# PermaCare®

## Membrane Chemicals

## By Nalco

# PermaCare® and RO

# PermaCare® Membrane Separations

PermaCare Membrane Separations Group is an Nalco sales support team that has over 50 years of practical experience in membrane technology throughout the world. This team supports Nalco field engineers to ensure our customers have access to world class products and services that enhance the performance of membrane systems.

These products include PermaTreat® scale inhibitors, PermaClean® membrane cleaners and biocides designed specifically for membrane systems. PermaCare services include membrane autopsy, plant evaluations, training, field cleanings, pretreatment and cleaning recommendations along with general support.

**Scale Inhibitors.** In addition to having antiscalants that can cover the demand of most water qualities, our products can also provide protection against high levels of iron and silica. All products are tested thoroughly to ensure compatibility with today's membranes.

**Cleaners.** Different types of cleaners are needed depending upon the type of scaling or fouling that is on the membrane. The PermaCare product range contains both acid and alkaline cleaners that have been tested to be compatible with today's membrane elements.

**Microbial Biocides.** Biofouling or microbiological contamination is one of the most common and difficult problems to treat in a membrane system. The PermaCare product range has non-oxidizing biocides that can handle a wide spectrum of microorganisms. Our biocides are well accepted for industrial applications when in-line "shock dosing" is desired in order to control microbiological growth without shutting down the system as well as for membrane preservation.

**Membrane Autopsy.** In order to determine the cause of plant performance decline, a membrane autopsy can be carried out that will identify the cause of the performance decline such as the type of fouling, scaling and mechanical damage of the membrane.

**Training.** PermaCare provides on-site training to plant operators and supervisors of membrane systems. This training is designed to provide operators with the basics and fundamentals of membrane system pretreatment, operation, monitoring and treatment. Our experience shows that improved operator understanding of membrane system operations, translates into better performance and extended membrane life.

*(Continued on Reverse Side)*

**Plant Evaluations.** For troubled installations that require frequent cleanings or have plant performance problems, PermaCare can send their specialist to inspect the installation to determine the cause of the problem and recommend a solution.

**Pretreatment and Cleaning Recommendations.** Based on the water analysis and system operation, PermaCare can recommend the optimum pretreatment. Also, in cases where there are plant problems, a change in pretreatment or cleaning regime can be recommended for better plant operation. When needed, a PermaCare specialist can assist the customers in cleaning the membrane system on-site.

## Remarks

For more information on PermaCare Programs and Services, contact your nearest Nalco representative or office:

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For more news about Nalco and PermaCare programs, visit our website at www.nalco.com.

