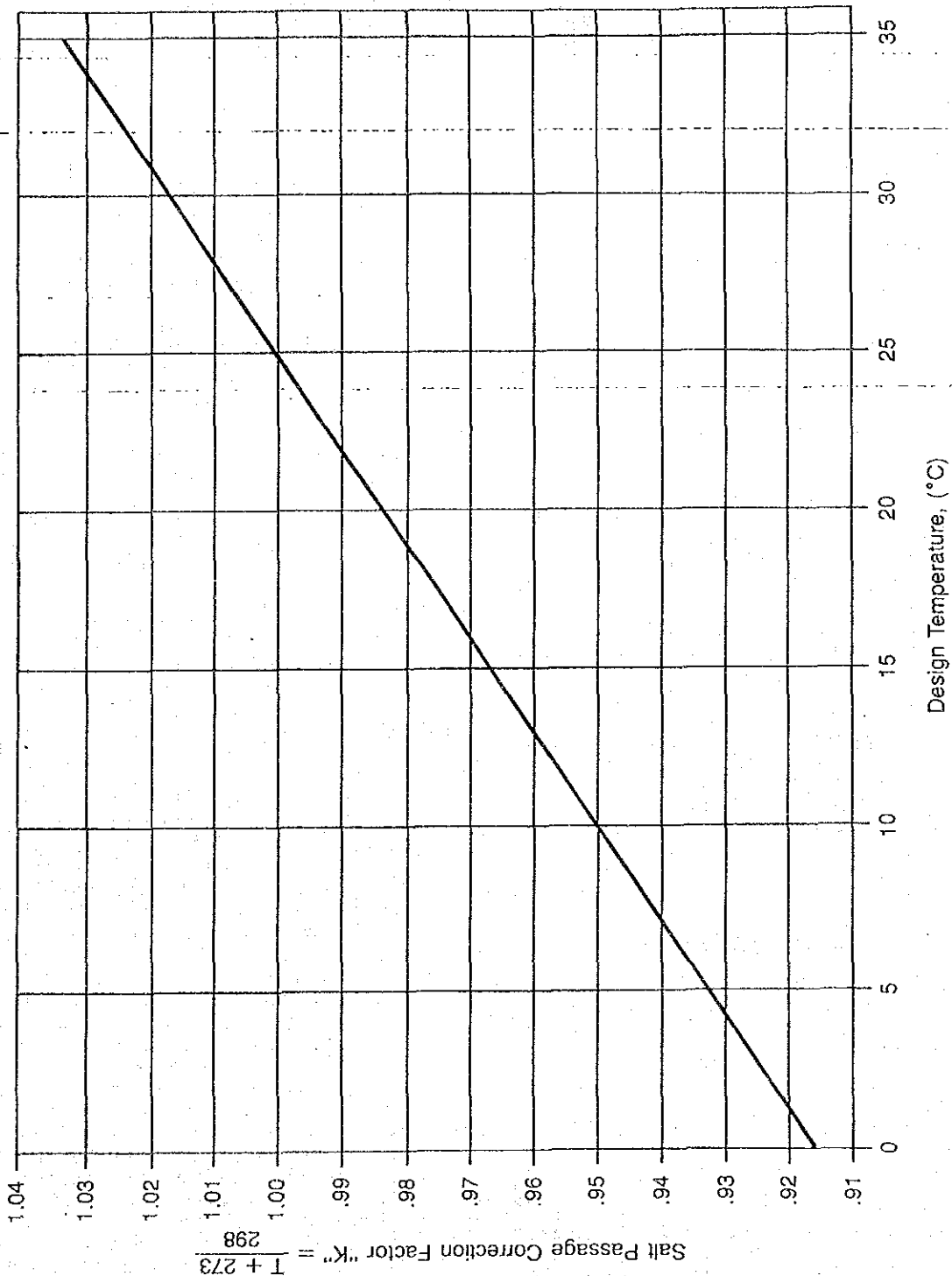


Figure 16. Salt Passage Correction Factor "K" for B-10



CAUTION: Follow manufacturers' recommendations on containers or in product bulletins for the safe handling of all chemicals and cleaning agents used with "Permasep" permeators. The information contained herein is based upon technical data and tests which we believe to be reliable and is intended for use by persons having technical skill, at their discretion and risk. Since conditions of use are outside Du Pont's control, we can assume no liability for results obtained or damages incurred through the application of the data presented. This information is not intended as a license to operate under, or a recommendation to infringe, any patent of Du Pont or others covering any material or use.

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SEAWATER RO SYSTEM DESIGN WITH "PERMASEP" PERMEATORS

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A. INTRODUCTION

To achieve satisfactory performance, each end-use application of B-10 permeators needs individual consideration. The fundamental elements needed to insure satisfactory performance are:

- Complete and accurate information about the feedwater and the operating conditions.
- A well-designed pretreatment system.
- A properly designed RO system.
- Correct plant operation and maintenance.

Seawater reverse osmosis (RO) systems are composed of basic, easily obtainable water-treatment equipment. Selecting the proper components is a key to a successful installation. This bulletin discusses seawater RO system design with "Permasep" B-10 permeators, including:

- Single Permeator Systems
- Multiple Permeator Systems
- Auxiliary Systems
- Energy Recovery Systems

- Materials of Construction
- Large Systems

Seawater RO systems require different design elements than those necessary for brackish water RO systems. Greater emphasis is placed on materials of construction and protecting the membrane during shutdowns. In addition:

- Pretreatment is usually not as extensive.
- Pumps, piping and instrumentation must be capable of greater corrosion resistance.
- Higher operating pressure is used in some portions of the system.
- An adequate supply of product water is required in a draw-back tank to prevent fiber dehydration at shutdown.
- A fresh-water flush that removes highly saline water from stainless steel portions of the system at shutdown is necessary to prevent corrosion.

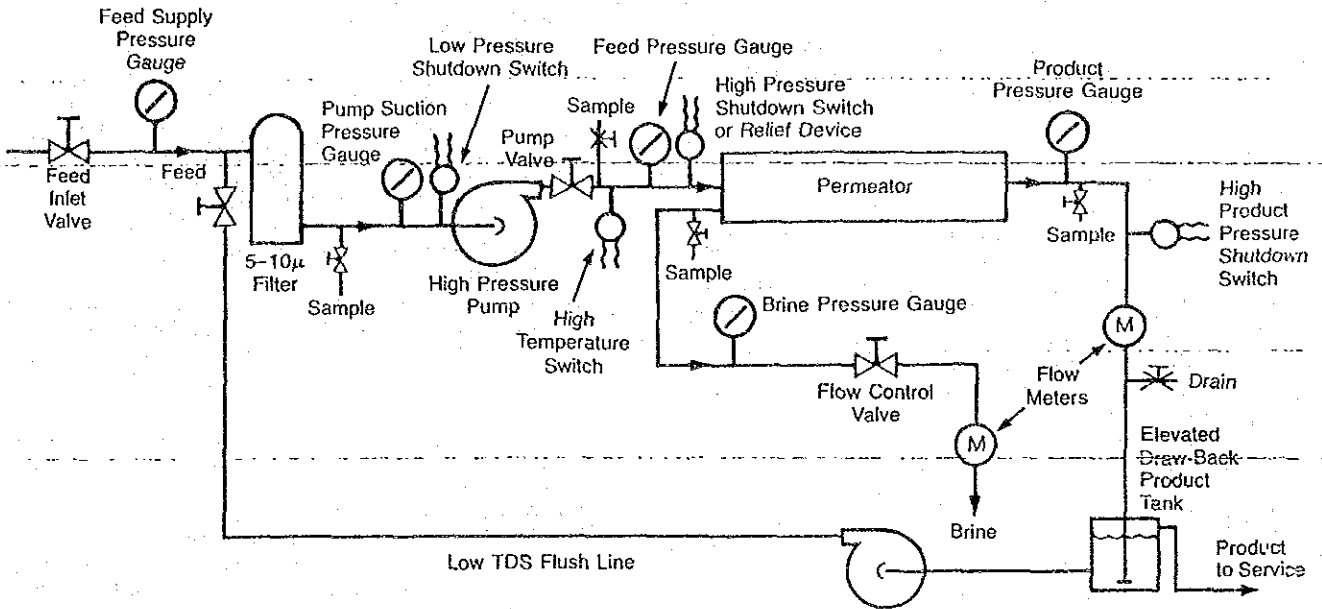
B. SINGLE PERMEATOR SYSTEMS

In its simplest design, a reverse osmosis system consists of a pump to pressurize the feedwater, a permeator, and a flow-regulating valve on the brine outlet to control conversion. A typical RO plant uses this basic design in modular form to achieve the desired capacity and water quality.

Figure 1 illustrates a single permeator system. Feedwater enters the system through the inlet valve and flows through the cartridge filter to the high-pressure pump. From the high-pressure pump, the feedwater flows to the feed-inlet connection of the permeator. Two water streams are shown leaving the permeator. The product stream should leave the permeator at essentially atmospheric pressure. Back pressure in the product stream from the permeator will reduce productivity. Brine leaves the brine-outlet connection at a pressure close to the feed pressure. Pressure drop across the permeator from feed inlet to brine outlet will usually be 35 to 138 kPa (5 to 20 psi). Brine flow rate is controlled by the brine flow control valve. An automatic pressure control valve should not be installed in this line. A drop in feed pressure would cause the valve to close and prevent brine flow from the permeator. This would result in operation at 100 percent conversion and would lead to precipitation of the minerals in the feed supply. The components of a basic RO system as shown in Figure 1 are:

1. **Feed-Inlet Valve**—This valve is used to stop the feedwater flow whenever the plant is shut down.
2. **Cartridge Filter**—A five- to ten-micron cartridge filter is used to remove large particulate matter that could damage the high-pressure pump or cause device plugging. The filter should be sized for a flow rate of 5 to 10 m³/h/m² (2 to 4 gpm/ft²) of filter medium surface area.

Figure 1. One Permeator Plant

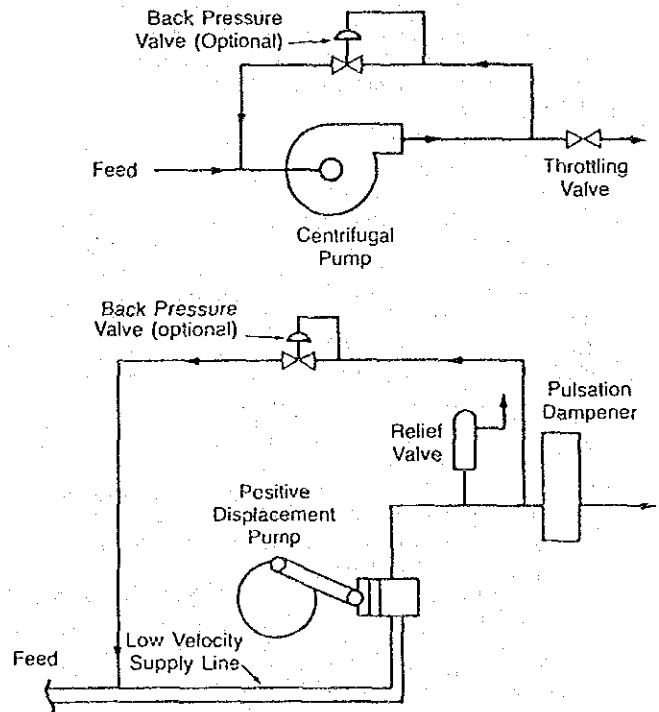


3. **High-pressure Pumps**—The two basic types of pumps generally used in RO systems are centrifugal and positive displacement, see Figure 2. The pump choice is at the designer's option.

- **Centrifugal Pumps (CP)**—Centrifugal pumps are the nearly universal choice for providing RC feed pressure in large B-10 systems. They are less complex than positive displacement pumps. A throttling valve in the pump discharge line is normally used to control the feed pressure to the permeator, but a variable speed electric motor drive can also be used. A back-pressure valve sized for about 10 percent of the total flow is used to "fine tune" the system by recirculating the excess flow when the pump capacity is greater than that needed to supply the permeator.

- **Positive-displacement Pumps (PD)**—Positive displacement pumps are frequently used in small and medium sized B-10 systems. They are also available for large systems. PD pumps are offered by many manufacturers and provide better operating efficiency than centrifugal pumps for the required 5,520 to 6,900 kPa (800 to 1,000 psig) service. Since PD pumps cannot be throttled, a relief valve is required on the discharge line. There must not be any positive flow restrictions such as a shut-off valve between the pump and the relief device. A back-pressure valve located on the recirculation loop can be used to control system pressure when the pump capacity is greater than that needed to supply the permeator. A pulsation dampener, sometimes called an accumulator, is recommended on the pump inlet and discharge lines to dampen pressure variations. If a low-flow velocity (1 to 2 fps) positive-pressure, suction head supply line is used; a pulsation dampener is usually not required on the inlet line.

Figure 2. Centrifugal and Positive Displacement Pumps: Typical Piping Configurations



4. **Shutdown Switches**—The permeator must be protected against high feed pressure, high temperature exposure and high product pressure. The pump must also have sufficient feed volume to prevent cavitation. The following system shutdown switches are recommended to avoid exposing permeators to conditions in excess of design limits:
 - High feedwater pressure shutdown.
 - Low feedwater pressure. Low feed pressure to the pump can cause damage to the pump.
 - High feedwater temperature shutdown.
 - High product pressure shutdown. To insure that the 50 psig product pressure guideline and the pressure rating of the piping are not exceeded, a pressure-relief device should be installed in the product line.
5. **Valves**—A flow-control valve in the brine stream is used to set conversion. An automatic pressure control valve should not be used. If the RO supply pressure were low enough, an automatic valve would close. This would result in operation at 100 percent conversion and thus cause scaling in the permeator.

Flow measurements should be used to set and control conversion. If needle valves are used in the brine stream, care must be exercised to insure that the valves do not plug.

Conductivity measurements should not be used to set conversion; this could result in improper brine flow rates and subsequently affect system performance.
6. **Meters and Gauges**—Meters are required to measure brine and product flow rates. Gauges are used to determine the pressure drop across the cartridge filter, the suction pressure at the pump inlet, the feed pressure to the permeator, the pressure drop between the feed and the brine, and the pressure in the product line. Liquid-filled gauges should contain permeator-compatible chemicals such as glycerine or water in place of oils or similar water-immiscible liquids. The accuracy of all meters and gauges is critical. Calibration on a regular maintenance schedule is strongly recommended.
7. **Auxiliary Equipment**—If acid is used to adjust the feed pH, a high and low pH shutdown switch in the feed stream is recommended.
8. **Sample Valves**—Sample valves in the product and brine stream are used to monitor permeator performance. A sample valve is also needed after the cartridge filter to permit sampling for determining the feedwater silt density index (*SDI*).
9. **Optional Equipment**—Various pieces of optional equipment can be useful in monitoring and controlling the RO system. These may include:
 - Continuous feedwater temperature recorder after the high-pressure pump.
 - Continuous *SDI* (Silt Density Index) monitor in the feed line before the high-pressure pump.
 - Continuous pH recorder in the feed line in front of the high-pressure pump.
 - Chlorine detection monitor with automatic shutdown before the RO pump.
 - Hour meter connected to the RO pump motor.
 - Differential pressure gauge between the feed and brine outlets of the permeator.
 - High product and brine conductivity alarms.
10. **Piping**—Design of the piping arrangement should include the following aspects:

- Minimize stresses at connections.
- Insure resistance to corrosion.
- Consider cost of materials.
- Protect plastic piping from vibration and water hammer.
- Design the racks to minimize the chances of accidental physical abuse of the piping.

