

Foulants and Cleaning Procedures for composite polyamide RO/NF Membrane Elements

This bulletin provides general information about the usual foulants affecting the performance of Hydranautics' Composite Polyamide Reverse Osmosis (RO) membrane elements and the removal of these foulants. The information in this bulletin applies to 4-inch, 6-inch, 8-inch, 8.5-inch, and 16-inch diameter RO membrane elements.

Note: The Composite Polyamide type of RO membrane elements may not be exposed to chlorinated water under any circumstances. Any such exposure will cause irreparable damage to the membrane. Absolute care must be taken following any disinfection of piping or equipment or the preparation of cleaning or storage solutions to ensure that no trace of chlorine is present in the feedwater to the RO membrane elements. If there is any doubt about the presence of chlorine, perform chemical testing to make sure. Neutralize any chlorine residual with a sodium bisulfite solution, and ensure adequate mixing and contact time to accomplish complete dechlorination. Dosing rate is 1.8 to 3.0 ppm sodium bisulfite per 1.0 ppm of free chlorine.

Note: It is recommended that all RO membrane cleaning operations should be closely coordinated with Hydranautics during the RO membrane element warranty period. Hydranautics field service personnel are available to be on site for cleaning assistance, should the need arise. Please contact Hydranautics for current charges for this service.

Note: The use of cationic surfactants should be avoided in cleaning solutions, since irreversible fouling of the membrane elements may occur. In regards to any proprietary chemicals, Hydranautics position is that the vendor of these proprietary chemicals is responsible for guaranteeing their product is compatible with Hydranautics membranes. Thus, the chemical vendor would be solely responsible for the financial and other impacts a negative interaction may have.

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RO Membrane Fouling and Cleaning

During normal operation over a period of time, RO membrane elements are subject to fouling by suspended or sparingly soluble materials that may be present in the feedwater. Common examples of foulants are:

- Calcium carbonate scale
- Sulfate scale of calcium, barium or strontium
- Metal oxides (iron, manganese, copper, nickel, aluminum, etc.)
- Polymerized silica scale
- Inorganic colloidal deposits
- Mixed inorganic/organic colloidal deposits
- NOM organic material (Natural Organic Matter)
- Man-made organic material (e.g. antiscalant/dispersants, cationic polyelectrolytes)
- Biological (bacterial bioslime, algae, mold, or fungi)

The nature and rapidity of fouling depends on a number of factors, such as the quality of the feedwater and the system recovery rate. Typically, fouling is progressive, and if not controlled early, will impair the RO membrane element performance in a relatively short time. Cleaning should occur when the RO shows evidence of fouling, just prior to a long-term shutdown, or as a matter of scheduled routine maintenance. The elements shall be maintained in a clean or “nearly clean” condition to prevent excessive fouling by the foulants listed above. Under normal circumstances, some fouling is allowed as long as the normalized parameters listed below are not allowed to deviate more than the “Typical” values. In specific cases, such as industrial and municipal wastewaters where fouling is more extreme, it may be necessary to allow for greater deviation in normalized parameters as listed under “High Fouling”. In such extreme cases, the deviation in normalized parameters should be based on the stabilized performance which may occur after a week of operation.

	Typical	High Fouling
normalized permeate flow decrease	10%	20%
normalized permeate quality	10%	20%
normalized pressure drop	15%	30%

Cleaning should be carried out as soon as is practical to maintain the elements in a clean or “nearly clean” condition. Effective cleaning is evidenced by the return of the normalized parameters to their initial, Start-up, value. In the event you do not normalize your operating data, the above values still apply if you do not have major changes in critical operating parameters.

Of special note are wastewaters which have high concentrations of soluble organic compounds. Historical studies have shown that it is common to have an initial sharp drop in normalized flow and decrease of salt passage, which are characterized by 10-20% decrease over a 2-4 week time period.¹ After this initial rapid decline, the normalized flow will decline marginally over the next 6-12 months. Research has shown that the initial drop is due to the adsorption of organics onto the membrane surface. Once the membrane surface is saturated with the mono-layer of organic, this effect no longer has significant impact on membrane performance. Aggressive cleaning can recover much of this loss, but studies show the gain is only short-lived and the system will quickly return to its previous performance. Thus, it is recommended that decisions to clean be based on the decline rate after this initial stabilization.

The operating parameters that have to stay constant are permeate flow, permeate back-pressure, recovery, temperature, and feed TDS. If these operating parameters fluctuate, then it is highly recommended that you normalize the data to determine if fouling is occurring or if the RO is actually operating normally based on the change in a critical operating parameter. Hydranautics offers a free normalization software program called ROData, which can be downloaded from our web site at www.membranes.com.

¹ UNDERSTANDING RO MEMBRANE FOULING AT WASTEWATER TREATMENT PLANTS”, Craig R Bartels and Rich Franks, AWWA/AMTA Membrane Technology Conference, Glendale, AZ, 2012.

Monitoring overall plant performance on a regular basis is an essential step in recognizing when membrane elements are becoming fouled. Performance is affected progressively and in varying degrees, depending on the nature of the foulants. Table 1 "RO Troubleshooting Matrix" provides a summary of the expected effects that common foulants have on performance.

RO cleaning frequency due to fouling will vary by site. A rough rule of thumb as to an acceptable cleaning frequency is once every 3 to 12 months. If you have to clean more than once a month, you should be able to justify further capital expenditures for improved RO pretreatment or a re-design of the RO operation. If the cleaning frequency is every one to three months, you may want to focus on improving the operation of your existing equipment but further capital expenditure may be harder to justify.