PermaCare®

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Questions and Answers

# Reverse Osmosis PermaCare®

## Water Treatment Program

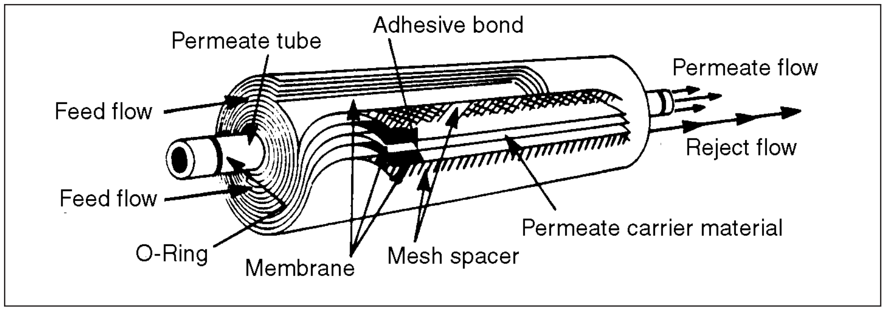



**Figure 1** — *Spiral wound membrane*

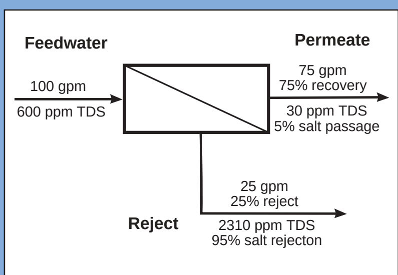



**Figure 2** — *Reverse osmosis basics*

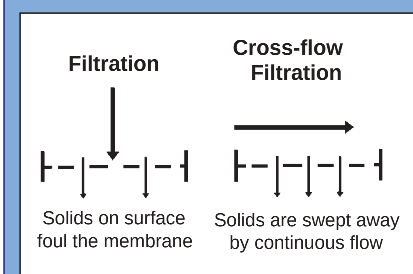



**Figure 3** — *Conventional and cross-flow filtration*

## What is Reverse Osmosis (RO)?

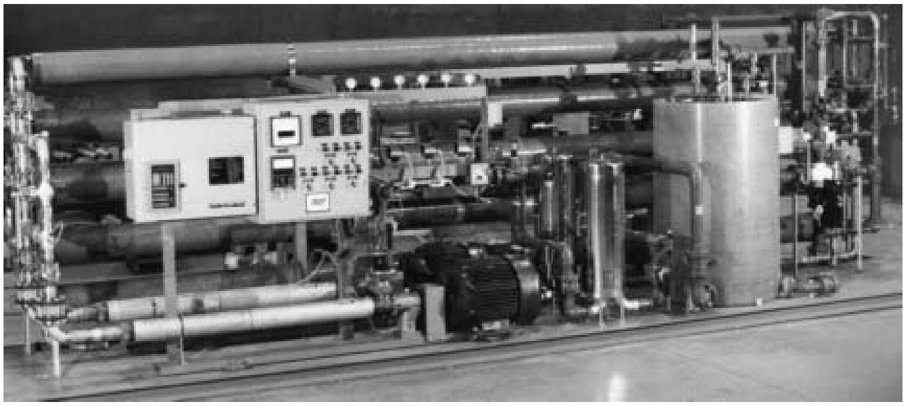
Reverse osmosis is a process that forces a feedwater stream containing dissolved impurities (salts and organics) through a semi-permeable membrane into two separate streams: one of purified water or permeate and one of removed solids (concentrate or reject). See Figure 1. Water pressure is used to reverse the natural osmotic tendency of the solution, hence the name reverse osmosis.

RO uses a membrane that is permeable to water and gases but not to ions or organics that may be present in the water. As the feedwater passes through the membrane, the ions and organics are left behind in the reject and the permeate remains with 90 to 98% fewer impurities. Permeate recoveries are typically limited to 75% due to the limited solubility of the dissolved salts left behind in the reject (Figure 2).

## How does RO differ from filtration?

Conventional filtration of suspended solids is accomplished by passing a feed solution through a filter media in a perpendicular direction (Figure 3). The entire solution passes through the filter media, creating only one exit stream. This type of filtration is generally referred to as dead-end filtration. Examples of this type of filtration include cartridge filters, bag filters, sand filters, and multimedia filters. These filtration methods are generally limited to suspended particles greater than 1 micron.

For the removal of small particles, colloids, and dissolved salts, a different method of particle removal is employed using a membrane where particles are captured on the surface, rather than a filter media, where particles are captured both on the surface and in the filter media matrix itself. Furthermore in this process the feed stream is pressurized and flows parallel to the membrane surface, and a portion of this stream passes through the membrane, which is the permeate, leaving behind the rejected particles in the reject. Since there is a continuous flow across the membrane surface, the rejected particles do not accumulate but instead are swept away



*Typical RO system for Industrial Applications*

by the concentrate stream. Cross flow membrane filtration is characterized by the size of particles removed. Micro filtration (MF) typically removes particles larger than 0.1 micrometers in diameter, Ultra filtration (UF) removes particles and dissolved solids larger with a molecular weight exceeding 1000, Nano filtration (NF) removes dissolved solids and many multivalent salts exceeding 200 molecular weight. Reverse Osmosis (RO) removes most dissolved materials, including dissolved salts down to a molecular weight of 10 or 20.

## What are the basic types of RO and NF membranes?

The RO and NF membrane consists of a very thin, dense skin on the surface of a thick microscopically porous film. There are two basic types of membrane that have been developed: cellulose acetate (CA) and thin film composite (TFC). Thin film composite membrane performance exceeds that of CA in most respects, and CA is only used in very special circumstances. A basic comparison between the two types of membranes is shown in Table 1.

Most RO installations operating today use TFC membranes.

**Table 1** — *Membrane comparisons*

| | Cellulose acetate | Thin film composite |
|---|---|---|
| pH range | 5.0–6.5 | 2–11 |
| Average % rejection | 95% | 98% |
| Microbio susceptibility | Yes | No |
| Temperature limit | 104°F | 112°F |
| Chlorine tolerance | Excellent | Poor |
| Typical operating pressure | 400 psi | 200 psi |

## Why is RO or NF used in water pretreatment?

RO can economically treat water that is moderate to high (500 to 3000 ppm) in total dissolved solids (TDS) *and have a conductivity of less than 40,000 mmho/cm from NaCl.* After RO treatment, the permeate will typically have 5% of the TDS remaining in solution that may not be adequate for high pressure boilers. Ion exchange, on the other hand, economically treats water that is low to moderate (<500 ppm) in TDS and retains only 1 to 3% TDS but is less effective in removing organics and silica that can lead to carryover and additional regeneration.

RO systems are occasionally used prior to ion exchange to reduce the TDS loading and decrease the amount of hazardous material used and stored. The benefits of using both systems together are increased savings due to:

- Decreased regenerant usage
- Extended resin life
- Extended run lengths
- Less organic fouling of the anion resin
- Improved water quality
- Lower manpower and maintenance requirements

For example, a typical 600 ppm TDS water that is treated by RO would have an effluent of approximately 30 ppm TDS, and treated by ion exchange would be approximately 12 ppm TDS. If this same water was treated by RO followed by ion exchange, the effluent would be approximately 1 ppm TDS (Figure 4). Therefore, plants that use both systems together can obtain an effluent water which is approximately 30 times more pure than RO alone, and 10 times more pure than ion exchange.

