REVERSE OSMOSIS

ESSENTIAL USERS GUIDE
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INTRODUCTION TO AVISTA

Avista Technologies is a specialty chemical company with its sole focus on providing products and services to help customers operate reverse osmosis systems more efficiently and economically.

To this end, we have developed products and services that focus on the needs of the membrane separations customer who deserves a technological leader to set the standard in dynamic chemical formulations.

With extensive and varied experience in the membrane separations industry, the Avista Technologies employees offer a tremendous value added resource.

This expertise, combined with cost effective, practical solutions, allows us to work with our customers to achieve optimum system performance.

Our formulated chemicals include:

- Antiscalant
- Biocide
- Coagulant
- Cleaner

Our services include:

- Offsite Cleaning
- Membrane Autopsy
- Troubleshooting
- Laboratory Services

www.avistatech.com
Reverse Osmosis is a salt separation process that occurs when pressure is applied to ‘salty water’ at a semi-permeable membrane. The pressure drives pure water through the membrane (permeate) leaving a more concentrated salt solution behind (concentrate or reject).

This separation process has been turned into a continuous process by using a crossflow membrane configuration.

Feedwater passes across a series of membranes, producing permeate and more concentrated feedwater to the next membrane. A feed pump generates the required pressure and a valve on the reject stream maintains the pressure across the membrane array.

The concentration process is continued to practical limits. Typically brackish water systems will be operated at 70-80% recovery and seawater systems at 35-50% recovery.

The diagram below shows the separation process that occurs across a membrane system operating at 75% recovery.

**Reverse Osmosis**: Applied pressure (in excess of osmotic pressure) is used to reverse the natural flow and separate salts from liquids across a semipermeable membrane.

**RO Terms**

Permeate = water passing through membrane  
Concentrate = reject = solution which is retained on the feed side of the membrane  
TDS = total dissolved solids  

%Recovery = (Permeate Flow/Feed flow) x 100%  
% Salt Rejection = 100% x [1 - (Permeate TDS/Feed TDS)]
To ensure reverse osmosis membranes perform well over a long period of time the feedwater must be pre-treated to remove any free chlorine and to reduce the suspended solids content to an SDI of less than 5 (Silt Density Index, see page 9 for a description of how this is measured).

The suspended solids are typically removed using one of the following pre-treatment filter combinations:

- Multimedia deep bed filtration, with coagulation (RoQuest) followed by guard cartridge filtration
- Ultra/Microfiltration membranes
- Clarifier, pre-coat filter, cartridge filter

To prevent the precipitation of sparingly soluble salts that are concentrated up through the RO process, antiscalant (Vitec) is dosed.

Chlorine is either present in the feedwater (if it is a municipal supply) or it is often added to prevent biological/marine organism growth in the intake system. This is removed by dosing sodium bi-sulphite (Anti-Chlor). A non-oxidising biocide (RoCide) is applied downstream of the SBS to prevent biological growth on the membranes.

A clean in place system is also provided to periodically remove the buildup of any contaminants that pass through the pre-treatment system and foul or scale the membranes. Cleaning is achieved by passing a warm solution of cleaning fluid (RoClean) across the membranes.
Membrane Construction

This is an outline of the components of a spiral wound reverse osmosis membrane and their functions:

**Membrane**
This material prevents salt passage while allowing water to permeate. The membrane sheet is typically made from polyamide, with a polysulphone support layer. Multiple membrane sheets are rolled together to form a ‘spiral wound membrane element’.

**Permeate Carrier (Tricot)**
Sandwiched between layers of membrane, this material carries permeate water to the permeate tube.

**Permeate Tube**
A perforated tube which collects permeate and, upon which, the membrane leaves are attached. The ends of the permeate tube are profiled to hold interconnectors. These allow permeate to travel from element to element, and finally to the take-off point on the pressure vessel.

**Anti-telescoping Device (ATD)**
This device is fitted over the feed and concentrate end of the membrane sheets. It is designed to prevent the rolled membrane sheets from elongating (“telescoping”) due to pressure differential from feed to concentrate. It also holds the brine seal.

**Feed Spacer (Vexar)**
Fitted between membrane leaves, the vexar forms a flow channel for the feed water to pass over. It is designed to generate turbulence, breaking down boundary layers close to the membrane and helping to reduce scaling and fouling potential.
Membrane Installation

Interconnector
Used to connect the permeate tube of one membrane element to another, or the permeate tube of a membrane element to the end cap of the pressure vessel (Figure 1). The interconnector uses o-rings to provide the seal.

Casing or Outer Wrap
Provides a rigid construction to maintain to the shape of the membrane element under pressure and to prevent membrane damage during handling. This is generally constructed from fiber reinforced plastic. Some membrane elements are simply tape wrapped. The membrane manufacturer model number and serial number are typically visible on or through the outer wrap.

U-Cup Brine Seal
Forms a seal between the membrane element and the pressure vessel. The design is such that the pressure of the feed water opens the ‘u-cup” and forms the seal. This ensures that the feed water passes through the element and not around it.

Pressure Vessel
Pressure vessels house the membrane elements, typically from one to seven membranes per tube depending on the length of the vessel. Vessels are typically made of stainless steel or fiberglass reinforced plastic (FRP).