It is important to clean the membranes when they are only lightly fouled, not heavily fouled. Heavy fouling can impair the effectiveness of the cleaning chemical by impeding the penetration of the chemical deep into the foulant and in the flushing of the foulant out of the elements. If normalized membrane performance drops 30 to 50%, it may be impossible to fully restore the performance back to baseline conditions.

When inorganic or polyelectrolyte coagulants are used in the pretreatment process, there can often be incomplete reaction of the coagulant and thus insufficient formation of a filterable floc. The user should ensure that excessive amounts of coagulant are not fed to the RO system, as it can lead to fouling. Polyelectrolyte fouling can often be very difficult to remove and result in higher than expected feed pressure. Excessive amounts of inorganic coagulant can be measured by using SDI filter equipment. In the case of iron, the iron on the SDI filter pad should typically be 3 µg/pad and never above 5 µg/pad. In regards to polymer coagulants, the user should discuss the concern with their chemical supplier and have them ensure that the chemical will not adversely affect the membrane.

In addition to the use of turbidity and SDI, particle counters are also very effective to accurately measure the suitability of the feedwater for NF/RO elements. The measure of particles greater than 2 microns in size should be < 100 particles per millilitre.

One RO design feature that is commonly overlooked in reducing RO cleaning frequency is the use of RO permeate water for flushing foulants from the system. Soaking the RO elements during standby with permeate can help dissolve scale and loosen precipitates, reducing the frequency of chemical cleaning.

What you clean for can vary site by site depending on the foulant. Complicating the situation frequently is that more than one foulant can be present, which explains why cleanings frequently require a low pH and high pH cleaning regimen.

Note: The membrane elements shall not be exposed to feed water containing oil, grease, or other foreign matter which proves to chemically or physically damage the integrity of the membrane.

Table 1: RO Troubleshooting Matrix
(Pressure Drop is defined as the Feed pressure minus the Concentrate pressure)

Possible Cause	Possible Location	Pressure Drop	Feed Pressure	Salt Passage
Metal Oxide Fouling (e.g. Fe, Mn, Cu, Ni, Zn)	1 st stage lead elements	Rapid increase	Rapid increase	Rapid increase
Colloidal Fouling (organic and/or inorganic complexes)	1 st stage lead elements	Gradual increase	Gradual increase	Slight increase
Mineral Scaling (e.g. Ca, Mg, Ba, Sr)	Last stage tail elements	Moderate Increase	Slight increase	Marked increase
Polymerized Silica	Last stage tail elements	Normal to increased	Increased	Normal to increased
Biological Fouling	Any stage, usually lead elements	Marked increase	Marked increase	Normal to increased
Organic Fouling (dissolved NOM)	All stages	Gradual increase	Increased	Decreased
Antiscalant Fouling	2 nd stage most severe	Normal to increased	Increased	Normal to increased
Oxidant damage (e.g Cl ₂ , ozone, KMnO ₄)	1 st stage most severe	Normal to decreased	Decreased	Increased
Hydrolysis damage (out of range pH)	All stages	Normal to decreased	Decreased	Increased
Abrasion damage (carbon fines, etc)	1 st stage most severe	Normal to decreased	Decreased	Increased
O-ring leaks (at interconnectors or adapters)	Random (typically at feed adapter)	Normal to decreased	Normal to decreased	Increased
Glue line leaks (due to permeate back-pressure in service or standby)	1 st stage most severe	Normal to decreased	Normal to decreased	Increased
Glue line leaks (due to closed permeate valve while cleaning or flushing)	Tail element of a stage	Increased (based on prior fouling & high delta P)	Increased (based on prior fouling & high delta P)	Increased

Discussion on Foulants

Calcium Carbonate Scale: Calcium carbonate is a mineral scale and may be deposited from almost any feedwater if there is a failure in the antiscalant/dispersant addition system or in the acid injection pH control system that results in a high feedwater pH. An early detection of the resulting calcium carbonate scaling is absolutely essential to prevent the damage that crystals can cause on the active membrane layers. Calcium carbonate scale that has been detected early can be removed by lowering the feedwater pH to between 3.0 and 5.0 for one or two hours. Longer resident accumulations of calcium carbonate scale can be removed by a low pH cleaning with a citric acid solution.

Calcium, Barium & Strontium Sulfate Scale: Sulfate scale is a much “harder” mineral scale than calcium carbonate and is harder to remove. Sulfate scale may be deposited if there is a failure in the antiscalant/dispersant feed system or if there is an over feed of sulfuric acid in pH adjustment. Early detection of the resulting sulfate scaling is absolutely essential to prevent the damage that crystals can cause on the active membrane layers. Barium and strontium sulfate scales are particularly difficult to remove as they are insoluble in almost all cleaning solutions, so special care should be taken to prevent their formation.

Calcium Phosphate Scale: This scale is particularly common in municipal waste waters and polluted water supplies which may contain high levels of phosphate. This scale can generally be removed with acidic pH cleaners. Calcium phosphate scaling potential is currently modelled in our IMSD software. As a rule of thumb, contact Hydranautics technical department if phosphate levels in the feed are 5 ppm or higher.

Metal Oxide/Hydroxide Foulants: Typical metal oxide and metal hydroxide foulants are iron, zinc, manganese, copper, aluminum, etc. They can be the result of corrosion products from unlined pipes and tanks, or result from the oxidation of the soluble metal ion with air, chlorine, ozone, potassium permanganate, or they can be the result of a pretreatment filter system upset that utilizes iron or aluminum-based coagulant aids.