11. **Straps**—Permeator mounting or retaining straps must be used. Excessive tightening of permeator mounting straps or retaining "U" bolts can cause distortion of the permeator shell resulting in O-ring seal leaks. Permeators can be mounted in any position. If mounted vertically, however, the product end should be down.
12. **Product Lines**—A drain point in the product-water line for use during the start-up and cleaning is required. Chlorine-free water such as permeate is required for flushing piping, pumps and permeators.

C. MULTIPLE PERMEATOR SYSTEMS

Most RO systems require more than one permeator to produce the desired quantity and quality of product water. Three basic permeator arrangements have been developed to solve most desalting problems. The nature of the feedwater and product quality specifications will usually dictate which arrangement is used. The pumps, valves, gauges, meters, etc., required for multiple permeator systems are the same as those needed for single permeator systems.

1. Parallel Single-staged Systems

Almost all B-10 small seawater designs will call for "single-stage" multi-permeator systems, as shown in Figure 3. A major difference between a single permeator system and the parallel configuration is the connection to common manifolds of feed, product and brine, as shown in Figure 4. Overall system controls are the same as in a single permeator system. Note that conversion for the entire system is controlled by a single valve in the brine manifold (Figure 3).

Flow balancing tubes are used to induce artificial pressure drops in the piping across each permeator that will equalize brine flow rates in any multipermeator parallel array. Slight differences in pressure drop among permeators operating in parallel could otherwise cause significant differences in brine flow rates. The flow-balancing tubes minimize the differences in conversion from permeator to permeator. A minimum pressure drop of 240 kPa (35 psig) for single-stage systems is recommended. Stainless steel tubing is usually used for flow-balancing tubes for B-10 Permasep[®] permeators. Figure 5 illustrates the expected pressure drop for various sizes and types of tubing.

In addition to the sample valves in the product and brine lines for each single permeator, sample valves are also required on the feed, product and brine manifolds in the parallel configuration for monitoring overall system plant performance.

2. Brine-staged Systems

Brine staging is rarely used for seawater B-10 systems since the TDS level of the first-stage brine is usually too high to make a second stage practical. When staging is necessary, however, design of such a system follows the same general rules as for B-9 systems. See

Figure 3. Single Stage Parallel System

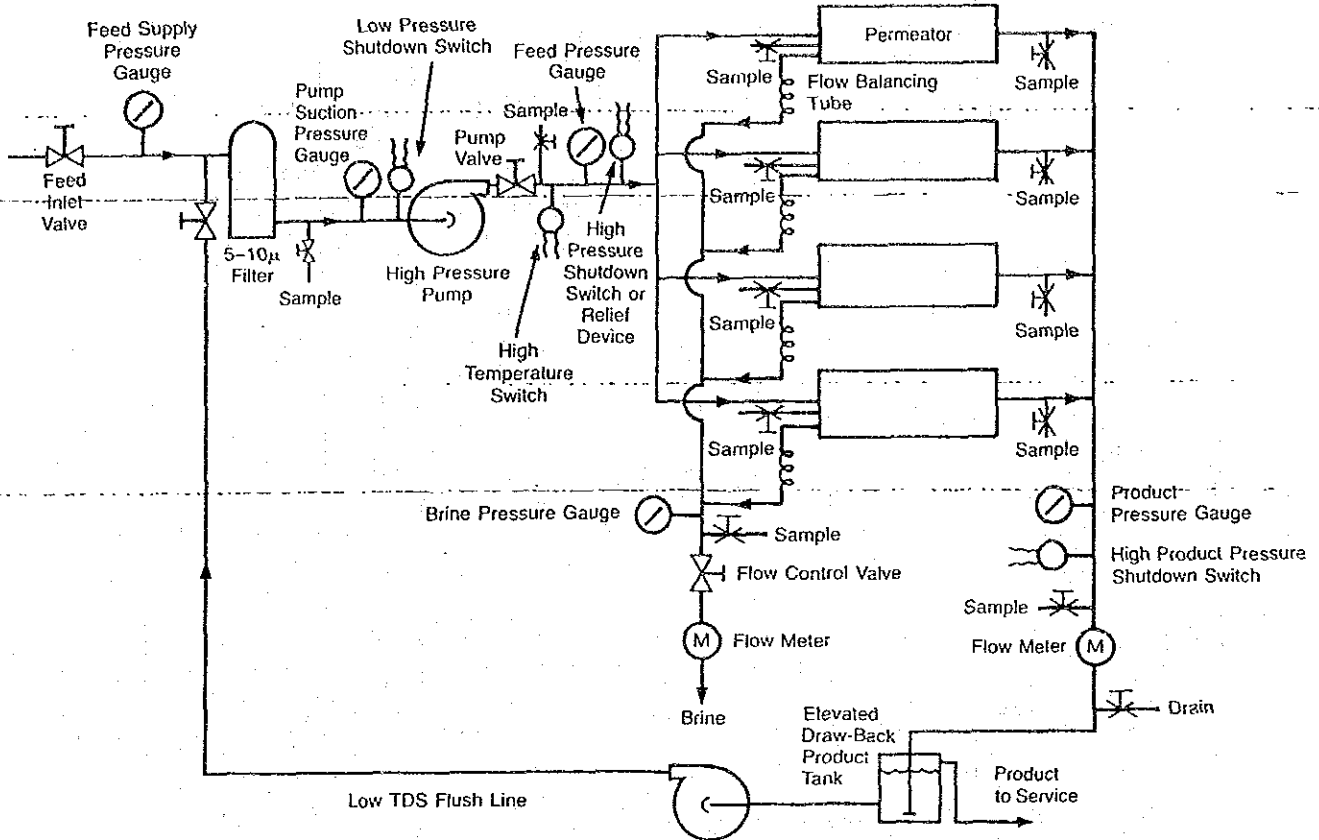


Figure 4. Permeator Manifold Piping Arrangement

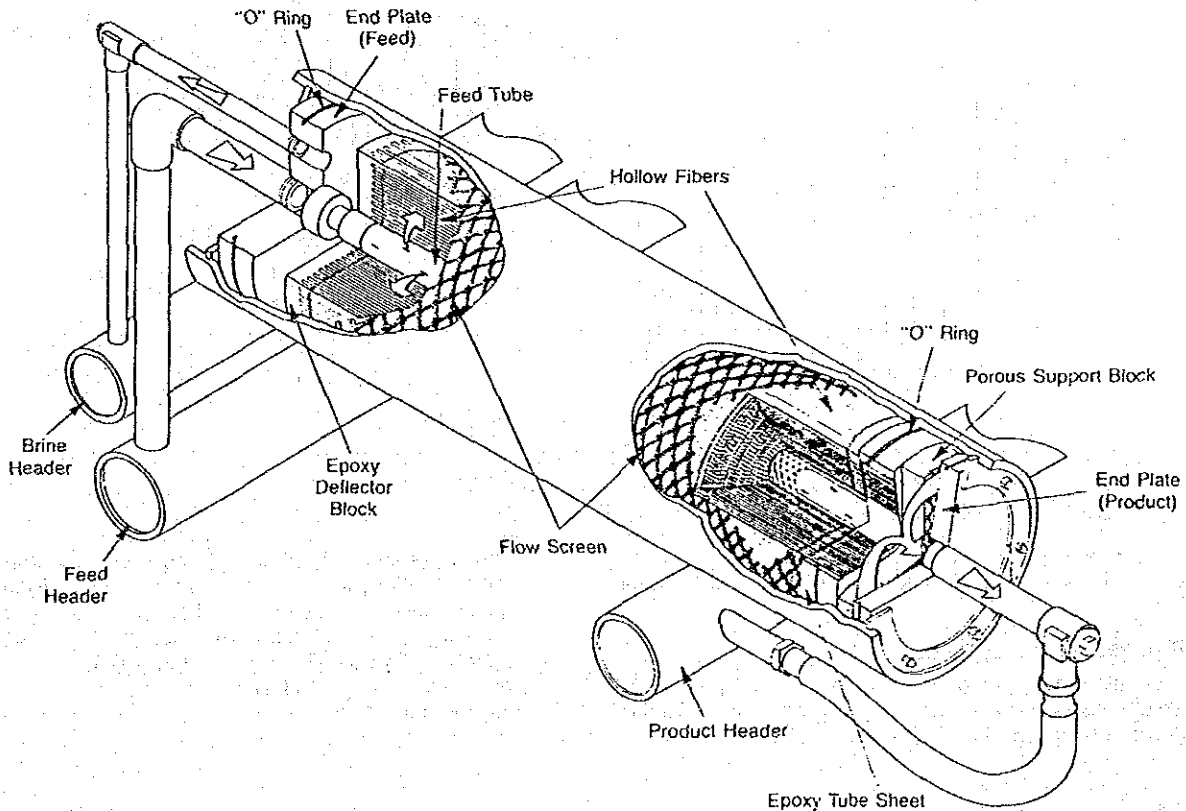
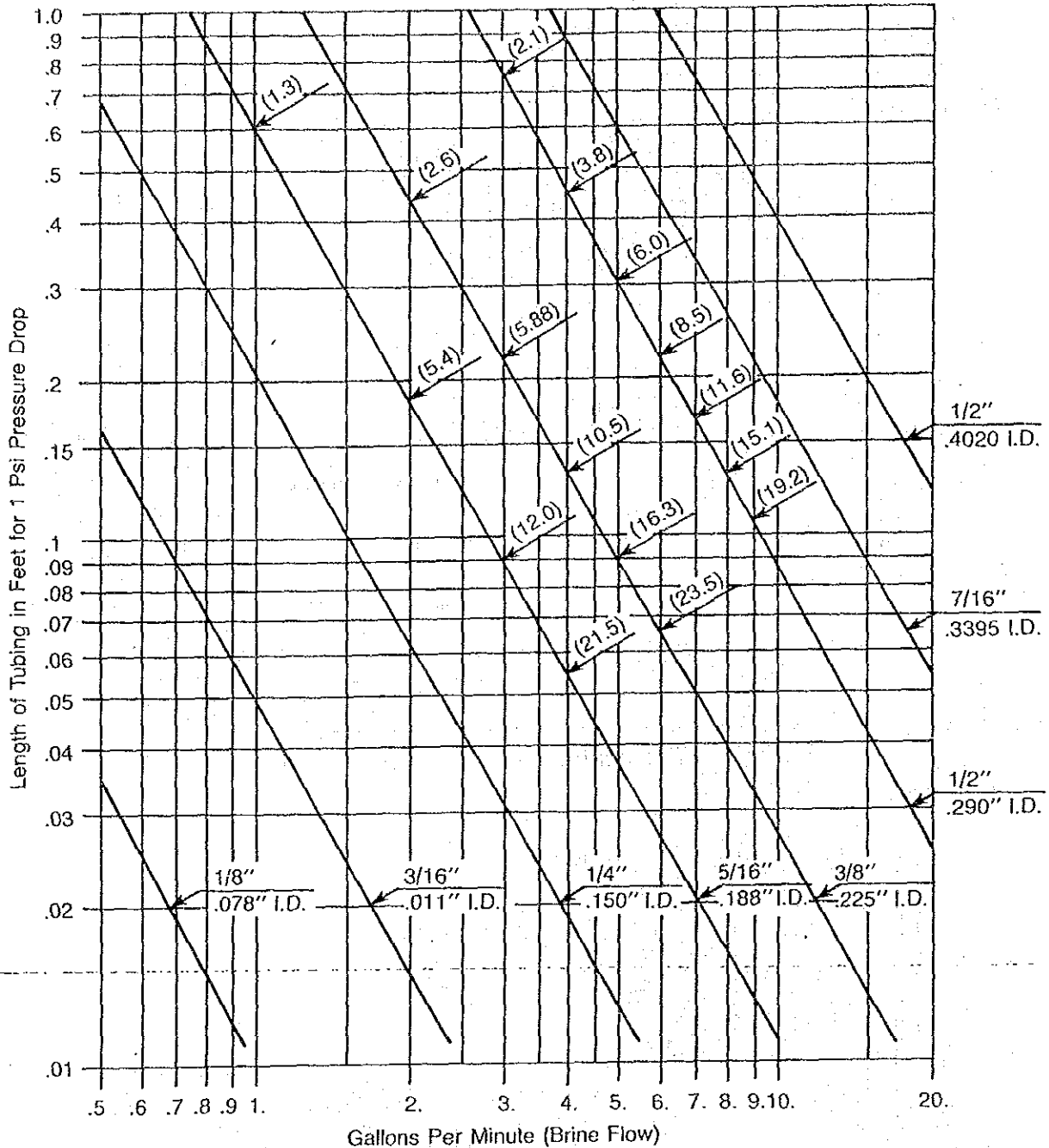


Figure 5. Pressure Drop (ΔP) Through Tubing



- 1.) Figures in Parenthesis are Additional Pressure Drops for Entrance and Exit Losses. (In psi)
- 2a.) Tubing at Less Than .290" I.D. is Type H Nylon—2500 psi Burst Rating.
- b.) Tubing of .3395 I.D. and .4020 I.D. is Stainless Steel.