## When is NF used rather than RO?

In instances where the TDS consist mainly of organic compounds rather than monovalent salts (such as sodium and chloride) NF is a more economic alternative due to the much lower operating pressure. NF is also a good solution when most of the dissolved salts are multivalent (i.e. sulphate or carbonate).

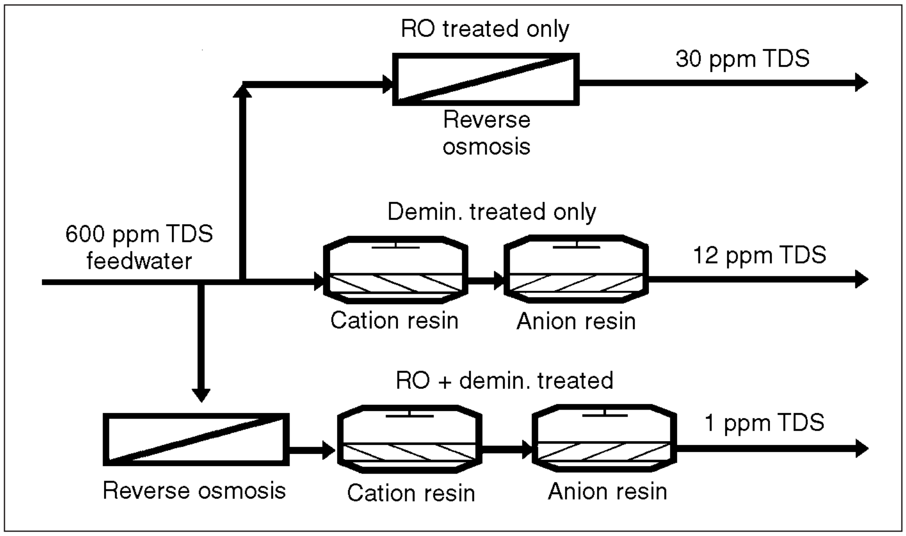



**Figure 4** — *RO and ion exchange treated water systems*

## What effect does temperature have on membrane performance?

Temperature has a direct impact on membrane performance. An increase in water temperature increases the permeate flow and also the passage of salts. As a consequence, if a system is operated at constant permate flow and the temperature increases, the quality of the permeate is reduced. The temperature effect can range from 1.0 to 2.0% increase in permeate flow per degree increase in temperature.

## What are the major causes of premature membrane failure?

Scaling, fouling, and membrane degradation (oxidation of TFC membranes, hydrolysis of CA membranes). RO systems are designed to use water velocity and recycling (if demand is variable) to keep the membrane surfaces clean of deposits and foulants. Unfortunately, changes in water quality and equipment can cause deposits that can lead to decreased permeate flow, poor water quality, membrane replacement, and unscheduled downtime.

## What Nalco chemicals are available to solve these problems?

The PermaCare product line has been developed to address the major problems associated with RO membranes: scaling, fouling, and degradation (see Table 2). These products are compatible with both CA and TFC membranes and have been approved by most major membrane manufacturers.

## What is membrane degradation?

RO membranes can degrade or hydrolyze when exposed to oxidants (e.g. sunlight, chlorine), pH changes, biodegradation, or temperature extremes. Once hydrolysis or degradation begins to occur, the water quality, permeate flow and membrane life will be adversely affected. It is extremely important to operate RO membranes within their designed pH and temperature ranges, and avoid the use of chemical oxidants that are not approved by the membrane manufacturers.

## How do I avoid oxidative damage to membranes?

Oxidative degradation is only a factor for TFC membranes. In order to insure that no oxidative damage occurs it is important to verify that the feed water does not contain any oxidizer such as chlorine or peroxide. For some feed waters it is necessary to add a reducing agent such as sodium bisulfite, or filter the water through an activated carbon filter to insure safe operation of the membrane system.

## What is the difference between scaling and fouling?

Foulants are soft, noncrystalline deposits that adhere to the membrane's surface. Typical foulants are: colloids, oil, metal oxides, silica, and microbes. Foulants are normally formed from suspended matter found in the feedwater. Foulants can be controlled with good pretreatment, regular maintenance (cleaning), and use of antifoulants.

Mineral scales are hard, crystalline deposits that adhere to the membrane's surface. The major scalants are: $CaCO_3$, $CaSO_4$, $BaSO_4$, $SrSO_4$, and $CaF_2$. Mineral scales are normally formed from dissolved solids that have concentrated in the membrane. Scale can rapidly cause the demise of the membrane. Mineral scale can be controlled by optimizing the pretreatment, flow rates, use of antiscalants, and regular maintenance (cleaning).

## Can the RO's cartridge prefilter prevent scaling or fouling?

No. The purpose of the cartridge prefilter is to protect the membranes from large debris that can physically block the flow channels.