Loading of Membrane Elements
Membrane elements should be loaded and removed in the same direction as the water flow. Glycerin (a water-soluble lubricant) should be used on the U-Cup seals and o-rings during the installation (see Figure 2). When installing membranes, record the membrane serial numbers and the location of each membrane within the vessel.
RO Daily Monitoring/Logging

Record keeping on a membrane system is important for a number of reasons, as it aids troubleshooting of problems, allows monitoring to schedule cleans and is essential for warranty claims. Data should be recorded at least once per day.

The minimum records that should be kept for a membrane system are those that are required to carry out membrane data normalisation. The sample logsheet below details these parameters.

In addition it is normally useful to record the performance of all pre-treatment equipment so performance patterns can be identified.

At startup it is useful to complete a log of the permeate conductivity of each pressure vessel in the system. This baseline data can then be compared against the plant performance if changes to product quality occur.

**SAMPLE REVERSE OSMOSIS LOGSHEET**

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Ro Unit</th>
<th>Date</th>
<th>11/5</th>
<th>12/5</th>
<th>13/5</th>
<th>14/5</th>
<th>15/5</th>
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</thead>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Startu p Values</td>
<td></td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>SDI</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Feed Flow</td>
<td>m³/hr</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeate Flow</td>
<td>m³/hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reject Flow</td>
<td>m³/hr</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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</tr>
<tr>
<td>Brine Pressure</td>
<td>bar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeate Pressure</td>
<td>bar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed Conductivity</td>
<td>μS/cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permeate Conductivity</td>
<td>μS/cm</td>
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Silt Density Index (SDI)

Although the values do not directly correlate to the fouling potential of a specific water, the Silt Density Index, or SDI, test is considered to be an industry standard for measuring the colloidal fouling potential of spiral wound membranes.

For SDI test results to be accurate, the feed line to the kit must be connected to the raw water line representative of the water to be treated by the RO system. It is also important to ensure that all of the air is purged from the apparatus and that the feed pressure is adjusted to 30 psig.

**SDI Test Procedure:**
The initial time required to fill a 500 ml graduated cylinder is measured and recorded as $t_0$. A measure of the time required to collect 500 ml volumes is noted again at 5, 10 and 15 minutes after the initial start. These times are recorded as $t_5$, $t_{10}$ and $t_{15}$ respectively.

**Calculation of Silt Density Index (SDI):**
The SDI value is then calculated using the following equation:

$$SDI = \left(1 - \frac{t_0}{t_{15}}\right) \times 100$$

$t_0$ = Initial time in seconds required to collect a 500 ml sample.
$t_{15}$ = Time in seconds required to collect a 500 ml sample after $T$ fifteen min.
$T$ = Total test time in minutes (up to start of second sample collection time.

**Recommended SDI Value:**
Depending on the membrane manufacturer, the typical recommendation is to maintain a SDI value of 3.0 to 5.0 for feedwater to a reverse osmosis system.

The filter pads shown on the right show the benefits of dosing coagulant
Turbidity is an important water quality indicator for almost any treatment application. Turbidity represents the presence of dispersed, suspended solids-particles not in true solution and often includes silt, clay, algae and other microorganisms, organic matter and minute particles.

Suspended solids obstruct the transmittance of light through a water sample and impart a qualitative characteristic, known as turbidity, to water. Turbidity is not a direct measure of suspended particles in water. Instead, it is a measure of the scattering effect such particles have on light.

The way in which suspended particles scatter light is very complex. Particle size, shape, and nature all affect scattering. In addition, colored solutions adsorb light and can affect turbidity. Very small particles (0.2 microns) scatter light equally in the forward and backward direction. Larger particles (1 micron) scatter light primarily in the forward direction. Forward scattering is intensified as the concentration of suspended solids increases.

Turbidity is determined electronically by the apparatus shown in Figure 1. Light from a tungsten filament (usually) passes through the sample to be measured. Light scattered at an angle of 90 degrees is measured. Ninety degrees is chosen because it is very sensitive to light scatter.

Dividing scattered light intensity by that transmitted in a forward direction compensates for the affect of sample color. An instrument of this type is known as a ratio turbidimeter.

A turbidity reading of around 0.2 NTU is typical of the feedwater to membrane systems.
Multi-Media Filter Operation

Membrane manufactures typically specify that RO feedwater should have an SDI (Silt Density Index) of <5.0 and a turbidity value <0.20 NTU. Low SDI and turbidity values are believed to mean that the potential for colloidal fouling is reduced. With proper application, design, and operation, a multi media filter (MMF) can achieve these goals.

**Turbidity** — When a MMF is put on-line following a backwash, the turbidity value can sometimes be similar to the feedwater turbidity. Over a brief period of time, the turbidity should drop and stabilize to an acceptable level. As the system operates, the turbidity rises. When the turbidity increases by 10%, a backwash should be initiated. If the MMF is not backwashed, the turbidity in the effluent may eventually exceed the feedwater turbidity.

**Pressure Drop (delta-P)** - It is important to monitor the delta-P of the MMF. Increases in delta-P signal the filter is working and removing particles. The MMF should be backwashed at or before the delta-P reaches ten (10 psi).

