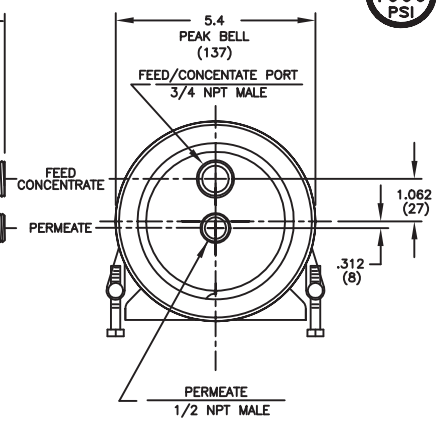
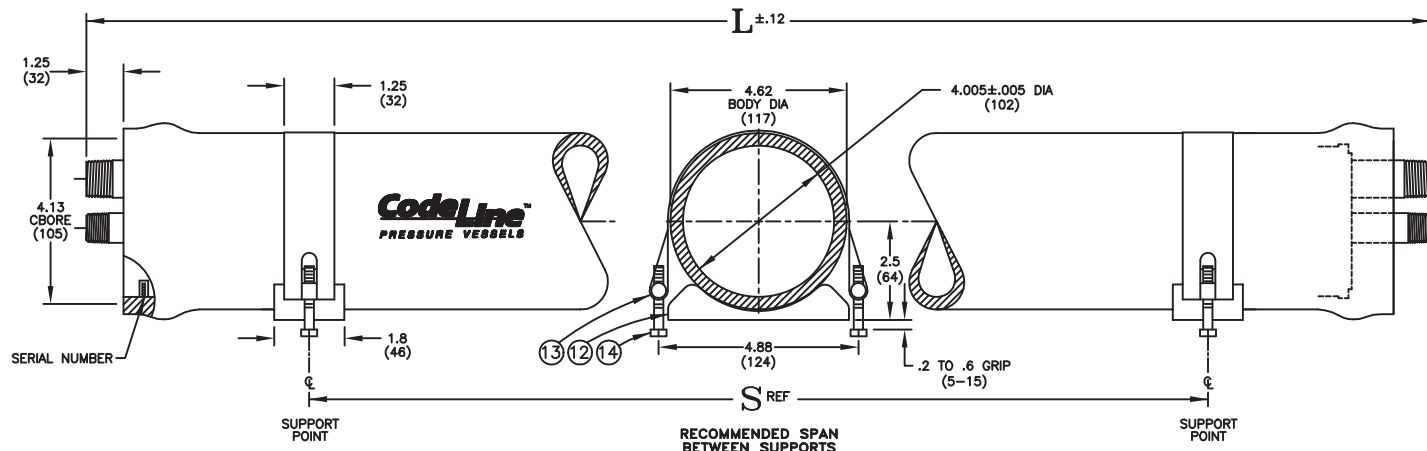


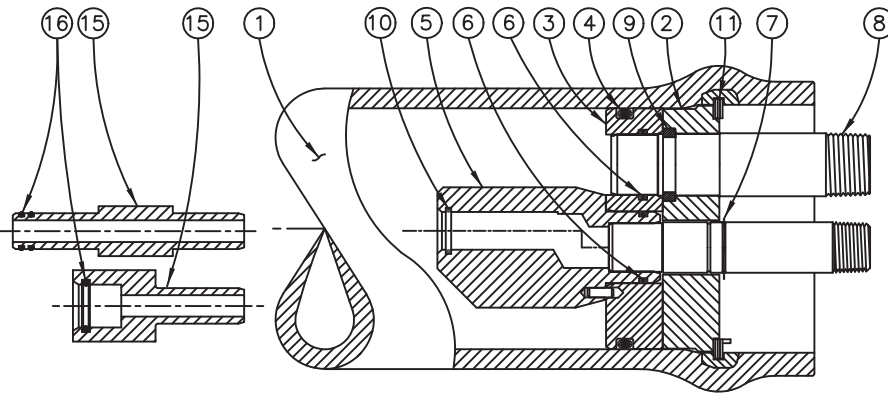
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RECOMMENDED SPAN BETWEEN SUPPORTS  
 CENTER VESSEL ON 2 OR 3 SUPPORTS AT SPAN(S) "S": 3 SUPPORTS REQUIRED FOR LENGTHS -4 AND OVER

\* PART LISTED ARE STANDARD OPTIONS

Dwg. Ref.	Qty. Per	* Part Number	Part Name	Materials/Remarks
<b>SHELL</b>				
①	1		Shell	Filament wound epoxy/glass composite. Head locking grooves integrally wound in place. Shell exterior coated with white high gloss polyurethane paint.
<b>HEAD</b>				
②	2	47471	Bearing Plate	6061-T6 hard anodized Alum. alloy
③	2	50481	Seal Plate	PVC Thermoplastic (gray) - 120' F Max
④	2	45317	Plug Seal	Ethylene Propylene - O-Ring
⑤	2	47469	Permeate Port	PVC Thermoplastic (gray)
⑥	4	45299	Permeate Port Seal	Ethylene Propylene - O-Ring
⑦	2	45244	Port Retainer	PH 15-7 MO SST
⑧	2	47472	Feed/Conc. Port	6% MO SST
⑨	2	50489	Port Retainer Set	CF8M Cast SST, Two-piece set
⑩	2	45294	Adapter Seal	Ethylene propylene O-Ring
<b>HEAD INTERLOCK</b>				
⑪	2	46414	Retaining Ring	302 SST
<b>VESSEL SUPPORT</b>				
⑫	*2	45058	Saddle	Cast Urethane Elastomer
⑬	*2	47459	Strap Assembly	304 SST - Thermoplastic cushion
⑭	*4	47458	Strap Screw	5/16-18 UNC, 18-8 Stainless Steel
<b>ELEMENT INTERFACE</b>				
⑮	2	As Required	Adapter	Engineering Thermoplastic
⑯	A/R	As Required	PWT Seal	Ethylene propylene O-Ring
*3 each furnished with length code 4, 5 & 6				



SECTION THROUGH END CLOSURE

Shell Length Code	L L.O.A. IN (MM)	S Span IN (MM)	APPROX. ASSEMBLY Weight LB (KG)
1	56.6 (1438)	28 X 1 (711)	21.0 (9.5)
2	96.6 (2454)	56 X 1 (1422)	31.0 (14.0)
3	136.6 (3470)	80 X 1 (2032)	41.0 (18.6)
4	176.6 (4486)	64 X 2 (1626)	51.0 (23.1)
5	216.6 (5502)	78 X 2 (1981)	62.0 (27.8)
6	256.6 (6518)	92 X 2 (2337)	71.0 (32.2)

**CodeLine™**  
 PRESSURE VESSELS  
 PENTAIR WATER TREATMENT

**MODEL 40E100**  
 HIGH PRESSURE MEMBRANE HOUSING

ECN 8631	SHEET 1 OF 2	SIZE B	NUMBER 518015	REV C
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NOTES  
 • DIMENSIONS IN INCHES (MM APPROX)  
 • NOT TO BE USED FOR CONSTRUCTION UNLESS CERTIFIED  
 • PATENT APPLIED FOR

## RATING:

DESIGN PRESSURE.....1000 PSI at 120°F  
(6.9 MPa at 49°C)  
MIN. OPERATING TEMP.....20°F  
(-7°C)  
FACTORY TEST PRESSURE.....1500 PSI  
(10.3 MPa)  
BURST PRESSURE.....6000 PSI  
(41.4 MPa)

## INTENDED USE

The CodeLine Model 40E100 Fiberglass RO Pressure Vessel is designed for continuous, long-term use as a housing for reverse osmosis membrane elements to desalt typical seawater at pressures up to 1000 psi. Any make of four-inch nominal diameter spiral-wound element is easily accommodated; the appropriate interfacing hardware for the element specified is furnished with the vessel.

The CodeLine Model 40E100 is designed in accordance with the engineering standards of the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME Code). At small additional cost, vessels can be inspected during construction by an ASME Authorized Inspector and ASME Code stamped.

The CodeLine Model 40E100 must be installed, operated and maintained in accordance with the precautions listed and good industrial practice to assure safe operation over a long service life.

The high performance reinforced plastic shell must be allowed to expand under pressure; undue restraint at support points or piping connections can cause leaks to develop in the shell. The end closure, incorporating close-fitting, interlocking metal components, must be kept dry and free of corrosion; deterioration can lead to catastrophic mechanical failure of the head.

Pentair Water Treatment will assist the purchaser in determining the suitability of this standard vessel for their specific operating conditions. The final determination however, including evaluation of the standard materials of construction for compatibility with the specific corrosive environment, shall be the responsibility of the purchaser.

Specifications subject to change without notice.

## PRECAUTIONS

- DO... read, understand and follow all instructions; failure to take every precaution will void warranty and may result in vessel failure
- DO... mount shell on horizontal members at central span "S" using compliant vessel supports furnished; tighten hold down straps just snug
- DO... provide overpressure protection for vessel set at not more than 105% of design pressure
- DO... inspect end closures regularly; replace components that have deteriorated and correct causes of corrosion
- DO NOT... make rigid piping connections to ports or clamp vessel in any way that restricts growth of fiberglass shell under pressure; ▲DIA = 0.02 in. (0.5mm) and ▲L = 0.2 in. (5mm) for a length code -6 vessel
- DO NOT... hang piping manifolds from ports or use vessel in any way to support other components.
- DO NOT... operate vessel at pressures and temperatures in excess of its rating
- DO NOT... operate vessel without permeate ports internally connected with a complete set of elements and and interconnecting hardware
- DO NOT... operate vessel with permeate pressure in excess of 125 psi at 120°F (0.9 MPa at 49°C)
- DO NOT... overtighten the connection to the permeate port (hand-tighten plus one-quarter turn, check for leaks.)
- DO NOT... tolerate leaks or allow end closures to be routinely wetted in any way
- DO NOT... pressurize vessel until double checking to verify that the Retaining Ring is in place and fully seated.
- DO NOT... work on any component until first verifying that pressure is relieved from vessel
- DO NOT... operate at pH levels below 3 or above 10

For complete information on proper use of this vessel please refer to the 40E Series USER'S GUIDE, Bulletin 526005

## ORDERING

Using the chart below, please check the features you require and fax them with your purchase order to our customer service department for expedited processing. For optional materials and or feature not listed below, please consult the factory for pricing and availability.

Please note that we require your membrane brand and model number when ordering. If this information is not initially available, you may provide it at a later date by checking the appropriate box below

VESSEL LENGTH CODE — please check one  
CODELINE MODEL 40E100 -1 -2 -3 -4 -5 -6

EXTERIOR FINISH — please check one

- Standard — white high-gloss polyurethane coating over sanded surface.
- Option — optional colors are available for 50 or more vessels per order. Call factory for pricing details.

CERTIFICATION — please check one

- Standard — certified by CodeLine, not code stamped.
- Option — Certified by ASME Authorized Inspector, Code stamped and registered with National Board. Call factory for pricing details.

MEMBRANE BRAND AND MODEL — please check one and fill in information

- Please supply adapters for the following membrane brand and specific model.  
Brand \_\_\_\_\_ Model \_\_\_\_\_
- Membrane brand and model information is not currently available, but will be supplied to CodeLine on or before the following date. \_\_\_\_/\_\_\_\_/\_\_\_\_

MATERIAL AND PORT CONFIGURATIONS OPTIONS — please check one

- Standard — all materials and port configurations per drawing 518015 on the opposite page.
- Option — feed/concentrate port, 3/4" victaulic.



# FILMTEC Membranes

## Cleaning Biofouling from FILMTEC FT30 Elements

The following cleaning procedure is designed specifically for a system that has been fouled with biological matter. Consult the general cleaning instructions for information that is common to all types of cleaning such as suggested equipment, pH and temperature limits, and recommended flow rates.

### Safety Precautions

1. When using any chemical indicated here in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
2. When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions through the elements.
3. It is recommended the elements be flushed with good-quality chlorine-free water (20°C minimum temperature) after cleaning. Permeate water is recommended; but a dechlorinated potable supply or pre-filtered feedwater may be used, provided that there are no corrosion problems in the piping system. Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, permeate must be diverted to drain for at least 10 minutes or until the water is clear when starting up after cleaning.
4. During recirculation of cleaning solutions, the temperatures must not exceed 50°C at pH 2-10, 35°C at pH 1-11, and 30°C at pH 1-12.
5. For elements greater than six inches in diameter, the flow direction during cleaning must be the same as during normal operation to prevent element telescoping, because the vessel thrust ring is installed only on the reject end of the vessel. This is also recommended for smaller elements.

### Cleaning Procedure

There are seven steps in cleaning elements with biofouling.

1. Make up the cleaning solution listed from Table 1.

**Table 1. Biofouling Cleaning Solutions**

Cleaning Solutions	Solution
Preferred	0.1% (wt) NaOH pH 12, 30°C maximum
Preferred	0.1% (wt) NaOH 0.025% (wt) Na-DSS pH 12, 30°C maximum
Alternate	0.1% (wt) NaOH 1.0% (wt) Na <sub>4</sub> EDTA pH 12, 30°C maximum

#### Notes

<sup>1</sup> (wt) denotes weight percent of active ingredient.

<sup>2</sup> Cleaning chemical symbols in order used: NaOH is sodium hydroxide; Na-DSS is sodium salt of dodecylsulfate; Sodium Laurel Sulfate; Na<sub>4</sub>EDTA is the tetra-sodium salt of ethylene diamine tetraacetic acid and is available from The Dow Chemical Company under the trademark VERSENE\*.

\*Trademark of The Dow Chemical Company

2. Low-flow pumping. Pump mixed, preheated cleaning solution to the vessel at conditions of low flow rate (about half of that shown in Table 2) and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no permeate is produced. A low pressure minimizes redeposition of dirt on the membrane. Dump the concentrate, as necessary, to prevent dilution of the cleaning solution.

**Table 2. Recommended feed flow rate per pressure vessel during high flow rate recirculation**

Feed Pressure <sup>1</sup>		Element Diameter (inches)	Feed Flow Rate per Pressure Vessel	
(psig)	(bar)		(gpm)	(m <sup>3</sup> /hr)
20-60	1.5-4.0	2.5	3-5	0.7-1.2
20-60	1.5-4.0	4 <sup>2</sup>	8-10	1.8-2.3
20-60	1.5-4.0	6	16-20	3.6-4.5
20-60	1.5-4.0	8	30-40	6.0-9.1
20-60	1.5-4.0	8 <sup>3</sup>	35-45	8.0-10.2

<sup>1</sup> Dependent on number of elements in pressure vessel.

<sup>2</sup> 4-Inch full-fit elements should be cleaned at 12-14 gpm (2.7-3.2 m<sup>3</sup>/hr).

<sup>3</sup> For full-fit, 400 and 440 sq. ft. area elements.

3. Recirculate. After the process water is displaced, cleaning solution will be present in the concentrate stream that can be recycled to the cleaning solution tank. Recycle the cleaning solution for 15 minutes or until there is no visible color change. If a color change occurs, dispose of the cleaning solution and prepare a new solution as described in step 2.
4. Soak. Turn the pump off and allow the elements to soak. Soak the elements for 1-15 hours (soaking overnight will give best results). To maintain temperature during an extended soak period, use a slow recirculation rate (about 10 percent of that shown in Table 2). Soak time will vary depending on the severity of the fouling. For lightly fouled systems, a soak time of 1-2 hours is sufficient.
5. High-flow pumping. Feed the cleaning solution at the rates shown in Table 2 for 45 minutes. The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. If the elements are heavily fouled, using a flow rate that is 50 percent higher than shown in Table 2 may aid cleaning. At higher flow rates, excessive pressure drop may be a problem. The maximum recommended pressure drops are 15 psi per element or 50 psi per multi-element vessel, whichever value is more limiting.
6. Flush out. Prefiltered raw water can be used for flushing out the cleaning solution, unless there will be corrosion problems (e.g., stagnant seawater will corrode stainless steel piping). To prevent precipitation, the minimum flush out temperature is 20°C. The system should be flushed for 1 hour.
7. The system should be restarted. Elements and the system need to stabilize before taking any data. The stabilization period will vary depending on the severity of the fouling. To regain optimum performance, it may take several cleaning and soak cycles.

## FILMTEC Membranes

For more information about FILMTEC membranes,  
call the Dow Liquid Separations business:  
North America . . . . . 1-800-447-4369  
Latin America . . . . . (+55) 11-5188-9277  
Europe . . . . . (+32) 3-450-2240  
Japan . . . . . (+81) 3-5460-2100  
Australia . . . . . (+61) 2-9776-3226  
<http://www.filmtec.com>

### Additional Information

By experience, the cleaning solution of Na<sub>4</sub>EDTA with caustic has been found to be slightly less effective than a standard caustic solution or a solution of caustic and Na-DSS.

For any solution, contact time is critical. Several overnight soaks may be necessary to restore the system performance.

After the elements are clean it is very beneficial to clean one additional time in order to clean off the last remaining biofilm layer on the surface of the membrane. Any remaining biofilm will tend to attract and trap dirt, so an extra cleaning will increase the time between cleanings.

For industrial systems where the permeate or product water is not used for drinking, a non-oxidizing biocide can be used prior to step 1 of the cleaning procedure to kill any bacteria or biofilm in the system. Please refer to separate instructions on methods for sanitizing membrane systems (i.e., "Sanitization with DBNPA - Tech Facts"). If the only choice for a sanitizing agent is an oxidant, such as hydrogen peroxide, the system must be cleaned before sanitization.

**NOTE:** Recommendations made here are specifically designed for FILMTEC Reverse Osmosis and Nanofiltration elements. These recommendations, such as cleaning procedures and chemicals employed, may not be compatible with other brands of membrane elements. It is your responsibility to ensure the suitability of our recommendations and procedures if they are applied to membrane elements other than FilmTec products.

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Published April 2002.





# FILMTEC Membranes

## Cleaning Carbonate Scale from FILMTEC FT30 Elements

The following cleaning procedure is designed specifically for a system that has had carbonate scale precipitated in the elements. Consult the general cleaning instructions for information that is common to all types of cleaning such as suggested equipment, pH and temperature limits, and recommended flow rates.

### Safety Precautions

1. When using any chemical indicated here in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
2. When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions through the elements.
3. It is recommended the elements be flushed with good-quality chlorine-free water (20°C minimum temperature) after cleaning. Permeate water is recommended; but a dechlorinated potable supply or prefiltered feedwater may be used, provided that there are no corrosion problems in the piping system. Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, permeate must be diverted to drain for at least 10 minutes or until the water is clear when starting up after cleaning.
4. During recirculation of cleaning solutions, the temperatures must not exceed 50°C at pH 2-10, 35°C at pH 1-11, and 30°C at pH 1-12.
5. For elements greater than six inches in diameter, the flow direction during cleaning must be the same as during normal operation to prevent element telescoping, because the vessel thrust ring is installed only on the reject end of the vessel. This is also recommended for smaller elements.

### Cleaning Procedure

There are seven steps in cleaning elements with carbonate scale.

1. Make up the cleaning solution listed from Table 1.

**Table 1. Carbonate Scale Cleaning Solutions**

Cleaning Solutions	Solution
Preferred	0.2% (wt) HCl pH 2, 45°C maximum
Alternative	2.0% (wt) Citric Acid
Alternative	1.0% Na <sub>2</sub> S <sub>2</sub> O <sub>4</sub>
Alternative	0.5% H <sub>3</sub> PO <sub>4</sub>

#### Notes

<sup>1</sup> (wt) denotes weight percent of active ingredient.

<sup>2</sup> Cleaning chemical symbols in order used: HCl is hydrochloric acid (Muriatic Acid).

- 
2. Low-flow pumping. Pump mixed, preheated cleaning solution to the vessel at conditions of low flow rate (about half of that shown in Table 2) and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no permeate is produced. A low pressure minimizes redeposition of dirt on the membrane. Dump the concentrate, as necessary, to prevent dilution of the cleaning solution.

**Table 2. Recommended feed flow rate per pressure vessel during high flow rate recirculation**

Feed Pressure <sup>1</sup>		Element Diameter (inches)	Feed Flow Rate per Pressure Vessel	
(psig)	(bar)		(gpm)	(m <sup>3</sup> /hr)
20-60	1.5-4.0	2.5	3-5	0.7-1.2
20-60	1.5-4.0	4 <sup>2</sup>	8-10	1.8-2.3
20-60	1.5-4.0	6	16-20	3.6-4.5
20-60	1.5-4.0	8	30-40	6.-9.1
20-60	1.5-4.0	8 <sup>3</sup>	35-45	8.0-10.2

<sup>1</sup> Dependent on number of elements in pressure vessel.

<sup>2</sup> 4-Inch full-fit elements should be cleaned at 12-14 gpm (2.7-3.2 m<sup>3</sup>/hr).

<sup>3</sup> For full-fit elements, 400 and 440 sq. ft. area elements.

3. Recirculate. After the process water is displaced, cleaning solution will be present in the concentrate stream that can be recycled to the cleaning solution tank. Recycle the cleaning solution for 10 minutes or until there is no visible color change. If at anytime during the circulation process there is a change in pH or a color change, dispose of the solution and prepare a new solution as described in step 2. A pH of 2 must be maintained for the cleaning to be effective.
  4. Soak. Turn the pump off and allow the elements to soak. Soak the elements for 1-15 hours (soaking overnight will give best results). To maintain temperature during an extended soak period, use a slow recirculation rate (about 10 percent of that shown in Table 2). Soak time will vary depending on the severity of the scaling. For lightly scaled systems, a soak time of 1-2 hours is sufficient.
  5. High-flow pumping. Feed the cleaning solution at the rates shown in Table 2 for 10 minutes. The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. If the elements are heavily fouled, using a flow rate that is 50 percent higher than shown in Table 2 may aid cleaning. At higher flow rates, excessive pressure drop may be a problem. The maximum recommended pressure drops are 15 psi per element or 50 psi per multi-element vessel, whichever value is more limiting.
  6. Flush out. Prefiltered raw water can be used for flushing out the cleaning solution, unless there will be corrosion problems (e.g., stagnant seawater will corrode stainless steel piping). To prevent precipitation, the minimum flush out temperature is 20°C. The system should be flushed for one hour.
  7. The system should be restarted. Elements and the system need to stabilize before taking any data. The stabilization period will vary depending on the severity of the fouling. To regain optimum performance, it may take several cleaning and soak cycles.
-

## FILMTEC Membranes

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Japan . . . . . (+81) 3-5460-2100  
Australia . . . . . (+61) 3-9226-3545  
<http://www.filmtec.com>

### Additional Information

Never recirculate the cleaning solution for longer than 20 minutes. With longer recirculation, the carbonate scale can reprecipitate and end up back on the membrane surface, making it more difficult to clean.

Carbonate scale reacts with HCl releasing carbon dioxide gas.

Depending on the severity of the fouling, it may take repeated cleanings to remove all the scale. Cleaning severe scale may not be economical and element replacement may be the best choice.

Citric acid was originally used as a cleaner for cellulose acetate membranes and is not as effective with thin film composite chemistry. Further, it has a disadvantage of being a nutrient source for systems, which have biological fouling. It is, however, easier to handle than HCl and is included as an alternative cleaner for that reason.

**NOTE:** Recommendations made here are specifically designed for FILMTEC Reverse Osmosis and Nanofiltration elements. These recommendations, such as cleaning procedures and chemicals employed, may not be compatible with other brands of membrane elements. It is your responsibility to ensure the suitability of our recommendations and procedures if they are applied to membrane elements other than FilmTec products.

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Published December 2002.





# FILMTEC Membranes

## Colloidal Fouling Prevention

### Introduction

Colloidal fouling of reverse osmosis elements can seriously impair performance by lowering productivity and sometimes salt rejection. An early sign of colloidal fouling is often an increased pressure differential across the system.

The source of silt or colloids in reverse osmosis feed waters is varied and often includes bacteria, clay, colloidal silica and iron corrosion products. Pretreatment chemicals used in a clarifier such as alum, ferric chloride, or cationic polyelectrolytes can also cause colloidal fouling if not removed in the clarifier or through proper media filtration. In addition, cationic polymers may coprecipitate with negatively charged antiscalants and foul the membrane.

The best available technology for determining the colloidal fouling potential of reverse osmosis feed water is the measurement of the Silt Density Index (SDI), sometimes referred to as the Fouling Index (FI). This is an important measurement to be carried out prior to designing an RO pretreatment system and on a regular basis during RO operation (three times a day is a recommended frequency for surface waters).

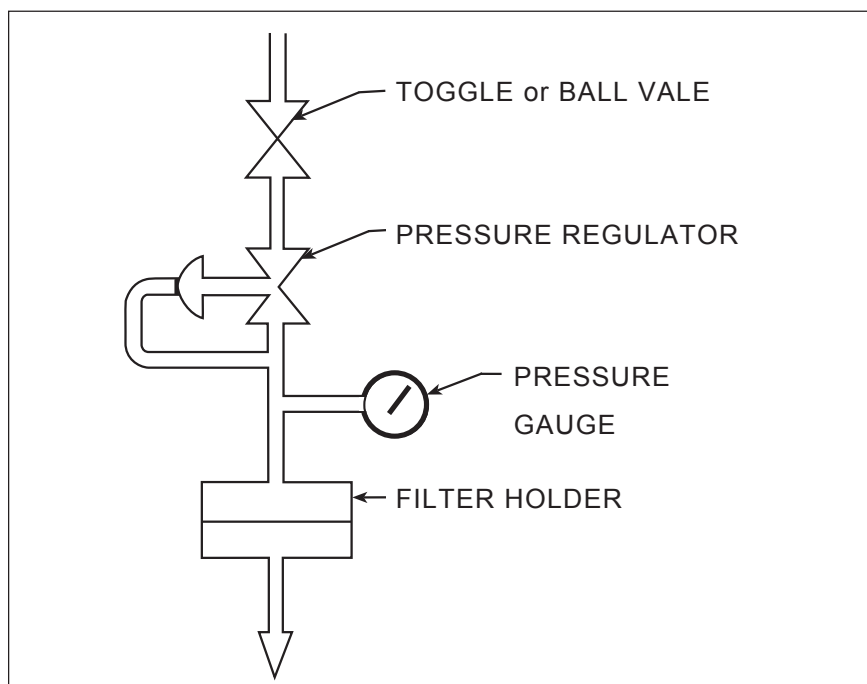
The Standard Test Method has been described in ASTM test D 4189-82.

### Equipment

(Available from Millipore Corporation)

- 47 mm diameter membrane filter support
- 47 mm diameter membrane filters (0.45  $\mu\text{m}$  pore size)
- 1 to 5 bar (10-70 PSI) manometer
- needle valve for pressure adjustment

Figure 1 shows the equipment needed to measure SDI.



**Figure 1: Apparatus for Measuring the Silt Density Index**

\*Trademark of The Dow Chemical Company

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## Procedure

- a. Place the membrane filter on its support, bleed water pressure on carefully, tighten the O-ring seal and fix the support vertically.
- b. Adjust feed pressure to 2.1 bar (30 PSI) and measure initial time,  $t_0$ , necessary to filter 500 ml of sample water (feed pressure to be kept constant by continuous adjustment).
- c. Keep filter in operation for 15 minutes under 2.1 bar (30 PSI) feed pressure.
- d. After 15 minutes measure again time,  $t_1$ , necessary to filter 500 ml. Membrane filter should be kept for further analysis.
- e. Calculation:

$$SDI = \left[ 1 - \frac{t_0}{t_1} \right] \times \frac{100}{15}$$

When  $t_1$  is four times as long as  $t_0$ , the resulting SDI is 5. A water sample that totally blocks the membrane filter has an SDI value of 6.7.

The guideline is to maintain SDI at less than or equal to 5. A number of pretreatment technologies have proven effective in SDI reduction including media filtration (such as sand/anthracite), ultrafiltration, cross flow microfiltration. Polyelectrolyte addition ahead of filtration sometimes improves SDI reduction.

Methods to prevent colloidal fouling are outlined in the following sections.

## Media Filtration

The removal of suspended and colloidal particles by media filtration is based on their deposition on the surface of filter grains, while the water flows through a bed of these grains (filter media). The quality of the filtrate depends on the size, surface charge and geometry of both suspended solids and filter media, as well as on the water analysis and operational parameters. With a well designed and operated filter, a  $SDI < 5$  can usually be achieved.

The most common filter media in water treatment are sand and anthracite. The effective grain size for fine sand filter is in the range of 0.35 to 0.5 mm, and 0.7 to 0.8 mm for anthracite filter. In comparison to single sand filter media, dual filter media with anthracite over sand permit more penetration of the suspended matter into the filter bed, thus resulting in more efficient filtration and longer runs between cleaning. The design depth of the filter media is normally about 0.8 m (31 inches) minimum. In the dual filter media, the filters are usually filled with 0.5 m (20 inches) of sand covered with 0.3 m (12 inches) of anthracite.

There are two types of filters employed, gravity and pressure filters. As the filter vessel for pressure filtration is designed for pressurization, a higher pressure drop can be applied for higher filter beds and/or smaller filter grains and/or higher filtration velocities. The design filtration flow rates are usually 10-20 m/h, and the back-wash rates are in the range of 40-50 m/h. For feedwaters with a high fouling potential, flow rates of less than 10m/h and/or second pass media filtration is preferred. The available pressure is usually about 5 m of head for gravity filters, and 2 bar (30 PSI) to more than 4 bar (60 PSI) for pressure filters.

During operation, influent water to be filtered enters at the top of the filter, percolates through the filter bed, and is drawn off through the collector system at the bottom. Periodically, when the differential pressure increase between the inlet and outlet of the filter is 0.3 to 0.6 bar (4 to 9 PSI) for the pressure filter, and about 1.4 m for the gravity filter, the filter is back-washed and rinsed to carry away the deposited matter. Backwash time is normally about 10 min.