Polymerized Silica Coating: A silica gel coating resulting from the super-saturation and polymerization of soluble silica can be very difficult to remove. It should be noted that this type of silica fouling is different from silica-based colloidal foulants, which may be associated with either metal hydroxides or organic matter. Silica scale can be very difficult to remove by traditional chemical cleaning methods. Contact Hydranautics technical department if the traditional methods are unsuccessful. There does exist harsher cleaning chemicals, like ammonium bifluoride, that have been used successfully at some sites but are considered rather hazardous to handle and can damage equipment.

Colloidal Foulants: Colloids are inorganic or mixed inorganic/organic based particles that are suspended in water and will not settle out due to gravity. Colloidal matter typically contains one or more of the following major components: iron, aluminum, silica, sulfur, or organic matter.

Dissolved NOM Organic Foulants: The sources of dissolved NOM (Natural Organic Matter) foulants are typically derived from the decomposition of vegetative material into surface waters or shallow wells. The chemistry of organic foulants is very complex, with the major organic components being either humic acid or fulvic acid. Dissolved NOMs can quickly foul RO membranes by being absorbed onto the membrane surface. Once absorption has occurred, then a slower fouling process of gel or cake formation starts. It should be noted that the mechanism of fouling with dissolved NOM should not be confused with the mechanism of fouling created by NOM organic material that is bound up with colloidal particles.

Microbiological Deposits: Organic-based deposits resulting from bacterial slimes, fungi, molds, etc. can be difficult to remove, particularly if the feed path is plugged. Plugging of the feed path makes it difficult to introduce and distribute the cleaning solutions. To inhibit additional growth, it is important to clean and sanitize not only the RO system, but also the pretreatment, piping, dead-legs, etc. The membranes, once chemically cleaned, will require the use of a Hydranautics approved biocide and an extended exposure requirement to be effective. For further information on biocides, refer to Hydranautics

Selection and Use of Cleaning Chemicals

There are a number of factors involved in the selection of a suitable cleaning chemical (or chemicals) and proper cleaning protocol. The first time you have to perform a cleaning, it is recommended to contact the manufacturer of the equipment, the RO element manufacturer, or a RO specialty chemical and service supplier. Once the suspected foulant(s) are identified, one or more cleaning chemicals will be recommended. These cleaning chemical(s) can be generic or can be private-labeled proprietary chemicals. Typically, the generic chemicals can be of technical grades and are available from local chemical supply companies. The proprietary RO cleaning chemicals can be more expensive, but may be easier to use and you cannot rule out the advantage of the intellectual knowledge supplied by these companies. Some independent RO service companies can determine the proper chemicals and cleaning protocol for your situation by testing at their facility a fouled element pulled from your system.

It is not unusual to use a number of different cleaning chemicals in a specific sequence to achieve the optimum cleaning. Typically, a high pH cleaning is used first to remove foulants like oil or biological matter, followed by a low pH cleaning to remove foulants like mineral scale or metal oxides/hydroxides fouling. There are times that order of high and low pH cleaning solutions is reversed or one solution only is required to clean the membranes. Some cleaning solutions have detergents added to aid in the removal of heavy biological and organic debris, while others have a chelating agent like EDTA added to aid in the removal of colloidal material, organic and biological material, and sulfate scale. An important thing to remember is that the improper selection of a cleaning chemical, or the sequence of chemical introduction, can make the foulant worse.

Hydranautics recommends that the membrane system operator thoroughly investigate the signs of fouling before they select a cleaning chemical and a cleaning protocol. Some forms of fouling (iron deposits and scaling commonly associated with well waters) may require only a simple low pH cleaning. However, for most complex fouling phenomena, Hydranautics recommends the following sequence:

1. Flushing with permeate with addition of non oxidizing biocide (DBNPA or similar type) at the end of the flushing
2. High pH CIP – Temperature versus pH as per recommendations in this TSB
3. Flushing with permeate until pH on the brine side is below pH 8.5
4. Low pH CIP
5. Acid flushing with permeate and non oxidizing biocide (DBNPA or similar type)

General Precautions in Cleaning Chemical Selection and Usage

- If you are using a proprietary chemical, make sure the chemical has been qualified for use with your Hydranautics membrane by the chemical supplier. The chemical supplier's instructions should not be in conflict with Hydranautics recommended cleaning parameters and limits listed in this Technical Service Bulletin.
- If you are using generic chemicals, make sure the chemical has been qualified for use with your Hydranautics membrane in this Technical Service Bulletin.
- Use the least harshest cleaning regimen to get the job done. This includes the cleaning parameters of pH, temperature, and contact time. This will optimize the useful life of the membrane.
- Clean at the recommended target temperatures to optimize cleaning efficiency and membrane life.
- Use the minimal amount of chemical contact time to optimize membrane life.
- Be prudent in the adjustment of pH at the low and high pH range to extend the useful life of the membrane. A "gentle" pH range is 4 to 10, while the harshest is 2 to 12.
- Oil and biologically -fouled membranes should not use a low pH clean-up first as the oil and biological matter will congeal.
- Cleaning and flushing flows should usually be in the same direction as the normal feed flow to avoid potential telescoping and element damage. In certain cases, where heavy feed end fouling has occurred, reverse flow cleaning may be more effective in removing the foulant. In these cases, please see TSB-125 "Reverse Direction Cleaning of RO Membrane Elements" and follow all recommended guidelines to prevent element damage.