**Delta-P and Turbidity are Independent** – It is important to understand that delta-P and turbidity breakthrough can be independent of each other. The MMF should be backwashed based on whichever occurs first.

**Turbidity vs. Dosage** – When dosing a coagulant, high turbidity does not always indicate an inadequate dosage. Both underdosing and overdosing can cause turbidity to rise. Additionally, significant overdosing can cause the effluent turbidity to exceed the feedwater NTU. The optimal dosing range at the bottom of the curve usually has a spread of 1 to 2 ppm.

**Important Operating Tips**
- Test MMF feed and effluent turbidity frequently.
- Use a drawdown tube to verify coagulant dosages.
- Use reliable pressure gauges to measure MMF delta-P
- Initiate MMF backwash based on turbidity, delta-P or time.

![Figure 4: Photo shows the interior of a failed MMF bed. The garnet, anthracite and sand are intermixed and the surface of the bed is cratered.](image-url)
Coagulant Optimisation Tips

Effective application of coagulant reduces membrane fouling rates and therefore reduces membrane cleaning frequency and increases membrane life.

**Step 1: Understand Site Feedwater Characteristics**

Seasonal factors such as algal blooms, storms and rotting vegetation may change the nature and level of suspended solids in the feedwater to an RO plant.

Consideration should be given to these effects during process design and full evaluation of their effect should be determined during the first year of plant operation.

**Step 2: Study the Effectiveness of Coagulant**

To determine the relative effectiveness of the range of membrane (and antiscalant) compatible coagulants a set of jar tests should be completed. The jar tests will result in a series of graphs relating dose rate and filtrate quality. The most cost effective dosing option should be selected and the dose rate optimised on the main plant or on pilot scale filtration units using the best jar test dose rate as a start point.

**Step 3: Continuously Monitor Performance**

During operation the level of suspended solids in the feed and filtrate of the MMF’s should be measured using SDI and other relevant parameters such as turbidity or TOC. If a drop off in solids removal is noted the following should be checked/carried out:

- Filter backwash frequency is correct
- Filter run profile as expected
- Re-optimised by jar test or direct dose variation
Determining Scaling Potential

An accurate feedwater analysis is critical to determine the scaling potential of a reverse osmosis application.

The conversion chart in Table 1 outlines the ions that must be known in order to complete an antiscalant projection. A complete analysis should also include the pH of the water at the time of sampling.

For ions such as Aluminum, Barium, Iron, and Strontium, it is important to ensure that the testing methods can detect ion levels in the range of 0.01 ppm.

The Avista Advisor™ computer program allows the user to enter site-specific feedwater and system data to:

- Recommend an antiscalant and dosage for a specific application.
- Determine the scaling potential of a feedwater.
- Calculate chemical injection rates
- Determining maximum system recovery based on scaling potential.
- System troubleshooting tool.

Table 1:

<table>
<thead>
<tr>
<th>ION</th>
<th>Symbol</th>
<th>Conversion Factors</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Ion to CaCO₃</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CaCO₃ to ion</td>
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<tr>
<td>Calcium</td>
<td>Ca</td>
<td>2.49</td>
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<tr>
<td>Magnesium</td>
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<tr>
<td>Sodium</td>
<td>Na</td>
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<tr>
<td>Potassium</td>
<td>K</td>
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<tr>
<td>Strontium</td>
<td>Sr</td>
<td>1.14</td>
</tr>
<tr>
<td>Barium</td>
<td>Ba</td>
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<tr>
<td>Iron (Ferric)</td>
<td>Fe⁺⁺</td>
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</tr>
<tr>
<td>Iron (Ferrous)</td>
<td>Fe⁺⁺</td>
<td>1.79</td>
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<tr>
<td>Manganese</td>
<td>Mn</td>
<td>1.82</td>
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<tr>
<td>Aluminum</td>
<td>Al</td>
<td>5.56</td>
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<tr>
<td>Bicarbonate</td>
<td>HCO₃⁻</td>
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<tr>
<td>Chloride</td>
<td>Cl</td>
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<tr>
<td>Sulfate</td>
<td>SO₄⁻</td>
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<tr>
<td>Fluoride</td>
<td>F</td>
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</tr>
<tr>
<td>Nitrate</td>
<td>NO₃⁻</td>
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</tr>
<tr>
<td>Silica</td>
<td>SiO₂⁻</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Figure 2: Data input screen for Avista Advisor Antiscalant projection program.
Antiscalant Dosing

Determining Required Dosage and Pump Flowrate:

1) Identify the optimum ppm (mg/l) dosage of the appropriate Avista antiscalant. This can be found on the Avista Advisor Dosing Report (both mg/l dose rate and pump flowrate are calculated). If this dose rate gives you a flowrate too low for your dosing pumps calculate a workable antiscalant dilution using the equation on the right. (Avista Advisor can do this calculation for you.)