Frequent shut-downs and start-ups should be avoided, because each filter velocity increase will release previously deposited particulate matter. Design and operational details of media filtration are available in the literature.

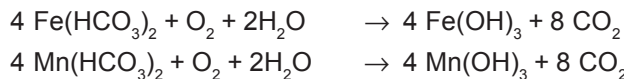
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### Oxidation Filtration

Some well waters, usually brackish waters, are in a reduced state. Typical for these waters is the absence of oxygen and the presence of divalent iron and manganese, sometimes also of hydrogen sulfide and ammonium.

If such a water has been chlorinated and then dechlorinated, or has taken up more than 5 mg/l of oxygen,  $\text{Fe}^{2+}$  is converted into  $\text{Fe}^{3+}$ , which forms insoluble colloidal hydroxide particles. The oxidation of iron and manganese is given by:



Iron fouling occurs more frequently than manganese fouling, since the oxidation of iron occurs at a much lower pH. Thus a fouling problem can be created even if the SDI is below 5, and the level of iron in the RO feed water is below 0.1 mg/l. Waters with low alkalinity usually have higher iron concentrations than waters with high alkalinity, because the  $\text{Fe}^{2+}$  concentration is usually limited by the solubility of  $\text{FeCO}_3$ .

One method of handling such waters is to prevent the exposure to air or to any oxidizing agent, e.g. chlorine, through the whole RO process. A low pH is favorable to retard  $\text{Fe}^{2+}$  oxidation. At  $\text{pH} < 6$  and oxygen  $< 0.5$  mg/l, the maximum permissible  $\text{Fe}^{2+}$  concentration is 4 mg/l. The other way is to deliberately oxidize iron and manganese by air,  $\text{Cl}_2$  or  $\text{KMnO}_4$ . The formed hydroxides can then be removed by media filtration. Colloidal sulfur as formed from hydrogen sulfide however, may be difficult to remove. Oxidation and filtration can be accomplished in one step by using a filter media with the ability to oxidize  $\text{Fe}^{2+}$  by electron transfer.

Greensand is such a granular medium, which is a green (when dry) mineral glauconite. It can be regenerated with  $\text{KMnO}_4$  when its oxidizing capability is exhausted. After the regeneration, the residual  $\text{KMnO}_4$  has to be thoroughly rinsed out in order to avoid an oxidation damage of the membranes. This technique is used when  $< 2$  mg/l  $\text{Fe}^{2+}$  is present in the raw water. For higher  $\text{Fe}^{2+}$  concentrations,  $\text{KMnO}_4$  can be continuously dosed into the inlet stream of the filter. In this case however, measures have to be taken to assure that no permanganate can reach the membranes, for example by installation of a carbon filter.

Birm filtration has also been used effectively for  $\text{Fe}^{2+}$  removal from RO feed water. Since with birm a pH increase and consequently a shift in the LSI value might occur, care should be taken to avoid  $\text{CaCO}_3$  precipitation in the filter and in the RO system.

### In-Line Filtration

The efficiency of media filtration to reduce the SDI value can be markedly improved if the colloids in the raw water are coagulated and/or flocculated prior to filtration. In-line filtration can be applied to raw waters with an SDI only slightly above 5. The method, also named in-line coagulation or in-line coagulation-flocculation, is described in ASTM Standard D 4188. A coagulant is injected into the raw water stream, effectively mixed, and the formed microflocs are immediately removed by media filtration.

Ferric sulfate and ferric chloride are used to destabilize the negative surface charge of the colloids and to entrap them into the freshly formed ferric hydroxide microflocs. Aluminium coagulants are also effective, but not recommended because of possible fouling problems with residual aluminium.

Rapid dispersion and mixing of the coagulant is extremely important. An in-line static mixer or injection on the suction side of a booster pump is recommended. The optimum dosage is usually in the range of 10 to 30 mg/l, but should be determined case by case.

To strengthen the hydroxide microflocs and thereby improving their filterability, and/or to bridge the colloidal particles together, flocculants can be used in combination with coagulants or alone. Flocculants are soluble high molecular mass organic compounds, e.g. linear polyacrylamides. Through different active groups, they may be positively charged (cationic), negatively charged (anionic), or close to neutral (non-ionic).

Coagulants and flocculants may interfere with an RO membrane directly or indirectly. Indirect interference occurs when the compound forms a precipitate which is deposited on the membrane. For example, channelling of the media filter may enable flocs to pass through and deposit on the membrane. A precipitate can also be formed when concentrating the treated feedwater, such as when aluminium or ferric coagulants are added without subsequently lowering pH to avoid supersaturation in the RO stage. Furthermore, reaction with a compound

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added after the media filter can cause a precipitate to form. This is most noticeable with antiscalants. Nearly all antiscalants are negatively charged and will react with cationic coagulants or flocculants present in the water. Several RO plants have been heavily fouled by a gel formed by reaction between cationic polyelectrolytes and antiscalants.

Direct interference occurs when the compound itself affects the membrane resulting in a flux loss. The ionic strength of the water may have an effect on the interference of the coagulant or flocculant with the membrane. If so, the result at brackish water conditions could be different from that at sea water conditions. To minimise the risk of direct or indirect interference with the RO membrane, anionic or nonionic flocculants are preferred rather than cationic ones. Overdosing must be avoided.

### **Coagulation – Flocculation**

For raw waters containing high concentrations of suspended matter resulting in a high SDI, the classic coagulation – flocculation process is preferred. The hydroxide flocs are allowed to grow and to settle in specifically designed reaction chambers. The hydroxide sludge is removed, and the supernatant water is further treated by media filtration.

For the coagulation – flocculation process, either a solids-contact type clarifier or a compact coagulation – flocculation reactor may be used. For details, please refer to the general water treatment textbooks.

### **Crossflow Microfiltration/Ultrafiltration**

Crossflow filtration through a microfiltration (MF) or ultrafiltration (UF) membrane removes virtually all suspended matter and, in the case of ultrafiltration, also dissolved organic compounds depending on their molecular mass and on the molecular mass cutoff of the membrane. Hence, an SDI < 1 can be achieved with a well designed and properly maintained microfiltration or ultrafiltration system. The fouling problem, now transferred from the RO membrane to the MF or UF membrane, has to be handled by this system. At the same time, a high MF/UF system recovery and a high specific permeate flow is requested for economic reasons. These objectives are usually achieved by periodic cleanings, either a forward flush or preferably a backflush. If a chlorine resistant membrane material is used, e.g. polysulfone or a ceramic membrane, chlorine can be added to the wash water in order to prevent biological fouling.

### **Cartridge Microfiltration**

A cartridge filter with a pore size of less than 10 µm is the minimum pretreatment required for every RO system. It is a safety device to protect the membranes and the high pressure pump from suspended particles. Usually it is the last step of a pretreatment sequence. We recommend to use a pore size of 5 µm or less. The better the prefiltration is, the less cleaning of the RO membranes is required. When the silica concentration in the concentrate stream exceeds the theoretical solubility, cartridge filtration with 1 µm pore size is recommended in order to minimise the interaction with iron and aluminium colloids.

The filter should be sized on a flow rate according to the manufacturer's recommendation, and replaced before the pressure drop has increased to the permitted limit, but at the latest, after three months. Backflushable filters are not recommended because of their lower efficiency and higher biofouling risk.

The cartridge filter should be made of a synthetic nondegradable material; e.g. nylon or polypropylene and equipped with a pressure gauge to indicate the differential pressure drop and thereby indicating the extent of its fouling. Regular inspections of used cartridges provide useful information regarding fouling risks and cleaning requirements. If the differential pressure across the filter increases rapidly, it is an indication of possible problems in the raw water supply or in the pretreatment process. The filter provides some degree of short term protection for the membranes while corrective action is taking place.

Replacing cartridge filters more often than every 1 to 3 months usually indicates a problem with the pretreatment. However, the cartridge filter is not meant to be a major component for the removal of high amounts of filterable solids. This would not only be an inefficient use of rather expensive filters, but would probably lead to premature failure of the membrane system due to the high probability that some of the unwanted material will break through. It may be considered however, to use upstream a second cartridge with larger pore size.

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### Other Methods

Other methods to prevent colloidal fouling than those described in the previous chapters also exist.

**Lime Softening** is described in separate information on Scale Control as a method for silica removal. Removal of iron and colloidal matter are further benefits.

**Strong acid cation exchange resin softening** does not only remove hardness, but also lowers concentrations of iron and aluminium that otherwise could foul the membranes. Softened water is also known to exhibit a lower fouling tendency than unsoftened water, because multivalent cations promote the adhesion of naturally occurring colloids, which are usually negatively charged.

Backflushable fine filters may be used upstream of the cartridge filters to protect these. They are, however, no substitute for disposable cartridges.

### Design and Operational Considerations

The prevention of colloidal fouling is not only a matter of the proper pretreatment technique, but also of the system design and operation. As an extreme example, a surface water could be pretreated by coagulation – flocculation and ultrafiltration. The RO system could then operate with a high permeate flux, and almost no cleaning would be required. If the same water, however, would just be cartridge filtered, then the RO system would need much more membrane area, and the membranes would require frequent cleaning and maintenance. A poor pretreatment can be partially compensated by adding more membrane area and modifying the system, and by more frequent and/or harsh cleaning. On the other hand, improving the pretreatment means savings in membrane costs. In order to minimize the pretreatment effort and/or improve the feed water quality, the best available raw water quality should be used. The intake of surface water, including sea water is of paramount importance. A contamination of the raw water with waste water effluent may cause serious problems in the RO plant. A deep well close to the shore or the river is preferred. If an open intake is required, it should be located well away from the shore and some meters below the water surface.

New wells often release suspended matter in the first days of operation. Care must be taken that wells are properly rinsed out.

Fouling by iron oxide is also a common problem. It can be avoided by selecting non-corrosive materials.

The technical information contained here is extracted from the **FILMTEC Membranes - Technical Manual**. References to other sections of the manual have been replaced with short references to additional but separate information available from our web site. The information in these extracts has been updated and supercedes that contained in the full manual.

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Form No. 609-00307-702QRP



# FILMTEC Membranes

## Cleaning Iron Fouling from FILMTEC FT30 Elements

The following cleaning procedure is designed specifically for a system that is fouled with iron. Consult the general cleaning instructions for information that is common to all types of cleaning such as suggested equipment, pH and temperature limits, and recommended flow rates.

### Safety Precautions

1. When using any chemical indicated here in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
2. When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions through the elements.
3. It is recommended the elements be flushed with good-quality chlorine-free water (20°C minimum temperature) after cleaning. Permeate water is recommended; but a dechlorinated potable supply or prefiltered feedwater may be used, provided that there are no corrosion problems in the piping system. Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, permeate must be diverted to drain for at least 10 minutes or until the water is clear when starting up after cleaning.
4. During recirculation of cleaning solutions, the temperatures must not exceed 50°C at pH 2-10, 35°C at pH 1-11, and 30°C at pH 1-12.
5. For elements greater than six inches in diameter, the flow direction during cleaning must be the same as during normal operation to prevent element telescoping, because the vessel thrust ring is installed only on the reject end of the vessel. This is also recommended for smaller elements.

### Cleaning Procedure

There are seven steps in cleaning elements with iron fouling.

1. Make up the cleaning solution listed from Table 1.

**Table 1. Iron Fouling Cleaning Solutions**

Cleaning Solutions	Solution
Preferred	1.0% (W) Na <sub>2</sub> S <sub>2</sub> O <sub>4</sub> pH 5, 30°C max.
Alternative	2.0% (wt) Citric Acid
Preferred	0.5% H <sub>3</sub> PO <sub>4</sub>
Alternative	1.0% NH <sub>2</sub> SO <sub>4</sub> H

#### Notes

<sup>1</sup> (wt) denotes weight percent of active ingredient.

<sup>2</sup> Cleaning chemical symbols in order used: Na<sub>2</sub>S<sub>2</sub>O<sub>4</sub> is sodium hydrosulfite.

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2. Low-flow pumping. Pump mixed, preheated cleaning solution to the vessel at conditions of low flow rate (about half of that shown in Table 2) and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no permeate is produced. A low pressure minimizes redeposition of dirt on the membrane. Dump the concentrate, as necessary, to prevent dilution of the cleaning solution.

**Table 2. Recommended feed flow rate per pressure vessel during high flow rate recirculation**

Feed Pressure <sup>1</sup>		Element Diameter (inches)	Feed Flow Rate per Pressure Vessel	
(psig)	(bar)		(gpm)	(m <sup>3</sup> /hr)
20-60	1.5-4.0	2.5	3-5	0.7-1.2
20-60	1.5-4.0	4 <sup>2</sup>	8-10	1.8-2.3
20-60	1.5-4.0	6	16-20	3.6-4.5
20-60	1.5-4.0	8	30-40	6.-9.1
20-60	1.5-4.0	8 <sup>3</sup>	35-45	8.0-10.2

<sup>1</sup> Dependent on number of elements in pressure vessel.

<sup>2</sup> 4-Inch full-fit elements should be cleaned at 12-14 gpm (2.7-3.2 m<sup>3</sup>/hr).

<sup>3</sup> For full-fit elements, 400 and 440 sq. ft. area elements.

3. Recirculate. After the process water is displaced, cleaning solution will be present in the concentrate stream that can be recycled to the cleaning solution tank. Recycle the cleaning solution for 15 minutes or until there is no visible color change. If at anytime during the circulation process there is a color change, dispose of the solution and prepare a new solution as described in step 2.
  4. Soak. Turn the pump off and allow the elements to soak. Soak the elements for 1-15 hours to remove the iron from the surface of the membrane (soaking overnight will give best results). Soak times are essential for the sodium hydrosulfite to be effective. To maintain temperature during an extended soak period, use a slow recirculation rate (about 10 percent of that shown in Table 2). Soak time will vary depending on the severity of the fouling. For lightly fouled systems, a soak time of 1-2 hours is sufficient.
  5. High-flow pumping. Feed the cleaning solution at the rates shown in Table 2 for 45 minutes. The high flow rate flushes out the iron removed from the membrane surface by the cleaning. If the elements are heavily fouled, using a flow rate that is 50 percent higher than shown in Table 2 may aid cleaning. At higher flow rates, excessive pressure drop may be a problem. The maximum recommended pressure drops are 15 psi per element or 50 psi per multi-element vessel, whichever value is more limiting. If there is a color change, dispose of the solution and prepare a new solution as described in step 2 and repeat the process from step 3.
  6. Flush out. Prefiltered raw water can be used for flushing out the cleaning solution, unless there will be corrosion problems (e.g., stagnant seawater will corrode stainless steel piping). The system should be flushed for one hour.
  7. The system should be restarted. Elements and the system need to stabilize before taking any data. The stabilization period will vary depending on the severity of the fouling. To regain optimum performance, it may take several cleaning and soak cycles.
-

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### Additional Information

The sodium hydrosulfite has a very pungent odor, so the room must be well ventilated. Follow all safety regulations and procedures.

Contact time is key to successful cleaning. The solution will sometimes change many different colors. Black, brown, yellow are all very normal for this type of cleaning. Anytime the solution changes color, it should be disposed of and a new solution prepared. The length of time and the number of soaking periods will depend on the severity of the fouling.

Citric acid was originally used as a cleaner for cellulose acetate membranes and is not as effective with thin film composite chemistry. Further, it has a disadvantage of being a nutrient source for systems, which have biological fouling. It is, however, easier to handle than sodium hydrosulfite and is included as an alternative cleaner for that reason.

**NOTE:** Recommendations made here are specifically designed for FILMTEC Reverse Osmosis and Nanofiltration elements. These recommendations, such as cleaning procedures and chemicals employed, may not be compatible with other brands of membrane elements. It is your responsibility to ensure the suitability of our recommendations and procedures if they are applied to membrane elements other than FilmTec products.

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# FILMTEC Membranes

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## Cleaning Organic Fouling from FILMTEC FT30 Elements

The following cleaning procedure is designed specifically for a system that has been fouled with organic species such as humic and fulvic acids, antiscalants, or oils. Consult the general cleaning instructions for information that is common to all types of cleaning such as suggested equipment, pH and temperature limits, and recommended flow rates.

### Safety Precautions

1. When using any chemical indicated here in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
2. When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions through the elements.
3. It is recommended the elements be flushed with good-quality chlorine-free water (20°C minimum temperature) after cleaning. Permeate water is recommended; but a dechlorinated potable supply or prefiltered feedwater may be used, provided that there are no corrosion problems in the piping system. Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, permeate must be diverted to drain for at least 10 minutes or until the water is clear when starting up after cleaning.
4. During recirculation of cleaning solutions, the temperatures must not exceed 50°C at pH 2-10, 35°C at pH 1-11, and 30°C at pH 1-12.
5. For elements greater than six inches in diameter, the flow direction during cleaning must be the same as during normal operation to prevent element telescoping, because the vessel thrust ring is installed only on the reject end of the vessel. This is also recommended for smaller elements.

### Cleaning Procedure

There are six steps in cleaning elements fouled with organics, but the six steps are repeated once with a high pH cleaning solution and once with a low pH cleaning solution.

1. Make up the desired high pH cleaning solution selected from Table 1.
2. Low-flow pumping. Pump mixed, preheated cleaning solution to the vessel at conditions of low flow rate (about half of that shown in Table 2) and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no permeate is produced. A low pressure minimizes redeposition of dirt on the membrane. Dump the concentrate, as necessary, to prevent dilution of the cleaning solution.

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**Table 1. Organic Fouling Cleaning Solutions**

Cleaning Solutions	Solution
Preferred	0.1% (wt) NaOH pH 12, 30°C maximum, followed by 0.2% HCl pH 2, 45°C maximum
Preferred	0.1% (wt) NaOH 0.025% (wt) Na-DSS pH 12, 30°C maximum, followed by 0.2% HCl pH 2, 45°C maximum
Alternate	0.1% (wt) NaOH 1.0% (wt) Na <sub>4</sub> EDTA pH 12, 30°C maximum, followed by 0.2% HCl pH 2, 45°C maximum

**Notes**

<sup>1</sup> (wt) denotes weight percent of active ingredient.

<sup>2</sup> Cleaning chemical symbols in order used: NaOH is sodium hydroxide; HCl is hydrochloric acid (Muratic Acid); Na-DSS is sodium salt of dodecylsulfate; Sodium Laurel Sulfate; Na<sub>4</sub>EDTA is the tetra-sodium salt of ethylene diamine tetraacetic acid and is available from The Dow Chemical Company under the trademark VERSENE\*.

**Table 2. Recommended feed flow rate per pressure vessel during high flow rate recirculation**

Feed Pressure <sup>1</sup> (psig)	(bar)	Element Diameter (inches)	Feed Flow Rate per Pressure Vessel	
			(gpm)	(m <sup>3</sup> /hr)
20-60	1.5-4.0	2.5	3-5	0.7-1.2
20-60	1.5-4.0	4 <sup>2</sup>	8-10	1.8-2.3
20-60	1.5-4.0	6	16-20	3.6-4.5
20-60	1.5-4.0	8	30-40	6.-9.1
20-60	1.5-4.0	8 <sup>3</sup>	35-45	8.0-10.2

<sup>1</sup> Dependent on number of elements in pressure vessel.

<sup>2</sup> 4-Inch full-fit elements should be cleaned at 12-14 gpm (2.7-3.2 m<sup>3</sup>/hr).

<sup>3</sup> For full-fit elements, 400 and 440 sq. ft. area elements.

- Recirculate. After the process water is displaced, cleaning solution will be present in the concentrate stream that can be recycled to the cleaning solution tank. Recycle the cleaning solution for 30 minutes. If a color change occurs, dispose of the cleaning solution and prepare a new solution as described in step 2.
- Soak. Turn the pump off and allow the elements to soak. Soak the elements for 1-15 hours (soaking overnight will give best results). To maintain temperature during an extended soak period, use a slow recirculation rate (about 10 percent of that shown in Table 2). Soak time will vary depending on the severity of the fouling. For lightly fouled systems, a soak time of 1-2 hours is sufficient.

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5. High-flow pumping. Feed the cleaning solution at the rates shown in Table 2 for 30 minutes. The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. If the elements are heavily fouled, using a flow rate that is 50 percent higher than shown in Table 2 may aid cleaning. At higher flow rates, excessive pressure drop may be a problem. The maximum recommended pressure drops are 15 psi per element or 50 psi per multi-element vessel, whichever value is more limiting.
6. Flush out. Prefiltered raw water can be used for flushing out the cleaning solution, unless there will be corrosion problems (e.g., stagnant seawater will corrode stainless steel piping). The system should be flushed for one hour during the final flush in preparation for restarting the system.
7. Repeat steps 2 through 6 with cleaning solution of HCl at pH 2.
8. The system should be restarted. Elements and the system need to stabilize before taking any data. The stabilization period will vary depending on the severity of the fouling. To regain optimum performance, it may take several cleaning and soak cycles.

### Additional Information

For maximum effectiveness, temperature of the cleaning solutions must be above 25°C. Elevating the temperature of the cleaning solutions helps them to lift the organic from the membrane surface.

Some organics such as oils are very difficult to remove. To remove them, experiment with different soak times for optimum effectiveness. In addition, the most effective cleaning solution usually contains a surfactant such as Na-DSS or perhaps some commercially available membrane cleaners containing surfactants or detergents that can help remove the oils. Consult your chemical supplier for their recommendation.

If the organic fouling is the result of overfeeding of a coagulant used for feed water pretreatment, reversing the order of the cleaners can be more effective. To determine the proper order of the cleaning solutions (high pH followed by low pH or vice versa), try to gather a sample of the organic foulant from your system. With the sample, try treating it with caustic and then acid and vice versa to determine qualitatively which order of cleaning solution treatment dissolves the foulant better. If both treatments appear to work equal, it is usually better to clean with the high pH solution first.

**NOTE:** Recommendations made here are specifically designed for FILMTEC Reverse Osmosis and Nanofiltration elements. These recommendations, such as cleaning procedures and chemicals employed, may not be compatible with other brands of membrane elements. It is your responsibility to ensure the suitability of our recommendations and procedures if they are applied to membrane elements other than FilmTec products.

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# FILMTEC Membranes

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## Cleaning Procedures for FILMTEC FT30 Elements

The following are general recommendations for cleaning FILMTEC™ FT30 elements. More detailed procedures for cleaning an RO system are typically included in the operating manual provided by the system supplier. It should be emphasized that frequent cleaning is not required for a properly designed and properly operated RO system, however because of the FT30 membrane's unique combination of pH range and temperature resistance, cleaning can be accomplished very effectively.

### Cleaning Requirements

In normal operation, the membrane in reverse osmosis elements can become fouled by mineral scale, biological matter, colloidal particles, and insoluble organic constituents. Deposits build up on the membrane surfaces during operation until they cause loss in normalized permeate flow, loss of normalized salt rejection, or both. Elements should be cleaned whenever the normalized permeate flow drops by  $\geq 10$  percent, or the normalized salt passage increases by  $\geq 5$  percent, or the normalized differential pressure (feed pressure minus concentrate pressure) increases by  $\geq 15$  percent from the reference condition established during the first 48 hours of operation.

Differential Pressure ( $\Delta P$ ) should be measured and recorded across each stage of the array of pressure vessels. If the brine channels within the element become plugged, the  $\Delta P$  will increase. It should be noted that the permeate flux will drop if feedwater temperature decreases. This is normal and does not indicate membrane fouling.

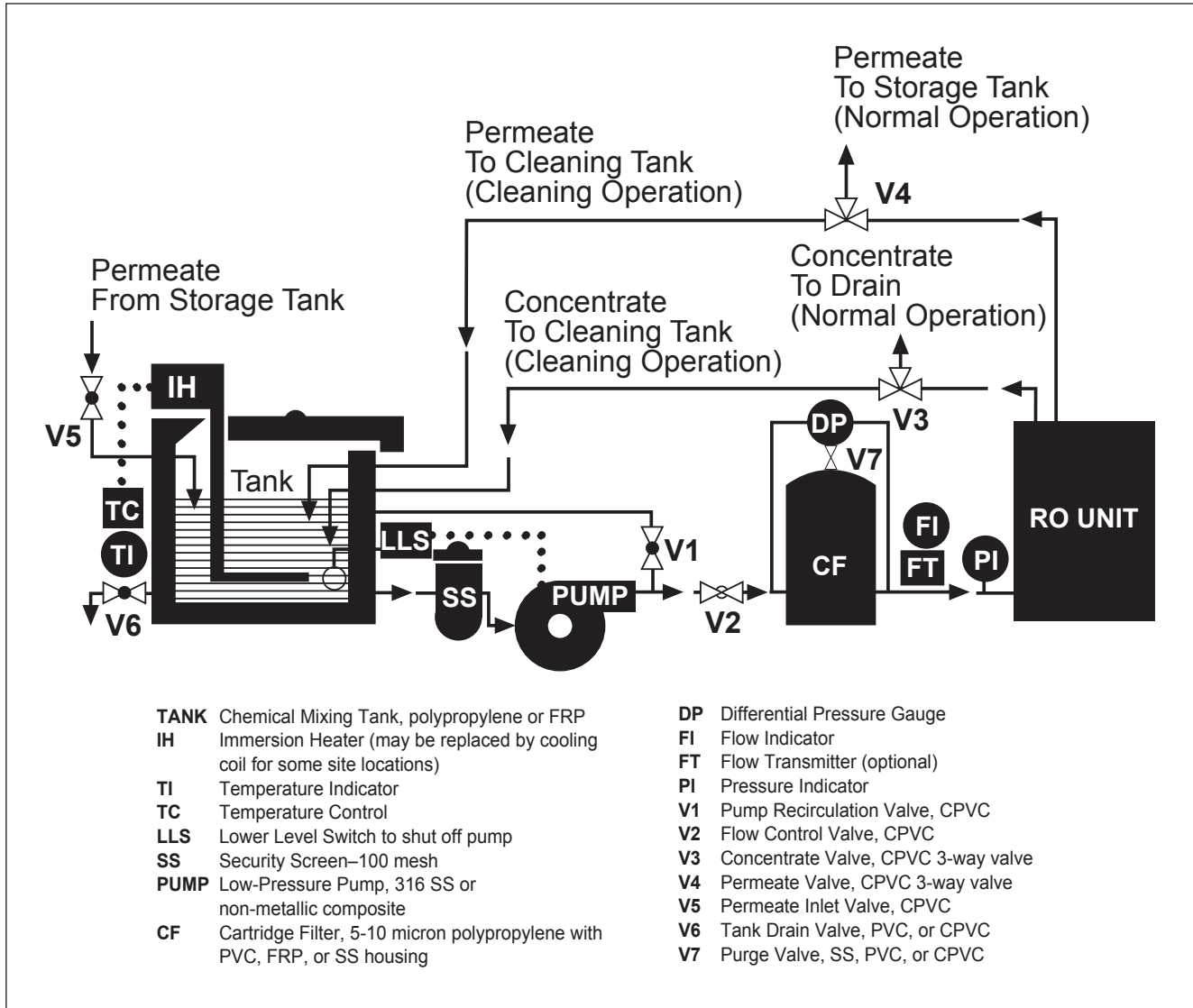
A malfunction in the pretreatment, pressure control, or increase in recovery can result in reduced product water output or an increase in salt passage. If a problem is observed, these causes should be considered first. The element(s) may not require cleaning. A computer program called FTNORM is available from FilmTec for normalizing performance data of FILMTEC RO membranes. This program can be used to assist in determining when to clean and can be downloaded from our web site.

### Safety Precautions

1. When using any chemical indicated here in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
2. When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions through the elements.
3. It is recommended the elements be flushed with good-quality chlorine-free water (20°C minimum temperature) after cleaning. Permeate water is recommended; but a dechlorinated potable supply or prefiltered feedwater may be used, provided that there are no corrosion problems in the piping system. Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, the permeate must be diverted to drain for at least 10 minutes or until the water is clear when starting up after cleaning.

4. During recirculation of cleaning solutions, the temperatures must not exceed 50°C at pH 2-10, 35°C at pH 1-11, and 30°C at pH 1-12.
5. For elements greater than six inches in diameter, the flow direction during cleaning must be the same as during normal operation to prevent element telescoping, because the vessel thrust ring is installed only on the reject end of the vessel. This is also recommended for smaller elements. Equipment for cleaning is illustrated below.

### Cleaning System Flow Diagram



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## Suggested Equipment

The equipment for cleaning is shown in the Cleaning System Flow Diagram. The pH of cleaning solutions used with FILMTEC elements can be in the range of 1 to 12 (see Table 2), and therefore non-corroding materials should be used in the cleaning system.

1. The mixing tank should be constructed of polypropylene or fiberglass-reinforced plastic (FRP). The tank should be provided with a removable cover and a temperature gauge. The cleaning procedure is more effective when performed at a warm temperature, and it is recommended that the solution be maintained according to the pH and temperature guidelines listed in Table 2. It is not recommended to use a cleaning temperature below 15°C because of the very slow chemical kinetics at low temperatures. In addition, chemicals such as sodium lauryl sulfate might precipitate at low temperatures. Cooling may also be required in certain geographic regions, so both heating/cooling requirements must be considered during the design. A rough rule of thumb in sizing a cleaning tank is to use approximately the empty pressure vessels volume and then add the volume of the feed and return hoses or pipes. For example, to clean ten 8-inch diameter pressure vessels with six elements per vessel, the following calculations would apply:

### A. Volume in Vessels

$$\begin{aligned}V_1 &= \pi r^2 L \\ &= 3.14 (4 \text{ in})^2 (20 \text{ ft}) (7.48 \text{ gal/ft}^3) / (144 \text{ in}^2/\text{ft}^2) \\ V_1 &= 52 \text{ gal/vessel (0.2 m}^3) \\ V_{10} &= 52 \times 10 = 520 \text{ gal (1.97 m}^3)\end{aligned}$$

### B. Volume in Pipes, assume 50 ft. length total 4" Sch 80 pipe

$$\begin{aligned}V_p &= \pi r^2 L \\ &= 3.14 (1.91 \text{ in})^2 (50 \text{ ft}) (7.48 \text{ gal/ft}^3) / (144 \text{ in}^2/\text{ft}^2) \\ &= 30 \text{ gals (0.11 m}^3) \\ V_{ct} &= V_{10} + V_p = 520 + 30 = 550 \text{ gal.}\end{aligned}$$

Therefore, the cleaning tank should be about 700 gals (1.5 m<sup>3</sup>).