- When cleaning a multi-stage RO, the most effective cleaning is one stage at a time so cleaning flow velocities can be optimized and foulants from upstream stages don't have to pass through downstream stages.
- Flushing out detergents with higher pH permeate can reduce foaming problems.
- Verify that proper disposal requirements for the cleaning solution are followed.
- If your system has been fouled biologically, you may want to consider the extra step of introducing a sanitizing biocide chemical before and after a successful cleaning. Biocides can be introduced before and immediately after cleaning, periodically (e.g. once a week), or continuously during service. You must be sure that the biocide is compatible with the membrane, does not create any health risks, is effective in controlling biological activity, and is not cost prohibitive.
- For safety reasons, make sure all hoses and piping can handle the temperatures, pressures and pH's encountered during a cleaning.
- For safety reasons, always add chemicals slowly to an agitated batch of make-up water.
- For safety reason, always wear safety glasses and protective gear when working with chemicals.
- For safety reasons, don't mix acids with caustics. Thoroughly rinse the 1st cleaning solution from the RO system before introducing the next solution.

Selecting a Cleaning Solution

Table 2 lists the recommended generic chemical solutions for cleaning an RO membrane element based on the foulant to be removed. See section below on Description of Cleaning Solutions and Table 4 for cleaning solution formulations.

Important: It is recommended that the SDS of the cleaning chemicals be procured from the chemical supplier and that all safety precautions be utilized in the handling and storage of all chemicals.

Table 2: Hydranautics Recommended Chemical Cleaning Solutions

Foulant	Gentle Cleaning Solution	Harsher Cleaning Solution
Calcium carbonate scale	1	4
Calcium, barium or strontium sulfate scale	2	4
Metal oxides/hydroxides (Fe, Mn, Zn, Cu, Al)	1	5
Inorganic colloidal foulants	1	4
Mixed Inorganic/organic colloidal foulants	2	6
Polymerized silica coating	None	7
Biological matter	2 or 3	6
NOM organic matter (naturally occurring)	2 or 3	6

Table 3 "Hydranautics Recipes for Cleaning Solutions" offers instructions on the volumes of bulk chemical to be added to 100 U.S. gallons (379 liters) of make-up water. Prepare the solutions by proportioning the amount of chemicals to the amount of make-up water to be used. Make-up water quality should be of RO permeate or deionized (DI) quality, and be free of chlorine and hardness (See Table 4 below). Before forwarding the cleaning solution to the membranes, it is important to thoroughly mix it, adjust the pH according to the target pH, and stabilize the temperature at the target temperature. Unless otherwise instructed, the cleaning design parameters are based on a chemical recirculation flow period of one hour and an optional chemical soak period of one hour.

Table 5 "Hydranautics Maximum pH and Temperature Limits for Cleaning" highlights the maximum pH and temperature limits for specific membranes, after which irreparable membrane damage can occur. A suggested minimum temperature limit is 70 °F (21 °C), but cleaning effectiveness and the solubility of the cleaning chemical is significantly improved at higher temperatures.

Description of Cleaning Solutions

Note: The notation (w) denotes that the diluted chemical solution strength is based on the actual weight of the 100% pure chemical or active ingredient.

Solution 1: This is a low pH cleaning solution of 2.0% (w) citric acid ($C_6H_8O_7$). It is useful in removing inorganic scale (e.g. calcium carbonate, calcium sulfate, barium sulfate, strontium sulfate) and metal oxides/hydroxides (e.g. iron, manganese, nickel, copper, zinc), and inorganic-based colloidal material. Note: Citric acid is available as a powder.

Solution 2: This is a high pH cleaning solution (target pH of 10.0) of 2.0% (w) of STPP (sodium tripolyphosphate) ($Na_5P_3O_{10}$) and 0.8% (w) of Na-EDTA (sodium salt of ethylenediaminetetraacetic acid). It is specifically recommended for removing calcium sulfate scale and light to moderate levels of organic foulants of natural origin. STPP functions as an inorganic-based chelating agent and detergent. Na-EDTA is an organic-based chelating cleaning agent that aids in the sequestering and removal of divalent and trivalent cations and metal ions. STPP and Na-EDTA are available as powders.

Solution 3: This is a high pH cleaning solution (target pH of 10.0) of 2.0% (w) of STPP (sodium tripolyphosphate) ($Na_5P_3O_{10}$) and 0.025% (w) Na-DDBS ($C_{6}H_5(CH_2)_{12}-SO_3Na$) (sodium salt of dodecylbenzene sulfonate). It is specifically recommended for removing heavier levels of organic foulants of natural origin. STPP functions as an inorganic-based chelating agent and detergent. Na-DDBS functions as an anionic detergent.

Solution 4: This is a low pH cleaning solution (target pH of 2.5) of 0.5% (w) of HCL (hydrochloric) acid. It is useful in removing inorganic scale (e.g. calcium carbonate, calcium sulfate, barium sulfate, strontium sulfate) and metal oxides/hydroxides (e.g. iron, manganese, nickel, copper, zinc) and inorganic-based colloidal material. This cleaning solution is considered to be harsher than Solution 1. HCL acid, a strong mineral acid, is also known as muriatic acid. HCL acid is available in a number of concentrations: (18 ° Baume = 27.9%), (20 ° Baume = 31.4%), (22 ° Baume = 36.0%).

Solution 5: This is a lower pH cleaning solution (natural pH is between pH 4 and 6. No pH adjustment is required) 1.0% (w) of $Na_2S_2O_4$ (sodium hydrosulfite). It is useful in the removal of metal oxides and hydroxides (especially iron fouling), and to a lesser extent calcium sulfate, barium sulfate and strontium sulfate. Sodium hydrosulfite is strong reducing agent and is also known as sodium dithionite. The solution will have a very strong odor so proper ventilation is required. Sodium hydrosulfite is available as a powder.