Remember 1mg/l = 1ppm = 1g/m³

2) For example, if you determine that you need a 30% dilution to bring the flow into the pump range then use the details in figure 1 to make up the dilute solution. The table provides details of chemical and water volumes for 1000 litres of dilute solution and a column providing a multiplication factor if you wish to make up different volumes. For example, to make up 400 litres of a 30% dilution:

Calculate the chemical volume to add by multiplying the total volume by the chemical volume factor, ie 400 x 0.3 = 120 litres.
Calculate the water volume by subtracting the chemical volume from the total ie 400 – 120 = 280 litres.

Add the chemical to the dosing tank and top up with the DI or RO permeate water. Note: 10% is the maximum recommended dilution for all antiscalants except Vitec 3000 which can go to 1%.

Dosage Confirmation

Using a drawdown assembly (as shown in Figure 2), verify that the proper ml/minute dosage is being delivered to the system. If there is no drawdown tube, calibrate the pump by placing the pump suction line into a graduated cylinder filled with the solution to be pumped. Measure the drop in solution over a one-minute period to verify the ml per minute injection rate. Adjust the pump accordingly until it is correct.
Biocide Optimisation Tips

Controlling the growth of biofilm on RO membranes will minimise energy costs, contribute to reduced cleaning frequency and ensure good product quality and membrane life.

It should be noted that the application of membrane compatible non-oxidising biocides may be limited depending on the product water usage.

**Tip – Understand the Characteristics of the Site**

Seasonal factors such as algal blooms and rotting vegetation may change the nutrient and bacteria level in the feedwater to an RO plant.

Consideration should be given to these effects during process design and full evaluation of their effect should be determined during the first year of plant operation.

It should be noted that continuous chlorination/dechlorination can contribute to significant biological aftergrowth in feedwaters rich in organic matter. Intermittent chlorination should be considered if at all possible.

**Tip – Take Plant Uptime into Account**

Intermittent biocide can be dosed while the RO is online or during shutdown flushing. If the plant is to be left dormant for any length of time ensure the biocide applied remains active in the system during that period.

**Tip – Ongoing Monitoring**

Biological activity can be monitored simply by monitoring differential pressure and by visual inspection of feed and brine piping. More accurate information can be obtained by feed and permeate sampling of both biofilm studs and water samples. However the situation is monitored it is essential to vary the biocide dose rate and frequency until the levels are steady. Seasonal changes in feedwater quality may require modification of the biocide dosing level/frequency.
Choosing a Cleaner Combination

Step 1 – Understand the Characteristics of the Site
Identify the site location to understand the feedwater source and constituents, evaluate any pretreatment issues, and review the existing cleaning procedures performed on the membranes.

Step 2 – Complete a Visual Inspection of the Membranes
Look for clues on the membrane exterior. If there is enough foulant on the outside of the element, a small sample can be removed and tested to determine its constituents. Cleaning procedures specific to that foulant can then be evaluated. The weight of an element can also indicate the extent of fouling.

Step 3 – Review Pre-Test Data
Review the pre-test data to determine the cleanability and health of the membrane. This is useful in selecting the appropriate cleaning chemicals and to help set performance expectations for the membranes after they’ve been cleaned.

<table>
<thead>
<tr>
<th>Polyamide or Equivalent Membranes</th>
<th>Cleaner Selection</th>
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<tbody>
<tr>
<td>Cellulose Acetate Membranes</td>
<td></td>
</tr>
<tr>
<td>Product Name</td>
<td>Metals</td>
</tr>
<tr>
<td></td>
<td>Iron, Manganese and Aluminum</td>
</tr>
<tr>
<td>RoClean L211</td>
<td>✓</td>
</tr>
<tr>
<td>RoClean L403</td>
<td>✓</td>
</tr>
<tr>
<td>RoClean L607</td>
<td>✓</td>
</tr>
<tr>
<td>RoClean L811</td>
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<tr>
<td>RoClean P111</td>
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<tr>
<td>RoClean P303</td>
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<tr>
<td>RoClean P507</td>
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<td>RoClean P703</td>
<td>✓</td>
</tr>
<tr>
<td>RoClean P911</td>
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</tr>
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</table>

* Acceptable Chemical(s) Choice
** Ideal Chemical(s) Choice
Avista laboratory personnel routinely perform cleaning studies on fouled membranes provided to us by our customers. Cleaner selection and site-specific cleaning procedures are determined using this analysis. The results are then duplicated by the customer on-site to achieve a significantly higher rate of success.

The element(s) is dissected and membrane samples are cut to size and placed in a closed cell test loop. A variety of cleaning solutions are recirculated across the membrane surface, simulating actual on-site cleaning characteristics (cross flow, flux, etc). A range of variables are applied including:

1. RoClean type and order of use
2. Solution temperature
3. Recirculation time
4. Soaking

The cleaner(s) and procedure that provided the most significant foulant removal and which restored overall membrane performance are then recommended to the customer for use on-site.
Membrane Cleaning Tips

Effective membrane cleaning involves proper procedures combined with chemistry that is specifically formulated to remove the target foulant. One without the other can result in ineffective cleaning.

**Use proper chemical dilutions** - When diluting cleaners, take into consideration the total volume of water in the system including: tanks, pipes and/or hoses and vessels. Table 1 gives a guide to membrane vessel volumes.