2. The cleaning pump should be sized for the flows and pressures given in Table 1, making allowances for pressure loss in the piping and across the cartridge filter. The pump should be constructed of 316 SS or nonmetallic composite polyesters.
  3. Appropriate valves, flow meters, and pressure gauges should be installed to adequately control the flow. Service lines may be either hard piped or hoses. In either case, the flow rate should be a moderate 10 ft/sec (3 m/sec) or less.
-

---

## Cleaning Elements In Situ

There are six steps in the cleaning of elements:

1. Make up cleaning solution.
2. Low-flow pumping. Pump mixed, preheated cleaning solution to the vessel at conditions of low flow rate (about half of that shown in Table 1) and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no permeate is produced. A low pressure minimizes redeposition of dirt on the membrane. Dump the concentrate, as necessary, to prevent dilution of the cleaning solution.
3. Recycle. After the process water is displaced, cleaning solution will be present in the concentrate stream. Then recycle the concentrate to the cleaning solution tank and allow the temperature to stabilize.

**Table 1. Recommended feed flow rate per pressure vessel during high flow rate recirculation**

Feed Pressure <sup>1</sup>		Element Diameter (inches)	Feed Flow Rate per Pressure Vessel	
(psig)	(bar)		(gpm)	(m <sup>3</sup> /hr)
20-60	1.5-4.0	2.5	3-5	0.7-1.2
20-60	1.5-4.0	4 <sup>2</sup>	8-10	1.8-2.3
20-60	1.5-4.0	6	16-20	3.6-4.5
20-60	1.5-4.0	8	30-40	6.-9.1
20-60	1.5-4.0	8 <sup>3</sup>	35-45	8.0-10.2

<sup>1</sup> Dependent on number of elements in pressure vessel.

<sup>2</sup> 4-Inch Full-fit elements should be cleaned at 12-14 gpm (2.7-3.2 m<sup>3</sup>/hr).

<sup>3</sup> For Full-fit, 400 and 440 sq. ft. area elements.

**Table 2. pH range and temperature limits during cleaning**

Element Type	Max Temp 50°C pH Range	Max Temp 35°C pH Range	Max Temp 30°C pH Range	Continuous Operation
SW30, SW30HR	3-10	2-11	1-12	2-11
BW30, TW30	2-10	1-11	1-12	2-11
NF45, SR90	3-10	2-11	1-12	3-10
NF70, NF90	3-10	2-11	1-11	3-9

4. Soak. Turn the pump off and allow the elements to soak. Sometimes a soak period of about 1 hour is sufficient. For difficult fouling an extended soak period is beneficial; soak the elements overnight for 10-15 hours. To maintain a high temperature during an extended soak period, use a slow recirculation rate (about 10 percent of that shown in Table 1).
  5. High-flow pumping. Feed the cleaning solution at the rates shown in Table 1 for 30-60 minutes. The high flow rate flushes out the foulants removed from the membrane surface by the cleaning. If the elements are heavily fouled, a flow rate which is 50 percent higher than shown in Table 1 may aid cleaning. At higher flow rates, excessive pressure drop may be a problem. The maximum recommended pressure drops are 15 psi per element or 50 psi per multi-element vessel, whichever value is more limiting.
-

6. Flush out. Prefiltered raw water can be used for flushing out the cleaning solution, unless there will be corrosion problems (e.g., stagnant seawater will corrode stainless steel piping). To prevent precipitation, the minimum flush out temperature is 20°C.

**Additional notes:** Check the pH during acid cleaning. The acid is consumed when it dissolves inorganic precipitates. So, if the pH increases more than 0.5 pH units, add more acid. Total circulation time for an acid cleaning solution should not exceed 20 minutes in length. After that time, it's possible for the solution to be fully saturated and the foulants can precipitate back onto the surface. If the system has to be shut down longer than 24 hours, the elements should be stored in a 1 percent solution (by weight) of sodium metabisulfite. For large system evaluation, it is recommended that this be done in a single element test stand that is included in the original system design.

### Multistage Systems

For multistage (tapered) systems, the flushing and soaking operations can always be done simultaneously in all stages. High-flow recirculation, however, should be carried out separately for each stage, so the flow rate is not too low in the first stage or too high in the last. This can be accomplished either by using one cleaning pump and operating one stage at a time, or by using a separate cleaning pump for each stage.

### Cleaning Chemicals

Table 3 below lists suitable cleaning chemicals. Acid cleaners and alkaline cleaners are the standard cleaning chemicals. The acid cleaners are used to remove inorganic precipitates including iron, while the alkaline cleaners are used to remove organic fouling including biological matter. Sulfuric acid should not be used for cleaning because of the risk of calcium sulfate precipitation. Preferably reverse osmosis permeate should be used for the cleaning solutions, but prefiltered raw water will also work in most cases. The raw water can be highly buffered, so more acid or hydroxide may be needed with raw water to reach the desired pH level, which is about 2 for acid cleaning and about 12 for alkaline cleaning.

**Table 3. Simple cleaning solutions for FT30 membrane**

Cleaner / Foulant	0.1% (W) NaOH and pH 12, 30°C max. or 1.0% (W) Na <sub>4</sub> EDTA and pH 12, 30°C max.	0.1% (W) NaOH and pH 12, 30°C max. or 0.025% (W) Na-DSS and pH 12, 30°C max.	0.2% (W) HCl	1.0% (W) Na <sub>2</sub> S <sub>2</sub> O <sub>4</sub>	0.5% (W) H <sub>3</sub> PO <sub>4</sub>	1.0% (W) NH <sub>2</sub> SO <sub>3</sub> H
Inorganic Salts (for example, CaCO <sub>3</sub> )			Preferred	Alternative	Alternative	
Sulfate Scales (CaSO <sub>4</sub> , BaSO <sub>4</sub> )	OK					
Metal Oxides (for example, iron)				Preferred	Alternative	Alternative
Inorganic Colloids (silt)		Preferred				
Silica	Alternative	Preferred				
Biofilms	Alternative	Preferred				
Organic	Alternative	Preferred				

#### Notes

<sup>1</sup> (W) denotes weight percent of active ingredient.

<sup>2</sup> Foulant chemical symbols in order used: CaCO<sub>3</sub> is calcium carbonate; CaSO<sub>4</sub> is calcium sulfate; BaSO<sub>4</sub> is barium sulfate.

<sup>3</sup> Cleaning chemical symbols in order used: NaOH is sodium hydroxide; Na<sub>4</sub>EDTA is the tetra-sodium salt of ethylene diamine tetraacetic acid and is available from The Dow Chemical Company under the trademark VERSENE<sup>®</sup> 100 and VERSENE 220 crystals; Na-DDS is sodium salt of dodecylsulfate; Sodium Laurel Sulfate; HCl is hydrochloric acid (Muratic Acid); H<sub>3</sub>PO<sub>4</sub> is phosphoric acid; NH<sub>2</sub>SO<sub>3</sub>H is sulfamic acid; Na<sub>2</sub>S<sub>2</sub>O<sub>4</sub> is sodium hydrosulfite.

<sup>4</sup> For effective sulfate scale cleaning, the condition must be caught and treated early. Adding NaCl to the cleaning solution of NaOH and Na<sub>4</sub>EDTA may help as sulfate solubility increases with increasing salinity. Successful cleaning of sulfate scales older than 1 week is doubtful.

<sup>5</sup> Citric Acid is another cleaning alternative for inorganic salts.



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# FILMTEC Membranes

## Cleaning Sulfate Scale from FILMTEC FT30 Elements

The following cleaning procedure is designed specifically for a system that has had sulfate scale precipitated in the elements. Sulfate scales are very difficult to clean, and if their presence is not detected early, the likelihood of cleaning is very low. More than likely, a flow loss will occur that cannot be recovered. For sulfate scales older than one week, it may not be economical to attempt cleaning and replacement may be the best alternative. Consult the general cleaning instructions for information that is common to all types of cleaning such as suggested equipment, pH and temperature limits, and recommended flow rates.

### Safety Precautions

1. When using any chemical indicated here in subsequent sections, follow accepted safety practices. Consult the chemical manufacturer for detailed information about safety, handling and disposal.
2. When preparing cleaning solutions, ensure that all chemicals are dissolved and well mixed before circulating the solutions through the elements.
3. It is recommended the elements be flushed with good-quality chlorine-free water (20°C minimum temperature) after cleaning. Permeate water is recommended; but a dechlorinated potable supply or prefiltered feedwater may be used, provided that there are no corrosion problems in the piping system. Care should be taken to operate initially at reduced flow and pressure to flush the bulk of the cleaning solution from the elements before resuming normal operating pressures and flows. Despite this precaution, cleaning chemicals will be present on the permeate side following cleaning. Therefore, the permeate must be diverted to drain for at least 10 minutes or until the water is clear when starting up after cleaning.
4. During recirculation of cleaning solutions, the temperatures must not exceed 50°C at pH 2-10, 35°C at pH 1-11, and 30°C at pH 1-12.
5. For elements greater than six inches in diameter, the flow direction during cleaning must be the same as during normal operation to prevent element telescoping, because the vessel thrust ring is installed only on the reject end of the vessel. This is also recommended for smaller elements.

### Cleaning Procedure

There are seven steps in cleaning elements with sulfate scale.

1. Make up the cleaning solution listed from Table 1.

**Table 1. Sulfate Scale Cleaning Solutions**

Cleaning Solutions	Solution
Preferred	0.1% (wt) NaOH 1.0% (wt) Na <sub>4</sub> EDTA pH 12, 30°C maximum

#### Notes

- <sup>1</sup> (wt) denotes weight percent of active ingredient.
- <sup>2</sup> Cleaning chemical symbols in order used: NaOH is sodium hydroxide; Na<sub>4</sub>EDTA is the tetra-sodium salt of ethylene diamine tetraacetic acid and is available from The Dow Chemical Company under the trademark VERSENE\*.
- <sup>3</sup> For effective sulfate scale cleaning, the condition must be caught and treated early. Adding NaCl to the cleaning solution of NaOH and Na<sub>4</sub>EDTA may help as sulfate solubility increases with increasing salinity. Successful cleaning of sulfate scales older than 1 week is doubtful.

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2. Low-flow pumping. Pump mixed, preheated cleaning solution to the vessel at conditions of low flow rate (about half of that shown in Table 2) and low pressure to displace the process water. Use only enough pressure to compensate for the pressure drop from feed to concentrate. The pressure should be low enough that essentially no permeate is produced. A low pressure minimizes redeposition of dirt on the membrane. Dump the concentrate, as necessary, to prevent dilution of the cleaning solution.

**Table 2. Recommended feed flow rate per pressure vessel during high flow rate recirculation**

Feed Pressure <sup>1</sup>		Element Diameter (inches)	Feed Flow Rate per Pressure Vessel	
(psig)	(bar)		(gpm)	(m <sup>3</sup> /hr)
20-60	1.5-4.0	2.5	3-5	0.7-1.2
20-60	1.5-4.0	4 <sup>2</sup>	8-10	1.8-2.3
20-60	1.5-4.0	6	16-20	3.6-4.5

<sup>1</sup> Dependent on number of elements in pressure vessel.

<sup>2</sup> 4-Inch full-fit elements should be cleaned at 12-14 gpm (2.7-3.2 m<sup>3</sup>/hr).

<sup>3</sup> For full-fit elements, 400 and 440 sq. ft. area elements.

3. Recirculate. After the process water is displaced, cleaning solution will be present in the concentrate stream that can be recycled to the cleaning solution tank. Recycle the cleaning solution for 30 minutes.
  4. Soak. Turn the pump off and allow the elements to soak. Soak the elements for 1-15 hours (soaking overnight will give best results). To maintain temperature during an extended soak period, use a slow recirculation rate (about 10 percent of that shown in Table 2). Soak times will vary depending on the severity of the scaling.
  5. High-flow pumping. Feed the cleaning solution at the rates shown in Table 2 for 30 minutes. The high flow rate flushes out the scale removed from the membrane surface by the cleaning. If the elements are heavily scaled, a flow rate which is 50 percent higher than shown in Table 2 may aid cleaning. At higher flow rates, excessive pressure drop may be a problem. The maximum recommended pressure drops are 15 psi per element or 50 psi per multi-element vessel, whichever value is more limiting.
  6. Flush out. Prefiltered raw water can be used for flushing out the cleaning solution, unless there will be corrosion problems (e.g., stagnant seawater will corrode stainless steel piping). To prevent precipitation, the minimum flush out temperature is 20°C. The system should be flushed for one hour.
  7. The system should be restarted, elements and the system need to stabilize before taking any data. The stabilization period will vary depending on the severity of the fouling. To regain performance it may take several cleaning and soak cycles, but for sulfate scale a permanent flow loss is expected.
-

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Form No. 609-00304-402XQRP  
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# FILMTEC Membranes

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## Disinfecting RO Systems With Hydrogen Peroxide

Hydrogen peroxide or a mixture of hydrogen peroxide and peracetic acid has been used successfully for disinfecting reverse osmosis (RO) systems that use FILMTEC® FT30 membranes.

Examples of commercial hydrogen peroxide/peracetic acid solutions are Renalin® and Minncare® from Minntech Corporation.

These solutions come in a concentrated form and are diluted 1:100 with RO permeate to obtain a 0.25 percent peroxide solution. For more than four years, an RO system in Minneapolis which uses the FT30 membrane has been disinfected once weekly by soaking overnight in diluted Renalin. There has been no indication of membrane degradation during this time.

There are two factors which greatly influence the rate of hydrogen peroxide attack on the membrane: temperature and iron.

The disinfecting solution should not exceed 25°C (77°F). FT30 membrane samples tested with 0.5 percent hydrogen peroxide at 34°C showed a very high salt passage after several hours. At 24°C, however, membrane samples demonstrated compatibility with 0.5 percent hydrogen peroxide after 96 hours.

The presence of iron or other transition metals in conjunction with hydrogen peroxide solutions can also cause membrane degradation. FT30 samples were tested using a 0.15 percent solution of hydrogen peroxide and tapwater containing iron. After 150 hours, the salt passage of the membrane began to increase dramatically.

For RO systems using the FT30 membrane, the following procedure for disinfection with hydrogen peroxide or Renalin solutions is recommended:

1. Any type of deposit on the membrane or other parts of the system should be removed with an alkaline cleaner before disinfecting. Removal of these deposits, which harbor microorganisms, will maximize the degree of disinfection. After alkaline cleaning, flush the system with RO permeate.
2. Clean the RO system with acid (e.g., 0.1 percent by volume hydrochloric acid or 0.4 percent by volume phosphoric acid) to remove any iron from the membrane surface. Flush the unit with RO permeate.
3. Circulate a solution of 0.20-0.25 percent hydrogen peroxide diluted with RO permeate at a temperature below 25°C (77°F) for 20 minutes. A pH of 3-4 gives optimal biocidal results and longer membrane lifetime.
4. Allow the elements to soak in the disinfecting solution for 2-12 hours. A soak time of 2 hours would be expected to kill more than 90 percent of the bacteria, whereas a 12-hour soak time would achieve a 99 percent kill.

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**FILMTEC**  
Membranes  
and  
**DOWEX**  
Ion Exchange Resins

**ENGINEERING INFORMATION**

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# DOWEX and FILMTEC Engineering Information

## 1. Particle Size Distribution

Test methods to establish and/or express the size distribution of DOWEX\* standard ion exchange resins are based on "U.S.A. Standard Series" of sieves. Table 1 gives the main characteristics of sieves of interest to the analysis of bead size distributions.

Due to the narrow particle size distribution of DOWEX uniform particle sized resins, the conventional method of using U.S.A. Standard Sieves does not provide sufficiently detailed information to describe the particle distribution effectively.

The particle distribution for DOWEX uniform particle sized resins is therefore given as a mean particle size covering a specified range and a uniformity coefficient which is <1.1. In addition, upper and/or lower maximum limits may be given, which are expressed as a percentage. This is illustrated in Table 2.

This resin therefore has a mean particle size between 600 and 700 microns with 90 percent of the beads within  $\pm 100$  microns of the mean. No more than 0.2 percent of the bead population is below 300 microns.

**Table 1. Main Characteristics of Sieves**

Sieve Mesh Number	Nominal Sieve Opening mm	Opening Tolerance $\pm\mu\text{m}$	Nominal Wire Diameter mm
10	2.00	70	0.900
12	1.68	60	0.810
14	1.41	50	0.725
16	1.19	45	0.650
18	1.00	40	0.580
20	0.841	35	0.510
25	0.707	30	0.450
30	0.595	25	0.390
35	0.500	20	0.340
40	0.420	19	0.290
45	0.354	16	0.247
50	0.297	14	0.215
60	0.250	12	0.180
70	0.210	10	0.152
80	0.178	9	0.131
100	0.150	8	0.110
120	0.125	7	0.091
140	0.104	6	0.076
170	0.089	5	0.064
200	0.074	5	0.053
230	0.064	4	0.044
270	0.053	4	0.037
325	0.043	3	0.030
400	0.038	3	0.025

**Table 2. Particle Distribution of DOWEX MONOSPHERE\* 650C**

Resin	DOWEX MONOSPHERE 650C
Mean particle size	650 $\pm 50$ microns
Uniformity Coefficient, max.	1.1
Greater than 840 microns (20 mesh), max.	5%
Less than 300 microns (50 mesh), max.	0.5%

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**Table 3. Conversion of Common Units**

<b>From to</b>	<b>to from</b>	<b>multiply by</b>	<b>divide by</b>
<b>LENGTH</b>			
inch (in.)	metre (m)	0.0254	
foot (ft)	metre (m)	0.3048	
yard (yd)	metre (m)	0.9144	
<b>AREA</b>			
in. <sup>2</sup>	m <sup>2</sup>	0.0006452	
ft <sup>2</sup>	m <sup>2</sup>	0.0929	
yd <sup>2</sup>	m <sup>2</sup>	0.8361	
<b>VOLUME</b>			
in. <sup>3</sup>	litre (l)	0.01639	
ft <sup>3</sup>	litre (l)	28.32	
yd <sup>3</sup>	litre (l)	764.6	
Imp. Gallon (U.K.)	litre (l)	4.546	
U.S. Gallon (gal.)	litre (l)	3.785	
<b>MASS</b>			
grain (gr)	gram (g)	0.0648	
Ounce	gram (g)	28.35	
pound (lb)	gram (g)	453.6	
<b>PRESSURE</b>			
Atmosphere (atm)	kilo Pascal	101.3	
Bar	kPa	100.0	
lb/ft <sup>2</sup>	kPa	0.04788	
lb/in. <sup>2</sup> = psi	bar	0.069	
lb/in. <sup>2</sup> = psi	kPa	6.895	
<b>PRESSURE DROP</b>			
psi/ft	kPa/m	22.62	
<b>VISCOSITY</b>			
poise	Pascal-second (Pa s)	0.1	
<b>FLOW RATE</b>			
gal./min. = gpm	m <sup>3</sup> /hr	0.227	
gal./min. = gpm	l/sec	0.063	
gal./day = gpd	m <sup>3</sup> /day	0.003785	
gal./day = gpd	l/hr	0.158	
million gal./day = mgd	m <sup>3</sup> /hr	157.73	
gal./day = gpd	m <sup>3</sup> /day	3785	
Imp gpm	m <sup>3</sup> /hr	0.273	
<b>FLOW VELOCITY</b>			
gpm/ft <sup>2</sup>	m/h	2.445	
gpd/ft <sup>2</sup>	l/m <sup>2</sup> hr	1.70	
<b>SERVICE FLOW RATE</b>			
gpm/ft <sup>3</sup>	(m <sup>3</sup> /h)/m <sup>3</sup>	8.02	
<b>RINSE VOLUME</b>			
gal./ft <sup>3</sup>	l/l	0.134	
<b>CHEMICAL DOSAGE</b>			
lb/ft <sup>3</sup>	g/l	16.0	

**2. Conversion of Common Units**

To convert non-metric units to the metric/S.I. units, multiply by the factors given; to convert S.I./metric units to the non-metric unit, divide by the factor given in Table 3. A unit converter is also available.

**3. Concentration of Ionic Species**

Table 4 gives multiplication factors for the conversion of concentration units of ionic species given as gram of the ion per litre (g/l) into equivalent per litre (eq/l) or of gram of CaCO<sub>3</sub> equivalents per litre (g CaCO<sub>3</sub>/l).

Concentrations of ionic species in water have been expressed in different units in different countries. Concentrations should normally be expressed in one of the following ways:

- As grams (g), milligrams (mg = 10<sup>-3</sup> g) or micrograms (mg = 10<sup>-6</sup> g) of the (ionic) species per litre (l) or cubic metre (m<sup>3</sup>) of water.
- As equivalents (eq) or milliequivalents (meq = 10<sup>-3</sup> eq) of the ionic species per litre (l) or cubic metre (m<sup>3</sup>) of water.

Still widely used concentration units are:

- Kilograins of CaCO<sub>3</sub> per cubic foot (kg/ft<sup>3</sup>)
- 1 French degree = 1 part CaCO<sub>3</sub> per 100.000 parts of water
- 1 German degree = 1 part CaO per 100.000 parts of water
- Grains CaCO<sub>3</sub>/gallon (U. S.)
- ppm CaCO<sub>3</sub>
- 1 English degree (Clark) = 1 grain CaCO<sub>3</sub> per (British) Imperial gallon of water

Table 5 gives the conversion factors for commonly encountered units to milliequivalents/litre (meq/l) and mg CaCO<sub>3</sub>/l. Multiply by the conversion factor to obtain mg CaCO<sub>3</sub>/l or meq/l. Divide by the conversion factor to obtain the different units from numbers expressed as mg CaCO<sub>3</sub>/l or meq/l.

**Table 4. Multiplication Factors for the Conversion of Concentration Units of Ionic Species**

Compound	Formula	Ionic Weight	Equivalent Weight	Conversion to	
				g CaCO <sub>3</sub> /l	eq/l
<b>POSITIVE IONS</b>					
Aluminum	Al <sup>+++</sup>	27.0	9.0	5.56	0.111
Ammonium	NH <sub>4</sub> <sup>+</sup>	18.0	18.0	2.78	0.0556
Barium	Ba <sup>++</sup>	137.4	68.7	0.73	0.0146
Calcium	Ca <sup>++</sup>	40.1	20.0	2.50	0.0500
Copper	Cu <sup>++</sup>	63.6	31.8	1.57	0.0314
Hydrogen	H <sup>+</sup>	1.0	1.0	50.0	1.0000
Ferrous Iron	Fe <sup>++</sup>	55.8	27.9	1.79	0.0358
Ferric Iron	Fe <sup>+++</sup>	55.8	18.6	2.69	0.0538
Magnesium	Mg <sup>++</sup>	24.3	12.2	4.10	0.0820
Manganese	Mn <sup>++</sup>	54.9	27.5	1.82	0.0364
Potassium	K <sup>+</sup>	39.1	39.1	1.28	0.0256
Sodium	Na <sup>+</sup>	23.0	23.0	2.18	0.0435
<b>NEGATIVE IONS</b>					
Bicarbonate	HCO <sub>3</sub> <sup>-</sup>	61.0	61.0	0.82	0.0164
Carbonate	CO <sub>3</sub> <sup>-</sup>	60.0	30.0	1.67	0.0333
Chloride	Cl <sup>-</sup>	35.5	35.5	1.41	0.0282
Fluoride	F <sup>-</sup>	19.0	19.0	2.63	0.0526
Iodide	I <sup>-</sup>	129	129	0.39	0.0079
Hydroxide	OH <sup>-</sup>	17.0	17.0	2.94	0.0588
Nitrate	NO <sub>3</sub> <sup>-</sup>	62.0	62.0	0.81	0.0161
Phosphate (tribasic)	PO <sub>4</sub> <sup>---</sup>	95.0	31.7	1.58	0.0315
Phosphate (dibasic)	HPO <sub>4</sub> <sup>-</sup>	90	48.0	1.04	0.0208
Phosphate (monobasic)	H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	97.0	97.0	0.52	0.0103
Sulfate	SO <sub>4</sub> <sup>-</sup>	91	48.0	1.04	0.0208
Bisulfate	HSO <sub>4</sub> <sup>-</sup>	97.1	97.1	0.52	0.0103
Sulfite	SO <sub>3</sub> <sup>-</sup>	80.1	40.0	1.25	0.0250
Bisulfite	HSO <sub>3</sub> <sup>-</sup>	81.1	81.1	0.62	0.0123
Sulfide	S <sup>-</sup>	32.1	10	3.13	0.0625
<b>NEUTRAL</b>					
Carbon dioxide	CO <sub>2</sub>	44.0	44.0	1.14	0.0227
Silica	SiO <sub>2</sub>	60.0	60.0	0.83	0.0167
Ammonia	NH <sub>3</sub>	17.0	17.0	2.94	0.0588

Note: Calculations based an conversion to monovalent neutral species.

**Table 5. Conversion Factors**

	mg CaCO <sub>3</sub> /l	meq/l
kgr/ft <sup>3</sup>	2288	45.8
1 grain/U.S. gallon	17.1	0.342
ppm CaCO <sub>3</sub>	1.0	0.020
1 English degree	14.3	0.285
1 French degree	10.0	0.200
1 German degree	17.9	0.357

**Table 6. Calcium Carbonate (CaCO<sub>3</sub>) Equivalent of Common Substances**

Compounds	Formula	Molecular Weight	Equivalent Weight	Substance to CaCO <sub>3</sub> equivalent	CaCO <sub>3</sub> equivalent to Substance multiply by
Aluminum Sulfate (anhydrous)	Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	342.1	57.0	0.88	1.14
Aluminum Hydroxide	Al(OH) <sub>3</sub>	78.0	26.0	1.92	0.52
Aluminum Oxide (Alumina)	Al <sub>2</sub> O <sub>3</sub>	101.9	17.0	2.94	0.34
Sodium Aluminate	Na <sub>2</sub> Al <sub>2</sub> O <sub>4</sub>	163.9	27.3	1.83	0.55
Barium Sulfate	BaSO <sub>4</sub>	233.4	116.7	0.43	2.33
Calcium Bicarbonate	Ca(HCO <sub>3</sub> ) <sub>2</sub>	162.1	81.1	0.62	1.62
Calcium Carbonate	CaCO <sub>3</sub>	100.1	50.0	1.00	1.00
Calcium Chloride	CaCl <sub>2</sub>	111.0	55.5	0.90	1.11
Calcium Hydroxide	Ca(OH) <sub>2</sub>	74.1	37.1	1.35	0.74
Calcium Oxide	CaO	56.1	28.0	1.79	0.56
Calcium Sulfate (anhydrous)	CaSO <sub>4</sub>	136.1	68.1	0.74	1.36
Calcium Sulfate (gypsum)	CaSO <sub>4</sub> • 2H <sub>2</sub> O	172.2	86.1	0.58	1.72
Calcium Phosphate	Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	310.3	51.7	0.97	1.03
Ferrous Sulfate (anhydrous)	FeSO <sub>4</sub>	151.9	76.0	0.66	1.52
Ferric Sulfate	Fe <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub>	399.9	66.7	0.75	1.33
Magnesium Oxide	MgO	40.3	20.2	2.48	0.40
Magnesium Bicarbonate	Mg(HCO <sub>3</sub> ) <sub>2</sub>	146.3	73.2	0.68	1.46
Magnesium Carbonate	MgCO <sub>3</sub>	84.3	42.2	1.19	0.84
Magnesium Chloride	MgCl <sub>2</sub>	95.2	47.6	1.05	0.95
Magnesium Hydroxide	Mg(OH) <sub>2</sub>	58.3	29.2	1.71	0.58
Magnesium Phosphate	Mg <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	262.9	43.8	1.14	0.88
Magnesium Sulfate (anhydrous)	MgSO <sub>4</sub>	120.4	60.2	0.83	1.20
Magnesium Sulfate (Epsom Salts)	MgSO <sub>4</sub> - 7H <sub>2</sub> O	246.5	123.3	0.41	2.47
Manganese Chloride	MnCl <sub>2</sub>	125.8	62.9	0.80	1.26
Manganese Hydroxide	Mn(OH) <sub>2</sub>	89.0	44.4	1.13	0.89
Potassium Iodine	KI	166.0	166.0	0.30	3.32
Silver Chloride	AgCl	143.3	143.3	0.35	2.87
Silver Nitrate	AgNO <sub>3</sub>	169.9	169.9	0.29	3.40
Silica	SiO <sub>2</sub>	60.1	30.0	1.67	0.60
Sodium Bicarbonate	NaHCO <sub>3</sub>	84.0	84.0	0.60	1.68
Sodium Carbonate	Na <sub>2</sub> CO <sub>3</sub>	106.0	53.0	0.94	1.06
Sodium Chloride	NaCl	58.5	58.5	0.85	1.17
Sodium Hydroxide	NaOH	40.0	40.0	1.25	0.80
Sodium Nitrate	NaNO <sub>3</sub>	85.0	85.0	0.59	1.70
Tri-sodium Phosphate	Na <sub>3</sub> PO <sub>4</sub> • 12H <sub>2</sub> O	380.2	126.7	0.40	2.53
Tri-sodium Phos. (anhydrous)	Na <sub>3</sub> PO <sub>4</sub>	164.0	54.7	0.91	1.09
Disodium Phosphate	Na <sub>2</sub> HPO <sub>4</sub> • 12H <sub>2</sub> O	358.2	119.4	0.42	2.39
Disodium Phos. (anhydrous)	Na <sub>2</sub> HPO <sub>4</sub>	142.0	47.3	1.06	0.95
Monosodium Phosphate	NaH <sub>2</sub> PO <sub>4</sub> - H <sub>2</sub> O	138.1	46.0	1.09	0.92
Monosodium Phos. (anhydrous)	NaH <sub>2</sub> PO <sub>4</sub>	120.0	40.0	1.25	0.80
Sodium Metaphosphate	NaPO <sub>3</sub>	102.0	34.0	1.47	0.68
Sodium Sulfate	Na <sub>2</sub> SO <sub>4</sub>	142.1	71.0	0.70	1.42
Sodium Sulfite	Na <sub>2</sub> SO <sub>3</sub>	126.1	63.0	0.79	1.26

#### 4. Conversion of Temperature Units

Conversions of temperature units between °C and °F can be made graphically using the grid in Figure 1 or by mathematical conversion using following equations:

$$^{\circ}\text{C to }^{\circ}\text{F: } (9/5 \times ^{\circ}\text{C}) + 32 = ^{\circ}\text{F}$$

$$^{\circ}\text{F to }^{\circ}\text{C: } 5/9 (^{\circ}\text{F} - 32) = ^{\circ}\text{C}$$

The S.I. unit is °C.