Solution 6: This is a high pH cleaning solution (target pH of 11.5) of 0.1% (w) of NaOH (sodium hydroxide) and 0.03% (w) of SDS (sodium dodecylsulfate). It is useful in the removal of organic foulants of natural origin, colloidal foulants of mixed organic/inorganic origin, and biological material (fungi, mold, slimes and biofilm). SDS is a detergent that is an anionic surfactant that will cause some foaming. This is considered to be a harsh cleaning regimen. **Note: Do not exceed maximum pH and temp limits for specific elements. See Table 5.**

Solution 7: This is a high pH cleaning solution (target pH of 11.5) of 0.1% (w) of NaOH (sodium hydroxide). It is useful in the removal of polymerized silica. This is considered to be a harsh cleaning regimen. **Note: Do not exceed maximum pH and temp limits for specific elements. See Table 5.**

Important: It is recommended that the SDS of the cleaning chemicals be procured from the chemical supplier and that all safety precautions be utilized in the handling and storage of all chemicals.

Table 3: Hydranautics Recipes for Cleaning Solutions

The quantities listed below are to be added to 100 U.S.gallons (379 liters) of dilution water. Dilution water should meet the water quality standards in Table 4.

Cleaning Solution	Bulk Ingredients	Quantity	Target ¹ pH Adjustment	Target ¹ Temp.
1	Citric acid (as 100% powder)	17.0 pounds (7.7 kg)	No pH adjustment is Required.	104 °F (40 °C)
2	STPP (sodium tripolyphosphate) (as 100% powder) Na-EDTA (Versene 220 or equal) (as 100% powder)	17.0 pounds (7.7 kg) 7.0 pounds (3.18 kg)	Adjust to pH 10.0 with sulfuric or hydrochloric acid.	104 °F (40 °C)
3	STPP (sodium tripolyphosphate) (as 100% powder) Na-DBBS Na-dodecylbenzene sulfonate	17 pounds (7.7 kg) 0.21 pounds (0.1 kg)	Adjust down to pH 10.0 with sulfuric or hydrochloric acid.	104 °F (40 °C)
4	HCl acid (hydrochloric acid (as 22° Baume or 36% HCL)	0.47 gallons (1.78 liters)	Slowly adjust pH down to 2.5 with HCL acid. Adjust pH up with sodium hydroxide.	95 °F (35 °C)
5	Sodium hydrosulfite (as 100% powder)	8.5 pounds (3.86 kg)	No pH adjustment is required.	95 °F (35 °C)
6	NaOH (sodium hydroxide) (as 100% powder) (or as 50% liquid) SDS (sodium dodecylsulfate)	0.83 pounds (0.38 kg) 0.13 gallons (0.49 liters) 0.25 pounds (0.11 kg)	Slowly adjust pH up to 11.5 with sodium hydroxide. Adjust pH down to 11.5 by adding HCL acid.	86 °F (30 °C)
7	NaOH (sodium hydroxide) (as 100% powder) (or as 50% liquid)	0.83 pounds (0.38 kg) 0.13 gallons (0.49 liters)	Slowly adjust pH up to 11.5 with sodium hydroxide. Adjust pH down to 11.5 by adding HCL acid.	86 °F (30 °C)

¹ - Note: These pH and temperature targets are recommendations only. For maximum pH and temperature limits for specific elements. See Table 5.

Table 4. Recommendations for Make-up Water Quality for Cleaning and Flushing.

Parameter	Units
Chlorine Free	0 ppm
pH	6.5.-7.5
Hardness	
RO permeate, DI, or Soft water	< 30 ppm as CaCO ₃
Calcium (Ca)	< 5 ppm
Iron (Fe)	< 0.05 ppm
Manganese (Mn)	< 0.02 ppm
Aluminium (Al)	< 0.05 ppm
Copper (Cu)	< 0.01 ppm
Cobalt (Co)	< 0.01 ppm
Silica (SiO ₂)	
Reactive silica	< 10 ppm
Colloidal silica	< 0.1 ppm
Particle Size	< 5 microns
Turbidity	< 0.5 NTU
Silt Density (SDI ₁₅)	< 1
Total Organic Carbon (TOC)	< 1 ppm
Fats, Oils and Grease	0 ppm

Table 5a: Hydranautics pH and Temperature Limits for Cleaning Standard Membranes

Membrane Family	Continuous Operation		Maximum Cleaning Temp			
	< 45 °C	≤ 35 °C	50 °C	≤ 45 °C	≤ 35 °C	≤ 25 °C
NANO-SW	3 to 8.5	3 to 9	Contact Hydranautics Technical Department	Contact Hyd Tech Dept	1 to 10.5	1 to 11.5
ESNA	3 to 9.5	2 to 10	Contact Hydranautics Technical Department	2 to 10.5	1 to 11	1 to 12
ESPA	3 to 10	2 to 10.6	Contact Hydranautics Technical Department	2 to 10.5	1 to 11	1 to 12
ESPAB	3 to 10.5	2 to 11	Contact Hydranautics Technical Department	2 to 11	1 to 11.5	1 to 12.5
LFC	3 to 9.5	2 to 10	Contact Hydranautics Technical Department	2 to 10.5	1 to 11	1 to 12
CPA	3 to 10.5	2 to 11	Contact Hydranautics Technical Department	2 to 11.5	1 to 12	1 to 13
SWC	3 to 10.5	2 to 11	Contact Hydranautics Technical Department	2 to 11	1 to 12	1 to 13

Note: The above cleaning parameters denote the maximum temperature limits for a corresponding range of pH. Cleaning operations performed at the extremes may result in a more effective cleaning, but can shorten the useful life of the membrane due to hydrolysis. To optimize the useful life of a membrane, it is recommended to use the least harshest cleaning solutions and minimize the contact time whenever possible. The pH of the feed stream or cleaning solution should be closely monitored and controlled. The pH meters used to measure and control pH should be regularly calibrated to ensure accuracy. It is typical to re-circulate cleaning chemicals through the RO for 1 hour. At the pH limits shown above, cleaning exposure at temperatures less than 40 °C is limited to 60 minutes, at temperatures greater than 40 °C exposure is limited to 30 minutes. Extended soaking is possible, but at less aggressive pH levels.