**Use proper flow rates** – The velocity of the solution across the membrane surface is critical. Clean 4” membranes at 10 to 12 gpm and 8” membranes at 35 to 40 gpm. Full-fit membranes require higher flow rates, 60 gpm for an 8” element.

**Always clean membranes in parallel** – If necessary, separate the vessels to achieve this. Never clean the vessels in series as it is difficult to ensure proper flow rates and pressures.

**Minimize cleaning pressure** - Clean at pressures less than 60 psig. This will minimize or eliminate foulants being pulled down to the membrane surface by water permeating during the cleaning procedure.

**Heat the cleaning solution** - Heat to the maximum temperature allowed by the membrane manufacturer. (Extreme over temperature may result in the kind of ATD damage shown in the photo.)

**Additional Tips** – 1) Use only DI or RO permeate water to dilute cleaning solutions. 2) Reduce cleaner foaming by placing return lines below the water level in the CIP tank. 3) Use a combination of low and high pH cleaning solutions. 4) Recirculate the cleaning solution for a minimum of 45 minutes.

### TABLE 1

<table>
<thead>
<tr>
<th>Number of membranes per vessel</th>
<th>Volume of water per 4” Diameter Vessel</th>
<th>Volume of Water per 8” Diameter Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gal</td>
<td>Liters</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>23</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>38</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>45</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>53</td>
</tr>
</tbody>
</table>
Particulate and Colloidal Fouling

Flow rates and good chemistry are the critical factors in successfully cleaning membranes fouled by colloidal material. The RoClean L211 contains dispersants that help push particles away from each other and away from the membrane surface, allowing a more effective clean.

The following are symptoms or indicators of silt and colloidal fouling:

- High pressure differential on elements.
- Surface water feed supply to system.
- High turbidity in feedwater.
- Element telescoping.
- Discoloration of the membranes.

**Cleaning Approach**

- Low pH clean with either RoClean P303 or L403 followed by a high pH clean with RoClean L211.
- Consider reverse flow and air sparging during cleaning procedure.
- Heat cleaning solution to maximum allowed by the membrane manufacturer.

**Steps to preventing silt and colloidal fouling:**

- Conduct SDI (Silt Density Index) and turbidity testing to determine colloidal fouling potential
- Conduct laboratory testing to determine fouling potential as well as filterability of the water.
- Consider a multi media pilot filter study.
- Inspect SDI pads under a microscope to identify the colloidal material.
- Use properly designed multi media filtration and consider the need for air scour or surface wash.
- Consider the use of a coagulant to increase the effectiveness of the multi media filter.
Organic Fouling (non-biological)

The following are symptoms of organics fouling:

- Membrane discoloration.
- Low flow on individual membrane test data.
- Possible high pressure differential on individual membrane test data.

The recommended cleaning approach is:

- A low pH clean using either RoClean P303 or L403, followed by a high pH clean using either RoClean P111 or, for severe cases, RoClean P112 or L212.

The combination of a low pH clean followed by the high pH solution is extremely effective in removing organics. The low pH cleaner helps break the bridge between the organics and the membrane. The high pH solution then lifts the foulant off the membrane surface. This is why there is sometimes a color discharge only when using the high pH cleaner. Don’t be misled though, the low pH clean was a vital step in the cleaning regime.

Steps to preventing organic fouling include:

- Remove the organics from the RO feedwater with a properly designed multimedia filter with coagulant addition. Metal salts blended with a polymer are usually the most effective coagulant for high organic waters.

Notes:

Figure 3 is an example of a spent cleaning solution where the foulant was humic acid, dissolved by the formulated cleaners.
Iron & Manganese

The following are symptoms of iron and manganese fouling:

- Discoloration of membranes.
- Poor salt rejection on individual membrane test data.
- Low flow on individual membrane test data.
- Possible high pressure differential on individual membrane test data.
- High iron or manganese values reported in feedwater.
- High pressure differential reported on first array.

The recommended cleaning approach is a low pH clean (RoClean P703) followed by a high pH clean (RoClean P111 or L211). Results can be further improved by heating the cleaning solution to the maximum allowed by the membrane manufacturer.

Steps to preventing iron and manganese fouling include:

- Conduct a complete and accurate water analysis.
- If the water supply contains a high amount of ferrous iron, it is important to prevent it from oxidizing. Oxidation can be caused by exposure to chlorine or aeration of the water (which occurs in the multimedia filter or other similar equipment).
- Iron and manganese can be removed using a greensand filter regenerated with potassium permanganate. However, if potassium permanganate is overdosed or is not properly rinsed from the greensand filter, it will oxidize the membrane surface.
- Iron can be removed by chlorinating the water then removing the oxidized iron or manganese with a multimedia filter.

Additional Notes:
Iron in water can be found as ferrous or ferric. Ferrous iron is dissolved iron that has not precipitated. Exposure to air turns ferrous iron into ferric (oxidized) iron, which essentially, has become rust.