#### 5. Conversion of Conductivity to Resistance

The salt content of a water or the impurities left after ion exchange are commonly expressed in terms of conductivity, expressed as Siemens per centimeter (S/cm) for a standard measuring cell with a cell constant of 1 cm (see Figure 2).

As the conductivity is the reciprocal of the resistance, such characteristics can alternatively be expressed in Ohm multiplied by centimeter (Ωcm) whereby:

$$\text{Scm}^{-1} = \frac{\text{S}}{\text{cm}} = \frac{1}{\Omega\text{cm}} = \Omega^{-1}\text{cm}^{-1}$$

Consequently, the following units of conductivity and resistance are different expressions relating to the same situation:

$$10^{-6} \text{ S/cm} = 1 \mu\text{S/cm} \sim 1 \text{ M}\Omega\text{cm} = 10^6 \Omega\text{cm}$$

$$10^{-3} \text{ S/cm} = 1 \text{ mS/cm} \sim 1 \text{ k}\Omega\text{cm} = 10^3 \Omega\text{cm}$$

Figure 1. Conversion of Temperature Units

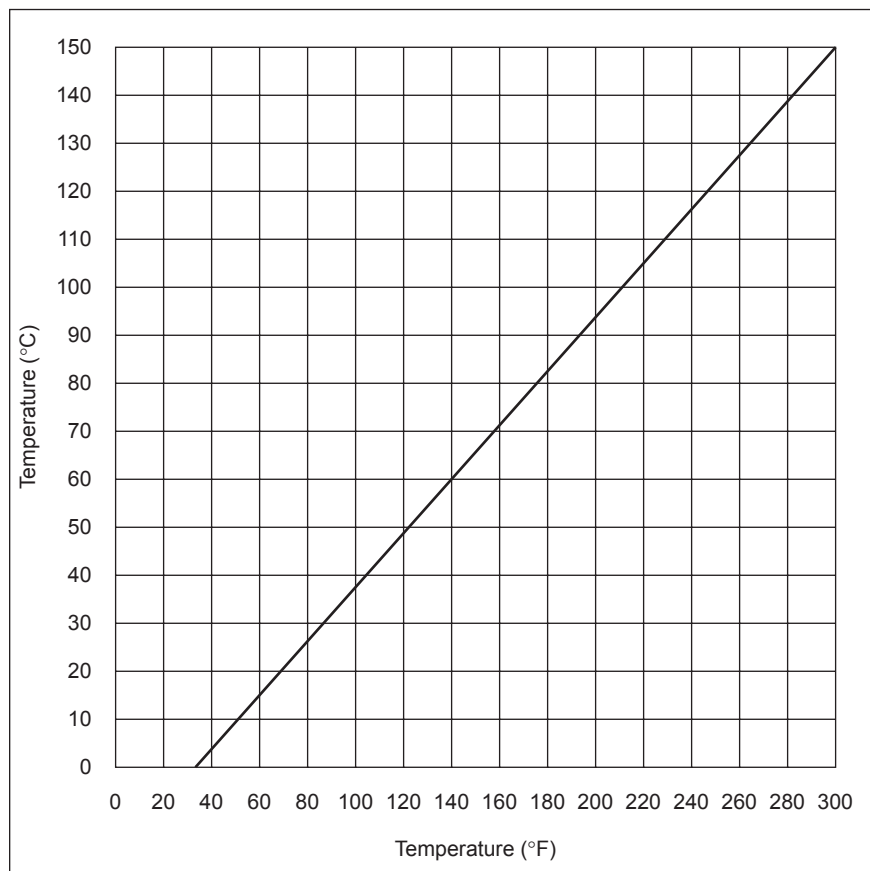
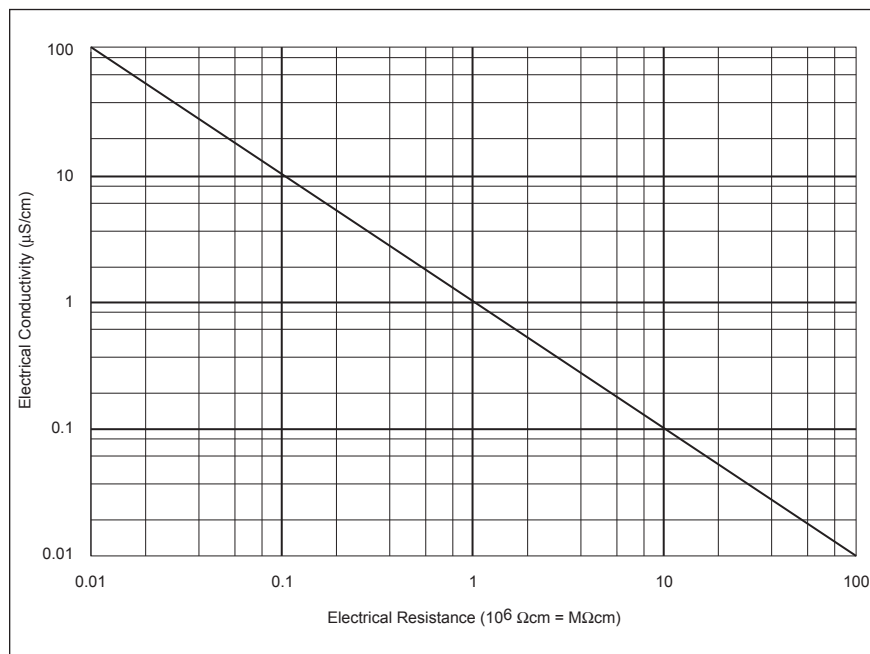


Figure 2. Conversion of Conductivity to Resistance



## 6. Conductivity of Water as Function of the Temperature

The conductivity of water, free of any impurities, will vary with temperature as presented in Figure 3 in accordance with its changing degree of auto-dissociation into  $H^+$  and  $OH^-$  and the different mobilities of these ions at different temperatures.

## 7. Conductivity of Ionic Solutions

Figures 4 through 7 show the relationship of the conductivity of a solution containing one given chemical, to the concentration of this chemical.

The conductivity of solutions at other temperatures can be calculated by multiplying conductivities at  $25^\circ C$  ( $77^\circ F$ ) with the correction factors in Table 7. These factors are only valid for diluted solutions as they suppose total ionic dissociation of the chemical.

Figure 3. Conductivity of Water as Function of the Temperature

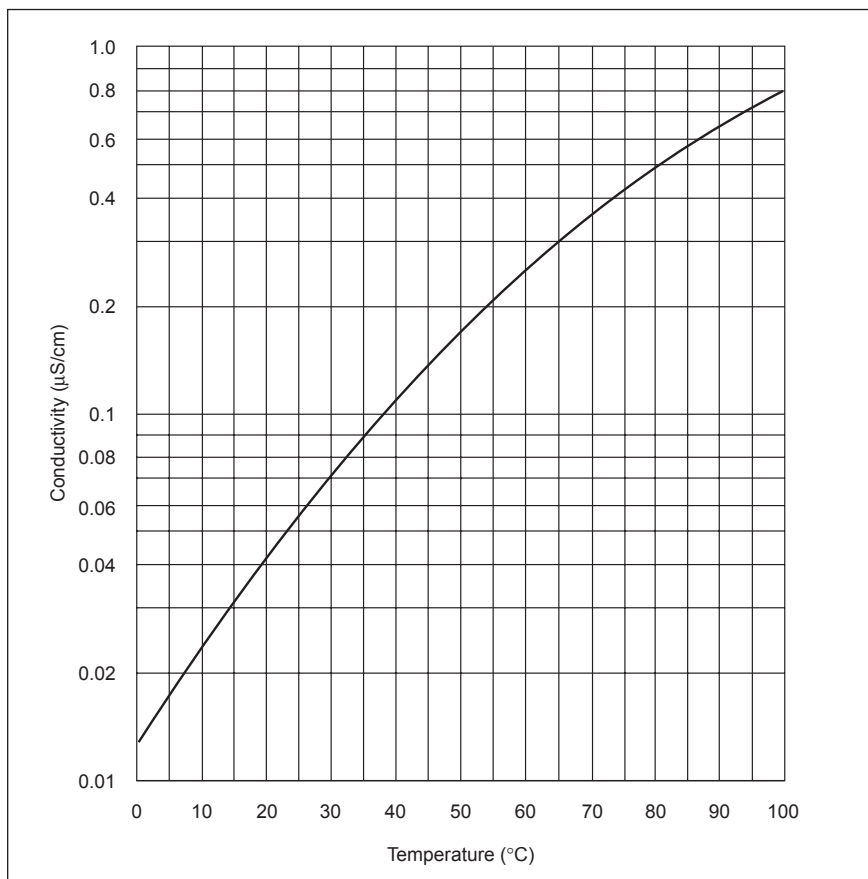
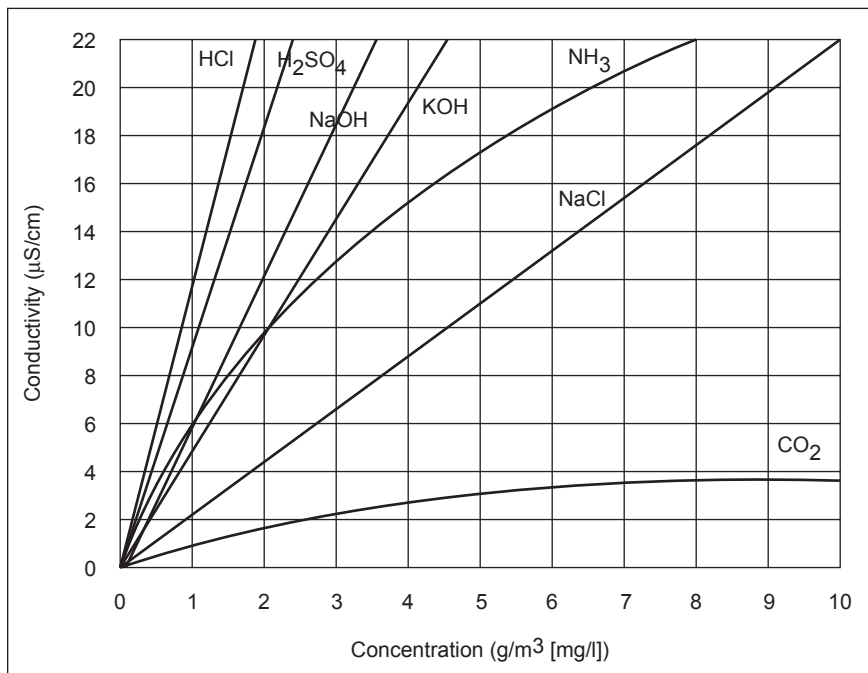


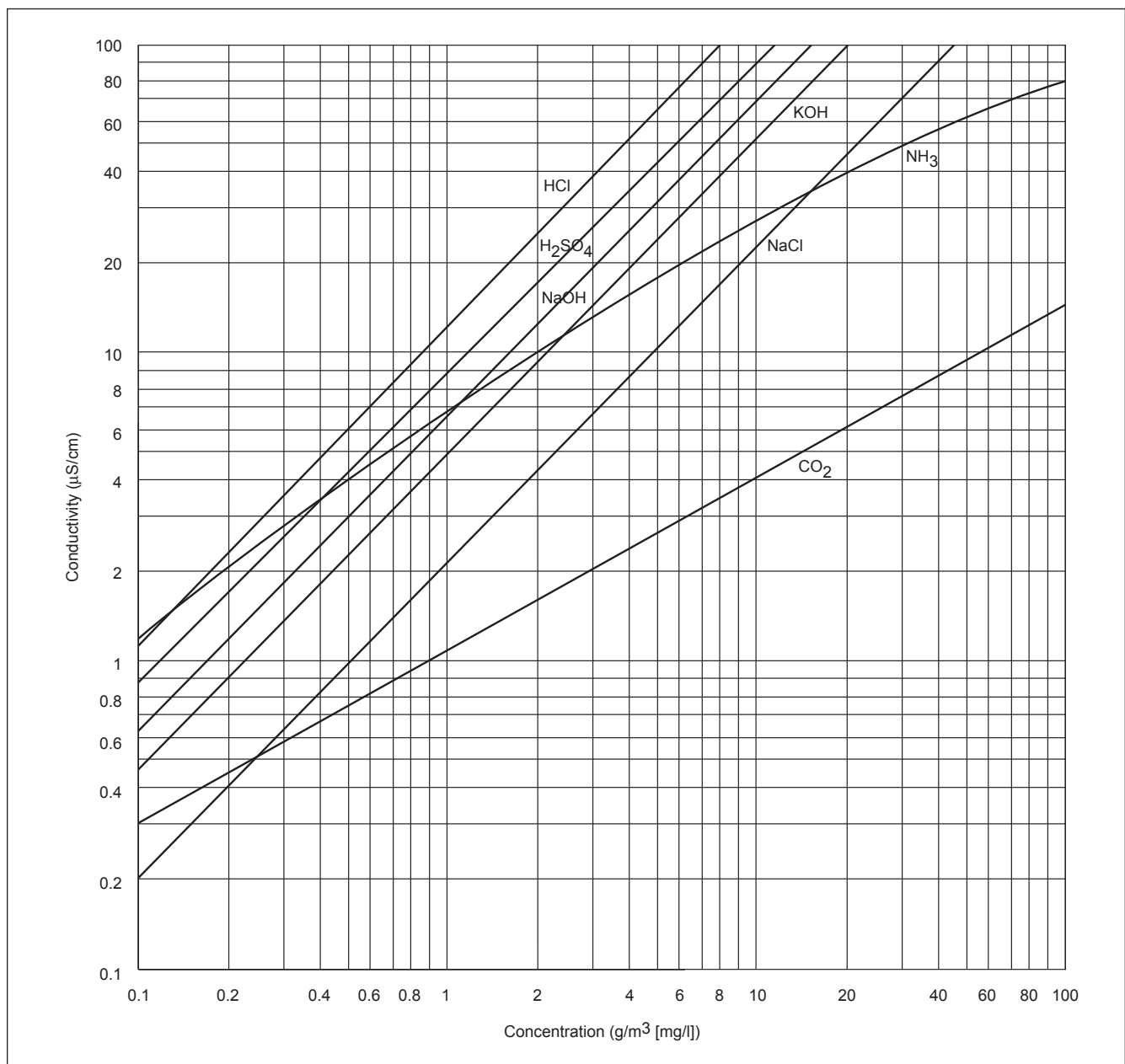
Figure 4. Conductivity vs. Concentration for Ionic Solutions at  $25^\circ C$



**Table 7. Conductivity of Solutions at Other Temperatures**

	0°C (32°F)	18°C (64°F)	25°C (77°F)	50°C (122°F)
HCl	0.66	0.89	1.00	1.37
H <sub>2</sub> SO <sub>4</sub>	0.66	0.87	1.00	1.38
NaCl	0.53	0.86	1.00	1.57
NaOH	0.54	0.89	1.00	1.51
KOH	0.55	0.89	1.00	1.50

**Figure 5. Conductivity vs. Concentrations for Ionic Solutions at 25°C**



**Table 8. Conductivity of Solutions, Acids, Alkalis and Salts at 25°C Expressed as  $\mu\text{S}/\text{cm}$  per meq/l**

Component	Concentration in meq/l							
	infin. diluted	0.1	0.5	1.0	5.0	10.0	50.0	100.0
HCl	426	425	423	421	415	412	399	392
HNO <sub>3</sub>	421	420	417	416	410	407	394	386
H <sub>2</sub> SO <sub>4</sub>	430	424	412	407	390	380	346	317
H <sub>3</sub> PO <sub>4</sub>	419	394	359	336	264	223	133	104
NaOH	248	247	246	245	241	238	227	221
KOH	271	270	269	268	264	261	251	246
NH <sub>4</sub> OH	271	109	49	36	17	12	5.6	3.9
NaCl	126	126	124	124	121	118	111	107
Na <sub>2</sub> SO <sub>4</sub>	130	128	126	124	117	113	97.7	90.0
Na <sub>2</sub> CO <sub>3</sub>	124	122	120	119	112	108	93.2	86.3
NaHCO <sub>3</sub>	96.0	95.2	94.2	93.5	90.5	88.4	80.6	76.0
KCl	150	149	148	141	144	141	133	129

Source: Landolt Börnstein 6<sup>o</sup> edition Band II/7.

**Table 9. Conductivity of Ions Expressed as  $\mu\text{S}/\text{cm}$  per meq/l, Infinitely Diluted**

Ion	20°C (68°F)	25°C (77°F)	100°C (212°F)
H <sup>+</sup>	328	350	646
Na <sup>+</sup>	45	50.1	155
K <sup>+</sup>	67	73.5	200
NH <sub>4</sub> <sup>+</sup>	67	73.5	200
Mg <sup>++</sup>	47	53.1	170
Ca <sup>++</sup>	53.7	59.5	191
OH <sup>-</sup>	179	197	446
Cl <sup>-</sup>	69.0	76.3	207
HCO <sub>3</sub> <sup>-</sup>	36.5	44.5	-
NO <sub>3</sub> <sup>-</sup>	65.2	71.4	178
H <sub>2</sub> PO <sub>4</sub> <sup>-</sup>	30.1	36.0	-
CO <sub>3</sub> <sup>--</sup>	63.0	72.0	-
HPO <sub>4</sub> <sup>--</sup>	-	53.4	-
SO <sub>4</sub> <sup>--</sup>	71.8	79.8	234
PO <sub>4</sub> <sup>---</sup>	-	69.0	-



Figure 6. Conductance vs. Total Dissolved Solids

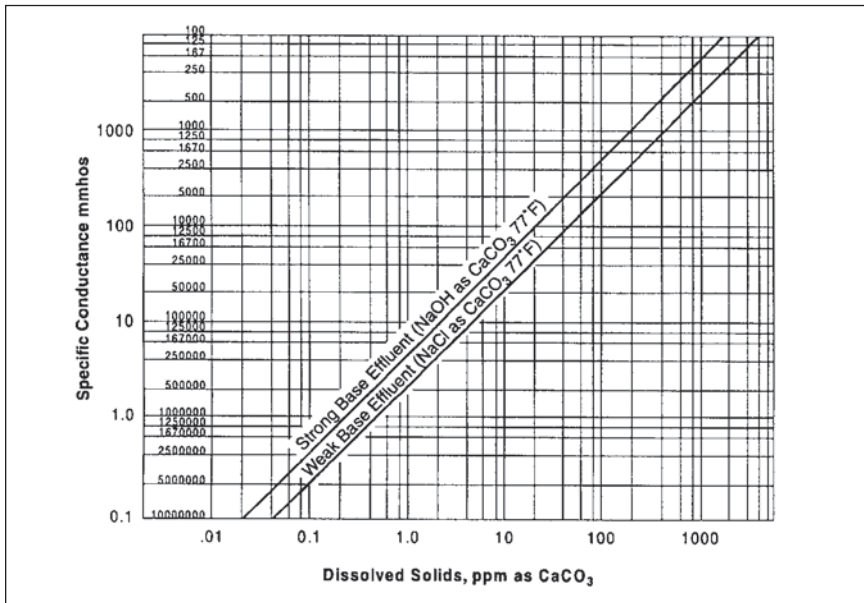
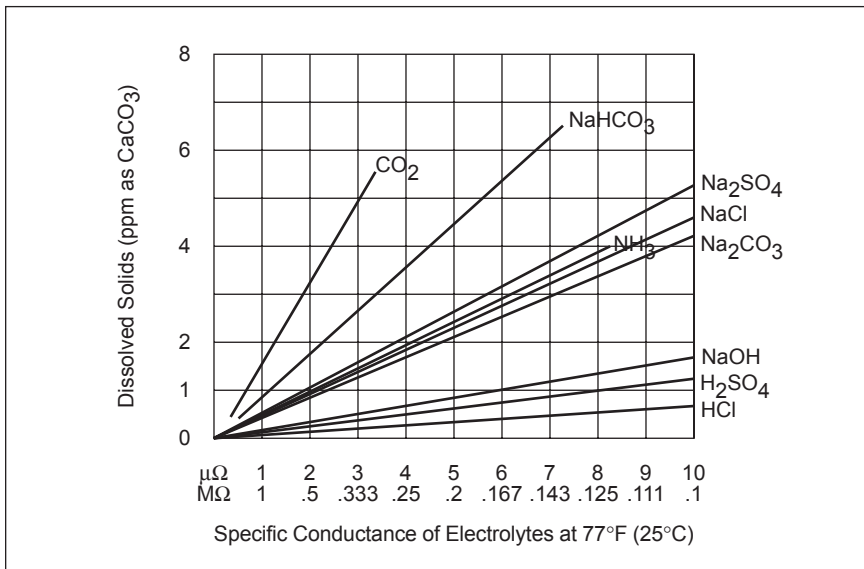


Figure 7. Relationship Between Dissolved Solids and Conductance in Demineralization Operations



**Table 10. Specific Conductance of Sodium Chloride**

$\mu\text{mhos/cm}$	ppm	$\mu\text{mhos/cm}$	ppm	$\mu\text{mhos/cm}$	ppm	$\mu\text{mhos/cm}$	ppm	$\mu\text{mhos/cm}$	ppm	$\mu\text{mhos/cm}$	ppm	$\mu\text{mhos/cm}$	ppm
10	5	620	307	1440	723	3350	1726	8600	4654	20000	11476	50000	30425
20	9	630	312	1460	733	3400	1753	8700	4710	20250	11630	51000	31103
30	14	640	317	1480	743	3450	1781	8800	4767	20500	11784	52000	31781
40	19	650	323	1500	754	3500	1808	8900	4823	20750	11937	53000	32459
60	28	660	328	1525	766	3550	1835	9000	4879	21000	12091	54000	33137
70	33	670	333	1550	770	3600	1863	9100	4935	21250	12245	55000	33815
80	38	680	338	1575	792	3650	1899	9200	4991	21500	12399	56000	34493
90	42	690	343	1600	805	3700	1917	9216	5000	21750	12552	57000	35171
100	47	700	348	1625	817	3750	1945	9300	5047	22000	12705	58000	35849
110	52	710	353	1650	830	3800	1972	9400	5103	22250	12860	59000	36527
120	57	720	358	1675	843	3850	1999	9500	5159	22500	13013	60000	37205
130	61	730	363	1700	856	3900	2027	9600	5215	22750	13167	61000	37883
140	66	740	368	1725	868	3950	2054	9700	5271	23000	13321	62000	38561
150	71	750	373	1750	881	4000	2081	9800	5327	23250	13474	63000	39239
160	75	760	378	1775	894	4100	2136	9900	5383	23500	13628	64000	39917
170	80	770	383	1800	907	4200	2191	10000	5439	23750	13782	65000	40595
180	85	780	388	1825	920	4300	2245	10200	5551	24000	13936	66000	41273
190	90	790	393	1850	932	4400	2300	10400	5664	24250	14089	67000	41961
200	95	800	399	1875	945	4500	2356	10600	5776	24500	14243	68000	42629
210	100	810	404	1900	958	4600	2412	10800	5888	24750	14397	69000	3307
220	105	820	409	1925	971	4700	2468	11000	6000	25000	14550	70000	43985
230	110	830	414	1950	983	4800	2524	11200	6122	25500	14858	71000	44663
240	115	840	419	1975	996	4900	2580	11400	6243	26000	15165	72000	45341
250	120	850	424	2000	1000	5000	2636	11600	364	26500	15473	73000	46091
260	125	860	429	2025	1022	5100	2692	11800	6485	27000	15780	74000	46697
270	130	870	434	2050	1034	5200	2748	12000	6607	27500	16087	76000	48053
280	135	880	439	2075	1047	5300	2805	12200	6728	28000	16395	77000	48731
290	140	890	444	2125	1073	5400	2861	12400	6843	28500	16702	78000	49409
300	145	900	449	2150	1085	5500	2917	12600	6970	29000	17010	79000	50087
310	150	910	454	2175	1098	5600	2973	12800	7091	29500	17317	80000	50765
320	155	920	459	2200	1111	5700	3029	13000	7213	30000	17624	81000	51443
330	160	930	464	2225	1124	5800	3085	13200	7334	30500	17932	82000	52121
340	165	940	469	2250	1137	5900	3141	13400	7455	31000	18239	83000	52799
350	171	950	474	2275	1140	6000	3197	13600	7576	31500	18547	84000	53477
360	176	960	480	2300	1162	6100	3253	13800	7898	32000	18854	85000	54155
370	181	970	485	2325	1175	6200	3309	14000	7819	32500	19161	86000	54833
380	186	980	490	2350	1188	6300	3365	14200	7940	33000	19469	87000	55511
390	191	990	495	2375	1200	6400	3421	14400	8061	34000	20084	88000	56130
400	196	1000	500	2400	1213	6500	3477	14600	8182	34500	20391	89000	56867
410	201	1020	510	2425	1226	6600	3533	14800	8304	35000	20698	90000	57545
420	206	1040	520	2450	1239	6700	3589	15000	8425	35500	21006	91000	58223
430	211	1080	540	2475	1251	6800	3645	15250	8576	36000	21313	92000	58901
440	216	1100	550	2500	1264	6900	3701	15500	8728	36500	21621	93000	59579
450	221	1120	561	2550	1290	7000	3758	15750	8879	37000	21928	94000	60257
460	226	1140	571	2600	1315	7100	3814	16000	9031	37500	22235	95000	60935
470	231	1160	581	2650	1344	7200	3870	16250	9182	38000	22543	96000	61613
480	236	1180	591	2700	1371	7300	3926	16500	9334	38500	22850	97000	62291
490	241	1200	601	2750	1398	7400	3982	16750	9486	39000	23158	98000	62969
500	247	1220	611	2800	1426	7500	4038	17000	9637	39500	23465	99000	63647
510	252	1240	621	285	1453	7600	4094	17500	9940	40000	23773	100000	64325
520	257	1260	632	2900	1480	7700	4150	1775	10092	41000	24387		
530	262	1280	642	2950	1508	7800	4206	18000	10247	42000	25002		
550	272	1300	652	3000	1535	7900	4262	18250	10400	43000	25679		
560	277	1320	662	3050	1562	8000	4318	18500	10554	44000	26357		
570	282	1340	672	3100	1589	8100	4374	18750	10708	45000	27035		
580	87	1360	682	3150	1617	8200	4430	19000	10852	46000	27713		
590	292	1380	692	3200	1644	8300	4486	19250	11015	47000	28391		
600	297	1400	702	3250	1671	8400	4542	19500	11169	48000	29069		
610	302	1420	713	3300	1699	8500	4598	19750	11323	49000	29747		

## 8. The pH of Pure Water as a Function of Temperature

The pH of pure water is 7.0 at 25°C (77°F). Deviations at other temperatures are due to the changing degree of auto-dissociation of water (see Figure 8).

The pH measurements in water of high purity become very difficult. The pH values registered with normal pH meters in water with conductivities below 0.2  $\mu\text{S}/\text{cm}$  should therefore be considered unreliable.

The pH meters will often have an internal temperature compensation; values measured at other temperatures will thereby be corrected to the value at 25°C (77°F).

## 9. The pH of Basic Solutions at 25°C (77°F)

The pH-values are a valuable tool to measure the concentration of ammonia ( $\text{NH}_3$ ) or hydrazine ( $\text{N}_2\text{H}_4$ ) in condensate circuits, freed of other impurities (see Figure 9).

NaOH and KOH concentrations can be monitored by pH measurements or conductivity measurements during the rinsing cycle of anion exchange resins, or to establish the Na leakage from the cation exchanger in a running unit.

Increments of conductivity over the value accounted for by pH can indicate the presence of neutral salts.

## 10. The pH of Acid Solutions at 25°C (77°F)

Analogous to the case of basic solutions, pH measurements can establish the concentration of acids during the rinsing cycle of cation exchange resins (see Figure 10).

$\text{CO}_2$  will be present in the effluent from a demineralizer consisting of a strongly acidic cation exchanger and a weakly basic anion exchanger. The pH measurements can establish the concentration of  $\text{CO}_2$ . Accounting for this contribution to conductivity, it is then possible to establish the leakage level of NaCl.