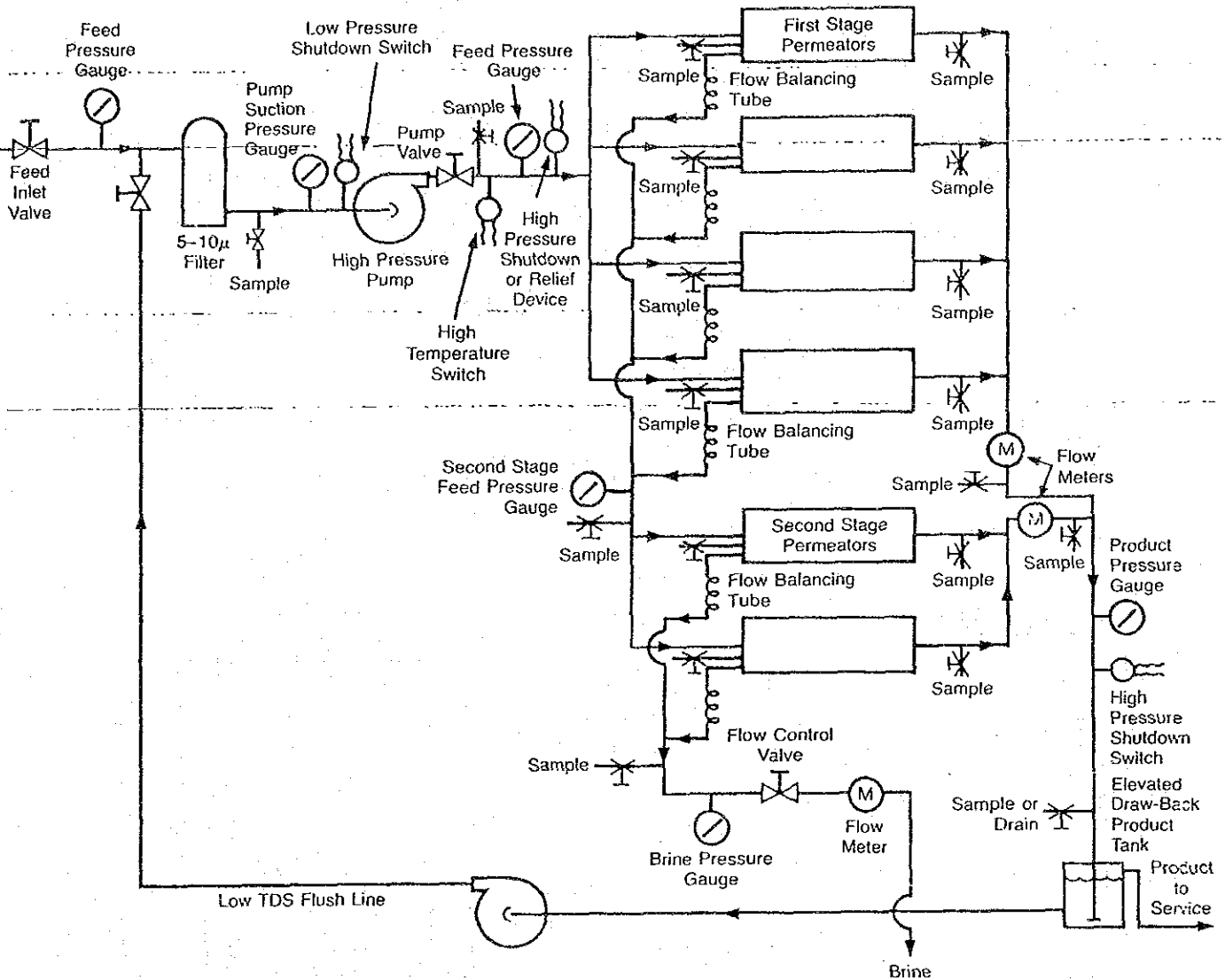
Bulletin 303. B-10 brine staging as shown in Figure 6 could be used in some highly brackish feedwater applications.

3. Product-staged Systems

Product staging can be used when a single-pass RO system does not yield the desired product quality. This design option consists of placing two RO systems in

series, as shown in Figure 7. The product water from the first RO system becomes the feedwater for the second system. Each system is a separate RO plant requiring its own high-pressure pump. Each system may be either single-staged or brine-staged. Since the brine from the second system has a lower TDS than the raw feed to the first unit, it can be recycled and added to the feedwater of the first system.

Figure 6. Brine Staging



The storage tank between the systems must be covered and vented to prevent contamination by dust or biological organisms. Since B-10 permeators operate at 1.5 percent maximum salt passage (at standard test conditions), the TDS of the first stage product is usually less than 1,000 mg/liter. Therefore, a lower pressure 2,760 kPa (400 psig) B-9 system provides a very efficient second stage. The final product water generally contains less than 100 mg/liter (ppm). Second pass conversions with B-9 system often reach 90 percent. If the second stage does operate at high conversions, it will usually be brine-staged in order to meet good hydraulic flow design practice.

D. AUXILIARY SYSTEMS

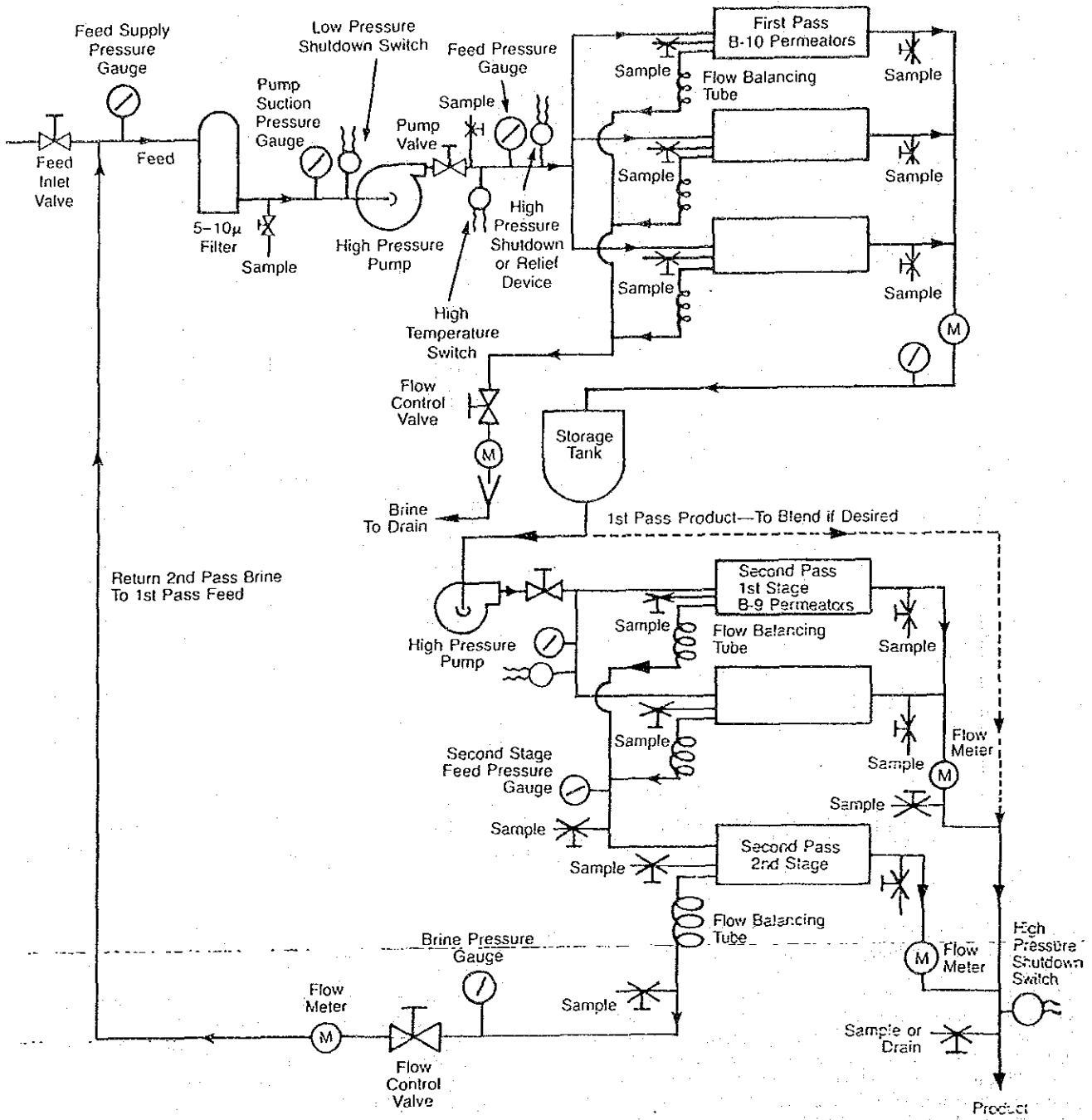
1. Shutdown Systems

High-salinity feedwater should be flushed from the stainless steel components and permeators after shutting down a B-10 system for the following reasons:

- Corrosion of stainless steel components in stagnant seawater is very high.
- Sequestrants produce a metastable state with respect to precipitation of sparingly soluble salts. Upon shutdown, precipitation can occur within four hours if the permeators are not flushed.
- Upon shutdown, reverse osmosis will cease and natural osmosis will occur. Natural osmosis is a process in which water flows from the fiber bore to the fiber feed-brine side (Figure 8). If an adequate volume of product water at positive pressure (draw-back tank) is not supplied, fiber dehydration could occur. Flushing the permeators with low TDS water at shutdown will also prevent natural osmosis. However, a draw-back tank is highly recommended as an additional precaution in case of an unexpected shutdown.

Figures 3, 6 and 7 all show the location of a suitably sized product water storage tank that can be used for these purposes. The tank should be elevated above the highest permeator. However, it should not exceed a positive head of 350 kPa (50

Figure 7. Product Staging



psig) on the lowest permeator. The tank must be large enough to provide sufficient water for system flushing and permeator draw-back using the following guidelines:

- About 0.011 m³ (3 gallons) for a 4-inch B-10 permeator
- About 0.038 m³ (10 gallons) for a 8-inch B-10 permeator

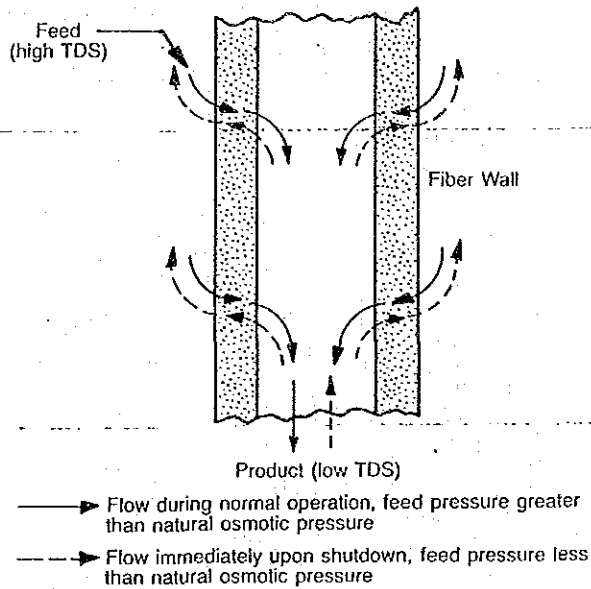
In addition, about 5 times the volume of system piping, filters, etc., will be needed to flush the system.

2. Cleaning, Sterilizing and Flushing Systems

Reverse osmosis systems, like most other water-treatment equipment, occasionally need cleaning, sterilizing or flushing. Permanent equipment, properly sized for the particular system, can handle all of these auxiliary operations. Figure 9 is a schematic of this equipment.

RO systems are generally designed with several control blocks which can be operated independently from other control blocks. RO systems are usually treated one block at a time to minimize plant downtime. For large installations, the treatment equipment is sized

Figure 8. Natural Osmosis and Draw-back at Shutdown of a B-10 System



for some fraction of the system capacity.

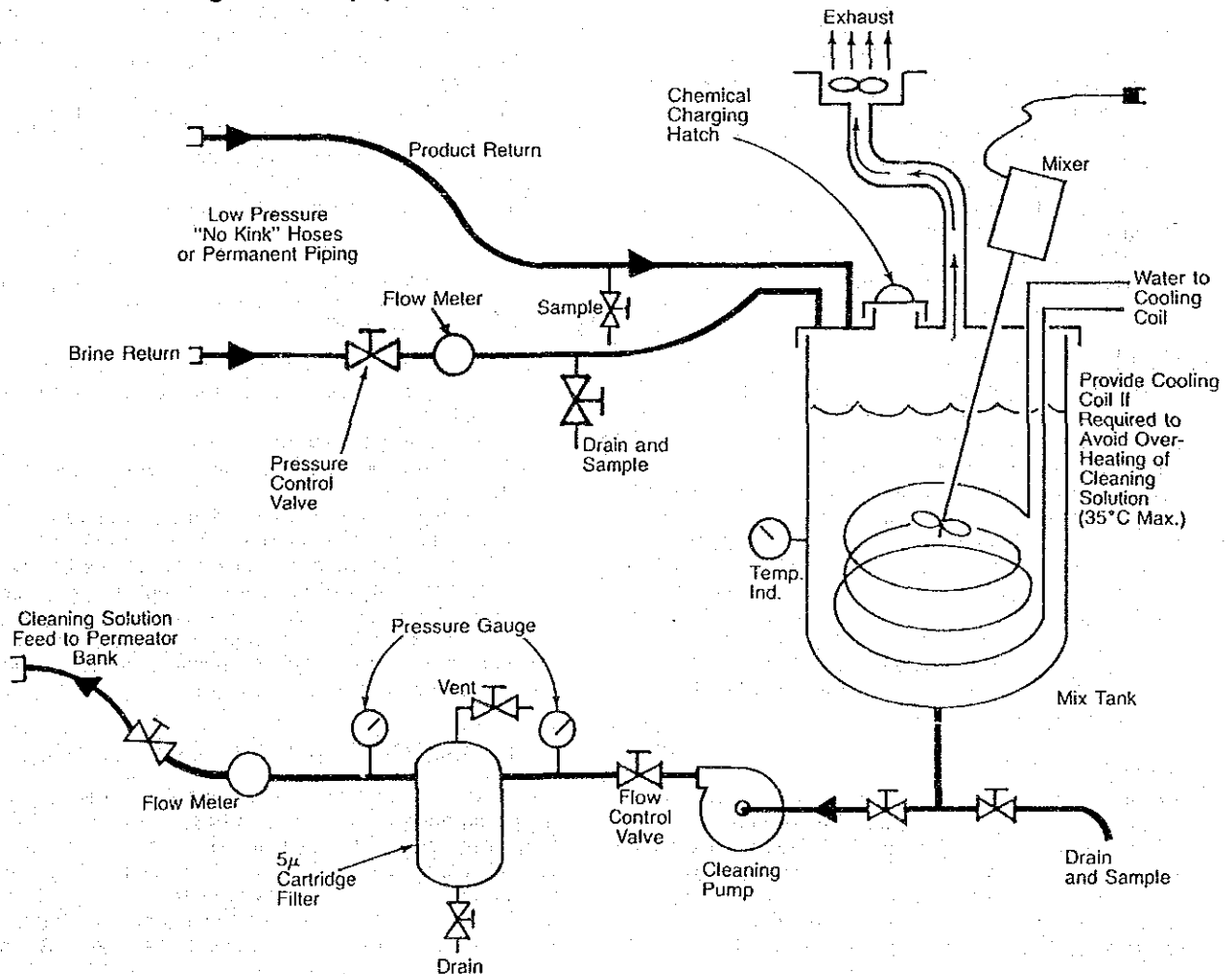
The mix tank should be made of non-corrosive materials such as reinforced plastic. The tank should be sized for at least a three-minute retention time, considering the number of permeators to be cleaned at one time and the volume of liquid in the cleaning pump and piping.

A tank cover, exhaust fan, mixer, and in some cases, a cooling coil should be provided. A temperature indicator and alarm assures that the temperature of the cleaning solution does not exceed 35 degrees C during the closed-circuit circulation of the cleaning fluid. Heat added by pumping will cause a rise in fluid temperature.