Ferrous iron can exist in relatively high levels and not precipitate so long as it is not oxidized. It becomes a filtration issue if it becomes oxidized. Ferric iron fouling can be removed using RoClean P703.
Sulfate Scale

Symptoms of sulfate scale include:

- Material extruding from the downstream end of the last membranes in the system.
- Foulant will not dissolve when introduced to a dilute hydrochloric acid solution.
- Poor salt rejection, low flow, and/or high pressure differential on individual test data.
- 8” x 40” element weight exceeds 40 pounds.
- Site reports interruption in the antiscalant or acid injection.
- Site reports scale in the last vessel or piping of the concentrate stream.

The recommended cleaning approach varies:

- If some of the material dissolved in a dilute hydrochloric solution, begin the clean with a low pH product such as RoClean L403.
- If none of the material dissolved in a dilute hydrochloric solution, then skip the low pH clean and use only a high pH solution, RoClean L811.
- If possible, heat the cleaning solution to the maximum temperature allowed by the membrane manufacturer.

Additional Notes:
Barium sulfate scale on a membrane, pressure vessel, or pipe feels like fine grit sandpaper. This abrasiveness can cause damage to a membrane surface during system operation. When the system is started and stopped, the vexar (feedspace) material shifts slightly. This shifting can cause the barium sulfate scale to scratch the membrane surface causing permanent damage and resulting in a loss of rejection.

Figures 1 and 2: SEM Photographs of Barium sulfate scale, Including a magnified view Of one of the crystals
Calcium Carbonate Scale

**Symptoms of calcium carbonate scale include:**

- Scale extruding out of the downstream end of the last membranes in the system.
- All of the scale dissolves when introduced to a dilute hydrochloric acid solution.
- Poor salt rejection, low flow, and or, high pressure differential on individual membrane test data.
- 8” x 40” Element weight exceeds 45 pounds.
- Site reports interruption in the antiscalant or acid injection.
- Site reports scale in the last vessel or piping of the concentrate stream.

**The recommended cleaning approaches are:**

- Low pH clean with RoClean L403
- In severe cases, add hydrochloric acid to the cleaning solution to maintain a pH of 3.0.

**Testing for calcium carbonate scale:**
Calcium carbonate scale is not always as white as shown in Figures 1 and 2. But, a quick test can be conducted to see if the foulant is comprised solely of calcium carbonate.

In a glass beaker, mix a small solution containing ½ DI water and ½ Hydrochloric acid (36%). Drop a small sample of the foulant into the solution. If the foulant contains calcium carbonate, it will bubble. Continue adding acid until the bubbling stops or until the scale disappears.

If the beaker contains residual material after the bubbling has stopped, then the foulant consists of more than just calcium carbonate.

---

Figure 1
Severe CaCO₃ scale on a membrane surface.

Figure 2
Element fouled with CaCO₃ scale

Figure 3
An acid test is used to determine if a foulant is comprised of CaCO₃ scale.
Biological Fouling

**Symptoms of biological fouling include:**

- Visible slime on the feed side of the membrane.
- Site reports slime in the cartridge filter housing and piping.
- Site reports high pressure differential in the first array.
- Individual membrane test data reports high pressure differentials.
- Membranes are telescoped.

**The recommended cleaning approaches are:**

- Add DB-20 biocide to a low pH cleaning solution (RoClean L403 or P303).
- Follow the low pH clean with RoClean P111 (for severe cases, consider P112)
- Heat the high pH solution (If P112 is used, temperature range is 90° – 100°F)

**Steps to prevent biological fouling include:**

- Properly dose sodium bisulfite
- Clean and sanitize the pretreatment equipment and piping.
- Consider an intermittent biocide treatment.
- Evaluate the necessity of a continuous injection biocide.

**Additional Notes:**

Figure 1 is a membrane sample that was taken from a single 8” x 40” element. The first 20” of both the membrane and vexar (feedspacer) were plugged with biological slime while the last 20” were free of the foulant.

This picture is a good demonstration of how biological fouling typically occurs in the front end of a system and how it may only affect the first one or two membranes.
Backpressure Damage ‘Delamination’

Backpressure is cause for concern because it can cause delamination of reverse osmosis membranes.

Delamination is a separation of the membrane from the backing material. This type of damage is caused by backpressure from the permeate side of the membrane and results in a loss of rejection.

Backpressure can be caused by restrictions in the line such as valves, resin beds, or elevated piping. It can also be caused by improper relief of product pressure in a product staged (double pass) RO system.

Figure 1 shows an example of severe backpressure damage where the pattern of the feedspacer (vexar) is clearly visible.

The bubbling of the membrane shown in Figure 2 is sometimes subtle and difficult to detect.

Figure 3 shows the membrane envelope, comprised of two sheets of membrane and one sheet of tricot (permeate carrier) between.

The yellow arrow is the tricot, the red arrow is the backing material and the blue arrows are the membrane that was pulled away from the backing material.

Delamination allowed easy separation of the membrane material from the backing material. This separation would not be possible on an undamaged element.
Membrane Telescoping

Telescoping of a membrane is caused by excessive differentials between the feed pressure and the concentrate pressure.

The maximum pressure differential for a single 40” long membrane is 10 psi. When this pressure is exceed, damage to the membrane and its materials of construction can occur.