Figure 8. The pH of Pure Water as a Function of Temperature

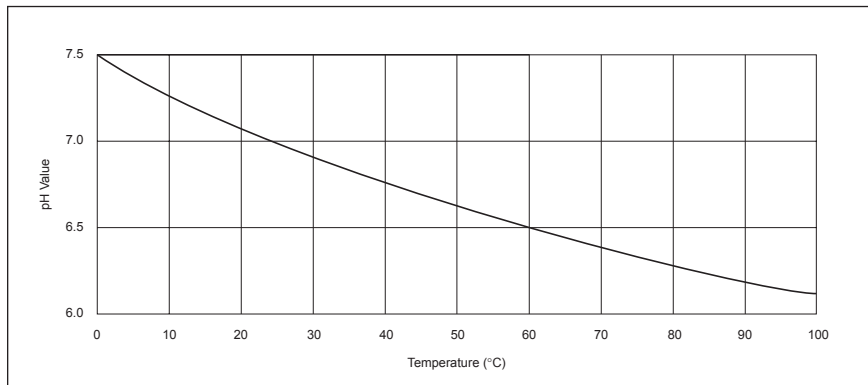


Figure 9. The pH of Basic Solutions at 25°C (77°F)

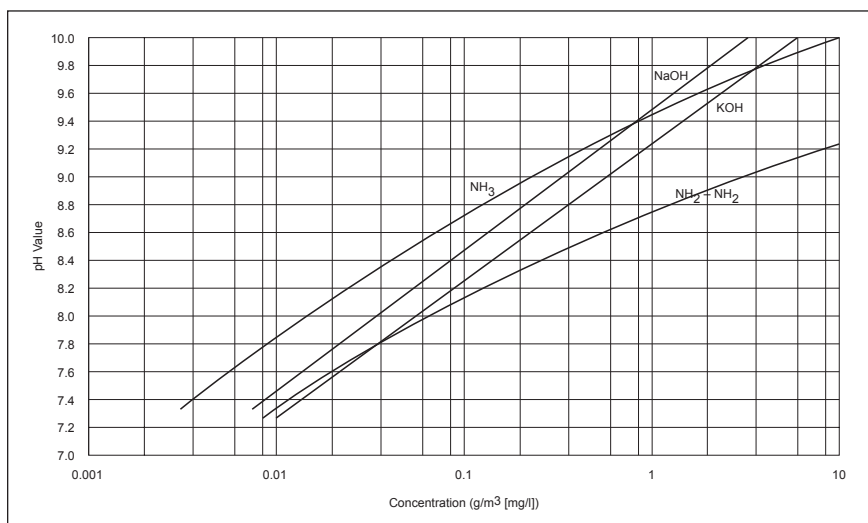
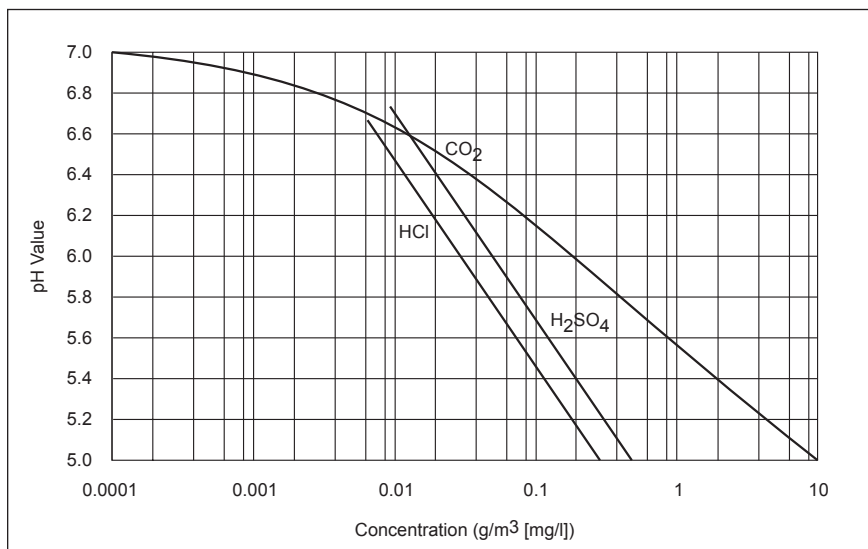


Figure 10. The pH of Acid Solutions at 25°C (77°F)



## 11. P- and M-Alkalinity

Alkalinity titrations are carried out using an acid solution of 0.1 N and a 100 ml water sample, or using a 1 N solution and a 1 l water sample. The volume of acid, expressed in ml of acid added to cause colour change of the indicator is reported as alkalinity; therefore:

1 ml acid = 1 meq/l alkalinity

If phenolphthalein is used as indicator, P-alkalinity is measured. If methylorange is used, M-alkalinity is measured.

Although alkalinity numbers as such are interesting, it is also necessary to know the concentrations of the species making up this alkalinity; the main contributors are hydroxyl (OH<sup>-</sup>), bicarbonate (HCO<sub>3</sub><sup>-</sup>) and carbonate (CO<sub>3</sub><sup>-</sup>) ions. Their concentrations can be calculated from P- and M-alkalinity assuming:

1. P-alkalinity determines all hydroxyl and half of the carbonate alkalinity.
2. M-alkalinity determines the total of carbonate, bicarbonate and hydroxyl alkalinity.

Table 11 can then be used to calculate the concentrations of the different species for different cases of P- and M-alkalinity. Results are obtained in meq/l.

Example: If P-alkalinity is 0.5 ml and M-alkalinity is 3 ml, then  $P < 1/2 M$  applies

! carbonate = 1.0 meq/l

! bicarbonate = 2.0 meq/l

## 12. Information on Regenerant Chemicals

### 12.1 Properties, Impurities and Concentrations

#### General

Sufficient precautions should be taken when handling, transporting or disposing of acidic or basic regenerants. Even after dilution to their operational concentrations or in the waste after regeneration, sufficient acid or base can be present to cause severe damage to mankind. Adequate protection for all parts of the body should therefore be provided whenever using these chemicals, and the manufacturer's guidelines for

handling these products should be carefully followed.

The specifications and the purity of the regenerant chemicals have to assure a trouble-free operation of the ion exchange resin after regeneration. Therefore, the chemicals have to be free of suspended materials, or other materials that may be precipitated and/or absorbed by the resin. They should also be free of ionic species other than the active regeneration agents, as this will decrease the regeneration efficiency and/or increase the leakage of this species during the operational cycle. For example, sodium hydroxide containing 2 percent NaCl will reduce the efficiency by 5 to 10 percent and cause a higher Cl-leakage from the strongly basic anion exchange resin.

In counter-current operations where low leakage levels are especially aimed for, regenerants should contain minimal levels of impurities.

Different processes and technologies and different requirements as to the quality of the treated effluent will therefore impose different restrictions on the impurity levels in the regeneration chemicals and the dilution water. In the same way, regenerant concentrations and flow rates can affect the efficiency of the operation.

Recommendations and the quality of regeneration chemicals are given in the following sections. The recommended qualities should prove sufficient for all ion exchange resin applications, and under certain conditions lesser qualities can be used, including eventual waste chemicals from process streams. Figures for impurity levels are the basis of a 100 percent regeneration chemical.

**1. Hydrochloric Acid: HCl (Muriatic Acid)** Both as a gas and in solution, HCl is very corrosive and can cause severe burns on contact. Mucous membranes of the eyes and of the upper respiratory tract are especially susceptible to high atmospheric concentrations. Avoid inhalation of

**Table 11. Calculating Concentrations for P- and M-Alkalinity**

P and M alkalinity	Hydroxyl (OH)	Carbonate (CO <sub>3</sub> )	Bicarbonate (HCO <sub>3</sub> )
P = 0	0	0	M
P < 1/2 M	0	2P	M - 2P
P = 1/2 M	0	M	0
P > 1/2 M	2P-M	2(M-P)	0
P = M	M	0	0

**Table 12. Recommended Maximum Impurity Levels for HCl**

Recommended Max. Impurity Levels	
Fe	0.01%
Other metals, total	10 mg/l
Organic matter	0.01%
Sulfuric acid, as SO <sub>3</sub>	0.4%
Oxidants (HNO <sub>3</sub> , Cl <sub>2</sub> )	5 mg/l
Suspended matter as turbidity	~ 0
Inhibitors	None

the fumes and provide adequate ventilation when handling the acid. The acid is commercially offered as a colorless to light yellow/green liquid in concentrations of about 28 to 36 weight to weight percent HCl (see Table 12).

Hydrochloric acid from hydrolysis of chlorinated organic materials is not suitable for use as regenerant. Acid from the salt-acid process or by the hydrogen-chlorine process is satisfactory.

Hydrochloric acid solutions are most diluted to 4 to 5 percent for the regeneration of strongly acidic ion exchangers, and from 1 to 5 percent for weakly acidic resins in water demineralization applications. Higher concentrations using 8 to 10 percent HCl are sometimes preferred in other applications.

**2. Sulfuric Acid: H<sub>2</sub>SO<sub>4</sub>** Sulfuric acid is dangerous when improperly handled. Concentrated solutions are rapidly destructive to tissues they contact, producing severe burns. Contact with eyes will cause severe damage and blindness. Inhaling vapors from hot acid or oleum may be harmful. Swallowing may cause severe injury or death. One should be well aware of the strong exothermicity of the dilution of H<sub>2</sub>SO<sub>4</sub> with water, which can raise the temperature very high and very fast. The acid is supplied as a colorless to yellow/brown liquid in concentrations of about 93 weight percent.

Sulfuric acid solutions are mostly diluted to 1 to 6 percent for the regeneration of strongly acidic ion exchangers and to 0.5 to 1 percent for weakly acidic ion exchangers in water demineralization applications. Stepwise increase of the acid concentration may be preferred under circumstances of high-hardness waters (see Table 13).

**3. Sodium Hydroxide: NaOH (Caustic Soda)** Sodium hydroxide or caustic soda can cause severe burns on contact with skin or eyes or when taken internally. Great care must be

**Table 13. Recommended Maximum Impurity Levels for H<sub>2</sub>SO<sub>4</sub>**

Recommended Max. Impurity Levels	
Fe	50 mg/l
Nitrogen compounds	20 mg/l
As	0.2 mg/l
Organic matter	0.01%
Suspended matter as turbidity	~ 0
Inhibitors	None
Other heavy metals	20 mg/l

**Table 14. Recommended Maximum Impurity Levels for NaOH**

Recommended Max. Impurity Levels	
NaCl	0.6%
NaClO <sub>3</sub>	30 mg/l
Na <sub>2</sub> CO <sub>3</sub>	0.75%
Fe	10 mg/l
Heavy metals (total)	5 mg/l
SiO <sub>3</sub>	50 mg/l
Na <sub>2</sub> SO <sub>4</sub>	0.2%

**Table 15. Typical Analyses for Different Caustic Qualities**

Compound	Mercury1 Grade	Rayon1 Grade	Regular Diaphragm Grade	Regular Technical Flake
NaOH	51%	50.1%	50.4%	98%
Na <sub>2</sub> CO <sub>3</sub>	0.02%	0.2%	0.2%	0.5-1%
NaClO <sub>3</sub>	1 mg/l	2 mg/l	0.5%l	2 mg/l
NaCl	0.002%	0.2-.05%	1-2%	0.4-1.5%
NaSO <sub>4</sub>	10 mg/l	0.1%l	0.03%	0.3%
Fe	1 mg/l	10 mg/l	15 mg/l	10 mg/l
Heavy metals (total)	2 mg/l	4 mg/l	N.S.	2 mg/l
SiO <sub>2</sub>	10 mg/l	40 mg/l	N.S.	500 mg/l

taken when handling the anhydrous material or when preparing or handling caustic soda solutions.

Caustic soda is offered as solid flakes or pellets of about 98 percent NaOH or as a 30 to 50 percent liquid (see Table 14).

Mercury cell or purified diaphragm cell (rayon) quality sodium hydroxide will normally meet such specifications. Regular diaphragm cell

quality caustic soda can contain over 2 percent NaCl and over 0.1 percent (1000 mg/l) NaClO<sub>3</sub>.

Sodium hydroxide solutions are mostly diluted to between 2 and 5 percent for the regeneration of weakly or strongly basic resins.

Regeneration of strongly basic resins can eventually be carried out with NaOH containing higher NaCl concentrations at the expense

however, of efficiency (2 percent NaCl will cause about 10 percent reduction in efficiency). NaClO<sub>3</sub> levels of 500 mg/l can be allowed for strongly basic resins in single beds.

Weakly basic resins will suffer mostly from high NaClO<sub>3</sub> levels as conversion to HClO<sub>3</sub> can create a strong oxidizing agent. Therefore, mixed bed anion exchangers should be regenerated with regular grade diaphragm cell caustic soda. On the other hand, regeneration of weakly basic resins will not suffer from high NaCl, Na<sub>2</sub>SO<sub>4</sub> or NaCO<sub>3</sub> levels. If very low chloride levels are required, mercury grade NaOH should be used.

Typical analyses for different caustic qualities are given in Table 15.

**4. Ammonia: NH<sub>3</sub>** Ammonia gas or fumes from concentrated solutions can cause serious irritation to eyes and the respiratory tract. Avoid inhalation and provide adequate ventilation when handling ammonia solutions.

Ammonia is mostly offered as a solution in water, containing 20 to 30 weight percent NH<sub>3</sub>. Impurities are normally minimal and cause no potential problem in ion exchange regeneration.

Ammonia is mostly used in concentrations between 3 and 5 percent for regeneration of weakly to medium basic anion exchange resins.

**5. Sodium Carbonate: NaCO<sub>3</sub> (Soda Ash)** Sodium carbonate does not require special handling precautions. It is supplied as a white, anhydrous powder with over 98 percent purity. Impurity levels are thus minimal and cause no potential problem in ion exchange regeneration. Moreover, higher levels of NaCl or Na<sub>2</sub>SO<sub>4</sub> will not adversely affect the regeneration efficiency, although they will of course not contribute as regeneration chemicals.

Sodium carbonate is mostly diluted to between 5 and 8 percent for the regeneration of weakly to medium basic ion exchange resins.

#### 6. Sodium Chloride: NaCl (Salt)

Sodium chloride does not require special handling precautions. It is offered as a white powdered, granulated or pelleted solid of 98 to 99 percent (see Table 16).

Sodium chloride is used for regeneration in different processes. Concentrations will differ depending upon the process, as is illustrated in Table 17.

#### 12.2 Ionization and Equilibrium Data

Sulfuric acid has two acidic protons (H<sup>+</sup>). The first H<sup>+</sup> is very acidic and will appear as an ion in all but very concentrated solutions. Ionization of the second H<sup>+</sup>, leaving free SO<sub>4</sub><sup>2-</sup> in solutions happens, however, only in more diluted solutions. Figures 11 and 12 give the proportions of non-ionized H<sub>2</sub>SO<sub>4</sub>, the partially ionized acid (HSO<sub>4</sub><sup>-</sup>) and proportions of the fully ionized acid (SO<sub>4</sub><sup>2-</sup>) as functions of the acid concentration.

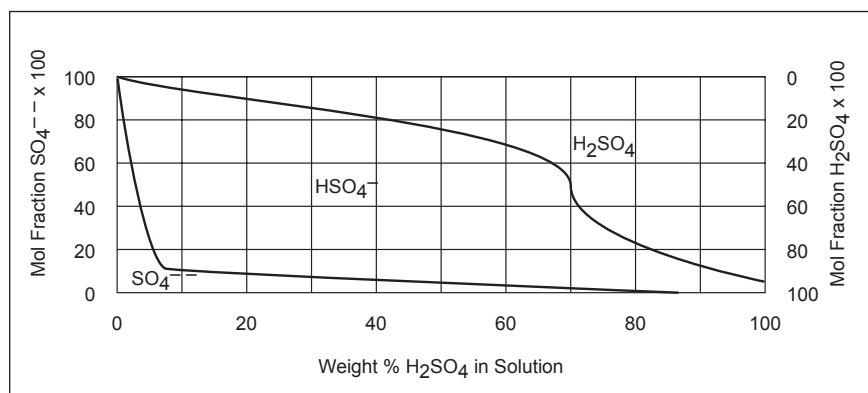
**Table 16. Recommended Maximum Impurity Levels for NaCl**

Recommended Max. Impurity Levels	
SO <sub>4</sub> <sup>2-</sup>	1%
Mg <sup>++</sup> Ca <sup>++</sup>	0.5%

**Table 17. Concentration of NaCl and Process Used**

Process	Resin	Concentration
Softening	e.g., DOWEX MARATHON C	8-26% NaCl
Dealkalization	e.g., DOWEX MARATHON A2	5-10% NaCl
Organic screen	e.g., DOWEX MARATHON 11	10% NaCl + 1% NaOH

**Figure 11. Ionization of Sulfuric Acid**

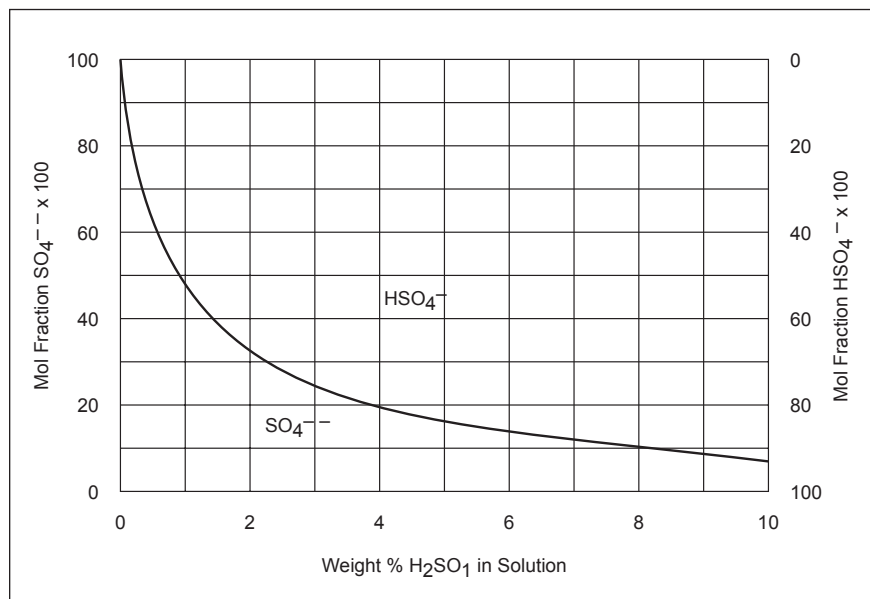


**1. Sulfate/Bisulfate Equilibrium as Function of pH at 25°C (77°F)** In the presence of other acids/bases the equilibrium between bisulfate ( $\text{HSO}_4^-$ ) and sulfate ( $\text{SO}_4^{--}$ ) will be shifted as a function of the overall pH of the solution. Figure 13 shows the proportions of  $\text{HSO}_4^-$  and  $\text{SO}_4^{--}$  for diluted solution at 25°C (77°F).

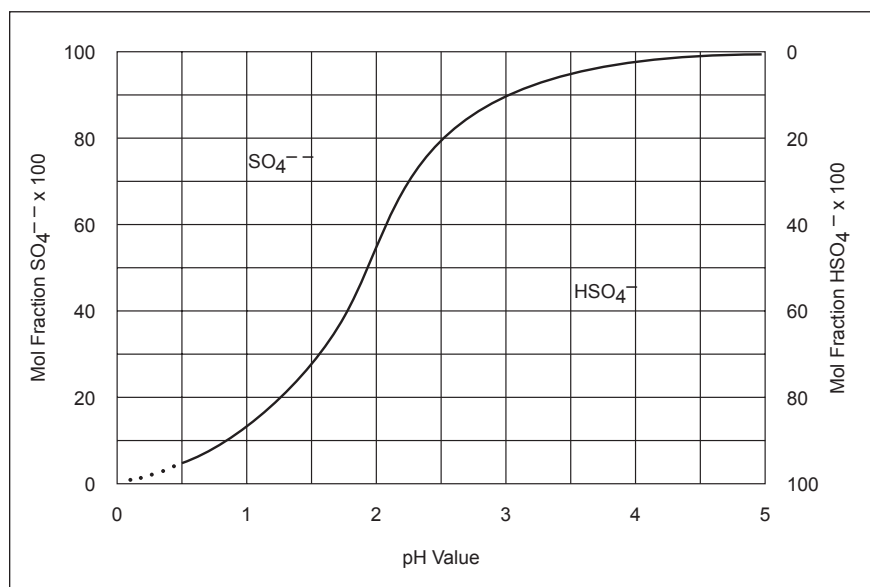
**2. Ionization of Diluted Ammonia Solutions as Function of the pH at 25°C (77°F)** Ammonia ( $\text{NH}_3$ ) is a weak base, accepting  $\text{H}^+$  in acidic and weakly basic media, but not in strongly basic solutions. Figure 14 allows to establish the proportion of protonated ammonia, appearing as an ammonium ion ( $\text{NH}_4^+$ ), and free ammonia ( $\text{NH}_3$ ) at different pH values. At pH 7 or lower, all ammonia will be present as  $\text{NH}_4^+$ ; at pH 12 or higher, only free ammonia will be present.

**3. Ionization of Carbon Dioxide Solutions as Function of the pH at 25°C (77°F)** Carbon dioxide ( $\text{CO}_2$ ), also present as carbonic acid ( $\text{H}_2\text{CO}_3$ ), is a weak acid with two weakly acidic protons. Depending upon the pH of the solution, the acid will be present as free acid ( $\text{CO}_2$ ), partially ionized, leaving bicarbonate ( $\text{HCO}_3^-$ ) in the solution, or fully ionized, leaving carbonate ( $\text{CO}_3^{--}$ ) in the solution. The proportions of the different species at different pH values can be established from Figure 15.

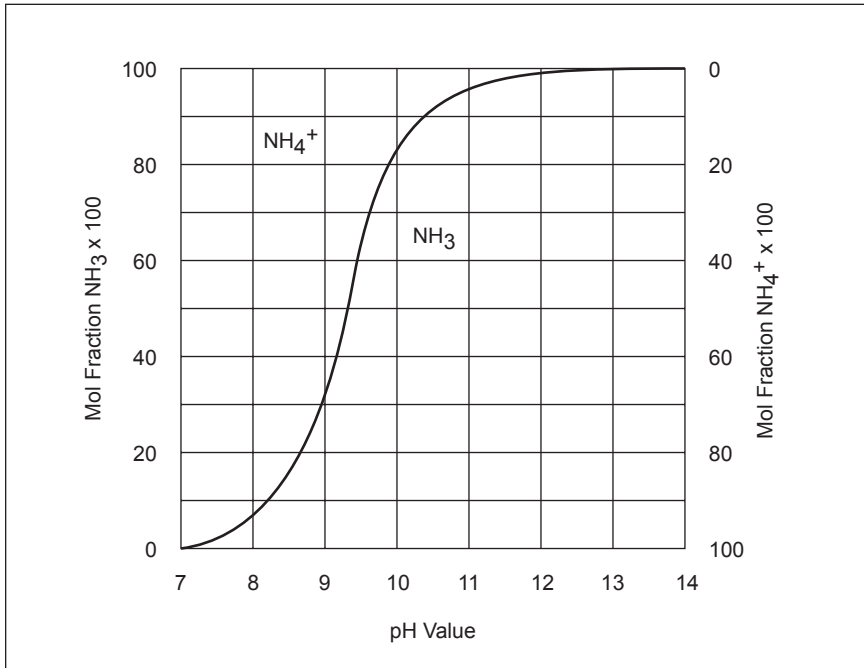
**Figure 12. Ionization of Diluted  $\text{H}_2\text{SO}_4$  Solutions at 25°C (77°F)**



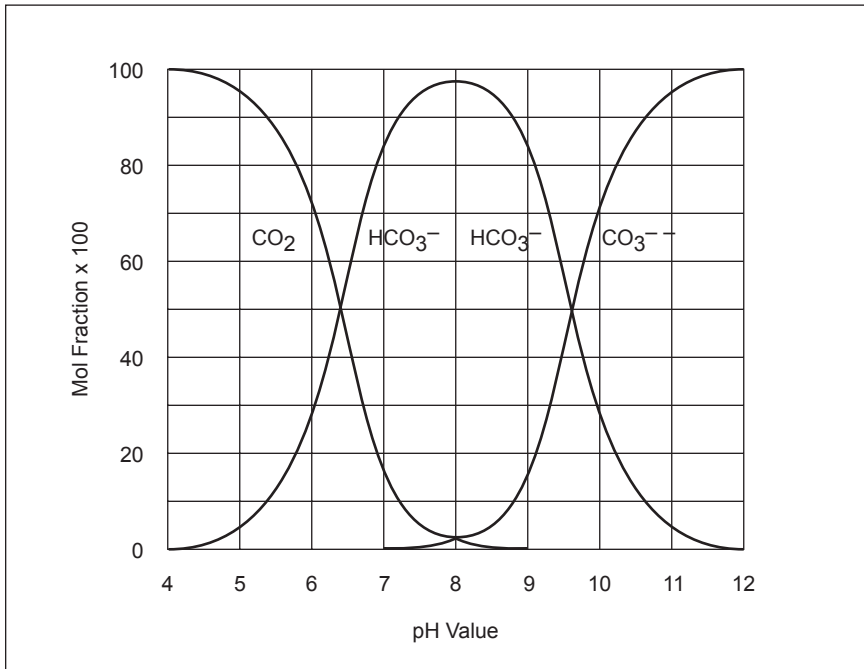
**Figure 13. Sulfate/Bisulfate Equilibrium as Function of pH at 25°C (77°F)**



**Figure 14. Ionization of Diluted Ammonia Solutions as Function of the pH at 25°C (77°F)**



**Figure 15. Ionization of Carbon Dioxide Solutions as Function of the pH at 25°C (77°F)**





### 12.3 Concentration and Density of Solutions

Tables 18 through 23 show the concentration and density of solutions.