Table 5b Hydranautics pH and Temperature Limits for Cleaning PRO Series Membranes

Membrane Family	Continuous Operation		Maximum Cleaning Temp			
	< 45 °C	≤ 35 °C	50 °C	≤ 45 °C	≤ 35 °C	≤ 25 °C
PRO-XS	3 to 8.5	3 to 9	Contact Hydranautics Technical Department	Contact Hyd Tech Dept	1 to 10.5	1 to 11.5
PRO-XT1	3 to 9.5	2 to 10	Contact Hydranautics Technical Department		2 to 10.5	1 to 11
PRO-XT2, PRO-LF1,XP PRO-XR1	3 to 10.5	2 to 11	Contact Hydranautics Technical Department		2 to 11	1 to 12

Note: The above cleaning parameters denote the maximum temperature limits for a corresponding range of pH. Cleaning operations performed at the extremes may result in a more effective cleaning, but can shorten the useful life of the membrane due to hydrolysis. To optimize the useful life of a membrane, it is recommended to use the least harshest cleaning solutions and minimize the contact time whenever possible. The pH of the feed stream or cleaning solution should be closely monitored and controlled. The pH meters used to measure and control pH should be regularly calibrated to ensure accuracy. It is typical to re-circulate cleaning chemicals through the RO for 1 hour. At the pH limits shown above, cleaning exposure at temperatures less than 40 °C is limited to 60 minutes, at temperatures greater than 40 °C exposure is limited to 30 minutes. Extended soaking is possible, but at less aggressive pH levels.

**Table 6a: Cleaning Flow Rates per RO Pressure Tube
(Non LD Elements = 26 mil spacer)**
(Pressures are not to exceed 60 psi (4 bar) at inlet to tubes.)

Element Diameter	GPM	LPM
4-inches – Non LD Elements	9 to 12	34 to 45
6-inches – Non LD Elements	18 to 24	68 to 91
8-inches – Non LD Elements	36 to 48	136 to 182
8.5-inches – Non LD Elements	40 to 52	151 to 197
16-inches – Non LD Elements	144 to 192	545 to 727

**Table 6b: Cleaning Flow Rates per RO Pressure Tube
(LD Elements = 34 mil spacer)**
(Pressures are not to exceed 60 psi (4 bar) at inlet to tubes.)

Element Diameter	GPM	LPM
4-inches – LD Elements	10 to 13	38 to 49
8-inches – LD Elements	40 to 53	151 to 201
8.5-inches – LD Elements	45 to 59	170 to 223

Note: In cases where the pressure drop in the membrane elements is excessively high, the cleaning flow rates should be limited to 1/3 of the normal cleaning flow rate initially. This will help prevent the element from telescoping and the feed spacer from migrating. As the foulant is removed, the cleaning flow can slowly be brought up to normal cleaning flow rates. When flushing system before and after cleaning flow rates should be half of values listed in Table 6.

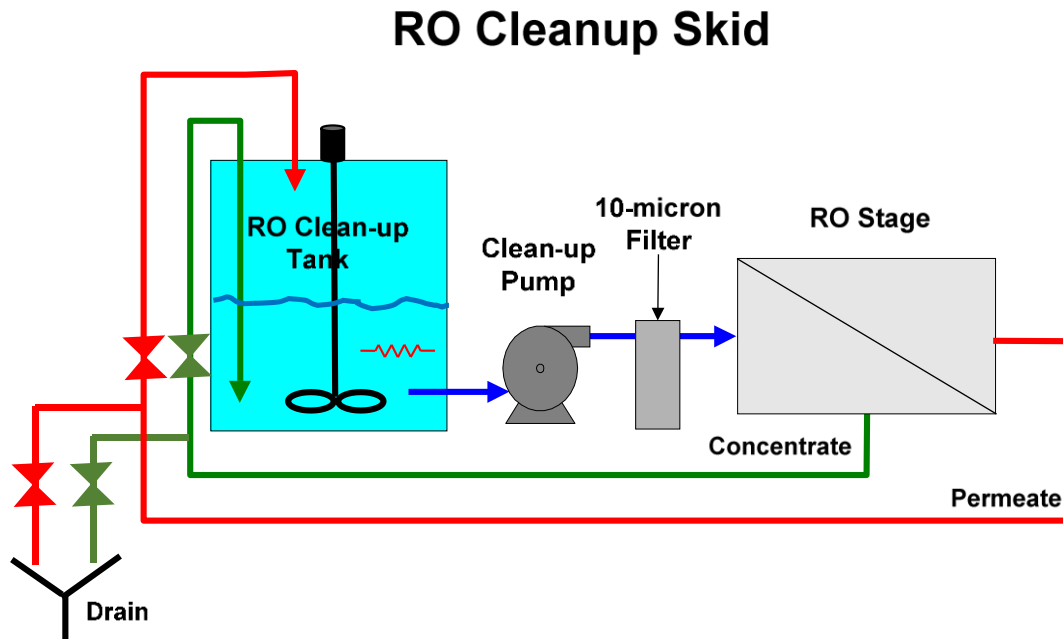
Table 7: Cleaning Solution Volume Requirement per RO Element

Element Size	Volume of Cleaning Solution*	
	(US Gallons)	(Liters)
(inches)		
4 x 40	2.5	9.5
6 x 40	5	19
8 x 40	9	34
8.5 x 40	10	38
16 x 40	36	136

(*) These are the minimum values recommended for sizing of the cleaning tank. Actual volume used during cleaning can be higher as more than one cleaning tank volume may be required in case of heavy fouling.