**Consequences of Telescoping:**

- Damage to the fiberglass outer wrapping allows water to flow on the outside of the element. This will reduce the crossflow across the membrane surface and increase the fouling potential.
- If the feed spacer (vexar) moves within the membrane area, it can scratch the membrane surface and cause permanent damage.
- Glue lines can be stressed and fail.
- Flow patterns will be disrupted, resulting in channeling over the membrane surface and uneven fouling.
- The membrane crease will be stressed and failure can occur at these points near the permeate tube.

**Prevention:**

- Monitor pressure differentials across the entire system as well as across each array.
- If the fiberglass is damaged, repair with vinyl tape or place the brine seals on the opposite end if the fiberglass and ATD are not damaged on that end.
- Clean the system before pressures exceed 10 psi per membrane element and correct any excessive fouling problems.
### Troubleshooting Guide

<table>
<thead>
<tr>
<th>INDIRECT CAUSE</th>
<th>DIRECT CAUSE</th>
<th>CORRECTIVE ACTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of antiscalant</td>
<td>Scaling</td>
<td>Carry out mass balance, check antiscalant present in concentrate and ensure shutdown flush operating to determine source of problem. Clean plant.</td>
</tr>
<tr>
<td>Excessive recovery</td>
<td>Colloidal Fouling</td>
<td>Improve pre-treatment performance</td>
</tr>
<tr>
<td>Poor pre-treatment</td>
<td>Compaction</td>
<td>Improve pre-treatment as colloidal fouling on front end membrane normally accompanies first element compaction.</td>
</tr>
<tr>
<td>Poor pre-treatment and operating outlet</td>
<td>Incompatible Chemicals</td>
<td>Review chemical compatibility Clean plant</td>
</tr>
<tr>
<td>Operating outlet below allowed limits</td>
<td>Biofouling</td>
<td>Carry out bacterial survey. Disinfect/clean whole system. Increase biocide programme and continue monitoring until system shown to be under control.</td>
</tr>
<tr>
<td>Using non approved products or carryover</td>
<td>Organic fouling</td>
<td>Investigate source water and improve pre-treatment</td>
</tr>
<tr>
<td>Ineffective biociding programme</td>
<td>Very high pressure, uneven flux</td>
<td>Replace elements and work at lower pressures, rebalance flows</td>
</tr>
<tr>
<td>Increase in biocide programme</td>
<td>Free chlorine or incompatible cleaner use</td>
<td>Replace elements (or treat with ReSize 3000 for temporary relief)</td>
</tr>
<tr>
<td>Poor pre-treatment and operating outlet</td>
<td>Oxidation damage</td>
<td>Remove source of backpressure/vacuum</td>
</tr>
<tr>
<td>Operating outlet below allowed limits</td>
<td>Product backpressure, or vacuum, abrasion, installation damage to membrane tube</td>
<td>Improve pre-treatment</td>
</tr>
<tr>
<td>Using non approved products or carryover</td>
<td>O-ring leak</td>
<td>Replace o-rings, shim vessel. Make startup/shutdown smoother</td>
</tr>
<tr>
<td>Ineffective biociding programme</td>
<td>Membrane fault</td>
<td></td>
</tr>
</tbody>
</table>

### Table

<table>
<thead>
<tr>
<th>DP</th>
<th>SALT REJECTION</th>
<th>PRODUCT FLOW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inc 2&lt;sup&gt;nd&lt;/sup&gt; stage</td>
<td>No Change</td>
<td>Decreasing (or Feed Pressure Increasing, depending on control system logic)</td>
</tr>
<tr>
<td>Inc 1&lt;sup&gt;st&lt;/sup&gt; stage</td>
<td>No Change</td>
<td>No Change</td>
</tr>
<tr>
<td>No change</td>
<td>Inc</td>
<td>NC</td>
</tr>
<tr>
<td>No change</td>
<td>Dec</td>
<td>Increasing</td>
</tr>
</tbody>
</table>

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Water Calculation Examples

1. Calculating Reverse Osmosis system recovery.

   Calculation: \[ \frac{\text{Permeate}}{\text{Feed}} \times 100 = \% \text{ Recovery} \]
   Example: \( \frac{75 \text{ GPM}}{100 \text{ GPM}} \times 100 = 75\% \text{ Recovery} \)

2. Calculating Reverse Osmosis Salt Rejection:

   Calculation: \[ \% \text{ rejection} = (1 - \frac{\text{permeate TDS}}{\text{feed TDS}}) \times 100 \]
   Example: \( (1 - \frac{20}{1000}) \times 100 = 98\% \)

3. Calculating the Concentration Factor

   A. Recovery Based Concentration Factor:

      Calculation: \[ \frac{1}{(1 - \text{recovery, expressed as a fraction})} \]
      Example: \( \frac{1}{(1 - 0.75)} = 4 \)

   B. Conductivity Based Concentration Factor

      Calculation: \[ \frac{\text{(Concentrate Conductivity} - \text{Permeate Conductivity})}{\text{(Feed Conductivity} - \text{Permeate Conductivity})} = \text{Conc. Factor} \]
      Example: \( \frac{(4000 \text{ us} - 3 \text{ us})}{(1000 \text{ us} - 3 \text{ us})} = 4 \)

4. Calculating Chemical Dilutions

   Creating a 10% dilution of Vitec 3000:

   Reason: If your dosing pump flowrate is higher than that required to dose the product into the system then pumping a higher volume of a lower concentration is just as good.