**Table 18. Concentration and Density of HCl Solution**

Concentration g HCl/100 g solution weight %	Concentration g HCl/l	Concentration eq/l	Concentration lbs/gal.	Density kg/l	Density ° Baumé
0.5	5.01	0.137	0.042	1.001	0.5
1	10.03	0.274	0.084	1.003	0.7
1.5	15.09	0.413	0.13	1.006	1.0
2	20.16	0.552	0.17	1.008	1.3
2.5	25.28	0.692	0.22	1.011	1.7
3	30.39	0.833	0.25	1.013	2.0
3.5	35.53	0.973	0.30	1.015	2.3
4	40.72	1.12	0.34	1.018	2.7
5	51.15	1.40	0.43	1.023	3.3
6	61.68	1.69	0.50	1.028	4.0
7	72.31	1.98	0.60	1.033	4.7
8	83.04	2.28	0.69	1.038	5.4
9	93.87	2.57	0.78	1.043	6.1
10	104.8	2.87	0.87	1.048	7.0
12	127.0	3.48	1.04	1.058	8.0
14	149.5	4.10	1.22	1.068	9.3
16	172.5	4.73	1.46	1.078	10.5
18	195.8	5.37	1.65	1.088	11.8
20	219.6	6.02	1.83	1.098	13.0
22	243.8	6.8	2.0	1.108	14.2
24	268.6	7.36	2.2	1.119	15.4
26	293.5	8.04	2.5	1.129	16.7
28	318.9	8.74	2.68	1.139	17.7
30	344.7	9.44	2.88	1.149	18.7
32	370.9	10.16	3.07	1.159	19.8
34	397.5	10.89	3.26	1.169	21.0
36	424.4	11.63	3.45	1.179	22.0
38	451.8	12.38	3.63	1.189	23.0
40	479.2	13.13	3.8	1.198	24.0

**Table 19. Concentration and Density of H<sub>2</sub>SO<sub>4</sub> Solutions**

Concentration g H <sub>2</sub> SO <sub>4</sub> /100 g solution weight %	Concentration g H <sub>2</sub> SO <sub>4</sub> /l	Concentration eq/l	Concentration lbs/gal.	Density kg/l	Density ° Baumé
0.5	5.01	0.102	0.042	1.002	0.6
1	10.05	0.205	0.084	1.005	0.9
1.5	15.12	0.309	126	1.008	1.3
2	20.24	0.413	0.169	1.012	1.9
3	30.54	0.623	0.255	1.018	2.8
4	41.00	0.837	0.342	1.025	3.6
5	51.60	1.05	0.43	1.03 2	4.6
6	62.34	1.27	0.52	1.039	5.5
7	73.15	1.49	0.61	1.045	5
8	84.16	1.72	0.70	1.052	7.3
9	95. 31	1.95	0.796	1:059	8.1
10	106	2.18	0.89	1.066	9.0
12	129.6	2.64	1.07	1.080	10.8
14	153.3	3.13	1.24	1.095	12.6
16	177.4	3.62	1.52	1.109	14.3
18	202.5	4.13	1.71	1.125	10
20	228.0	4.65	1.90	1.140	17.7
30	365.7	7.46	2.9	1.219	20
35	439.6	8.97	4.2	1.256	29.7
40	521.2	10.6	5.0	1.303	33.5
45	607.1	12.4	5.8	1.349	37.4
50	697.5	14.2	6.5	1.395	41.1
55	794.8	12	7.5	1.445	44.5
60	899.4	18.4	8.4	1.499	48.1
65	1010	20.6	9.2	1.553	51.4
70	1127	23.0	9.9	1.610	54.7
75	1252	25.5	11.1	1.669	57.9
80	1382	28.2	11.9	1.727	60.8
85	1511	30.8	12.6	1.777	63.4
90	1634	33.3	13.3	1.815	64.9
92	1678	34.2	14.0	1.824	65.3
94	1720	35.1	14.4	1.830	65.6
96	1763	30	14.7	1.836	66
98	1799	37	15.0	1.836	66
100	1831	374	15.3	1 831	65.6

**Table 20. Concentration and Density of NaOH Solutions**

Concentration g NaOH/100 g solution weight %	Concentration g NaOH/l	Concentration eq/l	Concentration lbs/gal.	Density kg/l	Density ° Baumé
0.5	5.02	126	0.042	1.004	0.8
1	10.10	0.253	0.084	1.010	1.5
1.5	15.2	0.381	0.13	1.015	2.3
2	20.4	0.510	0.17	1.021	3.0
2.5	25.7	0.641	0.22	1.026	3.7
3	31.0	0.774	0.26	1.03 2	4.6
3.5	33	0.907	0.30	1.038	5.4
4	41.7	1.04	0.35	1.043	5.9
5	52.7	1.32	0.44	1.054	7.3
6	63.9	1.60	0.53	1.065	8.9
7	75.3	1.88	0.63	1.076	10.1
8	89	2.17	0.73	1.087	11.5
9	98. 8	2.47	0.825	1.098	12.9
10	110.9	2.77	0.925	1.109	14.2
12	135.7	3.39	1.1	1.131	17
14	161.4	4.03	1.4	1.153	19.2
16	188.0	4.70	1.65	1.175	21.6
18	215.5	5.39	1.9	1.197	23.9
20	243.8	09	2.1	1.219	20
30	398.3	9.96	3.65	1.328	35.8
40	571.9	14.3	5.0	1.430	43.5
50	762.7	19.1	6.37	1.525	49.8

**Table 21. Concentration and Density of NH<sub>3</sub> Solutions**

Concentration g NH <sub>3</sub> /100 g solution weight %	Concentration g NH <sub>3</sub> /l	Concentration eq/l	Concentration lbs/gal.	Density kg/l	Density ° Baumé
1	9.94	0.58	0.083	0.994	10.9
2	19.8	1.16	0.17	0.990	11.5
3	29.6	1.74	0.25	0.985	12.2
4	39.2	2.30	0.33	0.981	12.8
5	48.8	2.87	0.41	0.977	13.3
6	58.4	3.43	0.49	0.973	13.9
7	67.8	3.98	0.57	0.969	14.4
8	77.2	4.53	0.64	0.965	15.1
9	85	5.08	0.73	0.961	15.7
10	95. 8	5.62	0.82	0.95 8	12
12	114.0	70	1.0	0.950	17.3
14	132.0	7.75	1.25	0.943	18.5
16	149.8	8.80	1.3	0.936	19.5
18	167.3	9.82	1.5	0.929	20.6
20	184.6	10.8	1.7	0.923	21.7
24	218.4	12.8	1.9	0.910	23.9
28	251.4	14.8	2.1	0.898	25.3
32	282.6	16	2.4	0.883	28.6

**Table 22. Concentration and Density of NaCl Solutions**

Concentration g NaCl/100 g solution weight %	Concentration g NaCl/l	Concentration eq/l	Concentration lbs/gal.	Density kg/l	Density ° Baumé
1	10.1	0.172	0.08	1.005	0.9
2	20.2	0.346	0.17	1.013	2.0
3	30.6	0.523	0.25	1.020	3.0
4	41.1	0.703	0.34	1.027	3.9
5	51.7	0.885	0.44	1.034	4.8
6	62.5	1.07	0.53	1.041	5.8
7	73.4	1.26	0.62	1.049	9
8	84.5	1.45	0.71	1.056	7.7
9	95.7	1.64	0.80	1.063	8.6
10	107.1	1.83	0.89	1.071	9.6
12	130.3	2.23	1.09	1.086	11.5
14	154.1	2.64	1.29	1.101	13.4
16	178.6	3.06	1.49	1.116	15.2
18	203.7	3.49	1.70	1.132	19
20	229.6	3.93	1.92	1.148	18.6
22	251	4.38	2.1	1.164	20.5
24	283.3	4.85	2.35	1.180	22.1
26	311.3	5.33	2.59	1.197	23.8

**Table 23. Concentration and Density of Na<sub>2</sub>CO<sub>3</sub> Solutions**

Concentration g Na <sub>2</sub> CO <sub>3</sub> /100 g solution weight %	Concentration g Na <sub>2</sub> CO <sub>3</sub> /l	Concentration eq/l	Concentration lbs/gal.	Density kg/l	Density ° Baumé
1	10.1	0.191	0.084	1.009	1.4
2	20.4	0.385	0.17	1.019	2.8
3	30.9	0.583	0.26	1.029	4.3
4	41.6	0.785	0.35	1.040	5.6
5	52.5	0.991	0.44	1.050	7.0
6	63.6	1.20	0.53	1.061	8.4
7	75.0	1.42	0.63	1.071	9.8
8	85	1.63	0.72	1.082	11.0
9	98.3	1.85	0.82	1.092	12.4
10	110.3	2.08	0.92	1.103	13.6
12	134.9	2.55	1.13	1.124	10
14	160.5	3.03	1.34	1.146	18.4
16	187.0	3.53	1.53	1.169	21.0
18	214.7	4.05	1.70	1.193	23.4

**12.4 Specific Gravity NaOH-H<sub>2</sub>O Solution (0 to 100°C) in g/ml**

Table 24 shows the specific gravity of NaOH-H<sub>2</sub>O solution.

**13. Solubility of CaSO<sub>4</sub>**

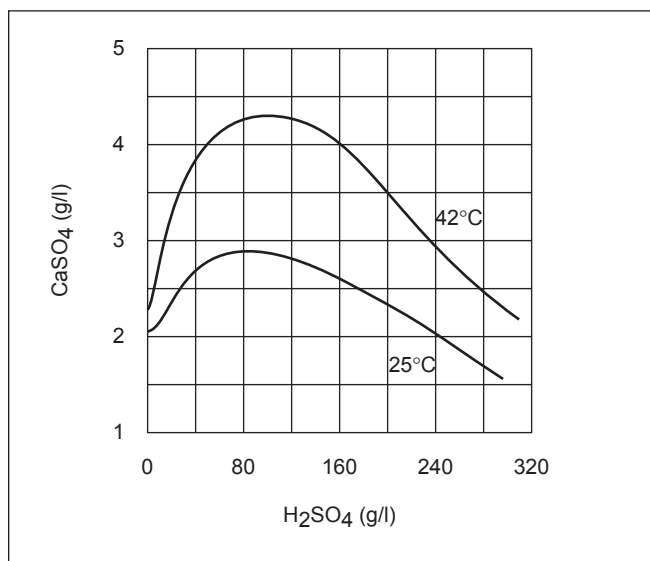
CaSO<sub>4</sub> is only very slightly soluble in water. Its solubility is increased in diluted sulfuric acid; however, CaSO<sub>4</sub>

precipitation should be prevented in an ion exchange bed, where it may occur when sulfuric acid is used to regenerate a cation exchange resin (see Figures 16 and 17).

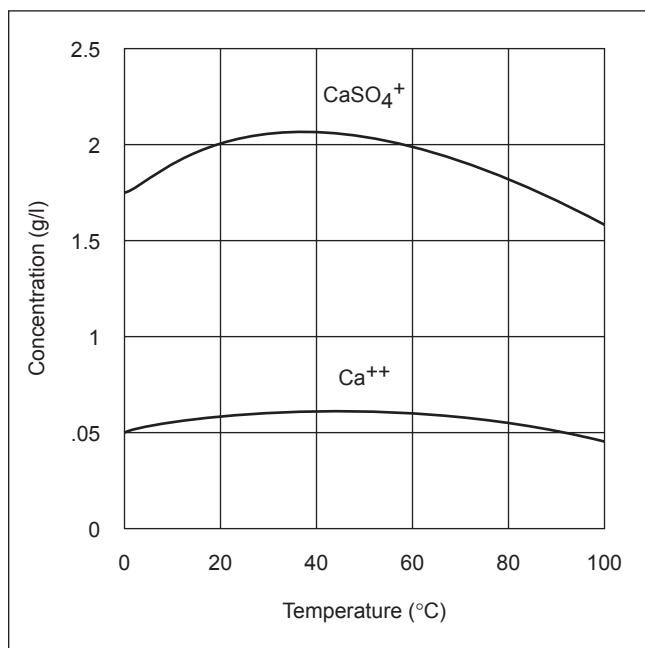
**Table 24. Specific Gravity NaOH-H<sub>2</sub>O Solution (0 to 100°C) in g/ml**

Concentration NaOH g/100 g solution	Temperature °C										
	0	10	20	30	40	50	60	70	80	90	100
1	1.0124	1.0115	1.0095	1.0069	1.0033	0.9990	0.9941	0.9884	0.9824	0.9760	0.9693
2	1.0244	1.0230	1.0207	1.0177	1.0139	1.0095	1.0045	0.9989	0.9929	0.9865	0.9797
3	1.0364	1.0345	1.0318	1.0285	1.0246	1.0201	1.0150	1.0094	1.0035	0.9970	0.9903
4	1.0482	1.0459	1.0428	1.0393	1.0352	1.0305	1.0254	1.0198	1.0139	1.0075	1.0009
5	1.0598	1.0571	1.0538	1.0501	1.0458	1.0412	1.0359	1.0302	1.0243	1.0179	1.0115
6	1.0713	1.0683	1.0648	1.0609	1.0564	1.0517	1.0463	1.0407	1.0347	1.0284	1.0220
7	1.0828	1.0795	1.0758	1.0717	1.0672	1.0623	1.0569	1.0513	1.0453	1.0390	1.0326
8	1.0943	1.0908	1.0869	1.0826	1.0780	1.0730	1.0676	1.0619	1.0560	1.0497	1.0432
9	1.1057	1.1020	1.0979	1.0934	1.0887	1.0836	1.0782	1.0725	1.0665	1.0602	1.0537
10	1.1171	1.1132	1.1089	1.1043	1.0995	1.0942	1.0889	1.0831	1.0771	1.0708	1.0643
12	1.1399	1.1355	1.1309	1.1261	1.1210	1.1157	1.1101	1.1043	1.0983	1.0920	1.0855
14	1.1624	1.1578	1.1530	1.1480	1.1428	1.1373	1.1316	1.1257	1.1195	1.1132	1.1066
16	1.1849	1.1801	1.1751	1.1699	1.1645	1.1588	1.1531	1.1471	1.1408	1.1343	1.1277
18	1.2073	1.2023	1.1972	1.1918	1.1863	1.1805	1.1746	1.1685	1.1621	1.1556	1.1489

**Figure 16. Solubility of CaSO<sub>4</sub> in Solutions of Sulfuric Acid in Water**



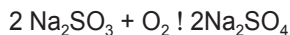
**Figure 17. Solubility of CaSO<sub>4</sub> at Different Temperatures in Water**



#### 14. The Removal of Oxygen

Figure 18 shows the solubility of oxygen in water as a function of temperature.

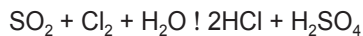
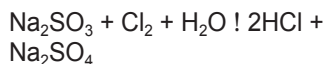
Dissolved oxygen can be reduced by using sodium sulfite according to following reaction:



Based on this equation, a minimum of 7.87 mg  $\text{Na}_2\text{SO}_3$  is necessary per mg dissolved  $\text{O}_2$ . Table 25 shows levels required to remove different amounts of dissolved oxygen.

#### 15. The Removal of Chlorine

Chlorine is a strong oxidant and may readily degrade ion exchange resins. Chlorine levels in water can be reduced using sulfur dioxide or sodium sulfite according to following reactions:



Per gram of chlorine to remove, one needs to add a minimum of 0.91 gram of  $\text{SO}_2$  or 1.78 gram of  $\text{Na}_2\text{SO}_3$ .

This leads to following amounts of reducing agents to add per 1000 liter of water for the given chlorine levels in Table 26.

Figure 18. Solubility of Oxygen in Water

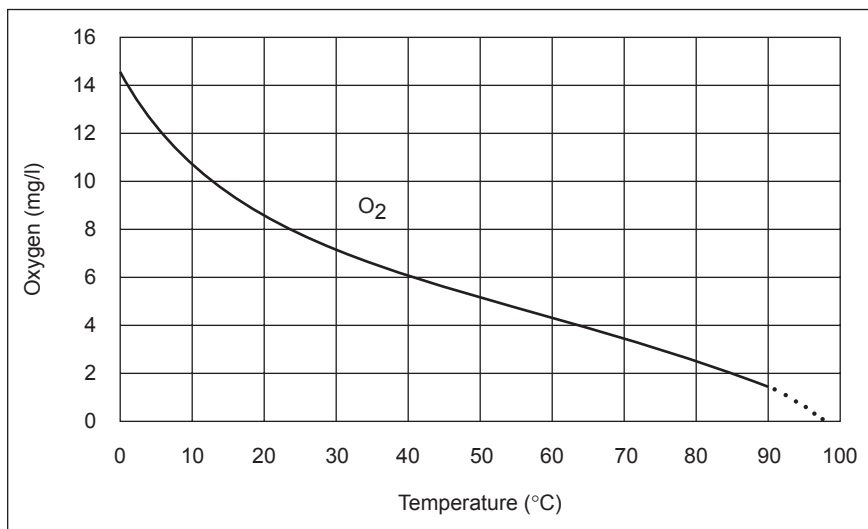


Table 25. Levels Required to Remove Dissolved Oxygen

Dissolved Oxygen		Sodium Sulfite (theoretical amount)	
cc/liter <sup>1</sup>	mg/l	mg/l	lbs/1000 gal.
0.1	0.14	1.1	0.0094
0.2	0.29	2.3	0.019
0.3	0.43	3.4	0.028
0.4	0.57	4.5	0.038
0.5	0.72	5.6	0.047
1.0	1.4	11.3	0.094
2.0	2.9	22.5	0.19
5.0	7.2	56.3	0.47
10.0	14.3	112.5	0.94

<sup>1</sup>1 cc dissolved oxygen per liter = 1.43 mg/l.

1 mg/l dissolved oxygen = 0.698 cc/liter.

Table 26. Levels Required for Removal of Chlorine

$\text{Cl}_2$	$\text{Na}_2\text{SO}_3$ (theoretical amount)		$\text{SO}_2$ (theoretical amount)	
	mg/l	g/1000 l	lbs/1000 gal.	g/1000 l
0.1	0.18	0.0015	0.09	0.00075
0.5	0.89	0.0075	0.45	0.0038
1	1.78	0.015	0.91	0.0075
2	3.56	0.030	1.82	0.015
3	5.34	0.045	2.73	0.0225
4	7.12	0.06	3.64	0.03
5	8.90	0.075	4.55	0.038
10	17.80	0.15	9.10	0.075

## 16. Osmotic Pressure of Sodium Chloride

Figure 19 shows the osmotic pressure of sodium chloride.

## 17. Osmotic Pressure of Solutions

Figure 20 shows the osmotic pressure of solutions.

Figure 19. Osmotic Pressure of Sodium Chloride

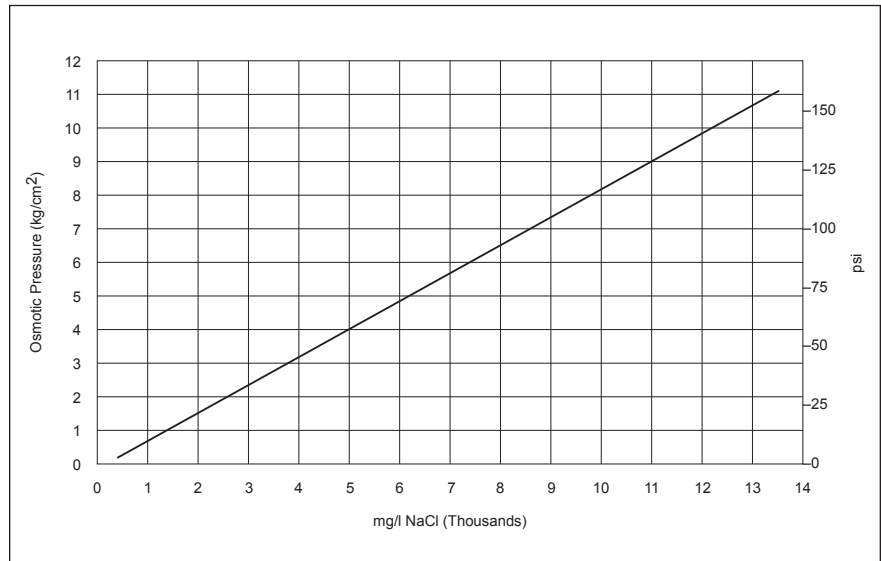
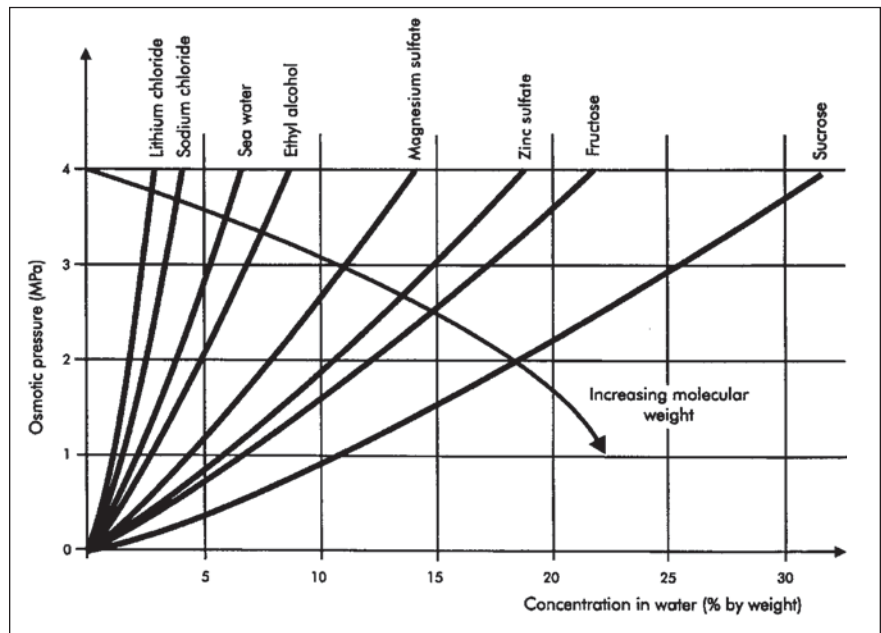


Figure 20. Osmotic Pressure of Solutions



**18. Tank Capacities, Vertical Cylindrical, in U.S. and Metric Units**

Table 27 shows tank capacities, vertical cylindrical, in U.S. and metric units.

**Table 27. Tank Capacities, Vertical Cylindrical, in U.S. and Metric Units**

Diameter in ft	Cubic feet per foot depth or Area in ft <sup>2</sup>	U.S. gal. per foot of depth	Diameter in m	m <sup>3</sup> per m depth or Area in m <sup>2</sup>
1'0"	0.79	5.87	0.3	0.07
1'1"	0.92	6.89	0.4	0.13
1'2"	1.07	8.00	0.5	0.2
1'3"	1.23	9.18	0.6	0.28
1'4"	1.40	10.44	0.7	0.39
1'5"	1.58	11.79	0.8	0.50
1'6"	1.77	13.22	0.9	0.64
1'7"	1.97	14.73	1.0	0.79
1'8"	2.18	16.32	1.1	0.95
1'9"	2.41	17.99	1.2	1.13
1'10"	2.64	19.75	1.3	1.33
1'11"	2.89	21.58	1.4	1.54
2'0"	3.14	23.50	1.5	1.77
2'6"	4.91	36.72	1.6	2.01
3'0"	7.07	52.88	1.7	2.27
3'6"	9.62	71.97	1.8	2.54
4'0"	12.57	94.0	1.9	2.84
4'6"	15.90	119.0	2.0	3.14
5'0"	19.63	146.9	2.1	3.46
5'6"	23.76	177.7	2.2	3.80
6'0"	28.27	211.5	2.3	4.16
6'6"	33.18	248.2	2.4	4.52
7'0"	38.48	287.9	2.5	4.91
7'6"	44.18	330.5	2.6	5.31
8'0"	50.27	376.0	2.7	5.73
8'6"	56.75	424.5	2.8	6.16
9'0"	63.62	475.9	2.9	6.61
9'6"	70.88	530.2	3.0	7.07
10'0"	78.54	587.5	3.2	8.04
10'6"	86.59	647.7	3.4	9.08
11'0"	95.03	710.9	3.6	10.2
11'6"	103.9	777.0	3.8	11.3
12'0"	113.1	846.0	4.0	12.6
12'6"	122.7	918.0	4.2	13.9
13'0"	132.7	992.9	4.4	15.2
13'6"	143.1	1071	4.6	16.6
14'0"	153.9	1152	4.8	18.1
14'6"	165.1	1235	5.0	19.6
15'0"	176.7	1322	5.2	21.2



## **Dow Liquid Separations Offices.**

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### **Internet**

<http://www.dowex.com>

† Toll-free telephone number for the following countries: Austria, Belgium, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom

**Warning:** Oxidizing agents such as nitric acid attack organic ion exchange resins under certain conditions. This could lead to anything from slight resin degradation to a violent exothermic reaction (explosion). Before using strong oxidizing agents, consult sources knowledgeable in handling such materials.

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Form No. 177-01831-802XQRP



# FILMTEC Membranes

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## Loading Procedures for FILMTEC Elements

This bulletin provides guidelines for loading or unloading FILMTEC™ reverse osmosis (RO) and nanofiltration (NF) elements. You should also use a drawing supplied by the manufacturer of your pressure vessels as a reference when assembling or disassembling the end cap assemblies.

### Loading RO or NF Elements

1. Remove all end cap assemblies and thrust rings (if provided) from all pressure vessels in the train or system.

*Note:* There are several manufacturers of pressure vessels used for spiral wound nanofiltration and reverse osmosis elements. Refer to the manufacturer's drawing for your pressure vessel during disassembling and assembling of end cap assembly.

2. Spray clean water through the open pressure vessels to remove any dust or debris present in the vessels.

*Note:* If additional cleaning is required, create a swab large enough to fill the inside diameter of the pressure vessel. Soak the swab in a glycerin/water solution (50 percent by volume) and move it back and forth through the pressure vessel until the vessel is clean and lubricated.

3. Place the leading end of the first RO or NF element into the feedwater end of the first pressure vessel and slide it in approximately one-half of the element length.

*Note:* Always load NF or RO elements into the feedwater end of the pressure vessel.

4. Verify that a chevron seal (i.e., brine seal) is properly seated in the end cap groove of the element, in such a way that the brine seal opens in the upstream direction. Then install the interconnector into the permeate tube of the element. Prior to installation of the interconnector, lubricate the o-ring seals on the interconnector with a very thin layer of silicon-base o-ring lubricant.

*Note:* Dow Corning 111 may be used as a substitute. FilmTec Corporation recommends using glycerin as the primary lubricant for interconnector and adapter o-rings. This product has been FDA listed.

5. Lift the next NF or RO element into position and install the leading end on the interconnector. Be very careful to hold the next element so that the weight is not supported by the interconnector, and push the element into the pressure vessel until about one-half of the element extends outside the vessel.
6. Repeat steps 4 and 5 until all elements are loaded into the pressure vessels. The number of elements loaded into an individual vessel will depend on the length of the elements and of the pressure vessel.
7. Install the thrust ring in the concentrate discharge end of the pressure vessel. Consult the manufacturer's drawing for specific information on thrust ring positioning.

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## FILMTEC Membranes

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call the Dow Liquid Separations business:  
North America . . . . . 1-800-447-4369  
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Japan . . . . . (+81) 3-5460-2100  
Australia . . . . . (+61) 2-9776-3226  
<http://www.filmtec.com>

8. Install end cap assemblies on each end of the pressure vessel, as follows:

- a) Carefully position the downstream end cap assembly in the pressure vessel and push the end cap assembly as a unit squarely into the end of the element. Use care when seating the o-ring seal on the adapter into the element and avoid pinching or rolling o-rings.
- b) Rotate the end cap assembly to ensure proper alignment with the connecting piping.
- c) Replace the hardware sealing the end cap assembly in place. Refer to the pressure vessel manufacturer's drawing.
- d) Push the NF or RO element stack from the feed (upstream) end towards the downstream side.
- e) Before closing the feed end of the pressure vessel, it may be advisable to shim the vessel to take up any free space between elements and the end cap assembly. This procedure helps to prevent movement and hammering of elements when the system starts and shuts down. Please refer to instructions on Shimming for additional detail.
- f) Repeat steps a) through e) for each pressure vessel in the train or system.

9. Replace any piping that was removed in order to load elements to the same location from which they were removed.

### NF or RO Element Removal

Two operators are recommended when removing NF or RO elements from a train or system. Remove the element from each pressure vessel as follows:

1. Disconnect the hard plumbing at each end of the pressure vessel. Refer to the vessel manufacturer's drawing as required. Mark or tag all removed items for return to the same location.
2. Remove the end cap assemblies from each end of the pressure vessel.
3. Push the NF or RO elements from the pressure vessel in the same direction as feedwater flows. Push the elements out one at a time. Support each element as it is being pushed out of the vessel until the element is free of the pressure vessel.

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## Reverse Osmosis Operating Log (Example)

<b>Operator</b>
Train #

		Design	Shift 1	Shift 2	Shift 3
	Date				
	Time				
	Operating hours				
Pressure (psig)	Feed Stage 1				
	Feed Stage 2				
	Permeate Stage 1				
	Permeate Stage 2				
Δ p (psid)	Cartridge				
	Stage 1				
	Stage 2				
Flow (gpm)	Feed				
	Permeate Stage 1				
	Permeate Stage 2				
	Concentrate				
	Recovery (%)				
Conductivity (mS/m)	Feed				
	Permeate Stage 1				
	Permeate Stage 2				
	Concentrate Stage 1				
	Combined Permeate				
	Concentrate Stage 2				
pH	Raw Water				
	Feed				
	Concentrate				
	Permeate				
Feed	Cl <sub>2</sub> (mg/l)				
	SDI				
	Turbidity (NTU)				
	Temperature (°C)				
Acid	Level				
	Refill (l)				
	Consumption (g/m <sup>3</sup> )				
Inhibitor	Level				
	Refill (l)				
	Consumption (g/m <sup>3</sup> )				
Normalised	Permeate flow (gpm) Stage 1				
	Permeate flow (gpm) Stage 2				
	Salt Passage (%)				
Remarks					

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The technical information contained here is extracted from the **FILMTEC Membranes - Technical Manual**. References to other sections of the manual have been replaced with short references to additional but separate information available from our web site. The information in these extracts has been updated and supercedes that contained in the full manual.

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## Important Information

Proper start up of reverse osmosis water treatment systems is essential to prepare the membranes for operating service and to prevent membrane damage due to overfeeding or hydraulic shock.

Following the proper start up sequence also helps ensure that system operating parameters conform to design specifications so that system water quality and productivity goals can be achieved.

Before initiating system start up procedures, membrane pretreatment, loading of the membrane elements, instrument calibration and other system checks should be completed.

Please refer to the application information literature entitled "How to

Start Up an RO Membrane System" (Form No. 609-00070) for more information.

## Operation Guidelines

Avoid any abrupt pressure or cross-flow variations on the spiral elements during start-up, shutdown, cleaning or other sequences to prevent possible membrane damage. During start-up, a gradual change from a standstill to operating state is recommended as follows:

- Feed pressure should be increased gradually over a 30-60 second time frame.
- Cross-flow velocity at set operating point should be achieved gradually over 15-20 seconds.
- Permeate obtained from first hour of operation should be discarded.

## General Information

- Keep elements moist at all times after initial wetting.
- If operating limits and guidelines given in this bulletin are not strictly followed, the limited warranty will be null and void.
- To prevent biological growth during system shutdowns, it is recommended that membrane elements be immersed in a preservative solution.
- The customer is fully responsible for the effects of incompatible chemicals and lubricants on elements.
- Maximum pressure drop across an entire pressure vessel (housing) is 50 psi (3.4 bar).
- Avoid permeate-side backpressure at all times.

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# FILMTEC Membranes

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## Control of Microbiological Activity

Biofouling is one of the most common and most severe problems in the operation of RO systems. Especially for plants using surface water or bacteriologically contaminated water as feed source, it is of paramount importance to control the microbiological activity. A properly designed and operated pretreatment is a prerequisite (see separate information on Biological Fouling Prevention).

A complete procedure for sampling and analysis should be part of the operating discipline, so that any increase of the microbiological activity can be responded to at an early stage. The methods to assess the biological fouling potential are described in Biological Fouling Prevention.

The sampling of microbiological activity can be done using presterilized sampling containers, or coupons, such as Millipore or Robbin biofilm samplers or other dynamic simulations of microbiological activity and its distribution in the real system.

If the lab equipment needed for analysis of the microbiological samples is not available at the RO-plant site, an adequate lab should be found to perform the needed analysis.

If the analysis cannot be done at the site, the samples should be put in the refrigerator and the analysis performed within 8 hours of sampling.

### Sampling Points

Adequate sampling points should be provided to make a microbiological balance and control in the plant possible. The minimum number of sampling points required are listed below:

1. Intake (surface) or well, before chlorination if any.
2. After a clarifier, settling pond, sludge contact unit or similar sedimentation process.
3. After filtration units (sand, multimedia, activated carbon or other).
4. After dechlorination (normally after cartridge filtration).
5. Concentrate stream.
6. Permeate stream.

The frequency of sampling and analysis depends on the risk of biofouling. For surface water plants, a daily check of the feed water (point 4) and a weekly check of all points is recommended.