**Table 2** — *PermaCare product offering*

| Antiscalants | | | |
|---|---|---|---|
| **Product** | **Application** | **Water type** | **Installation type** |
| PC-1100 | Broad spectrum, general purpose | Low to moderate scaling | Municipal |
| PC-1850 | Broad spectrum, general purpose | Low to moderate scaling | Municipal |
| PC-191/T | Broad spectrum, high performance | Moderate to high scaling | Industrial & Municipal |
| PC-391/T | Broad spectrum, high performance | Moderate to high scaling | Industrial |
| PC-1020/T | Broad spectrum, high performance | Moderate to high scaling | Municipal |
| PC-1638T | Broad spectrum, high performance | Moderate to high scaling | Municipal |
| PC-504 | Sulfate scaling | High sulfate | Industrial & Municipal |
| PC-510/T | Silica scaling | High silica | Industrial & Municipal |

| Cleaners | |
|---|---|
| **Product** | **Effective removal of** |
| PC-33 | acid insoluble scale |
| PC-67 | organic materials |
| PC-77 | iron fouling |
| PC-87 | inorganic, acid soluble scale |
| PC-99 | organic debris and biofouling |

| Biocontrol agents | | |
|---|---|---|
| **Product** | **Application** | **Unique use** |
| PC-11 | Eliminate most microbial growth | Fast acting, broad spectrum |
| PC-55 / 56 | Eliminate most microbial growth | Stable, broad spectrum<br>Membrane preservation |

| Pretreatment | |
|---|---|
| **Product** | **Application** |
| PC-305 | Medium/High Molecular weight organic polymer, effective over a broad pH range |
| PC-306 | Medium/High Molecular weight organic polymer, effective over a broad pH range |
| PC-407 | Low Molecular weight, high activity organic polymer, effective over a broad pH range |
| PC-603 | Ferric coagulant with organic polymer for mid-range pH |
| PC-604 | Ferric coagulant with low molecular weight organic polymer for mid-range pH |
| PC-607 | Ferric coagulant formulation for mid-range pH |
| PC-707 | Anionic polymeric flocculant |

These filters will remove most large particles, such as sand or anthracite, but will not stop small fines of diatomaceous earth or carbon from passing through the 1–10 micron filter and plugging the membrane. Since most foulants can be below 1 micron in size, the prefilter provides little protection. The best way to prevent scaling or fouling of your system is to utilize a good pretreatment, monitoring, and maintenance program.

## What can be done to prevent scaling and fouling?

Solving a scaling problem may involve slowing down the precipitation process by reducing the percent recovery, injecting antiscalant, altering the pH, changing the acid from sulfuric to hydrochloric, or periodically cleaning the system.

Solving a fouling problem may include such things as improving the pretreatment, pH adjustment to prevent precipitation, or use of antifoulants. Sanitizers may be required to prevent the growth of microbes. Cartridge prefilters can help remove large suspended solids (>1 micron).

## Why are antiscalants and antifoulants important?

Antiscalants and antifoulants are generally polymer solutions or phosphonate formulations that inhibit the formation and growth of carbonate and sulfate scales (e.g., $CaCO_3$, $CaSO_4$), silica or iron. By modifying the crystalline structure of the scale-forming minerals, they don't adhere well to the membrane surface and are removed with the concentrate.

For antiscalants or antifoulants to work properly, they must be fed continuously.

*Municipal RO Installation*

## What are the benefits of using an antiscalant or antifoulant?

These products provide the following benefits:

- Minimize or eliminate acid feed for scale control
- Help suspend dissolved solids and colloids in solution, thus minimizing membrane fouling
- Inhibit the precipitation of slightly soluble salts

## If I have problem on my TFC membranes, what should I do?

If microbial fouling causes a problem with the membrane, a sanitizer may be required. A sanitizer can quickly eliminate the microbial growth contaminating the system. Continual monitoring of the system is recommended to assure complete removal.

## What are the effects of increasing the percent recovery?

Depending on the water source RO or NF systems are designed for 40%-90% recovery. Increasing the percent recovery reduces the reject flow, which can lower the initial water and pretreatment costs and reduce energy consumption. However, as the recovery is increased there is a higher likelihood of membrane fouling and scaling, and hence the need for pretreatment and antiscalants is increased.

As recovery is increased it becomes critical that the right antiscalant is selected, and that the antiscalant dose is appropriate based on the specific water chemistry. Furthermore, maintaining and controlling antiscalant concentration is essential to guarantee trouble free operation.

## What are the three operating parameters that should be monitored daily?

The three most important parameters that should be monitored and graphed on a daily basis are: normalized permeate flow, differential pressure, and percent salt rejection. These simple measurements help indicate the extent of scaling or fouling in the membranes. These problems must be caught as early as possible to prevent premature membrane replacement.