The pump should be stainless steel for compatibility with the anticipated fluid reagents. A centrifugal pump is desirable for ease of operation and safety. Thin-walled hoses which have a tendency to kink should be avoided.

A 5- or 10-micron cartridge filter should be installed after the recirculation pump to avoid recirculating sediment which may dislodge from the system during the cleaning operation. Only one stage of a brine-staged system should be cleaned at a time so that material removed does not contaminate another stage.

Figure 9. Equipment for Cleaning, Sterilizing and Flushing



3. Additive Systems, General

a. Pumps

Positive-displacement diaphragm pumps or plunger pumps are generally used for adding acid, sodium hexametaphosphate, etc. Stainless steel (316), plastic or alloy 20 are the minimum acceptable materials of construction. These pumps should be sized to minimize surges in concentration of the additive in the feed stream. High-pressure relief devices must be provided for these pumps. In addition, a sample and drain tap should be provided on the discharge stream of an addition pump to allow for flow-rate calibration and for purging air to prevent vapor locks.

b. Check Valves

These systems should also be equipped with check valves and an anti-siphon device to prevent the additive from flowing into the feed stream on shut-down. A check valve is used to prevent back flow of feedwater into the additive tank. Also, positive-displacement diaphragm pumps and plunger pumps must be electrically interlocked with the RO pump-drive so that injection stops when the RO plant feedstream flow stops. The design should include devices and procedures to assure that the additive is in fact being injected at the designated dosage. The RO feedwater should be periodically analyzed to assure that the additive is present.

c. Mixers

One or more makeup tanks with appropriate mixing devices are needed for any chemical additive which must be diluted or dissolved. Uniform distribution of the additive solution in the feed stream is necessary for additives to be effective. Normal turbulence in the feed stream piping network, even when coupled with a central-stream injection nozzle, may not be sufficient for proper mixing. For this reason, an in-line static mixer is also recommended. Whenever possible, additives should be injected into the low-pressure system prior to the micron filter.

4. Chlorination Systems

Seawater from surface sources is usually chlorinated to control biological growth and then dechlorinated before entering the permeators. An automatic feed stream shutoff or a diversion valve is recommended for chlorinated feed streams to prevent accidental chlorination of the permeators. The feedwater stream supplying the high-pressure RO pump is pressurized by a feedwater supply pump, booster pump, or well pump. Pressurized feedwater can flow through a stopped centrifugal RO pump and into the permeators. Since additive pumps shut off immediately upon RO system shutdown, chlorinated stream flow must also be stopped immediately if dechlorination is by chemical (bisulfite) addition rather than by a carbon filter.

5. Cooling Systems

Seawater temperatures, at a given location, can vary greatly due to seasonal changes. The highest temperature is normally used as the design basis. For example, if a seawater source is assumed to fluctuate between 27 degrees and 35 degrees C, then an RO plant design would generally use 35 degrees C as the conservative design basis. This means that feed pressures

TABLE I
THE EFFECT OF FEEDWATER COOLING
ON PERMEATOR REQUIREMENTS
3,785 m³/d (1 MILLION GPD) PLANT

	No Cooling	Cooling
Feed TDS (mg/l)	39,500	39,500
Feed flow (m ³ /d)	16,450	12,630
B-10 Feed pressure (kPa)	5,520 (800 psi)	6,900 (1,000 psi)
B-9 Feed pressure (kPa)	2,760 (400 psi)	B-9 not required
Feed temperature (°C)	27-35	27
B-10 Conversion (%)	25	30
B-9 Conversion (%)	90	B-9 not required
Plant product flow (m ³ /d)	3,800	3,800
Plant product TDS	500	500
Permeator requirements, approximately	300 B-10 30 B-9	180 B-10

for the B-10 permeator would be limited to 5,520 kPa (800 psig) when the temperature is 35°C, at least for specific periods of time. Using the higher temperature often requires a two-pass system. At the lower temperature, however, a single-pass system would suffice since additional feed pressure could be used.

To lower the feedwater temperature and permit RO operation at higher pressures, feedwater coolers (chillers) are often recommended. The cost of cooling must be compared to the additional capital and operating cost of a system designed to operate at lower pressure.

The advantages of an RO system with cooling, operating at a constant feedwater temperature, compared to a fluctuating temperature design are shown in Table I and highlighted below:

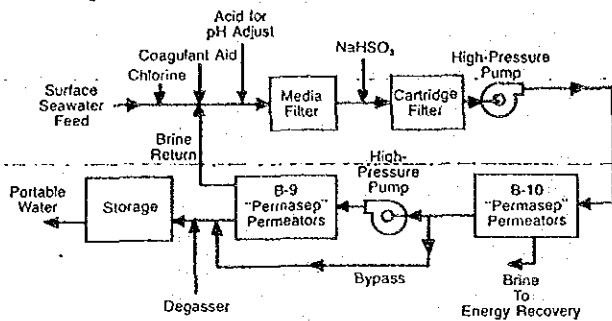
- Nearly 4,000 m³/d less feed flow and therefore, smaller pretreatment equipment and lower chemical consumption.
- Fewer B-10 permeators.
- No B-9 second stage required to meet product quality criteria.

Savings in capital, energy and chemical costs that result must be compared to the cost of the cooler (chiller) and the energy required to operate it. Costs to operate the B-10 section as its optimum pressure of 6,900 kPa (1,000 psig) must also be considered. At many sites the chiller would only operate during the hottest season. This economic balance will vary from case to case.

E. ENERGY RECOVERY SYSTEMS

Hydroturbines and impulse turbines are two devices for recovering energy from high-pressure hydraulic streams. They have been in use for many years in wide ranging applications, particularly in chemical refining and hydroelectric generation industries. Incorporating energy recovery equipment into RO system design is a logical and economically rewarding method for capturing the energy that

Figure 10. Large Seawater RO Plant Design



otherwise would be discarded with the high-pressure brine. Since seawater reverse osmosis systems operate at generally between 15 and 40 percent conversion, the remaining 60 to 85 percent of the seawater pumped into the permeator is discharged from the permeator as high-pressure brine. A flow diagram for a typical Middle East seawater system with energy recovery equipment is shown in Figure 10.

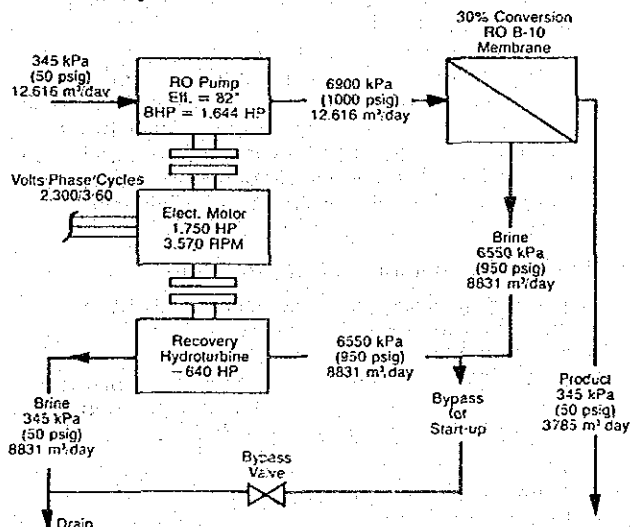
Seawater reverse osmosis systems such as depicted in Figure 10 usually operate at permeator feed pressures of 5,520 kPa (800 psig) to 6,900 kPa (1,000 psig). The brine stream is discharged from the permeators at pressures ranging from 5,175 kPa (750 psig) to 6,550 kPa (950 psig), carrying with it most of the original pumping energy.

Hydroturbines and impulse turbines are proven techniques for recovering hydraulic energy from liquid streams.

1. Hydroturbine

A process flow sketch for a 3,785 m³/day (1.0 million GPD) seawater plant incorporating a hydroturbine is shown in Figure 11. A hydroturbine is essentially a horizontal, split-case, multi-stage, centrifugal pump which runs backwards. Hydroturbines can be mounted on a common base plate with the high-pressure reverse osmosis pump. They can be directly connected to one end of the RO pump impeller shaft. The energy

Figure 11. 3,785 m³/Day (1,000,000 GPD) Permasep® Permeator Seawater RO System Hydraulic Power Recovery Turbine



recovered by the hydroturbine is shaft energy that is used to help turn the high pressure RO pump. The RO high-pressure pump and the hydroturbine are designed to operate at the same speed. The electric motor that drives the high-pressure pump operates at a constant speed and acts as the control device for the hydroturbine. The design technology for a hydroturbine is nearly-identical to that of centrifugal pumps. Consequently, most major centrifugal pump manufacturers can supply this type of equipment.

2. Impulse Turbine

The impulse turbine is the second type of energy recovery device for high-pressure hydraulic streams. It is also known as the "Pelton wheel," a wheel with a series of paddles or buckets attached to its circumference. A high-pressure water stream directed at the buckets on the wheel causes it to turn at high speed, generating mechanical energy. Small impulse turbines usually operate at very high shaft speeds (5,000 to 10,000 rpm), while very large impulse turbines usually operate at relatively low shaft speeds (200 to 1,000 rpm).

Impulse turbines can be connected to induction motor/generators which generate electricity that is returned to the power grid. When driven at slightly above its synchronous speed, an induction motor becomes a generator (in this case, driven by the impulse turbine). This is an unusual characteristic of an induction motor. The induction motor/generator will operate at the proper frequency without a governor or speed control as long as the generator power input to the electric supply grid is only a small part of the power generating capacity for the grid.

The combined efficiency of the impulse turbine/generator package is about equal to the efficiency of the hydroturbine. The impulse turbine/generator system will usually have a higher capital cost than the hydroturbine because the turbine/generator system consists of two pieces of equipment.

3. Energy Consumption

Large seawater RO plants with energy recovery equipment require only one-half to one-third the energy required by the most efficient MSF distillation plant and only two-thirds the energy required by vapor compression (VC) processes.

Energy and power requirements for a 3,785 m³/day (1.0 million GPD) seawater RO plant are shown in Table II. The energy users for a typical seawater reverse osmosis process are listed below:

- Seawater pump
- Additive pump (injector)
- Filtered water pump
- Reverse osmosis pump (high-pressure pump)
- Second-stage reverse osmosis pump (a second RO stage may be required if feed TDS exceeds 40,000 mg/l)
- Product water degassing blower.
- Product water distribution pump

About 30 percent of the overall energy input is recovered with energy recovery equipment. As plant sizes increase, this percentage should increase with the generally higher efficiency of larger size pumps and motors.

It should be noted that the power consumption for

TABLE II
SEAWATER RO SYSTEM¹
ENERGY POWER REQUIREMENTS
3,785 m³/day (1.0 million GPD)

	Pump flow m ³ /min.	Pump Eff. %	Pump Head Flow	Motor HP (90%) Eff.	Motor Kw	kWh/m ³ of Product Water
Sea Pump	8.8	80	115	95.9	71.5	.45
Additive Pumps	—	—	—	4.0	3.0	.02
Filter Water Pump	8.8	80	115	95.9	71.5	.45
B-10 RO Pump	8.8	80	2,079	1,726.0	1,287	8.16
Degas	—	—	—	4.0	3.0	.02
Product Pump	2.8	80	115	28.1	21.0	.13
B-9 RO Pump	1.2	80	924	97.6	72.8	.46
Energy Recovery Turbine	6.9	80	1,963	-630.7	-470.3	-2.98
TOTAL				1,420.8	1,059.5	6.71

¹Basis:

- Conversion of seawater to product water = 30%
- Feedwater TDS is 42,000 mg/l
- RO feed pressure is 6,210 kPa (900 psig) for B-10
- Feedwater temperature is 26 to 32 degrees C.

smaller RO seawater desalting systems may be higher than the values given in Table II because centrifugal pump efficiencies tend to decrease as pump size decreases.

F. MATERIALS OF CONSTRUCTION

1. Introduction

Metal corrosion can be a serious problem in many water treatment processes. All RO devices are particularly sensitive to metal corrosion products (see Bulletin 503, Pretreatment for Metal Oxides). If corrosion is not controlled, premature failure of the RO system will result. When designing a plant, the degree of corrosion and the effect it will have on the RO system must be carefully considered. The most effective way to minimize corrosion in an RO plant is to limit the use of metal. Non-metallic materials should be used on all wetted parts wherever they are practical and economical.

2. Metallic Materials of Construction

The corrosion rate of metallic materials is a complex phenomenon depending on the material itself and the environment to which it is exposed. Factors such as dissolved gasses (O₂, CO₂, H₂S), anions (Cl⁻, SO₄²⁻), and pH affect the rate and type of corrosion on a particular metal surface. Further, use of dissimilar metals in a connected system can lead to galvanic type corrosion if protective measures are not applied. Experience has shown that corrosion is high at threaded pipe connections. Therefore, this type of connection should be minimized. Where threads are required, the use of chemically compatible materials such as epoxies to fill thread voids when making the joint should be considered. The following precautions should be considered for specific metals:

- **Carbon Steel**—Carbon steel and other similar ferrous materials such as black, cast and wrought irons should be avoided since experience shows that

severe corrosion occurs with their use. If these materials are employed upstream of the permeator, proper pretreatment (Bulletin 503) must be used to prevent metal oxide fouling.

- **Stainless Steel**—Stainless steels are generally proven to be more corrosion resistant than carbon steel. In particular, Type 316, 316L and higher alloy stainless steels have been successfully used in many B-10 plants for piping, pumps and vessels. When corrosion of stainless steel does occur, it is usually localized and in stagnant flow zones, i.e., crevices. Crevices should be avoided. When designing and fabricating stainless steel pipe and equipment, a designed water flow of greater than 1.5 m/s (5 fps) should be used. Stainless steel can be corroded by the presence of bacteria which produce slimes that block the flow of water across metal surface and cause high salt concentration regions to form. This can occur during pipe fabrication and testing or when a plant is shut down for an extended time period. Therefore, proper sterilization procedures should be followed (Bulletin 509).
- **Non-ferrous Metals**—Galvanized lining is not recommended for piping or equipment. Experience has shown that the protective layer can be short lived. In general, copper, bronze, brass and aluminum also should be avoided since they can cause metal oxide fouling within RO devices. Nickel-aluminum-bronze alloys have been successfully used in plunger pumps.

3. Non-metallic Materials of Construction

Engineering plastics, plastic composites, glass, concrete, rubber and ceramics are desirable materials of construction which avoid metal corrosion. When these materials are used, they must be properly applied for the intended service. Factors to be considered in the selection and use of non-metals include:

- Pressure rating
- Thermal expansion and contraction
- Temperature rating

- Chemical compatibility
- Mechanical integrity

4. Non-metallic Liners and Coatings

Non-metallic liners and coatings such as phenolics, epoxies, rubber, acrylics, and glass are frequently used to protect pipe and equipment from corrosion and chemical attack. In selecting and applying the liner or coating, the following factors must be considered:

- Thermal expansion and contraction
- Chemical compatibility
- Temperature rating
- Mechanical integrity

The integrity of the coatings is the key to preventing problems. The base material must be totally (100 percent) covered. Pinhole leaks and unprotected flanges and crevices can result in shortened life for the pipe, equipment and permeators. Because epoxy paint tends to chip and expose the metal, this type of coating is not recommended.