   Procedure: Make up a 100 litre tank of 10% Vitec 3000. Add 10 litres Vitec 3000 (ie 12.5kg) to the tank, top up to 100 litres with demineralised water or RO permeate.
Water Calculation Examples

5. Calculating Chemical injection rates in litres/hr or ml/min

Calculation:

\[
\text{System Feed Flow (m}^3/\text{hr)} \times \text{Chem dose (mg/l)} = \text{chemical injection rate (litres/hr)}
\]
\[
\text{Specific Gravity} \times 1,000,000
\]

Example:

Vitec doserate required = 3ppm (=mg/l)
System feed flow = 500m³/hr
Vitec 3000 specific gravity = 1.25 (Equivalent to 1,250g/l and 1,250 kg/m³)

\[
\begin{align*}
\text{Vitec doserate} &= 3 \text{ mg/l} \times 500,000 \text{ l/hr} \\
&= 1500 \text{ g/hr} \\
&= 1500\text{g/hr}/1250\text{g/l} \\
&= 1.2 \text{ l/hr} \\
&= 20 \text{ ml/min}
\end{align*}
\]
**Water Calculation Worked Examples**

**Question:** The water temperature is 80 deg F. What is the temperature in Deg C?

**Answer:** 26.68 deg C

**Question:** The water temperature is 15 deg C. What is the temperature in deg F?

**Answer:** 59 deg F

**Question:** You want to create a 2% w/w concentration of RoClean L211 in a Clean in Place system that contains 5m³ (5,000 litres) of water. The bulk RoClean L211 has a specific gravity of 1.1 kg/litre. How many litres of RoClean L211 do you need to add to make a 2% w/w dilution?

**Answer:** 100kg or 91 litres of RoClean L211

**Question:** You’ve been advised to inject 3 ppm of Vitec 3000 into a system feed flow of 50m³/hr. Vitec 3000 has a specific gravity of 1.25. What ml/min dose rate is required?

**Answer:** 2 ml/min.

**Question:** A storage tank contains 3m of water. What is the head pressure at the bottom?

**Answer:** 3m or 0.3 bar
## Useful Unit Conversions

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Equals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume</strong></td>
<td></td>
</tr>
<tr>
<td>1 US gallon</td>
<td>3.785 litres = 3785 ml</td>
</tr>
<tr>
<td>1 m³</td>
<td>264.17 US gallons</td>
</tr>
<tr>
<td></td>
<td>219.97 UK gallons</td>
</tr>
<tr>
<td>1 barrel (oil)</td>
<td>159 lites</td>
</tr>
<tr>
<td>6.289 barrels</td>
<td>1 m³</td>
</tr>
<tr>
<td><strong>Flow</strong></td>
<td></td>
</tr>
<tr>
<td>1 UK gpm</td>
<td>0.2727 m³/hr, 4.5 lpm</td>
</tr>
<tr>
<td>1 US gpm</td>
<td>0.228 m³/hr, 3.8 lpm</td>
</tr>
<tr>
<td><strong>Membrane Flux</strong></td>
<td></td>
</tr>
<tr>
<td>1 gfd</td>
<td>1.7 lmh</td>
</tr>
<tr>
<td>0.58 gfd</td>
<td>1 lmh</td>
</tr>
<tr>
<td><strong>Filter Flows</strong></td>
<td></td>
</tr>
<tr>
<td>1 US gpm/ft²</td>
<td>2.935 m/hr</td>
</tr>
<tr>
<td><strong>Weights</strong></td>
<td></td>
</tr>
<tr>
<td>1 kg</td>
<td>2.2 lb</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td></td>
</tr>
<tr>
<td>1 ft³</td>
<td>0.0283 m³</td>
</tr>
<tr>
<td>35.3147 ft³</td>
<td>1 m³</td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td></td>
</tr>
<tr>
<td>1 kg/m³</td>
<td>0.06243 lb/ft³</td>
</tr>
<tr>
<td>16.0185 kg/m³</td>
<td>1 lb/ft³</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td></td>
</tr>
<tr>
<td>1 bar</td>
<td>14.5 psi</td>
</tr>
<tr>
<td>100 kPa</td>
<td></td>
</tr>
<tr>
<td>1 psi</td>
<td>2.3 ft water</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td></td>
</tr>
<tr>
<td>x °C = (1.8x+32) °F</td>
<td>5/9 (y-32) °C</td>
</tr>
<tr>
<td><strong>Hardness</strong></td>
<td></td>
</tr>
<tr>
<td>1 grain hardness</td>
<td>17.1 ppm</td>
</tr>
<tr>
<td>1 French Degree</td>
<td>10 mg/l as CaCO₃</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td></td>
</tr>
<tr>
<td>1 UG gallon</td>
<td>8.34 lbs</td>
</tr>
<tr>
<td><strong>Phosphorus to phosphate</strong></td>
<td>P tp PO4</td>
</tr>
<tr>
<td><strong>Silicon to silica</strong></td>
<td>Si to SiO₂</td>
</tr>
</tbody>
</table>
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