***Normalized Permeate Flow*** — The normalized permeate flow is one of the most sensitive forecasters of trouble in an RO system. Fouling can reduce the permeate flow rate, whereas, membrane degradation may increase it. Just measuring the permeate flow rate, however, is not sufficient because it varies with the feedwater temperature, feed pressure, and feedwater TDS. Normalized permeate flow is a simple calculation that corrects for temperature and pressure variations and adjusts the readings to what they would be if the system were operating at start-up pressure and 25 °C. If the normalized permeate flow rate is plotted, the fouling trends are easily observed. The graph alerts the operator to take corrective measures before irreversible damage occurs.

***Differential Pressure*** — The differential pressure is the difference between the feed pressure and the concentrate pressure. It is a measure of the hydraulic pressure losses through the RO membrane elements and the manifold piping. When the flow channels become clogged, the differential pressure increases. The differential pressure also depends upon the feed flow rate and the percent recovery. To accurately compare differential pressure readings taken at different times, make sure that the RO is adjusted to the same percent recovery and feed flow rate.

***Percent salt rejection*** — The percent salt rejection is the percentage of TDS that is rejected by the RO. When the RO membranes are in trouble, the percent salt rejection will usually decrease; however, certain foulants can plug the membrane and cause the percent salt rejection to actually increase.

## How do I know when the RO requires cleaning?

The RO system should be cleaned whenever one or more of the following occur: a decrease of 10 to 15% in either the normalized permeate flow or the percent salt rejection or a 10 to 15% increase in the differential pressure. Whenever a parameter is found to be high or abnormal, always check the instrument calibrations for accuracy before taking corrective action.

## What is a typical cleaning frequency?

As a rule of thumb, for industrial installatiions, if you are cleaning your system every month or less, further pretreatment or chemical addition is normally justified. If the cleaning frequency is greater than every month, additional pretreatment or chemical addition must be based on economic considerations.

In municipal drinking water installations the cleaning frequency is typically every 6-12 months.

## Which cleaner should I use?

PermaCare cleaners are specially formulated for removing deposits from RO membranes. There are two simple steps that can be used to determine the proper cleaner:

1. Determine the composition of the foulant on the membrane (contact your Nalco representative for more information).

2. Identify the appropriate PermaCare cleaner based on your particular foulant.

Nalco provides an autopsy service that will help you identify the membrane foulant, and specifies the best cleaning procedue to remove the foulant and restore membrane performance.

## What is a membrane autopsy?

PermaCare Autopsy service is a destructive analytical procedure to identify the foulants on the membrane surface. The autopsy procedure includes chemical and microbiological analysis, cleaning tests, ESEM and physical tests on the membrane.

The information obtained in an autopsy, combined with system design and operating data, will in most cases provide an accurate diagnosis of the cause of performance problems encountered in an RO or NF system. Based on this diagnosis corrective action can be taken to restore system performance.

## Have more questions about how to monitor and maintain your RO system?

Contact your local Nalco representative for more information.

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# What Do I Need to Think About When I'm Thinking About Installing a Reverse Osmosis System in My Industrial Plant

By Nalco Company

Reprint R-714


## SUMMARY

*Far too often the actual performance of a reverse osmosis system does not match up to the expectations of the system's owner. This often leads to excessive costs, frustration, and dissatisfaction with the supplier of the system. These unmet expectations are sometimes caused by a poor understanding on the part of the purchaser with regards to necessary system requirements which will enable the system to perform to expectations. This poor understanding leads to poor choices in the definition and specification stage of the project. This paper will attempt to help the purchaser of these systems define the important design parameters of the system so a better specification of the system can be written. Better specifications will help the system perform to the expectations of the purchaser.*


## INTRODUCTION

The application technology of reverse osmosis is improving every day. New membranes are very exciting and give the user much broader choices, allowing reverse osmosis systems to be better designed for specific applications. This means better performance and lower operating costs can be achieved. However, all too frequently these cost savings are not achieved and the performance expectations of the purchaser are not met. This can lead to a lot of frustration and animosity between the supplier and the purchaser of the system. Much of this could be avoided if the purchaser/user of the system became more knowledgeable of reverse osmosis technology upfront. This would allow them to write a much better specification for quotation — a specification that would provide the equipment, control, and training required to fully meet their expectations.

Every decision that requires capital expenditures for system upgrades, expansion, or new plants requires thorough economic analysis. Economic choices and compromises must be made. It is difficult to buy a new Mercedes when you only have enough money for a Ford Escort. However, driving any car in Dallas, Texas, without air conditioning is a miserable experience. Air conditioning is an option that is worth the expense for somebody living in Dallas. Upfront knowledge will allow one to make good economic decisions throughout the buying process. This will help the system meet the expectations of the purchaser and help the purchaser realize the downside risks and costs associated with the decisions being made.

Almost all industrial reverse osmosis systems being installed today utilize spiral wound membranes. While much of what is being said will apply to all reverse osmosis systems, the spiral wound system will be the focus of this paper. It is not within the limits of this paper to get into the specific details of various membranes and system configurations, but to simply bring to the attention of the potential purchaser/user areas of system design that must be focused and decided upon when writing system specifications.