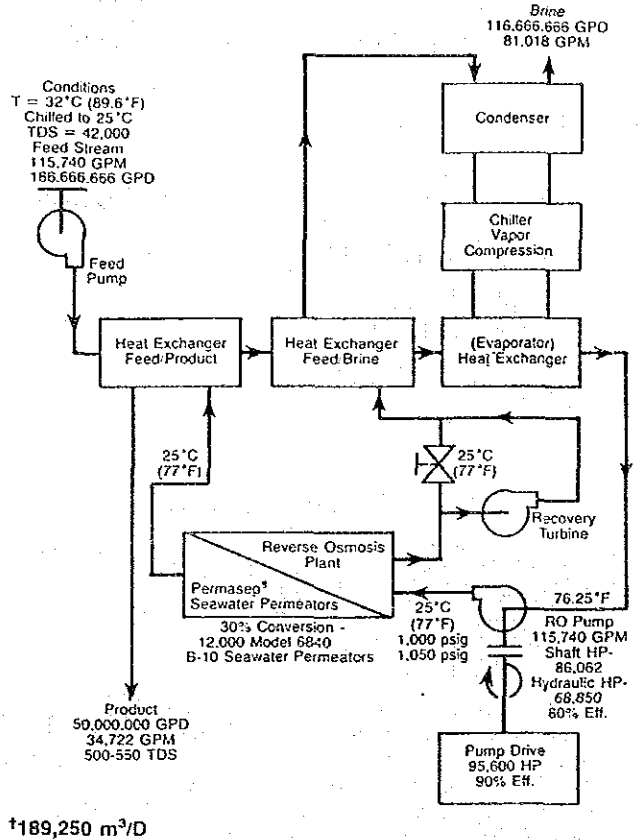
G. LARGE SYSTEMS

RO systems are generally designed with multiple blocks or modules. The modules are self contained and are connected either to an independent feed pump or by pipeline to a feed header. With this configuration a portion of the plant can be shut down via valves without interrupting other blocks. There is no restraint on the size of a single block. The larger the block, the larger and more efficient the pumps and recovery equipment. Five to ten million GPD blocks are conceivable in 40 to 50 million GPD plants.

Today's technology also permits design of an entire 50 million GPD plant in one block. Although this approach is not usually recommended for designing a plant of this size, high-pressure pumps and hydraulic turbines are available in sizes which have been proven reliable in operation of municipal water systems at similar volumes for many years. Figure 12 is a schematic of a 50 million GPD design.

If feedwater cooling is required, a heat pump system should be considered. These large plants could operate

Figure 12. Du Pont Permasep® Products (50 Million GPD)[†] Seawater Reverse Osmosis Plant



†189,250 m³/D

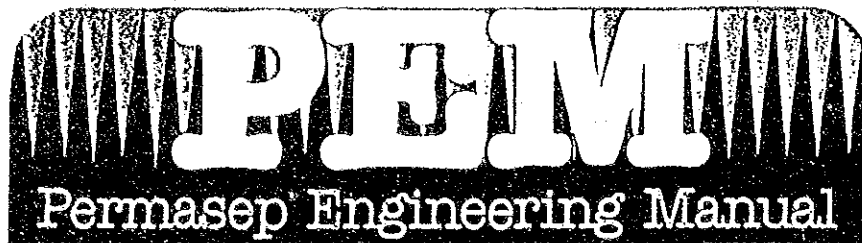
reliably 90 to 95 percent of the time. Equipment capable of handling these flow rates is commercially available.

REFERENCE

1. Landrum, R. J. "Materials of Construction Guide for 'Permasep' Seawater RO Systems," December 31, 1980. Published by E. I. du Pont de Nemours & Co., Inc.

CAUTION: Follow manufacturers' recommendations on containers or in product bulletins for the safe handling of all chemicals and cleaning agents used with "Permasep" permeators.

The information contained herein is based upon technical data and tests which we believe to be reliable and is intended for use by persons having technical skill, at their discretion and risk. Since conditions of use are outside Du Pont's control, we can assume no liability for results obtained or damages incurred through the application of the data presented. This information is not intended as a license to operate under, or a recommendation to infringe, any patent of Du Pont or others covering any material or use.



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BULLETIN 509

STERILIZING (SANITIZING) PROCEDURE

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- B. Safety Precautions..... 1
- C. Equipment 1
- D. Sterilization Procedure 1
- E. Flushing Sterilization Solution 2

A. INTRODUCTION

Treating permeators with a biocide may be required if:

- The RO plant will be out of service for an extended period of time (five days or longer).
- The RO plant will be out of service for a day or more after cleaning with an organic solution such as citric acid.
- Permeator product water is contaminated with bacteria.

For routine storage (items one and two above) a biostat solution of sodium metabisulfite and glycerine may be used. Permasep® permeators are routinely treated with a 1/4 wt. percent sodium metabisulfite and 18 wt. percent glycerine solution prior to shipment. If a permeator has become biologically fouled and sterilization is required, only formaldehyde is approved as an effective biocide. Formaldehyde may also be used as a storage solution for permeator and RO systems not in use.

B. SAFETY PRECAUTIONS

- In using any chemical follow accepted safety practice. Consult the manufacturer of the chemicals for detailed information with respect to safety, handling and disposal.
- When preparing chemical solutions for cleaning, be certain that all chemicals are dissolved and well mixed, before introducing them into permeators.
- Before sterilization, flush the permeators thoroughly with good quality chlorine-free water (TDS less than 5,000 mg/l). If available, product water is recommended.
- During recirculation, temperatures must not exceed 35 degrees C.

C. EQUIPMENT

The equipment for cleaning, sterilization and posttreatment is shown in Figure 1, Equipment for Cleaning, Sterilizing and Posttreating. The materials of construction must be chemically compatible with all the chemicals employed and corrosion resistant.

The mix tank should be sized for a minimum 3-minute retention time and provided with a cover, exhaust fan, mixer, cooling coil and a temperature indicator. The pump should be 316 stainless steel and sized for the flow and pressure used in the various procedures. A centrifugal pump is most suitable for flexibility and safety. If hoses are used for supply and return lines, be sure the pressure rating is adequate and that kinking will not occur. A 10µ cartridge filter is used to remove any dislodged solids. Appropriate valves must be provided to control system pressure and permit drainage and flushing of tank and lines. All cleaning and flushing must be performed as in normal operation mode, i.e., feed port to brine port. Flow meters are necessary to establish proper rates through the permeators. Sampling ports should be available for monitoring.

The flow requirements for effective permeator cleaning, sterilization and post-treatment vary. In many cases, plants may be treated stage by stage with the flow balancing tubes in place. Procedures which require high brine flows may necessitate a bypass around the flow balancing tubes.

D. STERILIZATION PROCEDURE

1. Flush the permeators with chlorine-free product or good quality water (TDS less than 5,000 mg/l) prior to sterilizing. Use a once-through flush (brine and product to drain) of 38 liters (10 gallons) of water per 4-inch permeator.[†]
2. If disinfection is required, prepare a well-mixed 1 to 2 wt. percent (active ingredient) solution of formaldehyde in the brine tank, taking into account the volume of water in piping, hoses and permeators (assume 9.5 liters [2.5 gallons of water] per 4-inch permeator). If the permeator is not biologically fouled and sterilization is required for storage purposes, then a 1/4 wt. percent solution of formaldehyde or sodium metabisulfite can be used. If sodium metabisulfite is used, 18 wt. percent glycerine must be added in order for it to be effective in preventing biological growth.

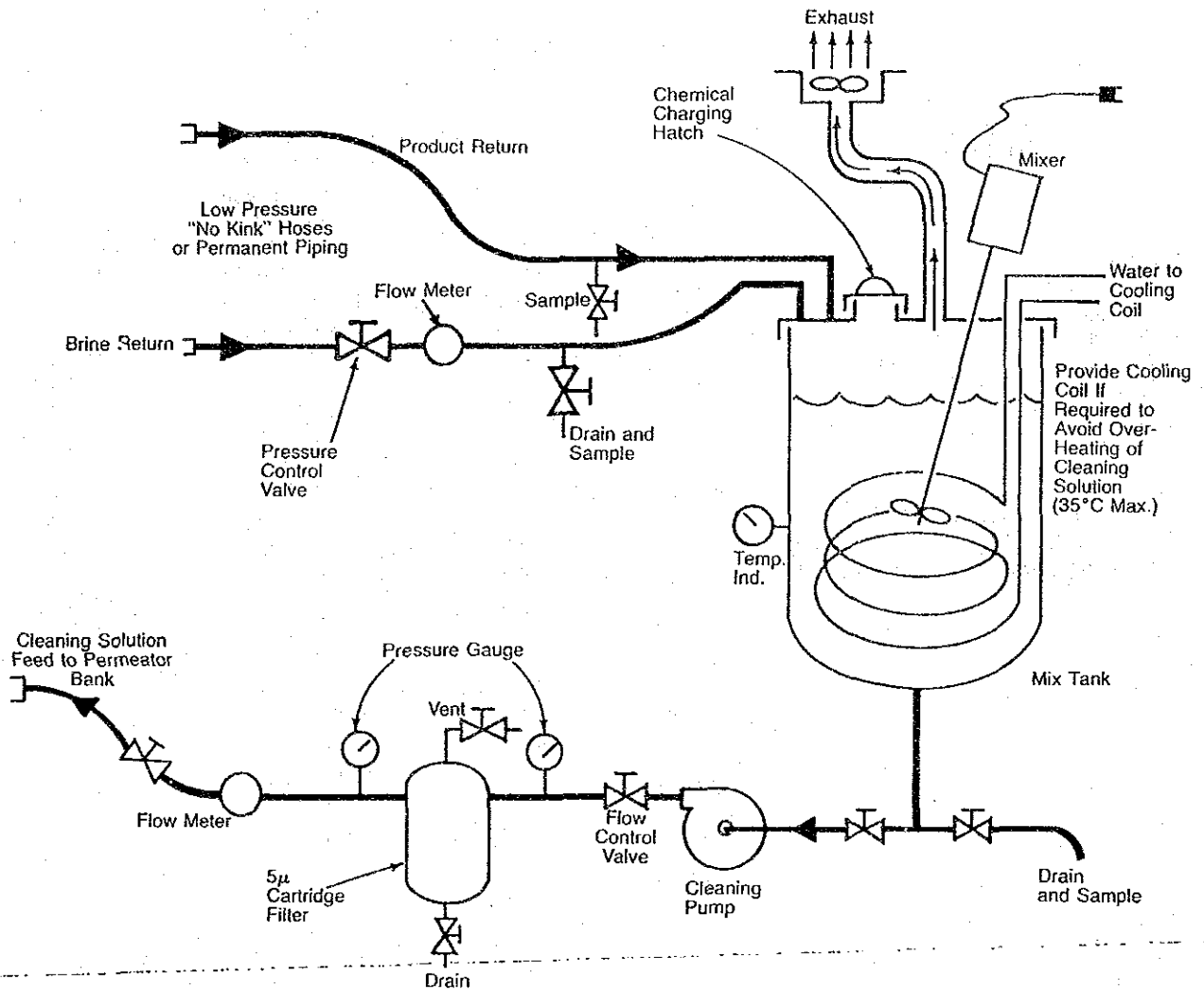
Glycerine (18 wt. percent) is also required with formaldehyde if the permeator is to be stored at temperatures less than 0 degrees C (32 degrees F). If storage is to be greater than one month, magnesium chloride (250 mg/l as Mg⁺⁺) should be added, regardless of which sanitizing solution is used to maintain fiber stability.

Chlorine-free product or good quality water (TDS less

[†]Flows and volumes stated are based on 4-inch diameter permeators (Model 0440, 6440). For 0420 and 0410, flows and volumes are one-half and one-fourth respectively of the 0440 rates. For 6410, flows and volumes are one-fourth of the 6440 rate. For 8-inch diameter permeators (Model 0840, 6840), flows and volumes should be increased by a factor of three. Cleaning 10-inch diameter permeators (Model 1040) flows and volumes are to be increased by a factor of six.



Figure 1. Equipment for Cleaning, Sterilization and Posttreatment



than 5,000 mg/l) should be used in preparing the above solutions.

3. Circulate the sterilization solution through the permeators and direct the first 20 percent of the solution to drain via the brine drain valve. Then recycle the brine through the mix tank for one hour. The temperature must not exceed 35 degrees C. A brine flow of about 7-ℓ/m (2 gpm) per 4-inch permeator is recommended, at a pressure of 345 to 517 kPa (50 to 75 psig).
4. When sterilization is complete, stop recirculating. Drain the mix tank to waste.
5. Leave the sanitizing solution in the permeator after completing the above steps if the permeators are to be stored at temperatures greater than 0 degrees C. If

temperatures are less than 0 degrees C, see Bulletin G-1, Shipping, Handling and Storage of Permeators.

E. FLUSHING STERILIZATION SOLUTION

The solution must be flushed from the units on a once-through basis (product and brine to waste) before being placed in service. Flushing can be achieved either on individual permeators or on complete modular assemblies using the procedures outlined below. Flows given are for single permeators and must be multiplied by the number of permeators in a given installation to arrive at the total flow needed for flushing.

Flushing can be readily achieved by a low-pressure flush of 276 to 552 kPa (40 to 80 psig) for 12 to 16 hours at the brine rates listed in Table I for the various permeator models.

**TABLE I
RECOMMENDED LOW PRESSURE
FLUSHING RATES[†]**

Model No.	Minimum Brine Rate Per Permeator, m ³ /hr. (gpm)	Minimum Quantity of Product m ³ (gal.)
0410, 0420, 6410	0.07 (0.3)	0.19 (50)
0440, 6440	0.11 (0.5)	0.39 (100)
0840, 6840	0.45 (2.0)	1.51 (400)
0040	0.68 (3.0)	3.79 (1,000)

[†]Using a feed pressure of 276 to 552 kPa (40-80 psig) and a feed TDS of about 1,000 mg/l or less.

Flushing can also be done at high pressure (2,760 kPa for B-9 and 5,516 kPa for B-10) using the brine rates in Table II and flushing for a period of 1.5 to 2 hours. The increased brine rate at the higher pressure is required to

maintain a low conversion under the elevated pressure operation.

The product side of the permeator must be vented to waste during flushing. See Bulletin G-1 for complete flushing instructions.