RO Cleaning Skid

The successful cleaning of an RO on-site requires a well designed RO cleaning skid. Normally this skid is not hard piped to the RO skid and uses temporary hosing for connections. It is recommended to clean a multi-stage RO one stage at a time to optimize cross-flow cleaning velocity. The source water for chemical solution make-up and rinsing should be clean RO permeate or DI water and be free of hardness, transition metals (e.g. iron), and chlorine (See Table 4 above). Components must be corrosion proof. Major cleaning system components are:



- **RO Cleaning Tank:** This tank needs to be sized properly to accommodate the displacement of water in the hose, piping, and RO elements. The **Table 7** above denotes the amount of chemical solution that needs to be made for a single RO element. The tank should be designed to allow 100 % drainage, easy access for chemical introduction and mixing, a recirculation line from the RO Cleaning Pump, proper venting, overflow, and a return line located near the bottom to minimize foam formation when using a surfactant.
- **RO Cleaning Pump:** This pump needs to be sized to develop the proper cross-flow velocity to scrub the membrane clean. The maximum recommended pressure is 60 psi (4 bar) at the inlet to the pressure vessels to minimize the production of permeate during cleaning and reduce the convective redeposition of foulant back on to the membrane surface. Table 6 above denotes the flow rate ranges for each pressure tube. The high pressure pump should not be used for cleaning.
- **RO Cleaning Cartridge Filter:** Normally 5 to 10-micron and is designed to remove foulants that have been displaced from the cleaning process.
- **RO Tank Heater or Cooler:** The maximum design temperature for cleaning is 113° F (45° C). It should be noted that heat is generated and imparted by the RO Cleaning Pump during recirculation. A less expensive option to consider for heating the cleaning solution is adding a return line from the discharge of the Clean-Up Pump back to the Cleaning Tank, which is plumbed to the bottom of the tank to reduce foaming and air introduction, but this can take a long time.
- **RO Tank Mixer:** This is recommended to get optimal mixing of chemical, though some designers rely solely on the slow introduction of chemical while maintaining a recirculation through the RO Cleaning Pump back to the tank.

- Instrumentation: Cleaning system instrumentation should be included to monitor flow, temperature, pressure, and tank level.
- Sample Points: Sample valves should be located to allow pH and TDS measurements off the RO Cleaning Pump discharge and the concentrate side recirculation return line. Permeate can be measured at the RO skid sample valves.
- Permeate Return Line: A small amount of the cleaning solution can permeate through the membranes and so a permeate-side return line back to the RO Cleaning Tank is required. The permeate return line should not be combined with the concentrate return line. If the permeate return line is combined with the concentrate line, there is the possibility that the permeate side of the membrane and the permeate lines may be exposed to contaminated cleaning solution. The permeate return line should terminate at a point above the cleaning solution tank level to avoid exposing the permeate side of the membranes or the permeate lines to the contaminated cleaning solution.
- Concentrate Return Line: The concentrate return line should terminate near the bottom of the cleaning tank to avoid foam formation in the cleaning tank caused by the introduction of air.

Important: The permeate line and any permeate valves must always be open to atmospheric pressure during the cleaning and flushing steps or damage to RO elements can occur. If the permeate line is closed, the permeate pressure can build up and become higher than the feed-side pressure of the tail elements. This can result in excessive permeate back-pressure which can damage the membrane glue lines in the tail elements. At no time should the elements be exposed to permeate back pressure
(where permeate static pressure exceeds feed static pressure) greater than 0.35 bar (5 psig.)

RO Membrane Element Cleaning and Flushing Procedures

The RO membrane elements can be cleaned in place in the pressure tubes by recirculating the cleaning solution across the high-pressure side of the membrane at low pressure and relatively high flow. A cleaning unit is needed to do this. RO cleaning procedures may vary dependent on the situation. The time required to clean a stage can take from 4 to 8 hours. It is recommended to take data for RO performance normalization just before and immediately after the cleaning to evaluate the efficiency of cleaning. It may also be beneficial to start the RO rack after first cleaning step (alkaline or acid) and collect data for normalization to evaluate efficiency of each cleaning step separately.

A general procedure for cleaning the RO membrane elements is as follows:

NOTE: The permeate valves should ALWAYS remain open when cleaning or flushing the elements. If the permeate valve is closed, the pressure on the permeate line will equalize to the feed pressure. This is likely greater than the concentrate pressure, which will result in the permeate pressure being greater than on the feed side of the tail element. This may result in membrane delamination and performance failure.

1. Perform a low pressure flush at 60 psi (4 bar) or less of the pressure tubes by pumping clean water from the cleaning tank (or equivalent source) through the pressure tubes to drain for several minutes to displace any feed/brine solution from RO membranes. Flush water should be clean water of RO permeate or DI quality and be free of hardness, transition metals, and chlorine. Flushing flow rates should normally be half of the cleaning flow rates listed in Table 6.
2. Mix a fresh batch of the selected cleaning solution in the cleaning tank. The dilution water should be clean water of RO permeate or DI quality and be free of hardness, transition metals, and chlorine. The temperature and pH should be adjusted to their target levels.

Check and record also the conductivity, turbidity and Iron concentration of freshly prepared cleaning solution.