## REVERSE OSMOSIS BASICS

There are several concepts in reverse osmosis system design that will help any purchaser specify and operate the system better.

Reverse osmosis is a crossflow filtration technology that is capable of removing contaminants in water down to the ionic level. It will also definitely remove anything in the water that is larger. Fouling by colloidal silt, scaling, and biological growth is the major operating problem in reverse osmosis systems and the potential for this fouling problem must be adequately handled in the system's design so major operating problems and costs are avoided.

You can see why bacteria are such a major problem when you look at how they can multiply with time (Table 1). Even one bug getting through the pretreatment system can eventually cause a problem.

A typical industrial reverse osmosis machine looks similar to Figure 1 where membranes are positioned in series within a pressure vessel. Several pressure vessels are positioned in parallel to form a stage, and

Presented at the International Water Conference, Pittsburgh, Pennsylvania, October 19–21, 1998.

**Table 1 — *Bacteria Growth***

| TIME, HOURS | # OF BACTERIA |
|---|---|
| 0 | 1 |
| 0.33 | 2 |
| 0.67 | 4 |
| 1 | 8 |
| 1.33 | 16 |
| 1.67 | 32 |
| 2 | 64 |
| 2.33 | 128 |
| 2.67 | 256 |
| 3 | 512 |
| 3.33 | 1,024 |
| 3.67 | 2,048 |
| 4 | 4,096 |
| 5 | 32,768 |
| 6 | 262,144 |
| 7 | 2,097,152 |
| 8 (First Shift) | 16,777,216 |
| 16 (Second Shift) | 281,470,000,000,000 |
| 24 (Third Shift) | 4,722,400,000,000,000,000,000 |

Source: DHP Inc.[1]

two or more stages are positioned in series to form a given array. The second stage is often designed to use the concentrate, leaving the first stage to improve system recovery.

Consider what is actually occurring as water passes through this system (Figure 2). The entire flow of feedwater passes through the lead membrane but some of the water is diverted by the membrane as permeate. Therefore, the feed to the second membrane is both slower and more concentrated in dissolved solids than the feed to the membrane in front of it. This process continues down the pressure vessel until the flow becomes too slow to maintain turbulent flow across the membrane's surface. Just before this point is where the second stage utilizing about half the membranes of the first stage is positioned. Computers calculate system design so the last membrane element in the last stage still has a feed flow and concentration within limits that will not cause problems in the operation. This is why RO systems should be operated well within their design limits. Any change that will cause an operating parameter to deviate away from the design specification has a potential for disaster. Such changes could be, but are not limited to, feed temperature, feed chemistry, or fouling which causes changes in flow rates and balance.

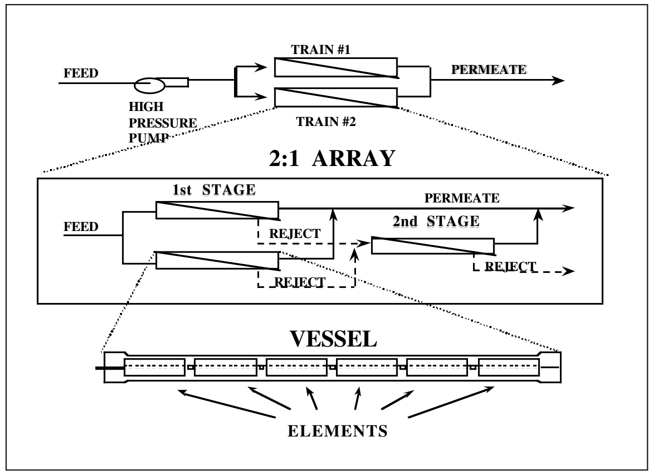


**Figure 1 — *Two-Stage RO System***

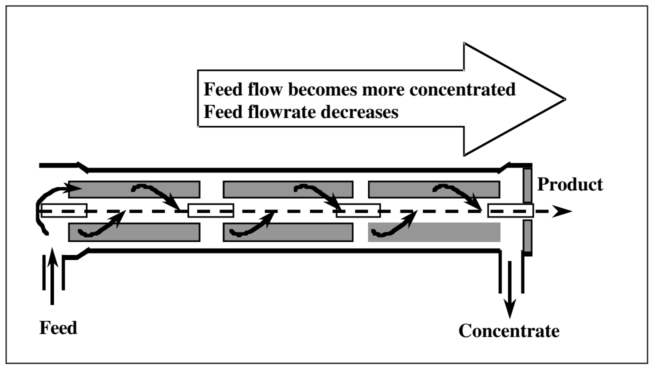


**Figure 2 — *Flow Through a Pressure Vessel***

## WATER

The next thing that must be thought about is water: how much is required, what quality do I require for the expected use, what is the source of water supply and what problems does this present.

The quantity of treated water required is usually fairly well understood but make sure future plans are included in your estimates. Also, make sure demand variations are considered in the design.