**TABLE II
RECOMMENDED HIGH PRESSURE
FLUSHING RATES**

Model No.	Minimum Brine Flow Rate Per Permeator, m ³ /hr. (gpm)	Minimum Quantity of Product m ³ (gal.)
For B-9 "Permasep" Permeators, using a feed pressure of 2,760 kPa (400 psig)		
0410 & 0420	0.34 (1.5)	0.19 (50)
0440	0.68 (3)	0.39 (100)
0840	2.27 (10)	1.51 (400)
0040	4.54 (20)	3.79 (1,000)
For B-10 "Permasep" Permeators, use a feed pressure of 5,515 kPa (800 psig).		
6410	0.34 (1.5)	0.19 (50)
6440	0.68 (3)	0.39 (100)
6840	2.27 (10)	1.51 (400)

CAUTION: Follow manufacturers' recommendations on containers or in product bulletins for the safe handling of all chemicals and cleaning agents used with "Permasep" permeators.

The information contained herein is based upon technical data and tests which we believe to be reliable and is intended for use by persons having technical skill, at their discretion and risk. Since conditions of use are outside Du Pont's control, we can assume no liability for results obtained or damages incurred through the application of the data presented. This information is not intended as a license to operate under, or a recommendation to infringe, any patent of Du Pont or others covering any material or use.

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Permasep Engineering Manual

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

BULLETIN 508

POSTTREATMENTS FOR PERMASEP* PERMEATORS

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A. INTRODUCTION

Every B-9 and B-10 "Permasep" permeator is post-treated with PT-A (polyvinyl methyl ether) during the manufacturing process. B-10 permeators are also post-treated with PT-B (tannic acid) during the manufacturing process. PT-A increases the salt rejection by reducing salt flow through membrane or fiber imperfections (coupled flow). Salt rejection of B-9 and B-10 permeators can usually be improved by treating with PT-A if a decrease in rejection occurred during storage or if rejection did not improve or actually decreased after cleaning. Polyvinyl methyl ether (PVME) can be purchased directly from the BASF Wyandotte Corporation and is sold under their trade name "Lutonol M40," as a 50 wt. percent aqueous solution. As a convenience, "Permasep" Licensees will supply PVME in small quantities.

New B-10 permeators usually must be treated with PT-B before placing on-stream after the initial flushing. Also, B-10 permeators MUST be retreated with PT-B after any cleaning operation. PT-B can be applied in a recycling mode or in a shock mode while the system is operating. The shock mode procedure is effective in restoring salt rejection when the permeators are not fouled, such as at start-up, after cleaning or after a chlorine upset. Care must be taken not to use this procedure as a substitute for proper design, operation or cleaning.

PT-B works differently compared to PT-A. All data indicate the PT-B absorbs on the membrane surface, which enhances the salt rejection. Thus, diffusive salt flow rather than coupled flow is reduced.

B-9 permeators are not treated with PT-B during the manufacturing process. However, PT-B can be used to increase salt rejection. A B-9 permeator treated with PT-B is estimated to have a salt rejection greater than 95 percent with initial product water capacity within 95 percent of nominal flow given in the Product Bulletin when operated at standard test conditions. A salt passage reduction of 4

to 5 times has been obtained on badly fouled permeators following cleaning and PT-B application. DO NOT use PT-B treatment as a substitute for proper pretreatment or proper B-9 plant operation.

Both chlorine and iron will react with PT-B and destroy its effect on salt rejection. Thus, all water used to prepare the solution and to rinse the permeators must be free of these materials (TDS less than 5,000 mg/l). PT-B will also react with PT-A and precipitate. When both posttreatments are used, the permeators must be thoroughly flushed between treatments. A procedure is available to remove PT-A/PT-B reaction product should these agents be inadvertently mixed. Consult "Permasep" Products for details. The tannic acid used for PT-B must be a good grade. In the United States, it can be purchased from J. T. Baker Chemicals Corp., Inc., Phillipsburg, New Jersey.

B. SAFETY PRECAUTIONS

- In using any chemicals follow accepted safety practice. Consult the manufacturer of the chemicals for detailed information with respect to safety, handling and disposal.
- When preparing chemical solutions for posttreatment, be certain that all chemicals are dissolved and well mixed, before introducing them into permeators.
- Before each treatment, flush the permeators thoroughly with good quality chlorine-free water (TDS less than 5,000 mg/l). If available, product water is recommended.
- During recirculation, temperatures must not exceed 35 degrees C.

C. EQUIPMENT

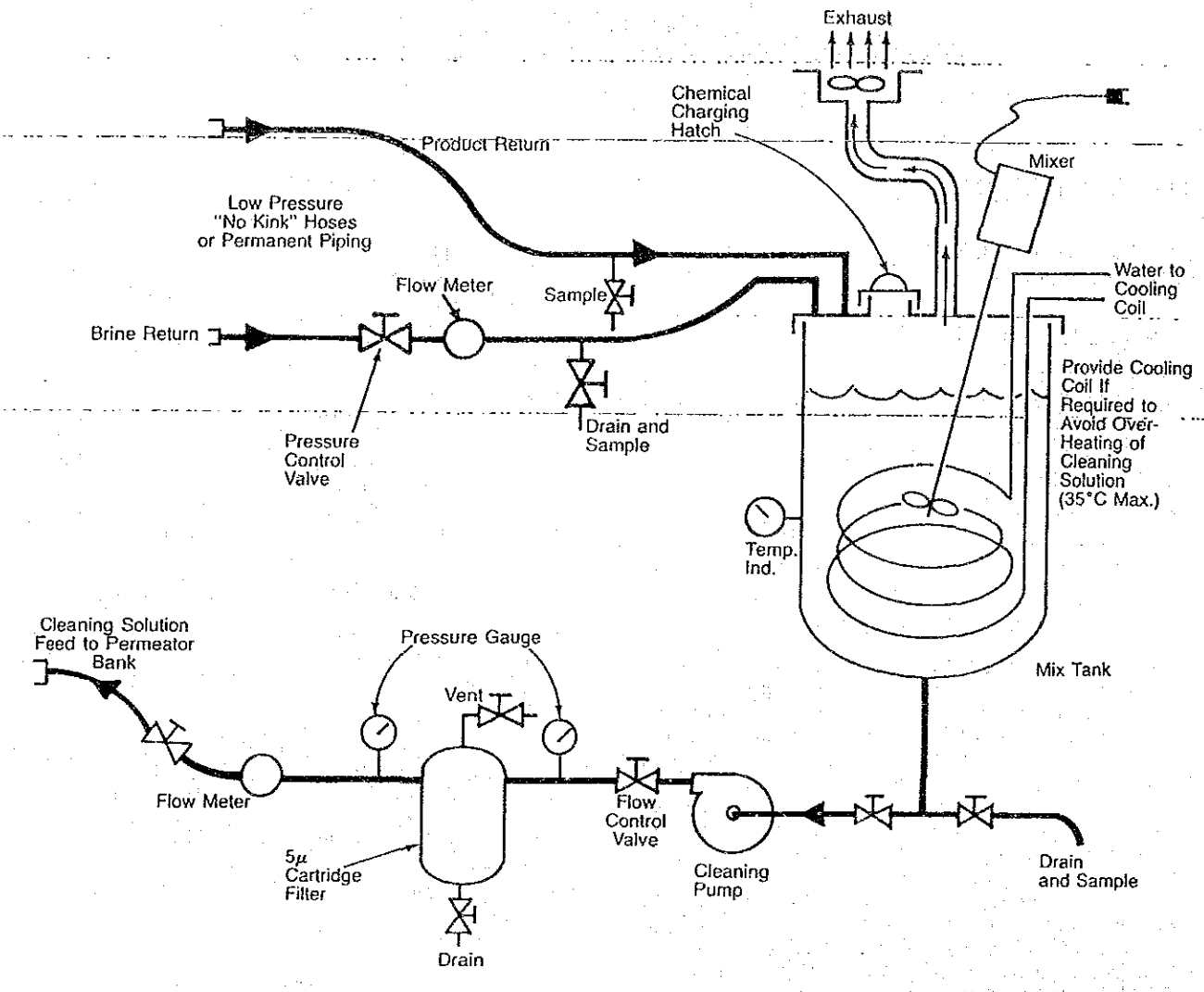
The equipment for cleaning, sterilization and posttreatment is shown in Figure 1. The materials of construction must be chemically compatible with all the chemicals employed and corrosion resistant.

The mix tank should be sized for a minimum 3-minute retention time. A cover, exhaust fan, mixer, cooling coil and temperature indicator are required. The pump should be 316 stainless steel and sized for the flow and pressure used in the various procedures. A centrifugal pump is most suitable for flexibility and safety. If hoses are used for supply and return lines, be sure the pressure rating is adequate and that kinking will not occur. A 10 μ cartridge filter is used to remove any dislodged solids. Appropriate valves must be provided to control system pressure and permit drainage and flushing of tank and lines. All cleaning and flushing must be performed as in normal operation mode; i.e., feed port to brine port. Flow meters are necessary to establish proper rates through the permeators. Sampling ports should be available for monitoring.

The flow requirements for effective permeator cleaning, sterilization and posttreatment vary. In many cases, plants



Figure 1. Equipment for Cleaning, Sterilization and Posttreatment



may be treated stage by stage with the flow balancing tubes in place. Procedures which require high brine flows may necessitate a bypass around the flow balancing tubes.

D. PT-A POSTTREATMENT

PT-A treatment can usually improve the salt rejection of B-9 and B-10 permeators following storage or a cleaning operation where rejection did not improve. Since PT-A and PT-B will react with each other, the permeators should be thoroughly flushed between treatments if both chemicals are used.

1. PREPARATION OF PT-A STOCK SOLUTION

Because the required PT-A dosage for treating permeators is 80 mg/l and the 50 wt. percent concentration is difficult to handle and is slow in dissolving, the PT-A is best added as a diluted aqueous stock solution containing 3 wt. percent PT-A which has been prepared carefully beforehand.

To prepare a supply of 3 wt. percent PT-A stock solution, add 65 grams of the 50 wt. percent PT-A concentrate per liter of good quality cold water. Stir at low speed for 3 hours to ensure complete dissolution. Monitor the temperature to avoid exceeding 30 degrees C.

2. PROCEDURE†

- a. Flush permeators with chlorine-free product or good quality water prior to posttreatment using a once-through flush (brine and product to drain) of 38 liters (10 gallons) of water per 4-inch permeator.¹
- b. In the mix tank, prepare a well mixed solution containing 80 mg/liter PT-A (active ingredient) plus:

¹Flows and volumes stated are based on 4-inch diameter permeators (Model 0440, 6440). For 0420 flow and volumes are one-half and for 0410 flows and volumes are one-fourth of the standard 0440 rates.
For 8-inch diameter permeators (Model 0840, 6840) flows and volumes should be increased by a factor of three. When cleaning 10-inch diameter permeators (Model 0040), flows and volumes are increased by a factor of six.

530 mg/ℓ NaCl taking into account the volume of water in piping, hoses, and permeators (assume 9.5 liters [2.5 gals.] of water per 4-inch permeator). Use chlorine-free product water.

- c. Recirculate the PT-A solution through the permeator. A brine flow of about 7 ℓ/m (2 gpm) per 4-inch permeator is recommended using a pressure of 345–517 kPa (50–75 psig). The temperature must not exceed 35 degrees C. This temperature maximum protects the permeator and prevents precipitation of PT-A (cloud point equals 37 degrees C).[†]
- d. Monitor the conductivity of the product every 15 minutes. Terminate the PT-A posttreatment when product conductivity is constant for 30 minutes. Usually, constant conductivity is obtained after one hour of treatment.
- e. When the posttreatment is complete, stop recirculating. Drain the Mix Tank solution to waste. Flush the residual PT-A solution from the permeator with RO product water by operating at 345–517 kPa (50 to 75 psig) and at a brine rate of 17 ℓ/m (4.5 gpm) per 4-inch permeator for five minutes in the normal feed direction. During this flush, the brine and product both go to drain. The units may then be flushed using regular feedwater at a reduced pressure (less than 1,380 kPa [200 psig]) for 15 minutes. Both the brine and product should go to drain.
- f. After the system is stabilized, check the performance to determine the effectiveness of PT-A treatment.

E. PT-B POSTTREATMENT

After the initial flush, new B-10 permeators usually must be treated with PT-B before placing them on-stream. B-10 permeators MUST also be retreated with PT-B after any cleaning operation. B-9 permeators can also be treated with PT-B. Permeators are normally treated with PT-B by shutting down the portion of the system requiring treatment, treating the units and returning them to service. However, under certain conditions, permeators can be treated while in operation. These procedures are discussed below.

1. PROCEDURE^{††}

- a. Flush the permeators with chlorine-free product or good quality water (TDS less than 5,000 mg/liter)

[†]At higher concentrations, the cloud point is lower; at 3 wt. percent or above, it is 30 degrees C. Thus, these solutions should be stored at temperatures lower than 30 degrees C.

prior to posttreatment. Use a once-through flush (brine and product to drain) of 38 liters (10 gallons) of water per 4-inch permeator.^{††}

- b. In the Mix Tank, prepare a solution containing 1 wt. percent citric acid plus 80 mg/liter of PT-B, taking into account the volume of water in piping, hoses and permeators (assume 9.5 liters [2.5 gallons] of water per 4-inch permeator). Use RO product or other good quality water (TDS less than 5,000 mg/liter). Since the PT-B is a solid which does not dissolve immediately, the PT-B is best added as a dilute aqueous stock solution containing 3 wt. percent of PT-B.
- c. Recirculate the PT-B solution through the permeators. A brine flow of about 7 ℓ/m (2 gpm) per 4-inch permeator is recommended using a pressure of 690 to 1034 kPa (100 to 150 psig). The temperature must not exceed 35 degrees C.
- d. After one hour, stop recirculating. Drain the mix tank solution to waste. Flush the residual PT-B solution from the permeators with product water at 345–517 kPa (50–75 psig) and a brine rate of 17 ℓ/m (4.5 gpm) per 4-inch permeator for five minutes in the normal feed direction. During this flush, the brine and product water go to the drain. The units may then be flushed with regular feed water at a reduced pressure (less than 1,379 kPa [200 psig]) for 15 minutes. The brine and product water go to drain.
- e. After the system operation has stabilized, check the performance to determine the effectiveness of PT-B treatment.

2. ON-LINE PT-B TREATMENT

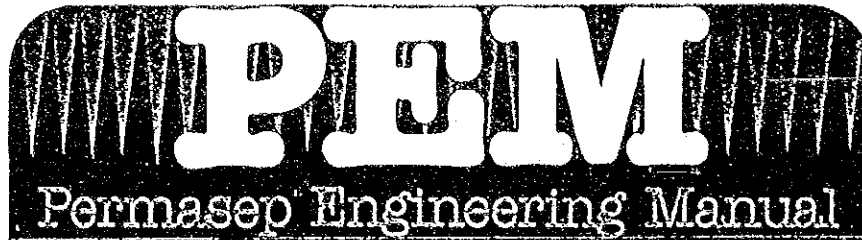
B-10 permeators can be PT-B treated while in operation provided the feed pH during treatment is less than 5.0. At a pH greater than 5.0, PT-B is relatively insoluble in seawater and forms a brown precipitate even at a PT-B concentration of only 10 mg/ℓ. However, if the seawater pH is less than 5.0, no precipitate is formed even at PT-B concentrations of 80 mg/ℓ. The on-line PT-B treatment is performed by injecting a PT-B and citric acid solution into the feed stream. A mix tank and injection system are required. If operating conditions permit on-line treatment, "Permasep" Products Licenses can provide design assistance and operating procedures.