3. Circulate the cleaning solution through the pressure tubes for the desired period of time. At the start of circulation, send the displaced water to drain so you don't dilute the cleaning chemical and then divert up to 20% of the most highly fouled cleaning solution to drain before returning the cleaning solution back to the RO Cleaning Tank. For the first 5 minutes, slowly throttle the flow rate to 1/3 of the maximum design flow rate. This is to minimize the potential plugging of the feed path with a large amount of dislodged foulant.. For the second 5 minutes, increase the flow rate to 2/3 of the maximum design flow rate, and then increase the flow rate to the maximum design flow rate. If required, readjust the pH back to the target when it changes more than 0.5 pH units. Temperature of cleaning solution should be controlled and kept at maximum allowed value during the whole cleaning cycle for best cleaning efficiency. After each circulation step, check the conductivity, turbidity and Iron content of cleaning solution. If these will increase significantly compared to the initial startup values, the cleaning solution shall be drained and new solution prepared to continue with cleaning to improve cleaning efficiency.

Note: *Do not exceed maximum pH and temperature limits for specific elements. See Table 5.*

4. A soak and recirculation sequence is sometimes used during cleaning. The soak time can be from 0.5 to 8 hours depending on the manufacturer's and/or chemical supplier's recommendations. Typically, the cleaning consists of 30 minutes circulation followed by a 30 minutes soaking cycle, followed by another 30 minutes of circulation. Caution should be used to maintain the proper temperature and pH during the whole cleaning cycle. Soaking time does increase the chemical exposure time of the membrane.

Note: *Do not exceed maximum pH and temperature limits for specific elements. See Table 5.*

5. Upon completion of the chemical cleaning steps, a low pressure Cleaning Rinse with clean water (RO permeate or DI quality and free of hardness, transition metals, and chlorine) is required to remove all traces of chemical from the Cleaning Skid and the RO Skid. Drain and flush the cleaning tank; then completely refill the Cleaning Tank with clean water for the Cleaning Rinse. Rinse the pressure tubes by pumping all of the rinse water from the Cleaning Tank through the pressure tubes to drain. A second cleaning can be started at this point, if required. Cleaning rinse flows should be half of those used for cleaning as listed in Table 6.
6. Once the RO system is fully rinsed of cleaning chemical with clean water from the Cleaning Tank, a Final Low Pressure Clean-up Flush can be performed using pretreated feed water. The permeate line should remain open to drain. Feed pressure should be less than 60 psi (4 bar). This final flush continues until the flush water flows clean and is free of any foam or residues of cleaning agents. This usually takes 15 to 60 minutes. The operator can sample the flush water going to the drain for detergent removal and lack of foaming by using a clear flask and shaking it. A conductivity meter can be used to test for removal of cleaning chemicals, such that the flush water to drain is within 10-20% of the feed water conductivity. A pH meter can also be used to compare the flush water to drain to the feed pH.

7. Once all the stages of a train are cleaned, and the chemicals flushed out, the RO can be restarted and placed into a Service Rinse. The RO permeate should be diverted to drain until it meets the quality requirements of the process (e.g. conductivity, pH, etc.). It is not unusual for it to take from a few hours to a few days for the RO permeate quality to stabilize, especially after high pH cleanings.

Alternative Cleaning Procedures

Other methods of recovering membrane performance are available and may be considered. Hydranautics does not guarantee the effectiveness of these alternative procedures nor does Hydranautics accept responsibility for any adverse effect such procedures may have on membrane performance. However, Hydranautics is aware of instances where these procedures have proven to be very effective.

1. Electro Magnetic Fields (EMF). Claims have been made that the introduction of a continuous electromagnetic field (EMF) around the RO membranes during operation will reduce the tendency for the membranes to foul and will particularly reduce their tendency toward scaling. (Reference : Ng, H. Y. and Winters, H., *A Novel 16-Inch RO System for Water Reuse and Desalination*. Israel Desalination Society Annual Conference, 19-20 December, 2006.)
2. Direct Osmosis at High Salinities (DO-HS) is a process of daily backwashing of BWRO during normal operation of desalination plant in which about 7% NaCl pulse is intentionally introduced for 6-12 seconds into the suction stream of high pressure pump without stopping the pump. As the high salinity plug proceeds through the RO system, the reverse osmosis flow is momentarily changed to a direct osmosis flow and permeate is sucked back through to the feed side of the membrane. This process, if conducted regularly, may lift foulants, dehydrate bacteria, and sweep out debris by increased flow velocity from the membrane surface to the brine outlet. (Reference: USA Patent 7658852, Pat. Singapore, Australia, Israel WEB: www.membrane-recovery.com.)
3. Proprietary Cleaning Chemicals. There exist several RO cleaning chemical suppliers with a number of proprietary formulations designed to address specific types of fouling. These formulations are typically based on generic chemical formulations that have been enhanced or modified through the suppliers' own research and development. (see web sites for specific chemical companies).
4. Air Scouring. It is known that two-phase (air bubbles and water) can increase shear forces and improve the removal of foulants from a membrane surface. This has been used more in the cleaning of individual elements.
5. Reverse Direction Cleaning. When the fouling is located primarily at the feed end of the RO system, it is sometimes more effective to do reverse direction cleaning. There are certain precautions that must be taken to ensure that damage to the membrane elements does not occur. Please see TSB-125 "Reverse Direction Cleaning of RO Membrane Elements" for the guidelines on this.
6. NaCl light salinity cleaning. As compared to the DO-HS above, NaCl light salinity is usually dosed at 1% weight of total cleaning volume. Dissolve the NaCl into the CIP tank and it can be used in 2 different ways. First, as an NaCl solution by itself to use as a pre-cleaner prior to standard High / Low pH solutions or, Second, as a supplement to High / Low pH solutions. NaCl increases osmotic pressures of solution to suppress the production of permeate while cleaning.

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