The product water quality required is dictated by the end use process. The cost of producing water generally increases with the purity of the final product. If the end use of the water doesn't require the high quality water that reverse osmosis is capable of producing, other treatment alternatives should be seriously considered. Ion exchange processes are generally more forgiving than reverse osmosis and this fact should be taken into account when deciding on the treatment process.

The chemistry and nature of the water supply must be well understood and any system design must be capable of adequately handling both best and worse case conditions. Well waters are generally more stable in temperature and chemical composition, and lower in suspended solids (SS). Each well must be considered a separate source. Surface waters can be highly variable and can change composition rapidly. They tend to be lower in dissolved solids (TDS) but often have high SS and microbio. City waters can also be quite variable based on the operation of their treatment systems and the water source.

**SAMPLING —** It is mandatory to have good baseline data on the source water quality. This data will not be reliable unless proper sampling and analytical methods are being used. Bottles should be acid washed and have plastic lid liners. Sample points should be free flowing and not located in dead legs. Never use just one sample. A series of samples covering all seasons and conditions, such as after rains or during dry spells, should be obtained. Every potential water source must be thoroughly analyzed. Table 2 lists the tests required to profile a potential water source.

## PRETREATMENT

Now that we intimately know the characteristics of our water supply, it is the pretreatment of this water before the RO that is *absolutely critical* to the successful operation of the system. Normal pretreatment methods can include clarification or lime softening, followed by several stages of filtration. The filtration can include the use of multimedia filters, carbon filters, cartridge filters and microfilters. Often, softeners are used to eliminate scale potential and to act as another filter in the system. Ultraviolet (UV) sterilizers are also being installed after cartridge filtration in an effort to minimize bacterial growth.

Good analytical work along with a thorough pilot plant study will prevent many pretreatment problems. The best test for multimedia filtration design outside of a pilot plant study is the Particle Distribution Test. All pretreatment filters or softeners should be constructed from lined vessels to minimize the potential of iron in the RO feed.

Experience proves that conservative designs usually experience fewer operating problems and can handle broader variations of the source water quality. This must be balanced with cost factors since conservative designs, while promising lower operating costs overall, are usually larger and more expensive initially. Troubleshooting experience indicates that the extra upfront cost for conservative designs are normally well worth it. Table 3 lists some conservative design figures for various equipment frequently used in RO pretreatment systems.

**Table 2 —** ***Source Water Analysis***

| Category | Specific Tests & Comments |
|---|---|
| Cations & Metals | Al, Ba, Ca, Fe, K, Mg, Na, Sr |
| Anions | $HCO_3$, $CO_3$, $SO_4$, Cl, $NO_3$, $SiO_2$, F, $PO_4$ |
| Alkalinity | Total "M" |
| Colloids | Silt Density Index (SDI), Particle Counts, Particle Profile |
| Gases | $H_2S$, $CO_2$ |
| Biological | Standard Plate Count (SPC) |
| Organic | Total Organic Carbon (TOC) |
| General | pH, Conductivity, Temperature, Ionic Strength |

**Table 3 —** ***Conservative Design Estimates for Pretreatment Equipment***

| Equipment Type | Design Guidelines & Comments |
|---|---|
| Clarifiers | 0.75-0.85 gpm/ft$^2$ for turbidity removal. |
| Multimedia Filters | 3-5 gpm/ft$^2$ - Good for particle removal down to about 10 microns. |
| Carbon Filters | 1-2 gpm/ft$^3$ - Can be a source of carbon fines and bacteria. Make sure that the filter is steam sterilizable. |
| Cartridge Filters | 2-5 gpm/10 inches of filter element length. Always specify absolutely rated filters 5µ maximum. |
| Softeners | 2 gpm/ft$^3$ - Can minimize many potential problems. |
| UV Sterilizers | 30,000 µ watt seconds/cm$^2$. May be higher based on site specific conditions. |

**Table 4 —** ***Guidelines for Judging the Efficiency of the RO Pretreatment System***

| Cleaning Frequency | Adequacy Estimate |
|---|---|
| Quarterly or less | Adequate |
| Every 1-3 months | Marginal |
| Every month or more | Not adequate |

I cannot overemphasize the importance of planning for and operating a pilot study with leased or rented equipment before the plant is constructed. This will prevent many surprises and gives your operators an opportunity to run the system and be trained in the technology.

A good guideline for the adequacy of the RO pretreatment system is the frequency of membrane cleaning that is required. Table 4 provides rule-of-thumb guidelines for judging the efficiency of the RO pretreatment system.[2]

Chemical feeds can create pretreatment problems. Cationic coagulants used in the clarification and filtration process must be carefully controlled to prevent overfeed. Streaming Current Detectors are recommended to improve the control of these products. When properly fed, coagulants are removed with the sludge in the clarification and filtration process. However, overdosing can cause soluble coagulant to get to the membrane surface and severely foul it.

Another problem can occur when a cationic coagulant reacts with an anionic scale inhibitor. A precipitate can form which will foul the membrane.

If sodium bisulfate is used to dechlorinate the feed, it should be fed as late in the system as possible.