^{††}Flows and volumes stated are based on 4-inch diameter permeators (Model 0440, 6440). For 0-20 flow and volumes are one-half and for 0410 flows and volumes are one-fourth of the standard 0440 rates.

For 8-inch diameter permeators (Model 0840, 6840) flows and volumes should be increased by a factor of three. When cleaning 10-inch diameter permeators (Model 0040), flows and volumes are increased by a factor of six.

CAUTION: Follow manufacturers' recommendations on containers or in product bulletins for the safe handling of all chemicals and cleaning agents used with "Permasep" permeators.

The information contained herein is based upon technical data and tests which we believe to be reliable and is intended for use by persons having technical skill, at their discretion and risk. Since conditions of use are outside Du Pont's control, we can assume no liability for results obtained or damages incurred through the application of the data presented. This information is not intended as a license to operate under, or a recommendation to infringe, any patent of Du Pont or others covering any material or use.



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Date 12/1/82

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

BULLETIN 507

CLEANING PROCEDURES

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A. INTRODUCTION

Each bulletin on potential membrane problems briefly describes the cleaning agents for that particular problem. A summary of these chemical cleaning agents is presented in Table I. A system supplier will typically provide an operating manual with detailed procedures for cleaning the RO system. The procedures included in this section illustrate the simplicity of cleaning an RO system.

Frequent cleaning is not required for properly designed and properly operated RO systems. But if cleaning is required, the synthetic aramid membrane used in B-9 and B-10 "Permasep" permeators permits a broader range of cleaning chemicals than can be tolerated by most other commercial membranes.

Large RO plants are usually designed with more than one control block (independent units). Cleaning is then performed on one block at a time permitting the balance of the plant to continue normal operation.

B. SAFETY PRECAUTIONS

1. In using any of the chemicals listed in Table I, Chemical Cleaning Agents, follow accepted safety practice. Consult the manufacturer of the chemicals for detailed information with respect to safety, handling and disposal.
2. When preparing chemical solutions for cleaning, be certain that all chemicals are dissolved and well mixed, before introducing them into permeators.
3. Before and after each cleaning, flush the permeators thoroughly with good quality chlorine-free water (TDS less than 5,000 mg/l). If available, product water is recommended. If cleaning agents are used sequentially, it is mandatory that the permeators be thoroughly flushed between cleanings to prevent possible harmful interaction between different cleaning solutions. Following a "Biz" cleaning, it is desirable to have the flush

water at pH 10 to avoid the formation of fatty acids, which will precipitate at low pH.

4. During recirculation, temperatures must not exceed 35 degrees C.

C. EQUIPMENT

The equipment for cleaning, sterilization and posttreatment is shown in Figure 1, Equipment for Cleaning, Sterilization and Posttreatment. The materials of construction must be chemically compatible with all the chemicals employed and corrosion resistant.

The mix tank should be sized for a minimum 3-minute retention time. Provide a cover, exhaust fan, mixer, cooling coil and a temperature indicator. The pump should be 316 stainless steel and sized for the flow and pressure used in the various procedures. A centrifugal pump is most suitable for flexibility and safety. If hoses are used for supply and return lines, be sure the pressure rating is adequate and that kinking will not occur. A 10 μ cartridge filter is used to remove any dislodged solids. Appropriate valves must be provided to control system pressure and permit drainage and flushing of tank and lines. All cleaning and flushing must be performed as in normal operation mode; i.e., feed port to brine port. Flow meters are necessary to establish proper rates through the permeators. Sampling ports should be available for monitoring.

The flow requirements for effective permeator cleaning, sterilization and posttreatment vary. In many cases, plants may be treated stage by stage with the flow balancing tubes in place. Procedures which require high brine flows may necessitate a bypass around the flow balancing tubes.

D. DETERGENT FLUSHING PROCEDURES

Cleaning with "Biz"[†] detergent, using the method described below, is effective in removing colloidal foulants.

1. CLEANING PROCEDURE USING "BIZ"[†] (WITH PHOSPHATE)

- a. Flush permeators with product water prior to cleaning using a once-through flush (brine and product to drain) of 38 ℓ (10 gallons) per 4-inch permeator.^{††} The brine pH must be 6.0 or above.
- b. In the mix tank, prepare a 0.5 wt. percent "Biz" detergent (with 17.6% phosphorus) solution taking

[†]Trademark of Proctor and Gamble, U.S.A. for a detergent sold in the U.S.A.

^{††}Flows and volumes stated are based on 4-inch diameter permeators (Model 0440, 6440). For 0420 and 0410, flows and volumes are 1/2 and 1/4 respectively of the 0440 rates. For 6410 the flows and volumes are 1/4 of the 6440 rates. For 8-inch diameter permeators (model 0840, 6840) flows and volumes should be increased by a factor of three. Cleaning 10-inch diameter permeators (model 0440) flows and volumes are to be increased by a factor of six.



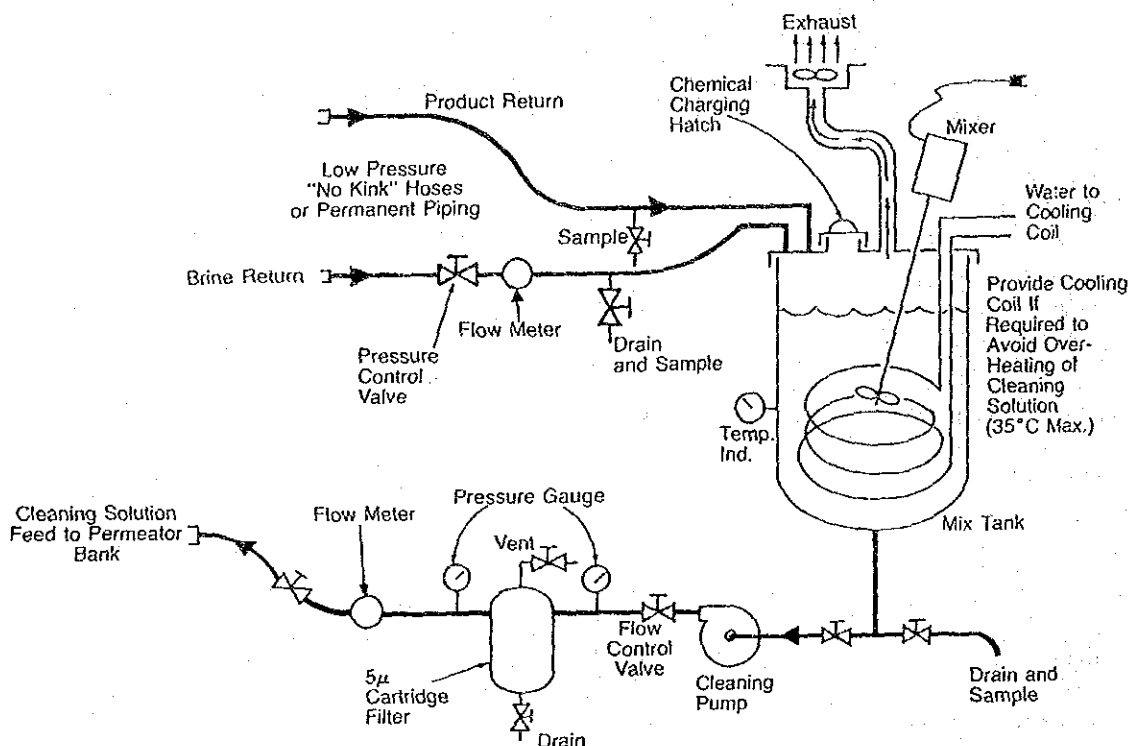
TABLE I
CHEMICAL CLEANING AGENTS

Chemicals	Foulants						
	CaCO ₃	CaSO ₄ BaSO ₄ SrSO ₄ CaF ₂	SiO ₂	Metal Oxides	Inorganic Colloids	Biological Matter	Organics
Hydrochloric Acid ¹ (HCl)(pH 4.0)	X				X		
2.0 wt. % Citric Acid + NH ₄ OH (pH 4.0)	X			X	X		
5 wt. % Nutek NT-600	X						
2 wt. % Citric Acid + NH ₄ OH (pH 8)		X					
1.5 wt. % Na ₂ EDTA ³ + NaOH (pH 7-8) or 1.5 wt. % Na ₂ EDTA + HCl (pH 7-8)		X					
1.0 wt. % Na Hydro- sulfite (Na ₂ S ₂ O ₄)		X		X			
NaOH (pH 11.0) ²			X		X		X
2.0 wt. % Citric Acid + 2.0 wt. % Na ₂ EDTA + NH ₄ OH (pH 4.0)	X			X			
0.5 wt. % "Biz" ⁴ (with phosphate) + NaOH (pH 11.0)			X		X		X
1 wt. % Drewspers 738					X		
1 wt. % NaHMP				X	X		X
1/4-2 wt. % Formaldehyde followed by 0.25 wt. % "Biz" (with phosphate)						X	

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

- into account the volume of water in the piping and permeators (assume 9.5ℓ [2.5 gal.] of water per 4-inch permeator).
- With agitation add sufficient NaOH solution to increase the pH to 11.0. NOTE: Solid caustic (flake, solid, etc.) is difficult to dissolve and may settle to the bottom of the chemical cleaning tank. This can result in what appears to be acceptable pH measurements taken at the top of the tank and an excessive pH at the bottom of the tank where the pump suction is located. If the solution is not properly mixed, the high pH portion of the solution can be pumped into the permeator causing irreversible damage.
 - Circulate the cleaning solution through the permeator. Take the first 20 percent of the solution to drain via the brine return valve, and then recycle the cleaning solution through the mix tank. A brine flow of about 17 ℓ/m (4.5 gpm) per 4-inch permeator is recommended at a pressure of 345-1,035 kPa (50-150 psig).
 - The effects of the "Biz" cleaning can be monitored by observing the effluent. If the effluent is darker than the feed, colloidal material is being removed. The flushing operation should be conducted for at least 2 hours and/or as dictated by the amount of foulants.
 - In place of continuous recycling as described in Step d, a flush/soak method in 15 minute cycles provides an alternative. With this method, the cleaning cycle is easily monitored by watching the effluent at the beginning of each flush. The effluent usually will be very dark (as compared to the feed) for the first 1 to 2 minutes after starting the flush. Agglomerated colloidal materials may be dispersed and placed in suspension during soak and are then removed more easily from the bundle to the mix tank. The flush/soak cleaning should be continued until the effluent is no longer badly discolored.
 - When cleaning is complete, stop recirculation. Drain mix tank solution to waste. Do not reuse cleaning solution. Flush residual cleaning solution from permeators with product water by operating at 345-518 kPa (50-75 psig) and 17 ℓ/m (4.5 gpm) per

Figure 1. Equipment for Cleaning, Sterilization and Posttreatment



4-inch permeator brine rate in the normal feed direction. During this flush, brine and product go to drain. The units may then be flushed with brine and product to drain using regular feedwater at reduced pressure of less than 1,380 kPa (200 psig) until no foaming occurs. Collect a sample of the brine in a jar and shake it to test for any remaining detergent. If foaming occurs, continue the flushing until foaming is no longer present.

- h. After posttreatment (See Bulletin 508), return permeators to normal operation and check the performance to determine cleaning and posttreatment effectiveness.

2. ALTERNATE DETERGENTS

The following detergents have been tested for compatibility with the B-9 and B-10 membranes. No significant change in fiber properties was noted during a three-month exposure to 0.25–0.50 wt. percent concentrations. The materials are not tested for effectiveness. They may be considered as alternates when "Biz" is not available. Note that all detergents should be free of significant amounts of insoluble matter.

COMPATIBLE CLEANING AGENTS

Biz (17.6%, phosphorus)	Procter & Gamble U.S.
Ariel	Procter & Gamble France
Ariel	Procter & Gamble England
Ariel	Procter & Gamble Belgium
Ariel	Procter & Gamble Spain
Ariel	Procter & Gamble Mexico
Terg-A-Zyme	Fisher Scientific

OMO	Lever France
Drive	Lever Australia
Amaze	Lever Canada
Skip	Lever France
Skip	Lever Spain
Lava (60°)	Procter & Gamble France
Dato (60°)	Henkel
Xtra	Henkel
Alconox	Alconox Inc. U.S.
Alcojet	Alconox Inc. U.S.
Nutek NT 600	Nuclear Techn. Corp.
Na ₂ EDTA	Several Commercial Sources
Na ₄ EDTA	Several Commercial Sources
Drewspers 738	Drew Chemical
Decon 90	United Kingdom
Dobanol 91/6	United Kingdom
Tergitol 15/5/7	Union Carbide Co.
Biox	Unibound
Microdetergent	International Product Group
Spee	East Germany
Miltwok 71	East Germany
Detergent 28-77	East Germany

E. CLEANING WITH CITRIC ACID

Iron fouling will cause increased pressure drop and associated decrease in flux and increase in salt passage. Permeators should be cleaned if the pressure drop increases more than 50 percent.

- 1. Flush Permeators—Flush permeators with product water prior to cleaning using a once-through flush

- (brine and product water to drain) of 38ℓ (10 gals) of water per 4-inch permeator.[†]
- In the mix tank, prepare a 2 wt. percent solution of citric acid, taking into account the volume of water in piping, hoses and permeators (assume 9.5ℓ [2.5 gals.] of water per 4-inch permeator). Citric acid is very soluble in water (see Table II). A small volume of concentrate can be made up in a container in which complete dissolution is assured by visual inspection. This concentrate can then be transferred to the mix tank for final adjustment to the proper concentration.

TABLE II
CITRIC ACID SOLUBILITY IN WATER

Temperature (°C)	Citric Acid (% by Weight)
10	54
20	60
30	64
40	69
50	71
60	74
70	76
80	79
90	81
100	89

Source: Technical Files of Chas. Pfizer and Company, Inc.

- With agitation, add sufficient NH₄OH to increase the pH to 4.0 (about 10 ml of a concentrated NH₄OH [24.4 percent] per liter of 2 wt. percent citric acid solution is required to obtain a pH of 4.0). It is important that the pH be 4.0 ± 0.2 at the end of the NH₄OH addition as well as during the entire cleaning period. Positive ventilation will be needed while adding concentrated ammonia, but odor will be negligible once mixing is complete.
- Circulate the Cleaning Solution—In large permeator installations, it is desirable that cleaning chemicals be

[†]Flows and volumes stated are based on 4-inch diameter permeators (Model 0440, 6440). For 0420 and 0410, flows and volumes are 1/2 and 1/4 respectively of the 0440 rates. For 6410 the flows and volumes are 1/4 of the 6440 rates. For 8-inch diameter permeators (model 0840, 6840) flows and volumes should be increased by a factor of three. Cleaning 10-inch diameter permeators (model 0440) flows and volumes are to be increased by a factor of six.