### System Checking

Before start-up and whenever problems related to microbiological activity are suspected, the following checks should be carried out:

- In case intermediate open basins or tanks are used, provisions should be made to ensure proper disinfection at that open source and the part of the system downstream from it.
- If intermediate sealed tanks are used, their air breathing or ventilation systems should be equipped with bacteria retaining devices (e.g. HEMA filters).
- Blind long pieces of piping should be avoided by design, and when unavoidable, should be periodically disinfected.

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- Stand-by devices with large surfaces, like sand or cartridge filters should be avoided. If they are not avoidable, drains should be installed to discharge the disinfection chemicals after the devices have been disinfected, and before connecting them to the active system.

The periodic disinfection of the pretreatment system should be done according to the biological loading of the raw water, the efficiency of the continuous breakpoint chlorination, and the specific characteristics of each individual plant design.

In this sense, it is also recommended that the backwash of the media filters be done with sufficiently chlorinated water.

In general terms, the water used for disinfection, flushing and to prepare cleaning solutions should be of good quality and free of biological life.

- The components of the pretreatment system such as pipes, manifolds, filters and retention tanks should be opaque to sunlight to avoid enhancing the biological growth.
- All piping, tanks, manifolds as well as the retention tanks, filters etc.; i.e. the whole pretreatment system shall be disinfected previous to each start-up, following shutdown times as well as periodically when the RO plant is being operated continuously. A good way to do it is by dynamic breakpoint chlorination of the system with the exception of the RO section. In this case RO section and in particular the FT30 membranes shall be protected from chlorine. The best way to protect them, is to physically isolate the RO section from the rest by using a flange. For these cases, a drain should be installed at a low point close to the flange.
- Adequate chemicals for storage, cleaning and disinfection should always be available at the RO plant site.

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Published August 2000.





# FILMTEC Membranes

## Adjustment of Operation Parameters

### Introduction

An RO membrane system is designed on the basis of a defined set of data such as the permeate flow, feedwater composition and temperature. In reality, the plant operation has to be flexible to respond to changing needs or changing conditions.

### Brackish Water

The normal way of operating brackish water RO plants is to keep the flows and thus the recovery constant at the design values. Any change in the membrane flux, e.g. by temperature or fouling, are compensated by adjusting the feed pressure. However, the maximum specified feed pressure must not be exceeded, nor should too much fouling be tolerated (See separate information on Cleaning Elements).

If the feedwater analysis changes such that the scaling potential increases, the system recovery has to be decreased, or other measures have to be taken to cope with the new situation. Please refer to separate information on Water Chemistry and Pretreatment.

The most common situation is that the permeate capacity of the plant has to be adjusted to the needs. Normally, the capacity is designed to meet the peak needs. Operating with overcapacity is generally not recommended. Thus, adjustment means lowering the design permeate output. The easiest way is to shut the plant down when no permeate is needed. A high start/stop frequency, however, can lower the performance and the lifetime of the membranes. A permeate buffer tank may be used to allow a more constant operation.

Reducing the feed pressure is another way to reduce the permeate flow. Preferably, this is done by using a speed controlled pump in order to save energy. Normally, the system recovery is kept constant when the permeate flow is reduced. It has to be ensured by a system analysis using the computer program, that single element recoveries do not exceed their limits. During low flow operation, the system salt rejection is lower than during design flow operation. Also, you must be certain that minimum concentrate flows are maintained during low flow operation.

The net permeate flow can also be reduced by recycling the excess permeate back to the feedwater. This allows to keep the hydraulic and pressure conditions for the membranes about constant. The permeate quality is improved during this operation, and the recycled permeate has a cleaning effect on the membranes.

### Sea Water

In principle, the operation parameters of sea water plants are adjusted the same way as in brackish water applications. However, the maximum allowed feed pressure of 6.9 MPa (1000 PSI) and the permeate TDS are often the limiting factors.

Decreasing feedwater temperature can be compensated by increasing the feed pressure up to the maximum. Once the maximum pressure is reached, a further decreasing temperature causes the permeate flow to decrease. Increasing

temperature is compensated by lowering the feed pressure. This is only possible, however, as far as the tolerated permeate TDS is not exceeded. Alternatively, increasing temperature can be compensated by taking a number of pressure vessels out of service. By reducing the active membrane area, the feed pressure and the permeate TDS are kept about constant. A system analysis has to be run to make sure that maximum element permeate flows are not exceeded. When some vessels are taken out of service, they have to be properly isolated and preserved.

An increase in the feedwater salinity can be compensated by increasing the feed pressure up to the maximum. If further pressure increase is not possible, than a lowered permeate flow and system recovery has to be accepted. A lower feedwater salinity allows to decrease the feed pressure and/or to increase the system recovery and/or to increase the permeate flow.

The adjustment of the permeate capacity to reduced needs is normally accomplished by sufficiently dimensional permeate tanks.

Big plants are split up into a number of identical trains. Then the number of trains in service can be adjusted to the needs.

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## FILMTEC Membranes

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# FILMTEC Membranes

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## Prevention of Organic Fouling by Organics

Adsorption of organic substances on the membrane surface causes flux loss, which is irreversible in serious cases. The adsorption process is favored with high molecular mass compounds when these are hydrophobic or positively charged. A high pH value helps to prevent fouling, because both the membrane and many organic substances assume a negative charge at  $\text{pH} > 9$ . Organics present as an emulsion may form an organic film on the membrane surface, and must therefore be removed in the pretreatment.

Organics occurring in natural waters are usually humic substances in concentrations between 0.5 and 20 mg/l TOC. Pretreatment should be considered when TOC exceeds 3 mg/l. Humic substances can be removed by a coagulation process with hydroxide flocs, by ultrafiltration, or adsorption on activated carbon. See separate information on Colloidal Fouling Prevention.

Coagulation or activated carbon must also be applied when oils (hydrocarbons or silicone-based) and greases are contaminating the RO feed water at levels above 0.1 mg/l. These substances are readily adsorbed onto the membrane surface. They can be cleaned, however, with alkaline cleaning agents if the flux has not declined by more than 15%.

In waste water applications, the rejection and concentration of organics is a major objective. Depending on the kind of substances, organics even in the percent concentration range can be handled. This has to be evaluated in field tests on a case-by-case basis. See separate information estimating the rejection characteristics of organic and other compounds.

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# FILMTEC Membranes

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## Biological Fouling Prevention

### Introduction

All raw waters contain microorganisms: bacteria, algae, fungi, viruses and higher organisms. The typical size of bacteria is 1 to 3  $\mu\text{m}$ . Microorganisms can be regarded as colloidal matter and removed by the pretreatment as discussed in separate information on Colloidal Fouling Prevention. The difference from dead particles however, is their ability to reproduce and form a biofilm under favorable living conditions.

Microorganisms entering an RO system find a large membrane surface where the dissolved organic nutrients of the water are concentrated (due to concentration polarization): an ideal environment for the formation of a biofilm. Biological fouling of the membranes may seriously affect the performance of the RO system. The symptoms are an increase of the differential pressure from feed to concentrate, finally leading to telescoping and mechanical damage of the membrane elements and a membrane flux decline. Sometimes biofouling develops even on the permeate side, thus contaminating the product water.

A biofilm is difficult to remove, because it protects its microorganisms against the action of shear forces and disinfection chemicals. In addition, incompletely removed biofilms lead to a rapid regrowth.

Biological fouling prevention is therefore a major objective of the pretreatment process. The potential for biological fouling is higher with surface water than with well water. The assessment of this potential and the possible measures against biofouling are discussed in the following sections.

### Assessment of Biological Fouling Potential

#### Culture Techniques

The concentration of bacteria in water is directly related to the water's biological fouling potential. The Total Bacteria Count (TBC) is a quantitative expression of the total number of viable microorganisms in a water sample. It is determined according to ASTM F60 by filtering a measured quantity of water through a membrane filter. Subsequently, the organisms thus retained on the filter surface are cultured on the proper nutrient medium to develop colonies, which are then observed and counted at low power magnification.

The main advantage of this method is that it can be easily performed without expensive equipment. The test results however, are only available after up to seven days, and the counted colonies may represent as little as 1-10 % of the actual number of living microorganisms. Nevertheless, culture techniques are still valuable as indicators of the level and the trend of the biological fouling potential. They can be applied to monitor the water quality from the intake through the subsequent treatment steps up to the concentrate stream and the permeate. An increase of the TBC in the concentrate stream is an indication of a biofilm development on the membranes.

#### Direct Bacteria Count

Direct count techniques employ filtration of the water sample and counting the retained microorganisms on the filter plate directly under a microscope. To make the microorganisms visible, they are stained with acridine orange and viewed with an epi-illuminated fluorescent microscope.

Thus an accurate count of total microorganisms is obtained immediately. The types of microorganisms can be assessed and differentiated from debris particles. Living and dead cells, however, cannot be differentiated. This can be accomplished by the INT technique, where the INT stain is reduced and accumulated only by living cells. Those can be readily distinguished from dead cells with phase microscopy.

Direct count methods should be preferred, because they are much faster and more accurate than culture techniques.

#### Biofilm Monitoring

The concentrations of microorganisms in raw water, in the feed stream and in the concentrate stream are important numbers to assess the biological fouling potential. However, other factors like the concentration and the kind of nutrients, and operating parameters can also determine the development of a biofilm. The formation of biofilms is being studied by several researchers, but not yet fully understood. The best method to detect

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biofouling in its early stage is to observe a test surface in the feed stream. The “Robbin sampler” is a simple device to expose small test surfaces to a water stream (details: see). These surface samples can be removed and examined for attached bacteria on a regular basis. A careful and periodic inspection of the cartridge filters and the interior of the feed and brine piping is also helpful. The presence of slime or odor is an indication for biofouling.

### Other Methods

The bacterial growth potential of a given water sample can be assessed with the Werner method. The sample is filter-sterilized, and an inorganic sterile nutrient salt solution is then added. Then, the sample is inoculated with a specific volume of a suspension of bacteria washed from the sterilizing filter. The growth rate of the bacteria can be quantified from a turbidity increase as measured by forward light scattering. Other techniques measure the assimilable organic carbon or the biodegradable organic carbon.

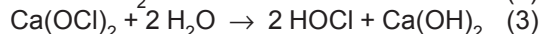
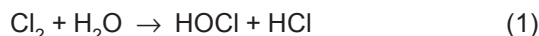
### Chlorination

Chlorine ( $\text{Cl}_2$ ) has been used for many years to treat municipal and industrial water and wastewaters as a disinfectant, because of its capacity to inactivate most pathogenic microorganisms quickly. The effectiveness of chlorine is dependent on the chlorine concentration, time of exposure and the pH of the water. Chlorine is used for the disinfection of potable water where a residual chlorine concentration near 0.5 mg/l is commonly used. In an industrial water treatment scheme, fouling of water intake lines, heat exchangers, sand filters, etc., may be prevented by maintaining a free residual chlorine concentration of 0.5-1.0 mg/l or higher, dependent on the organic content of the incoming water.

Chlorination as RO pretreatment is usually applied where biological fouling prevention is required, i.e. typically for surface waters. Chlorine is added at the intake, and a reaction time of 20-30 min. should be allowed. A free residual chlorine concentration of 0.5-1.0 mg/l should be maintained through the whole pretreatment line. Dechlorination upstream of the membranes is required however, to protect the membranes from oxidation (See subsequent section on Dechlorination).

### Chlorination chemistry

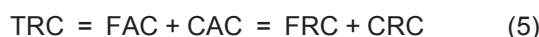
Chlorine is most commonly available as chlorine gas and the hypochlorites of sodium and calcium. In water, they hydrolyze instantaneously to hypochlorous acid:



Hypochlorous acid dissociates in water to hydrogen ions and hypochlorite ions:



The sum of  $\text{Cl}_2$ ,  $\text{NaOCl}$ ,  $\text{Ca(OCl)}_2$ ,  $\text{HOCl}$  and  $\text{OCl}^-$  is referred to as free available chlorine (FAC) or free residual chlorine (FRC), given as mg/l  $\text{Cl}_2$ . As discussed later, chloramines are formed from the reaction of chlorine with ammonia compounds present in the water. These chlorine-ammonia compounds are referred to as combined available chlorine (CAC) or combined residual chlorine (CRC). The sum of free and combined available/residual chlorine is called the total residual chlorine (TRC).



The germicidal efficiency of free residual chlorine is directly related to the concentration of undissociated  $\text{HOCl}$ . Hypochlorous acid is 100 times more effective than the hypochlorite ion  $\text{OCl}^-$ . The fraction of undissociated  $\text{HOCl}$  increases with decreasing pH.

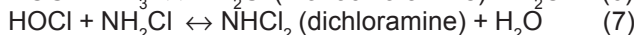
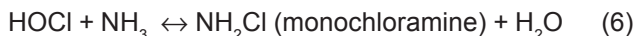
At pH = 7.5 (25°C, TDS = 40 mg/l), only 50% of free residual chlorine is present as  $\text{HOCl}$ , but 90% at pH = 6.5. The fraction of  $\text{HOCl}$  also increases with decreasing temperature. At 5°C, the  $\text{HOCl}$  mole fraction is 62% (pH = 7.5, TDS = 40 mg/l). In high salinity waters, less  $\text{HOCl}$  is present (30% at pH 7.5, 25°C, 40,000 mg/l TDS).

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### Chlorine demand

A part of the chlorine dosage reacts with ammonia nitrogen to combined available chlorine in a series of stepwise reactions:

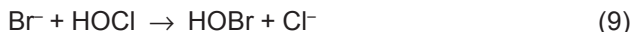


These reactions are governed primarily by pH and chlorine-to-nitrogen weight ratio. Chloramine also has a germicidal effect, albeit lower than that of chlorine. Another part of the chlorine is converted to nonavailable chlorine. This chlorine demand is caused by the reaction with reducing agents such as nitrite, cyanide, sulfide, ferrous iron and manganese. Chlorine is also consumed by the oxidation of organic compounds present in the water.

To determine the optimum chlorine dosage, best point of injection, pH and contact time to prevent biofouling, the ASTM method D 1291, "Standard Practice for Determining Chlorine Requirement of Water", should be applied on a representative water sample. For further details, the Handbook of Chlorination is recommended.

### Sea water

The major difference of sea water chlorination chemistry in contrast to brackish water is the presence of bromide in sea water in concentrations of typically 65 mg/l. Bromide reacts rapidly with hypochlorous acid to hypobromous acid:



Thus, in chlorinated sea water the biocide is predominantly HOBr rather than HOCl. Hypobromous acid then dissociates to hypobromite ions as follows:



HOBr dissociation is less than HOCl dissociation. At pH 8, where only 28% of HOCl is undissociated, about 83% of HOBr is undissociated. In other words, effective disinfection can be performed at a higher pH than in brackish water, where no bromide is present. Both hypobromous acid and hypobromite ions interfere with free residual chlorine measurements and are included in the free residual chlorine value.

The reactions of HOBr with other compounds of the water are analogous to the reactions of HOCl. Bromamines and brominated compounds are the reaction products.

### Dechlorination

When FILMTEC FT30 membrane is used in the reverse osmosis process, the RO feed must be dechlorinated to prevent oxidation of the membrane. FT30 membrane has some chlorine tolerance before noticeable loss of salt rejection is observed. Eventual degradation may occur after approximately 200-1,000 hours of exposure to one mg/l of free chlorine (200-1,000 ppm-h tolerance). The rate of chlorine attack depends on various feedwater characteristics. Under alkaline pH conditions, chlorine attack is faster than at neutral or acidic pH. An acidic pH is anyhow preferred for a better biocidal effect during chlorination. Chlorine attack is also faster at higher concentrations of heavy metals (e.g. iron), which catalyze membrane degradation, and at higher temperatures.

By comparison, some other polyamide RO membranes have essentially zero chlorine tolerance. The superior chlorine tolerance of the FT30 membrane can be attributed to the thicker barrier layer (about 2,000 Angstrom) and the fact that the polyamide is crosslinked. If dechlorination upsets occur in a FT30 RO system, and if corrected in a timely manner, membrane damage can be minimized.

For chloramine the tolerance of the FT30 membrane is 300,000 ppm-h, which implies that dechlorination is not required. However, since chloramines are formed by adding ammonia to chlorine, it is possible that free chlorine will be present. Since this free chlorine can be damaging to the membrane, dechlorination should still be considered.

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Residual free chlorine can be reduced to harmless chlorides by activated carbon or chemical reducing agents. An **activated carbon** bed is very effective in dechlorination of RO feed water according to following reaction:



**Sodium Metabisulfite** (SMBS) is most common for removal of free chlorine and as a biostatic. Other chemical reducing agents exist, e.g. sulfur dioxide, but have not yet been proven cost-competitive with SMBS.

When dissolved in water, sodium bisulfite (SBS) is formed from SMBS:



SBS is then reducing hypochlorous acid according to:



In theory, 1.34 mg of sodium metabisulfite will remove 1.0 mg of free chlorine. In practice however, 3.0 mg of sodium metabisulfite is normally used to remove 1.0 mg of chlorine.

Solid sodium metabisulfite has a usual shelf life of 4-6 months under cool, dry storage conditions. However, in aqueous solutions, sodium bisulfite can oxidize readily when exposed to air. A typical solution life can vary with concentration as follows:

Solution (wt.%)	Life (Maximum)
2	3 days
10	1 week
20	1 month
30	6 months

The SMBS should be of food grade quality and free of impurities. SMBS should not be cobalt-activated. Although the dechlorination itself is rapid, good mixing is required to ensure completion; static mixers are recommended. The injection point is preferably downstream of the cartridge filters in order to have these protected by chlorine. In this case, the SMBS solution should be filtered through a separate cartridge before being injected into the RO feed. Dechlorinated water must not be stored in tanks.

The absence of chlorine should be monitored using an oxidation-reduction potential (ORP) electrode downstream of the mixing line. The electrode signal shuts down the high pressure pump when chlorine is detected.

### Shock Treatment

Shock treatment is the addition of a biocide into the feed stream during normal plant operation for a limited time period. Sodium bisulfite is the most commonly used biocide for this purpose. In a typical application, 500-1,000 mg/l  $\text{NaHSO}_3$  are dosed for 30 minutes.

The sodium metabisulfite should be food grade, free of impurities and not cobalt-activated. The treatment can be carried out on a periodic basis, e.g. every 24 hours, or only when biogrowth is suspected. The efficiency of such treatment should be studied. The permeate produced during dosage will contain 1-4% of the bisulfite feed concentration. Depending on the permeate quality requirements, the permeate can be used or discarded during shock treatment. Bisulfite is more effective against aerobic bacteria than against an aerobic microorganisms. Therefore, the efficiency of the shock treatment should be carefully assessed using the techniques for assessing biological fouling potential preseiously describel.

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## Sanitization

Instead of continuously adding a biocide to the raw water, biofouling can be controlled by periodic sanitization of the system. This is usually practiced in medium risk applications. In high risk applications, sanitations may be an additional measure to a continuous biocide dosing.

Preventive sanitization are much more effective than corrective disinfections, because single attached bacteria are easier to kill and remove than a thick, aged biofilm.

Typical sanitization intervals are one per month, but they can be as short as one per day, depending on the feed water quality (e.g. waste water) or the permeate quality required (e.g. pharmaceutical grade water). The membrane life however, may be shortened by extensive sanitizations, depending on the type of chemical.

## Other Methods

**Microfiltration/Ultrafiltration** offers advantages in that it can remove microorganisms and especially algae, which are sometimes very difficult to remove by standard techniques. The MF/UF membranes should be made from a chlorine-resistant material to withstand periodic sanitization.

**Copper sulfate** can also be used to control the biogrowth. Typically, copper sulfate is fed continuously at 0.1 to 0.5 mg/l concentrations. The generalized use of copper sulfate is however, not recommended due to the following:

- Commercial  $\text{CuSO}_4$  may contain some impurities detrimental to the RO membranes.
- $\text{CuCO}_3$  and  $\text{Cu(OH)}_2$  tend to precipitate outside of a given pH range of operation, causing fouling to RO devices, and making  $\text{CuSO}_4$  ineffective.
- Copper ions can have negative effects on the environment.
- $\text{CuSO}_4$  only works properly against a limited range of microorganisms (e.g. some algae) but has only a marginal effect on most bacteria.
- Environmental protection standards of several countries limit the discharge amount of Cu salts, making it difficult to change dosage of this chemical if the biolife situation of a given plant requires it.

**Ozone** is an even stronger oxidizing agent than chlorine. However, it decomposes readily. A certain ozone level must be maintained to kill all microorganisms. The resistance of the materials of construction against ozone has to be considered. Usually, stainless steel is employed. De-ozonation must be performed carefully to protect the membranes. Ultraviolet irradiation has been used successfully for this purpose.

**Ultraviolet irradiation** at 254 nm is known to have a germicidal effect. Its application has come into use especially for small scale plants. No chemicals are added, and the equipment needs little attention other than periodic cleanings or replacement of the mercury vapor lamps. UV treatment is limited however, to relatively clean waters, because colloids and organic matter reduce the penetration of the radiation.

**Sodium bisulfite** concentrations in the range of up to 50 mg/l in the feed stream of sea water RO plants have proven effective to control biological fouling. Colloidal fouling has also been reduced by this method. As a side benefit, no acid is required for calcium carbonate control because of the acidic reaction of bisulfite:



**Granular activated carbon (GAC)** filtration as pretreatment method is known to be a risk of releasing bacteria which might cause biofouling of the membranes. The high inner surface of the carbon pores together with adsorbed organic nutrients promote biological activity in the filter. However, when such filters are operated at sufficiently low filter velocities (2-10 m/h) and with sufficiently high beds (2-3 m), all the biolife activity takes place in the upper region of the filter bed, and the filtered water is almost free of bacteria and nutrients. This technique is widely used in public water works, where the biological activity of the carbon filter is further enhanced by ozonation of the feed.

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The strategy of promoting biological growth in a restricted place where it is of no harm to the membranes, rather than trying to kill all microorganisms, might be a good approach to control biofouling of the membranes. However, there is little practical experience to date.

To prevent biological fouling of the membranes, the entire system from the raw water intake up to the membranes has to be kept clean and in a sanitary state. Please refer to separate information on Control of Microbiological Activity, for more details.

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# FILMTEC Membranes

## Commercial Design Guidelines for Midsize FILMTEC™ Elements

The following tables show the recommended guidelines for designing RO systems with 2.5 and 4-inch FILMTEC elements in Light Industrial and Small Commercial applications.

**Table 1. Design Guidelines for FILMTEC Elements in Light Industrial and Small Sea Water Applications**

Feed Source	RO Permeate	Well Water	Softened Municipal	Surface	Wastewater (Filtered Municipal Effluent)		Seawater	
					MF <sup>1</sup>	Conventional	Well or MF <sup>1</sup>	Open Intake
Feed Silt Density Index	SDI<1	SDI<3	SDI<3	SDI<5	SDI<3	SDI<5	SDI<3	SDI<5
Max. Element Recovery %	30	19	17	15	14 <sup>1</sup>	12	13	10
Typical Target Flux, gfd (l/m <sup>2</sup> h)	22 (37)	18 (30)	16 (27)	14 (24)	13 (22)	11 (19)	13 (22)	11 (19)
<b>Max. Permeate Flow Rate, gpd (m<sup>3</sup>/d)</b>								
2.5-inch Diameter	800 (3.0)	700 (2.6)	600 (2.3)	500 (1.9)	500 (1.9)	400 (1.5)	700 (2.6)	600 (2.3)
4.0-inch Diameter	2300 (8.7)	1900 (7.2)	1700 (6.4)	1500 (5.7)	1400 (5.3)	1200 (4.5)	1800 (6.8)	1500 (5.7)
<b>Element Type</b>								
	<b>Min. Concentrate Flow Rate, gpm (m<sup>3</sup>/h)</b>							
2.5-inch Diameter	1 (0.2)	1 (0.2)	1 (0.2)	1 (0.2)	1 (0.2)	1 (0.2)	1 (0.2)	1 (0.2)
4.0-inch Diameter (except Full-Fits)	4 (0.9)	4 (0.9)	4 (0.9)	4 (0.9)	5 (1.1)	6 (1.4)	4 (0.9)	5 (1.1)
Full-Fit 4040	6 (1.4)	6 (1.4)	6 (1.4)	6 (1.4)	7 (1.6)	8 (1.8)	NA	NA

Element Type	Active Area ft <sup>2</sup> (m <sup>2</sup> )	Max. Feed Flow Rate	Max. Pressure Drop	Maximum Feed Pressure
		U.S. gpm (m <sup>3</sup> /h)	Per Element psig (bar) <sup>2</sup>	psig (bar)
Tape-Wrapped 2540	28 (2.6)	6 (1.4)	13 (0.9)	600 (41)
Fiberglassed 2540	28 (2.6)	6 (1.4)	15 (1.0)	600 (41)
Seawater 2540	29 (2.7)	6 (1.4)	13 (0.9)	1000 (69)
Tape-Wrapped 4040	82 (7.6)	14 (3.2)	13 (0.9)	600 (41)
Fiberglassed 4040	82 (7.6)	16 (3.6)	15 (1.0)	600 (41)
SW Fiberglassed 4040	80 (7.4)	16 (3.6)	15 (1.0)	1000 (69)
Full-Fit 4040	85 (7.9)	18 (4.1)	15 (1.0)	600 (41)

<sup>1</sup> MF: Microfiltration - continuous filtration process using a membrane with pore size of <0.5 micron.

<sup>2</sup> We recommend that the pressure drop for new/clean elements be at least 20% below the maximum.

Note: The limiting values listed above have been incorporated into the ROSA (Reverse Osmosis System Analysis) software. Design of systems in excess of the guidelines results in a warning message on the ROSA printout.

Note: System designer must thoroughly review Product Selection Guide before applying above information. For ultrapure applications refer to UPW System Design Guidelines.

**Table 2. Design Guidelines for FILMTEC Elements in Small Commercial Applications**

Feed Source	RO Permeate	Softened Municipal	Well Water	Surface or Municipal Water
Feed Silt Density Index	SDI<1	SDI<3	SDI<3	SDI<5
Max. Element Recovery %	30	30	25	20
Typical Target Flux, gfd (l/m <sup>2</sup> h)	30 (51)	30 (51)	25 (42)	20 (34)
<b>Max. Permeate Flow Rate, gpd (m<sup>3</sup>/d)</b>				
2.5-inch Diameter	1100 (4.2)	1100 (4.2)	900 (3.4)	700 (2.7)
4.0-inch Diameter	3100 (11.7)	3100 (11.7)	2600 (9.8)	2100 (7.9)
<b>Min. Concentrate Flow Rate, U.S. gpm (m<sup>3</sup>/h)<sup>1</sup></b>				
2.5-inch Diameter	0.5 (0.11)	0.5 (0.11)	1 (0.2)	1 (0.2)
4.0-inch Diameter	2 (0.5)	2 (0.5)	4 (0.9)	4 (0.9)

Element Type	Active Area ft <sup>2</sup> (m <sup>2</sup> )	Max. Feed Flow Rate U.S. gpm (m <sup>3</sup> /h)	Max. Pressure Drop Per Element psig (bar) <sup>3</sup>	Maximum Feed Pressure psig (bar)
Tape-Wrapped 2540	28 (2.6)	6 (1.4)	13 (0.9)	600 (41)
Fiberglassed 2540	28 (2.6)	6 (1.4)	15 (1.0)	600 (41)
Seawater 2540	29 (2.7)	6 (1.4)	13 (0.9)	1000 (69)
Tape-Wrapped 4040	82 (7.6)	14 (3.2)	13 (0.9)	600 (41)
Fiberglassed 4040	82 (7.6)	16 (3.6)	15 (1.0)	600 (41)
SW Fiberglassed 4040	80 (7.4)	16 (3.6)	15 (1.0)	1000 (69)

<sup>3</sup>We recommend that the pressure drop for new/clean elements be at least 20% below the maximum.

Note: The limiting values listed above have been incorporated into the ROSA (Reverse Osmosis System Analysis) software. Design of systems in excess of the guidelines results in a warning message on the ROSA printout.

Note: System designer must thoroughly review Product Selection Guide before applying above information. For ultrapure applications refer to UPW System Design Guidelines.

The factor which has the greatest influence on the membrane system design is the fouling tendency of the feed water. Membrane fouling is caused by particles and colloidal material which are present in the feed water and are concentrated at the membrane surface. The concentration of the fouling materials at the membrane surface increases with increasing permeate flux (the permeate flow rate per unit membrane

area) and increasing FILMTEC element recovery (the ratio of permeate flow rate to feed flow rate for a single element). A system with high permeate flux rates is, therefore, likely to experience higher fouling rates and more frequent chemical cleaning. The Silt Density Index (SDI) value of the pretreated feed water correlates fairly well with the amount of fouling material present.

“Light Industrial” systems in Table 1 have the same requirements as for large systems, requiring stable performance over several years. They are typically for piloting large systems, with continuous operation, CIP facilities and none (or minimal) recirculation. The expected membrane lifetime is more than 3 years.

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In Table 2, the "Small Commercial" systems are typically between 1-6 elements that are either regularly replaced or else cleaned (every half year or year) or performance loss is acceptable. The expected element lifetime is not more than 3 years. This is a low-cost, compact solution for intermittently operated systems.

The proposed limits are recommended guidelines based on many years of experience with FILMTEC membranes. If the fouling tendency of the feed water has been underestimated in the system design, the membranes will require more frequent cleaning, or the capacity of the system will decrease due to fouling. On the other hand, a

conservative approach is to anticipate a higher fouling tendency and enjoy a troublefree system operation and an increased membrane lifetime.