- circulated by an auxiliary pump made of corrosion-resistant materials such as stainless steel or plastic. Circulate the cleaning solution through the permeators. Take the first 20 percent of the solution to drain via the brine drain valve, and then recycle the brine through the mix tank. A brine flow of about 7 ℓ/m (2 gpm) per 4-inch permeator is recommended using a pressure of 345 to 518 kPa (50 to 75 psig).
- Using an iron test kit, monitor the cleaning solution in the mix tank for iron about every 30 minutes. Cleaning is considered complete when three successive analyses agree within 10 percent. This usually requires 1 to 4 hours. Observe the color of the ammoniated citric acid solution in the mix tank. If the citric acid is in excess with respect to iron, a green-yellow color will be observed. If the iron is in excess with respect to citric acid, a red-brown color will be observed, and the cleaning solution should be changed.
- When cleaning is complete, stop recirculation. Drain mix tank solution to waste. Do not save for reuse. Flush residual cleaning solution from permeators by operating at 276 kPa (40 psig) and 7 to 11 ℓ/m (2 to 3 gpm) per 4-inch permeator brine rate for one hour in the normal feed direction. A four-hour flush at 345 kPa (50 psig) and 4 ℓ/m (1 gpm) per 4-inch permeator brine flow is also satisfactory. Brine and product must be discharged to waste during this period.
- After posttreatments (See Bulletin 508), return permeators to normal operation and check the RO performance to determine cleaning and posttreatment effectiveness.

F. CLEANING WITH OTHER SOLUTIONS

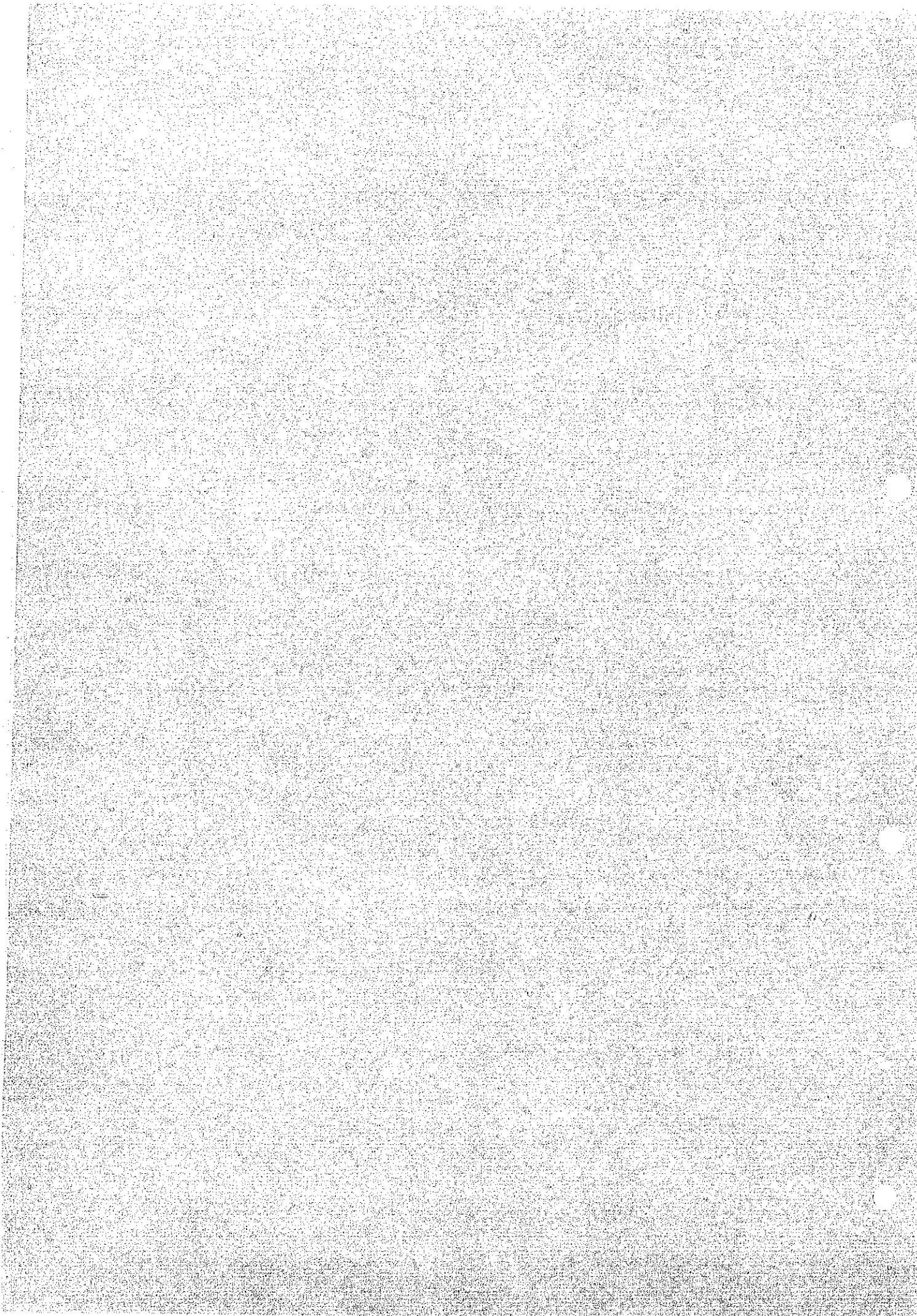
- When using other cleaning solutions, as indicated in Table I, Chemical Cleaning Agents, use the flow rates given for the citric acid cleaning procedure when cleaning for CaCO₃, CaSO₄, BaSO₄, SrSO₄, CaF₂ and metal oxides.
- Use the flow rates given for the Cleaning Procedure Using "Biz" when cleaning for SiO₂, inorganic colloids, biological material and organic matter.
- If metal oxide fouling is suspected as a result of corrosion, the higher flow rates given for the Cleaning Procedure Using "Biz" should be used.

CAUTION: Follow manufacturers' recommendations on containers or in product bulletins for the safe handling of all chemicals and cleaning agents used with "Permasep" permeators.

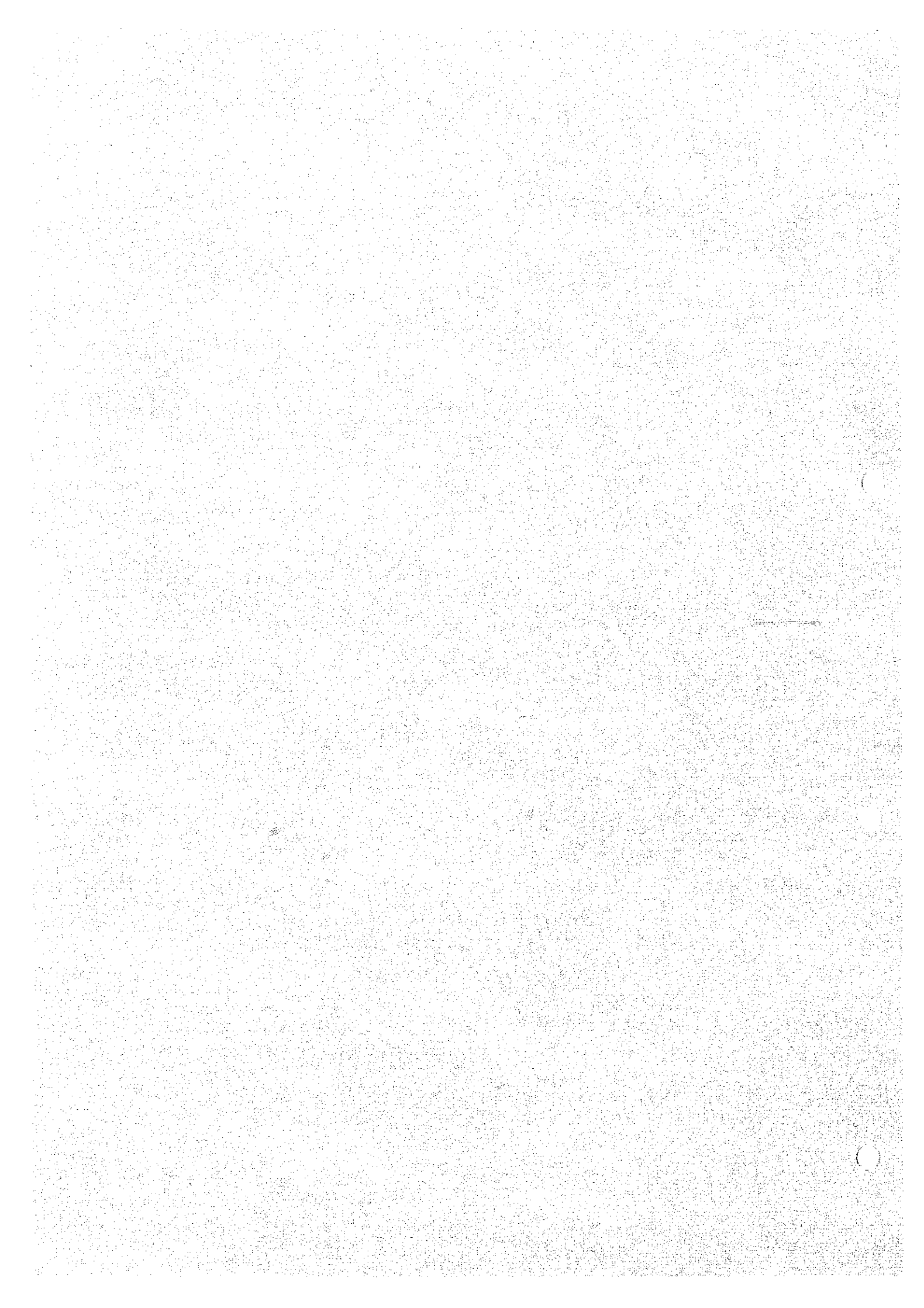
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7. APPENDIX for R6 (Selection of Membrane for Hybrid RO Process)

APPENDIX R6-1 How to Analyze the Fouling Membranes 7-1
APPENDIX R6-2 Result of Literature Survey 7-27
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APPENDIX R 6 - 1



APPENDIX R6-1

HOW TO ANALYZE FOULED MEMBRANE

1. Scopy of Application
2. Sampling method
 - 2.1. External appearance
 - 2.2. Disassembly of element
 - 2.3. Flat-sheet membrane sample
 - 2.4. FT-IR, EDX(also konwn as XMA) samples analysis
3. How to analyze fouled membranes
 - 3.1. FT-IR analysis
 - 3.2. SEM-ESX

1. Scope of Application

This text describes the sample preparation, the analytical method used to test fouled membranes, and the methods for determining the possible causes of fouling of spiral-type RO membrane module, in which chlorination-dechlorination is applied.

2. Sampling Method

2.1 External appearance

- (1) Take out the element from the RO module.
- (2) Write down the element lot number
- (3) Record that the position inside the RO unit where the element was located.
- (4) Check closely the external appearance of the element taken out, in particular whether any foreign material is deposited on the upstream end of the element. If deposits are found, write down the degree of deposition; or better take a photograph. Also, sample the foreign material.

2.2 Disassembly of element

- (1) Prepare the following tools:

- Electric circular sawing precision cutter
(Circular saw: For cutting FRP, preferably with diameter of 300 mm or more),
- Angle grinder (usable grinder outer dimensions of 100 mm or so),
- Cutter knife,
- Cleaning pure water and container and
- Sampling plastic sachets

- (2) Cut both ends of the element for about 10 cm by the electric circular sawing precision cutter.
- (3) Make an incision, to about 2 cm depth, almost in straight line at two position of the FRP outer lateral side of the element by using the angle grinder so that the two positions are located at nearly 180 degrees to each other.
- (4) Peel off the FRP outer layer by pulling with hand; this way, the membrane leaf part and the

raw water spacer will be exposed.

- (5) The normal 8-inch element is composed of 10 or more leaves; By unrolling the element, it will expose the flat-sheet membrane for each leaf.
- (6) By removing the raw water spacer, sandwiched between two leaves, you may now observe the overall membrane surface. Visually check whether there exists uneven fouling all over the membrane surface, and also check for the hue distribution of the membrane surface and any other abnormality.

2.3 Flat-sheet membrane sample

A flat-sheet membrane with dimensions large enough to allow collecting samples for the RO test is prepared.

At this time, record the sample number so that you could verify it to the sample position on the leaf. Prepare the necessary number of samples depending on the RO performance test (at least 3 per test) or the cleaning test (3 times the cleaning test conditions).

Immerse and quickly clean the flat-sheet membrane samples for measuring RO performance in pure water in order to remove foreign matters; then, cut them into the specified test cell dimensions; and, store them into plastic sachets. Keep the samples in these plastic sachets in the refrigerator until the testing time.

2.4 FT-IR, EDX (also known as XMA) samples analysis

First air dry the samples. Prepare samples by following the analytical method which is explained later.

3. How to Analyze Foul Membranes

3.1 FT-IR analysis

(1) KBr Method

Isolate to such a degree as to allowing for scraping off the fouling materials adhered on the RO membrane; mix them with KBr by ordinary method to prepare analytical samples.

(2) ATR Method

Establish the spectrum analysis of the membrane surface by means of the ATR (attenuated total reflection) method. The MIR (multiple internal reflection) method is mainly used for this purpose.

Analytical conditions for this analysis are as follows:

* Reflecting plate: KRS-5 (thallium bromide / thallium iodide) = (42 / 58)

* Reflecting angle: 45

(KRS-5 enables spectrum over a wide range of 400 to 4000 cm^{-1})

* No. of scans: Varies depending on the make.

(e.g.) Nikore Sx60: 128 times

Parkin-Elmer 1750: 30 times

(because of higher precision of interferometer)

Try different number of scans in order to find out the most optimum number of scans for obtaining the clean spectrum without noise component.

(3) Remarks

* Keep record of the spectrum data of a new film, and record the differential spectrum for the fouled membrane.

As the spectrum of fouling components more or less shows certain pattern, it will be necessary to improve the analytical information/skill for the standard so that the spectrum of fouling components could be determined from the spectrum library of standard samples or the standard spectrum collection.

* The analysis of the membrane surface after cleaning will serve as an effective means for confirming the cleaning effects of the fouled membrane.

3.2 SEM - EDX

(1) Sample Preparation

After air drying, fix the sample on the SEM hold ($\phi 15$ to 25mm) by using double-sided adhesive tape; make the holder conductive to the sample by means of conductive paint. Deposition is made under the following conditions:

Purpose: SEM sample

Sample holder: Aluminum

Conductive paint: Silver paste

Ion coater: Au-Pd coater; Au coater

Features: Micro-fine (x 20,000 to 50,000) is possible.

Purpose: EDX sample

Sample holder: Carbon (mostly, $\phi 15$ mm)

Conductive paint: Carbon paste

Ion coater: Carbon coater Features: Resolution x 4000 is the upper limit, beyond which