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CH 172-286-E-102



# FILMTEC Membranes

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## Record Keeping

### Introduction

In order to be able to follow the performance of the RO unit, it is necessary that all relevant data are collected, recorded and kept on file. Apart from keeping track of the performance, the logsheets are also valuable tools for troubleshooting, and are needed in the cases of warranty claims.

These instructions are for general guidance only and must not be used in place of the operating manual for a particular plant. Site dependent factors prevent specific recommendations for all record keeping. Thus, only the more general record keeping is covered here.

### Start-Up Report

- Provide a complete description of the RO plant. This can be done using a flow diagram and equipment, instrumentation, and material list to show water source, pretreatment system, RO configuration and post-treatment system.
- Give results of checking according to check list (Startup checklist).
- Provide calibration curves of all gauges and meters based on manufacturers' recommendations.
- Record initial performance of RO and pretreatment system as provided below.

### RO Operating Data

The following data must be recorded and logged into an appropriate logsheet at least once per shift, unless otherwise stated (see Table 2 for an example).

- Date, time and hours of operation.
- Pressure drop per cartridge and per stage.
- Feed, permeate and concentrate pressure of each stage.
- Permeate and concentrate flows of each stage.
- Conductivity of the feed, permeate and concentrate streams for each stage. Permeate conductivity of each pressure vessel weekly.
- TDS of feed, permeate and concentrate streams for each stage. The TDS is calculated from the water analysis. It can also be calculated from the conductivity (at 25°C)  $EC_{25}$  and an appropriate K factor:

$$TDS = K EC_{25}$$

The K factor has to be determined for each specific stream. Typical K factors are shown in Table 2.

- pH of the feed, permeate and concentrate streams.
- Silt Density Index (SDI) or turbidity of the RO feed stream, or both.
- Water temperature of the feed stream.
- Langelier Saturation Index (LSI) of the concentrate stream from the last stage (for concentrate streams < 10,000 mg/l TDS).
- Stiff and Davis Stability Index (S&DSI) of the concentrate stream from the last stage (for concentrate streams > 10,000 mg/l).
- Calibration of all gauges and meters based on manufacturer's recommendations as to method and frequency but no less frequent than once every three months.

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## Reverse Osmosis Operating Log (Example)

<b>Operator</b>
Train #

		Design	Shift 1	Shift 2	Shift 3
	Date				
	Time				
	Operating hours				
Pressure (psig)	Feed Stage 1				
	Feed Stage 2				
	Permeate Stage 1				
	Permeate Stage 2				
	Concentrate				
Δ p (psid)	Cartridge				
	Stage 1				
	Stage 2				
Flow (gpm)	Feed				
	Permeate Stage 1				
	Permeate Stage 2				
	Concentrate				
	Recovery (%)				
Conductivity (mS/m)	Feed				
	Permeate Stage 1				
	Permeate Stage 2				
	Concentrate Stage 1				
	Combined Permeate				
	Concentrate Stage 2				
pH	Raw Water				
	Feed				
	Concentrate				
	Permeate				
Feed	Cl <sub>2</sub> (mg/l)				
	SDI				
	Turbidity (NTU)				
	Temperature (°C)				
Acid	Level				
	Refill (l)				
	Consumption (g/m <sup>3</sup> )				
Inhibitor	Level				
	Refill (l)				
	Consumption (g/m <sup>3</sup> )				
Normalised	Permeate flow (gpm) Stage 1				
	Permeate flow (gpm) Stage 2				
	Salt Passage (%)				
Remarks					



- 
- Any unusual incidents, for example, upsets in SDI, pH and pressure and shutdowns.
  - Complete water analysis of the feed, permeate and concentrate streams and the raw water at start-up and every week thereafter.

The water analysis shall include:

- Calcium
- Magnesium
- Sodium
- Potassium
- Strontium
- Barium
- Iron (total, dissolved and ferrous)
- Aluminium (total and dissolved)
- Bicarbonate
- Sulfate
- Chloride
- Nitrate
- Fluoride
- Phosphate (total)
- Silica (dissolved)
- Total dissolved solids
- Conductivity
- pH
- TOC

**Table 1: Factors for Estimating TDS from Conductivity**

Water	EC <sub>25</sub> <sup>1</sup> (mS/m)	K
Permeate	0.1-1	0.50
	30-80	0.55
Sea water	4,500-6,000	0.70
Concentrate	6,500-8,500	0.75

<sup>1</sup> EC<sub>25</sub> does not include the conductivity caused by dissolved CO<sub>2</sub>

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### Pretreatment Operating Data

Since the RO system performance depends largely on the proper operation of the pretreatment, the operating characteristics of the pretreatment equipment should be recorded. Specific recommendations for all record keeping cannot be given, because pretreatment is site dependent. Typically, the following items must be recorded:

- Total residual chlorine concentration in the RO feed (daily - unless known to be completely absent).
- Discharge pressure of any well or booster pumps (twice a day).
- Pressure drop of all filters (twice a day).
- Consumption of acid and any other chemicals (daily - if used).
- Calibration of all gauges and meters based on manufacturer's recommendations as to method and frequency but no less frequent than once every 3 months.
- Any unusual incidents, for example, upsets and shutdowns as they occur.

### Maintenance Log

- Record routine maintenance.
- Record mechanical failures and replacements.
- Record any change of membrane element locations with element serial numbers.
- Record replacements or additions of RO devices.
- Record calibration of all gauges and meters.
- Record replacement or additions of pretreatment equipment, for example cartridge filters and include date, brand name and nominal rating.
- Record all cleanings of RO membranes. Include date, duration of cleaning, cleaning agent(s) and concentration, solution pH, temperature during cleaning, flow rate and pressure (for cleaning procedures see separate information).

The technical information contained here is extracted from the **FILMTEC Membranes - Technical Manual**. References to other sections of the manual have been replaced with short references to additional but separate information available from our web site. The information in these extracts has been updated and supercedes that contained in the full manual.

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# FILMTEC Membranes

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## Standardizing Reverse Osmosis Performance Data

### Significance and Use

During the operation of an RO system, system conditions such as pressure, temperature, system recovery and feed concentration can vary, causing permeate flow and salt passage to change. To effectively evaluate system performance, it is necessary to compare permeate flow and salt passage data at the same conditions. Since data may not always be obtained at the same conditions, it is necessary to convert the RO data obtained at actual conditions to a set of selected conditions, thereby standardizing the data.

### How to use FTNORM

#### Introduction

FTNORM is a spreadsheet-based program designed to standardize the operating data from a reverse osmosis or nanofiltration system using FILMTEC™ membranes. This program is based on the use of Microsoft Excel and provides for automatic standardization of operating data. Charts are created showing standardized permeate flow, standardized salt passage/salt rejection and differential pressure ( $\Delta P$ ). You should use one spreadsheet for each train in the system.

#### Entering Data

1. From within Microsoft Excel, open the file containing the data standardization template, Data Normalization Template (System or One Stage). All of the cells requiring data entry contain red lettering. Blue lettering is used for calculated values. You can choose to enter the data in U.S. units or in metric units.
2. At the top of the spreadsheet, enter the "plant identification" and "start-up date" in the designated cells.
3. The operating data is entered beginning in row 11 with the date. You will overwrite the existing sample data, which is present. The equations performing the standardization calculations will allow approximately one year (365 days) of data entry. You will need to copy the equations for each column when additional operating data is entered.
4. When you have completed entering data, save the spreadsheet using a unique name associated with the train.

#### Graphing Data

The charts contained in the template are designed to show the first five data points in cells 11 through 15. As additional data is entered you must update the chart using the chart\source data portion of the menu. In this section, you will increase the maximum values for the X-axis and Y-axis to reflect the operating data entered. When you do so the chart will update to include the new data.

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# FILMTEC Membranes

## Scale Control

### Introduction

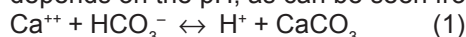
Scaling of a reverse osmosis membrane may occur when sparingly soluble salts are concentrated within the element beyond their solubility limit. For example, if a reverse osmosis plant is operated at 50% recovery, the concentration in the concentrate stream will be double the concentration in the feed stream. As the recovery of a plant is increased, so is the risk of scaling. Therefore, care must be taken not to exceed the solubility limits of slightly soluble salts, or precipitation and scaling may occur.

In a reverse osmosis system the most common sparingly soluble salts encountered are  $\text{CaSO}_4$ ,  $\text{CaCO}_3$  and silica. Other salts creating a potential scaling problem are  $\text{CaF}_2$ ,  $\text{BaSO}_4$  and  $\text{SrSO}_4$ . Solubility products of sparingly soluble inorganic compounds are listed in Table 1.

In order to prevent scaling of a reverse osmosis membrane the following design practices are possible.

### Acid Addition

Most natural surface and ground waters are almost saturated with respect to  $\text{CaCO}_3$ . The solubility of  $\text{CaCO}_3$  depends on the pH, as can be seen from the following equation:



Accordingly, by adding  $\text{H}^+$  as acid, the equilibrium can be shifted to the left side in order to keep calcium carbonate dissolved. The acid used should be of food grade quality.

**Table 1: Solubility Products of Sparingly Soluble Inorganic Compounds<sup>1</sup>**

Substance	Formula	Temp. °C	Solubility Product	Negative Log K
Aluminium Hydroxide	$\text{Al}(\text{OH})_3$	20	$1.9 \times 10^{-33}$	32.7
Barium Carbonate	$\text{BaCO}_3$	16	$7 \times 10^{-9}$	8.15
Barium Sulfate	$\text{BaSO}_4$	25	$1.08 \times 10^{-10}$	9.97
Calcium Carbonate	$\text{CaCO}_3$	25	$8.7 \times 10^{-9}$	8.06
Calcium Fluoride	$\text{CaF}_2$	26	$3.95 \times 10^{-11}$	10.61
Calcium Sulfate	$\text{CaSO}_4$	10	$6.1 \times 10^{-5}$	4.21
Cupric Sulfide	$\text{CuS}$	18	$8.5 \times 10^{-45}$	44.07
Ferric Hydroxide	$\text{Fe}(\text{OH})_3$	18	$1.1 \times 10^{-36}$	35.96
Ferrous Hydroxide	$\text{Fe}(\text{OH})_2$	18	$1.64 \times 10^{-14}$	13.78
Lead Carbonate	$\text{PbCO}_3$	18	$3.3 \times 10^{-14}$	13.48
Lead Fluoride	$\text{PbF}_2$	18	$3.2 \times 10^{-6}$	7.50
Lead Sulfate	$\text{PbSO}_4$	18	$1.06 \times 10^{-8}$	7.98
Magnesium Ammonium Phosphate	$\text{MgNH}_4\text{PO}_4$	25	$2.5 \times 10^{-13}$	12.6
Magnesium Carbonate	$\text{MgCO}_3$	12	$2.6 \times 10^{-5}$	4.58
Magnesium Hydroxide	$\text{Mg}(\text{OH})_2$	18	$1.2 \times 10^{-11}$	10.92
Manganese Hydroxide	$\text{Mn}(\text{OH})_2$	18	$4 \times 10^{-14}$	13.4
Nickel Sulfide	$\text{NiS}$	18	$1.4 \times 10^{-24}$	23.85
Strontium Carbonate	$\text{SrCO}_3$	25	$1.6 \times 10^{-9}$	8.80
Strontium Sulfate	$\text{SrSO}_4$	17.4	$2.81 \times 10^{-7}$	6.55
Zinc Hydroxide	$\text{Zn}(\text{OH})_2$	20	$1.8 \times 10^{-14}$	13.74

<sup>1</sup> At zero ionic strength

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Sulfuric acid is easier to handle and in many countries more readily available than hydrochloric acid, but on the other hand, additional sulfate is added to the feed stream. This might be critical with respect to sulfate scaling.

In order to avoid calcium carbonate scaling,  $\text{CaCO}_3$  should tend to dissolve in the concentrate stream rather than to precipitate. This tendency can be expressed by the Langelier Saturation Index (LSI) for brackish waters and the Stiff & Davis Stability Index (S&DSI) for sea waters. At the pH of saturation ( $\text{pH}_s$ ), the water is in equilibrium with  $\text{CaCO}_3$ . The definitions of LSI and S&DSI are:

$$\text{LSI} = \text{pH} - \text{pH}_s \quad (\text{TDS} < 10,000 \text{ mg/l}) \quad (2)$$

$$\text{S\&DSI} = \text{pH} - \text{pH}_s \quad (\text{TDS} > 10,000 \text{ mg/l}) \quad (3)$$

To control calcium carbonate scaling by acid addition alone, the LSI or S&DSI in the concentrate stream must be negative. If a high quality scale inhibitor is used, the LSI in the concentrate stream can be  $< 1.5$ . This will reduce or eliminate the acid consumption. Many inhibitors allow operation up to an LSI of  $< 1.8$  in the concentrate. Please refer to the inhibitor manufacturer's own literature for reference points.

### Scale Inhibitor Addition

Scale inhibitors (antiscalants) can be used to control carbonate scaling, sulfate scaling and calcium fluoride scaling. Scale inhibitors have a "threshold effect", which means that minor amounts adsorb specifically to the surface of microcrystals thereby preventing further growth and precipitation of the crystals.

The most widely used scale inhibitor is sodiumhexametaphosphate (SHMP). Food grade quality should be used. Care has to be taken in order to avoid hydrolysis of SHMP in the dosing feed tank. Hydrolysis would not only decrease the scale inhibition efficiency, but also create a calcium phosphate scaling risk. SHMP should be dosed to give a concentration in the concentrate stream of 20 mg/l. For example, the dosage into the feed stream of a system with 75% recovery will be 5 mg/l.

Polymeric organic scale inhibitors are more effective than SHMP. However, precipitation reactions may occur with cationic polyelectrolytes or multivalent cations, e.g. aluminium or iron. The resulting gumlike products are very difficult to remove from the membrane elements.

For dosage rates please contact the antiscalant manufacturers. Overdosing should be avoided. In RO plants operating on sea water with TDS in the range of 35,000 mg/l, scaling is not such a problem as in brackish water plants, because the recovery of sea water plants is limited by the osmotic pressure of the concentrate stream to 30-45%. However, for safety reasons we recommend using a scale inhibitor when operating above a recovery of 35%.

### Softening with a Strong Acid Cation Exchange Resin

The scale forming cations such as  $\text{Ca}^{++}$ ,  $\text{Ba}^{++}$ ,  $\text{Sr}^{++}$  are removed and replaced by sodium cations. The resin has to be regenerated with NaCl at hardness breakthrough. The pH of the feed water is not changed by this treatment. Therefore, no degassifier is needed. Only a little  $\text{CO}_2$  from the raw water is present that can pass into the permeate creating a conductivity increase there. One can even lower the permeate conductivity by adding some NaOH to the softened feed water (up to pH 8.2) in order to convert residual carbon dioxide into bicarbonate which is then rejected by the membrane. The rejection performance of the FT30 membrane is optimal at the neutral pH range.

With DOWEX\* ion exchange resins, the removal efficiency for  $\text{Ca}^{++}$ ,  $\text{Ba}^{++}$  and  $\text{Sr}^{++}$  is  $> 99.5\%$ , which usually eliminates any risk of carbonate or sulfate scaling. Softening with a strong acid cation exchange resin is very effective and safe, provided the regeneration is done properly. It is used mainly in small or medium size brackish water plants, but not in sea water plants.

A drawback of this process is its relatively high sodium chloride consumption, which might cause an environmental or an economic problem. With DOWEX\* MONOSPHERE\* ion exchange resins and a countercurrent regeneration technique, for example UPCORE\*, it is possible to minimize the sodium chloride consumption to 110% of the stoichiometrical value.

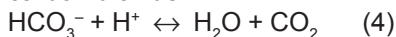
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### Dealkalization with a Weak Acid Cation Exchange Resin

Dealkalization with a weak acid cation exchange resin is used mainly in large brackish water plants for partial softening in order to minimize the consumption of regeneration chemicals.

In this process, only  $\text{Ca}^{++}$ ,  $\text{Ba}^{++}$  and  $\text{Sr}^{++}$  linked to bicarbonate (temporary hardness) are removed and replaced by  $\text{H}^+$ , thus lowering the pH to 4-5. As the acidic groups of the resin are carboxylic groups, the ion exchange process stops when the pH reaches a value of 4.2, where the carboxylic groups are no longer dissociated. Therefore, it is only a partial softening. Only those scale forming cations are removed which are bound to bicarbonate. Therefore, this process is ideal for waters with a high bicarbonate content. The bicarbonate is converted into carbon dioxide:



In most cases, carbon dioxide is not desired in the permeate. It can be removed by degassing either in the permeate or in the feed stream.

Degassing the permeate is favored where a potential for biofouling is suspected (surface waters, high TOC, high bacteria counts). A high  $\text{CO}_2$  concentration on the membranes helps to keep bacteria growth low. Degassing the feed is preferred when optimum salt rejection is the priority. Removing  $\text{CO}_2$  also leads to an increase in pH (see equation (4)), and at  $\text{pH} > 6$  the rejection is better than at  $\text{pH} < 5$ .

The **advantages** of dealkalizing with a weak acid cation exchange resin are:

- For regeneration, acid of not more than 105% of the stoichiometrical value is needed. This minimizes the operating costs and the environmental impact.
- The TDS value of the water is reduced by the removal of bicarbonate salts. Accordingly, the permeate TDS value is also lower.

The **disadvantages** are:

- Residual hardness.

If a complete softening is required, a sodium exchange process with a strong acid cation exchange resin can be added, even in one vessel. The overall consumption of regeneration chemicals is still lower than softening with a strong acid cation exchange resin alone. Due to the higher investment costs however, this combination will only be attractive for plants with high capacity.

Another possibility to overcome this drawback of incomplete softening is to dose an antiscalant into the dealkalized water. Although we have so far never encountered scaling problems with waters dealkalized by weak acid cation exchange alone, we strongly recommend to calculate the solubilities of the residual sparingly soluble salts and to take the respective measures.

- Variable pH of the treated water.

The pH of the dealkalized water ranges from 3.5 to 6.5 depending on the degree of exhaustion of the resin. This cyclic pH variation makes it difficult to control the salt rejection of the plant. At  $\text{pH} < 4.2$ , the passage of mineral acid may increase the permeate TDS. It is therefore recommended to use more than one filter in parallel and to regenerate them at different times in order to level out the pH. Other possibilities to avoid extremely low pH values are  $\text{CO}_2$  removal or pH adjustment by NaOH afterwards.

### Lime Softening

Lime softening can be used to remove carbonate hardness by adding hydrated lime:



The noncarbonate calcium hardness can be further reduced by adding sodium carbonate (soda ash):



The lime-soda ash process can also be used to reduce the silica concentration. When sodium aluminate and ferric chloride are added, the precipitate will include calcium carbonate and a complex with silicic acid, aluminium oxide and iron. With the hot lime silicic acid removal process at 60-70°C, silica can be reduced to 1 mg/l by adding a mixture of lime and porous magnesium oxide.

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With lime softening, barium, strontium and organic substances are also reduced significantly. The process requires a reactor with a high concentration of precipitated particles serving as crystallization nuclei. This is usually achieved by upflow solids-contact clarifiers. The effluent from this process needs media filtration and pH adjustment prior to the RO elements. Iron coagulants with or without poly-meric flocculants (anionic and non-ionic) may be used to improve the solid-liquid separation.

Lime softening should be considered for brackish water plants larger than 200 m<sup>3</sup>/h (880 gpm). More details are described in the literature.

### Preventative Cleaning

In some applications, scaling is controlled by preventive membrane cleaning. This allows the system to run without softening or dosage of chemicals. Typically, those systems operate at low recovery in the range of 25%, and the membrane elements are replaced after 1-2 years. Accordingly, those systems are mainly small single-element plants for potable water from tap water or sea water. The simplest way of cleaning is a forward flush at low pressure by opening the concentrate valve. Short cleaning intervals are more effective than long cleaning times, e.g. 30 seconds every 30 minutes.

Cleaning can also be carried out with cleaning chemicals. In batch processes like in waste water treatment it is common practice to clean the membranes after every batch.

The cleaning procedure, cleaning chemicals and the frequency of cleaning, has to be determined and optimized case by case. Special care has to be taken not to allow a scaling layer to develop in the course of time.

### Adjustment of Operating Variables

When other scale control methods do not work, the operating variables of the plant have to be adjusted in such a way that scaling will not occur. The precipitation of dissolved salts can be avoided by keeping their concentration below the solubility limit, that means by reducing the system recovery until the concentrate concentration is low enough.

Solubility depends also on temperature and pH. In the case of silica, increasing temperature and pH increases its solubility. Silica is usually the only reason for considering adjustment of operating variables as a scale control method, because these adjustments have economic drawbacks (energy consumption) or other scaling risks (CaCO<sub>3</sub> at high pH).

For small systems, a low recovery combined with a preventive cleaning program might be a convenient way to control scaling.

The technical information contained here is extracted from the **FILMTEC Membranes - Technical Manual**. References to other sections of the manual have been replaced with short references to additional but separate information available from our web site. The information in these extracts has been updated and supercedes that contained in the full manual.

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# FILMTEC Membranes

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## RO Systems Shutdown and Lay-up Considerations

A RO system is designed to be operated continuously. However, in reality RO systems will start-up and shutdown on some frequency. When the RO membrane system is shutdown, the system must be flushed with either permeate water or high quality feedwater, to remove the high salt concentration from the modules until concentrate conductivity matches feedwater conductivity. Flushing is done at low pressure (about 3 bar/40 PSI). A high feed flow rate is beneficial for a cleaning effect; however, a pressure drop of 1.0 bar (15 PSI) per element or 3.5 bar (50 PSI) per multi-element vessel must not be exceeded.

The water used for flushing shall contain no chemicals used for the pretreatment. Therefore, any chemical injection is stopped before flushing the system. After flushing the system, the feed valves are closed completely. If the concentrate line ends into a drain below the level of the pressure vessels, then an air break should be employed in the concentrate line at a position higher than the highest pressure vessel. Otherwise, the vessels might be emptied by a siphoning effect.

When the system must be shutdown for longer than 48 hours, take care that:

- The elements do not dry out. Dry elements will irreversibly lose flux.
- The system is adequately protected against micro-biological growth, or regular flushing is carried out every 24 hours.
- When applicable, the system is protected against temperature extremes.

The RO train can be stopped for 24 hours without preservation and precautions for microbiological fouling. If feedwater for flushing every 24 hours is not available, preservation with chemicals is necessary for longer stops than 48 hours.

Depending on the previous operational history of the plant, it will be necessary in almost all cases to perform a cleaning of the RO membranes prior to preservation. This is especially applicable when the membranes are known or assumed to be fouled. A typical sequence for the cleaning can be as follows:

Perform a soft alkaline cleaning at pH=11 for 2 hours, disinfect and perform a short acid cleaning. If the plant has been operated with a feedwater which is free of scalants and metal hydroxides, the acid cleaning can be omitted.

After cleaning and disinfection, the preservation should follow within the next 10 hours as follows:

1. Preservation of the plant using "total immersion" of elements into a solution of 1 to 1.5% of sodium bisulfite (SBS), venting the air outside of the pressure vessels. Use the overflow technique: circulate the SBS solution in such a way that the remaining air in the system is minimized after the recirculation is completed. The SBS solution shall be allowed to overflow through an opening located higher than the upper end of the highest pressure vessel being filled in order to ensure all of the air has been eliminated.
2. Separate the preservation solution from the air outside by closing all valves. Any contact with oxygen will oxidize the SBS.
3. Check the pH once a week. When the pH becomes 3 or lower, change the preservation solution.
4. Change the preservation solution at least once a month.

During the shutdown period, the plant must be kept frost-free, and the temperature must not exceed 45°C (113°F). A low temperature is desirable.

For additional information, please refer to the product information bulletin entitled *FT30 Reverse Osmosis Membrane Biological Protection and Disinfection*, Form No. 609-24010/172-120-E.

## FILMTEC Membranes

For more information about FILMTEC membranes,  
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# FILMTEC Membranes

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## Initial Start-Up

### Pre-Start-Up Checklist

- Corrosion resistant materials of construction are used for all equipment including piping and wetted parts of pumps
- All piping and equipment is compatible with designed pressure
- All piping and equipment is compatible with designed pH range (including cleaning)
- All piping and equipment is protected against galvanic corrosion
- Media filters are backwashed and rinsed
- New/clean cartridge filter is installed directly upstream of the high pressure pump
- Feed line, including RO feed manifold, is purged and flushed, before pressure vessels are connected
- Chemical addition points are properly located
- Check valves are properly installed in chemical addition lines
- Provisions exist for proper mixing of chemicals in the feed stream
- Provisions exist for preventing the RO system from operating when the dosage pumps are shut down
- Provisions exist for preventing the dosage pumps from operating when the RO system is shut down
- If chlorine is used, provisions exist to ensure complete chlorine removal prior to the membranes
- Planned instrumentation allows proper operation and monitoring of the pretreatment and RO system
- Planned instrumentation is installed
- Instrumentation is calibrated
- Pressure relief protection is installed and correctly set
- Provisions exist for preventing the product pressure from exceeding the feed/brine pressure more than 0.3 bar (5 PSI) at any time
- Interlocks, time delay relays and alarms are properly set
- Provisions exist for sampling permeate from individual modules
- Provisions exist for sampling feed, permeate and reject streams from each stage and the total plant permeate stream
- Pressure vessels are properly piped both for operation and cleaning mode
- Pressure vessels are secured to the rack or frame
- Precautions are taken as given in pressure vessel manufacturers information on Assembly and Loading of Pressure Vessels
- Membranes are protected from temperature extremes (freezing, direct sunlight, heater exhaust, etc.)
- Pumps are ready for operation (lubricated, proper rotation)
- Fittings are tight
- Permeate line is open
- Permeate flow is directed to drain
- Reject flow control valve is in open position
- Feed flow valve is throttled and/or pump bypass valve is partly open to limit feed flow to less than 50 % of operating feed flow

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The technical information contained here is extracted from the **FILMTEC Membranes - Technical Manual**. References to other sections of the manual have been replaced with short references to additional but separate information available from our web site. The information in these extracts has been updated and supercedes that contained in the full manual.

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# FILMTEC Membranes

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## System Design Suggestions for Troubleshooting Success

When considering the design and purchase of large membrane systems, there are a number of possible equipment designs and additions that can be added to help with future troubleshooting. Depending on the size and complexity of the system, some or all of these suggestions could be discussed with your system supplier. None are required for successful operation, but all make day-to-day operation and troubleshooting easier, quicker and more effective.

### Access to Load and Troubleshoot the System

Even though membrane systems are quite compact, there is often a temptation to save even more floor space by crowding equipment, pipelines and supports so close together as to limit access to the membrane system. Ideally, one should have unrestricted access to both the feed and brine end of each and every vessel for loading, unloading and troubleshooting of the membrane elements. When loading, at least the length of one element is necessary between the feed end of the vessels and the nearest equipment or supports. When unloading, often more room could be used so that a large wooden board or some other device can be used to push the element stack toward the brine end.

### Connections Allowing Probing, Profiling and Sampling

When troubleshooting potential element problems, one of the first operations is always to attempt to localize any problem, either to a stage, a vessel, or even an element. Having sample points on all the vessel permeates greatly facilitates these operations. Ideally, the permeate sample points can allow a probe tube to be passed through. Having additional sample points on the feed, the concentrate and any interstage headers, can help localize problems to a stage and even allow for mass balance measurements to corroborate flow measurements and ultimately setting of the system recovery.

### Instrumentation to Allow Performance Monitoring by Stage

Beyond simple sample points, the next step in system sophistication is to instrument the stages so that performance data can be gathered and normalized, showing day to day variation in the system performance against a reference condition such as startup. Adequate instrumentation means having conductivity or TDS measurements, pressure measurements, temperature measurements and flow measurements on the feed, concentrate and permeate of each stage. Given this data, performance of the stage can be monitored and early signs of trouble can be easily detected from the normalized data. Even though a mass balance around the system can be used to eliminate some of the instrumentation, having all the instrumentation means that the mass balance can be used to test the internal consistency of the data and thus monitor the performance of the instruments.

### Real-Time Online Normalization

In terms of system monitoring, online instruments feeding an ongoing and continuous normalization program is the ultimate. For very large systems, or for systems with highly variable feed conditions, real-time control may be warranted.

### Provisions to Clean Each Stage Individually

Many large systems are provided with so called clean in place systems (CIP). One design suggestion to consider is that by providing sufficient piping and valving to clean each stage of a system individually will invariably make the cleanings more effective. Cleaning multiple stages together means that dirt, debris, bio-mass and scale must be pushed from the first stage and through subsequent stages before being removed from the system. CIP systems should also provide adequate flow rates for effective cleanings as well as facilities to heat the cleaning solutions.

### Permeate Flushing Capability

A potential system feature that can lower the frequency of cleanings is to provide for periodic permeate flushing of the system. Permeate flushing is accomplished by recycling permeate or product water through the system at a high rate to loosen and push out foulant layers before they adhere to the membrane surface. This capability is especially useful in systems handling treated waste water.

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### **SDI Measurement Device and Connection Points in the System**

A great diagnostic tool especially for the pretreatment end of a system is having and using an SDI instrument. Like profiling and probing the elements can localize a potential membrane problem, and SDI instrument with connections throughout the pretreatment system can help quickly localize pretreatment problems.

### **Wet Lab at the Plant Site**

Having the capability to do laboratory work at the plant site means that water analyses can be more easily monitored, especially for setting up and maintaining pretreatment chemical additions.

### **Single Element Test Unit**

Having a single element test unit at the plant can be a real advantage. Suspect membrane elements be quickly tested and judged good or bad. In addition, cleaning strategies can be tested and proven on fouled elements before tried on whole stages of the plant.

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