## REVERSE OSMOSIS EQUIPMENT

We can now begin to think about the RO machine itself. The actual design of the RO machine will be based on the membranes being used.

There are many new membranes on the market today and selecting the membranes for the system is a critical decision that is no longer a simple one. Until recently, there was only a choice of Thin Film Composite (TFC) and Cellulose Acetate (CA) membranes. Most membranes specified in industrial applications are TFC, and the TFC variations available are exploding. We have high flux, high rejection, high surface area, low fouling, and heat sanitizable. Both chemistry and materials of construction vary. Different membranes can even be combined in the same system to tailor the salt rejection to the specific need. Involve the membrane manufacturers in the decision process to select the best membrane for your application.

Each membrane has its own operating characteristics and these must be taken into account in the design and operation of the RO skid. There are three things to key on:

1. Lead membrane flux
2. Last element feed rate
3. Recovery per element

Flux is the measure of permeate volume per fixed area over time. Its common unit of measurement is gallons/square foot/day (gfd). Specific Flux is the measure of permeate volume per fixed area over time and over driving energy. Its unit of measurement is gfd/Net Driving Pressure (NDP).

Computer design programs are available from all membrane manufacturers. Make sure you get a copy of the printout for the design of your system. These programs are also useful to define what's happening when parameters change. System balance must be carefully watched, especially when high flux membranes are being used. The programs can be used to compare membranes with varying listed test conditions. Use a fixed average flux rate or use specific flux in the program.

The average flux a system can tolerate will be based on the quality of feedwater. The general rules of thumb are listed in Table 5.[2]

**Table 5 — *Average Flux a System Can Tolerate Based on Feedwater Quality***

| SOURCE WATER | AVERAGE FLUX |
|---|---|
| Seawater | 8-12 gfd |
| Brackish Surface Water | 10-14 gfd |
| Brackish Well Water | 14-18 gfd |
| RO/UF Permeate | 20-30 gfd |

Another design criteria related to flux is the concentration polarization factor. Since water is permeating through the membrane, the concentration of solids at the membrane is higher than the concentration of the bulk feedwater. Good system design usually keeps this factor at or below 1.2.

Another factor of good design is the feedwater flow. Look for a flow of about 25-30 gpm per pressure vessel.

Use of space is another factor in good design. Is there enough room on the ends of the RO skid to easily remove and install the membranes? Can other membranes such as the 60-inch elements be installed? Can a cleaning be performed without a lot of setup work? Are sample taps installed for each required sample for both normal and troubleshooting conditions? Are the pressure vessels equipped for easy sampling and probing of the permeate? Are all the dead legs eliminated? Will the system automatically flush with permeate or feedwater upon shutdown and flush about every 6 hours if not used? Will the system insure that it will not drain down under standby conditions and provide for a soft startup that won't hammer the membranes? These are all things that must be thought about when you are thinking about installing an RO system.

If your system is used for industrial applications, consider the use of stainless steel for all piping and components that handle permeate which can be quite corrosive. PVC components and piping can crack and leak frequently under industrial conditions.

## WASTE

One must also be thinking about wastewater when thinking about reverse osmosis. On the positive side, the waste flow is generally only concentrated source water which is not hazardous. However, about 25%

of the feed flow will be wasted and this is normally a lot of water. Prudent design will consider all potential uses for this water and reuse as much of it as possible. Cooling systems are one of the most frequently chosen applications for concentrate use.

## MONITORING

Monitoring is the key to minimizing operating problems. Appendix 1 lists the various tests and calculations required for proper monitoring of RO systems. It assumes an automated system. Automation and trending data should be seriously considered for all but the smallest of systems. The computer industry has coined the phrase "user friendly." Make the effort to make your RO system as user friendly as possible. You will be rewarded with a better, more consistent operation. Computers can be used to automate the system's operation; log data; calculate, trend, and statistically handle data; and alarm operating problems. Get as much automation as you can afford. Membrane manufacturers have monitoring and data handling computer programs. Get them and use them.

Startup data is absolutely critical for normalization data. All data points should be recorded after 24 hours of operation and kept for reference and for use in the normalization calculations. It is recommended to probe each pressure vessel at startup so this data is available for comparison purposes when troubleshooting is necessary.

Membrane management requires the recording of each membrane's position within the system by serial number and keeping a log book for recording the membrane's position, cleaning frequency and results, and operating hours. Any pertinent comments should also be recorded.

## CLEANING

Sooner or later the membranes will require cleaning. This should be made as simple as possible for the operators. The Clean In Place (CIP) skid should be permanently hooked up to the RO skid or at least both skids should have quick hose connects. Figure 3 illustrates a typical CIP.

There are several points to make when designing the CIP. The tank should have a holding capacity of 2-3 times the capacity of the first stage. It is better to have a cone bottom on the tank so it can be completely drained and cleaned between uses.

The cleaning pump should be sized so it is capable of delivering 35-40 gpm per first stage pressure vessel.

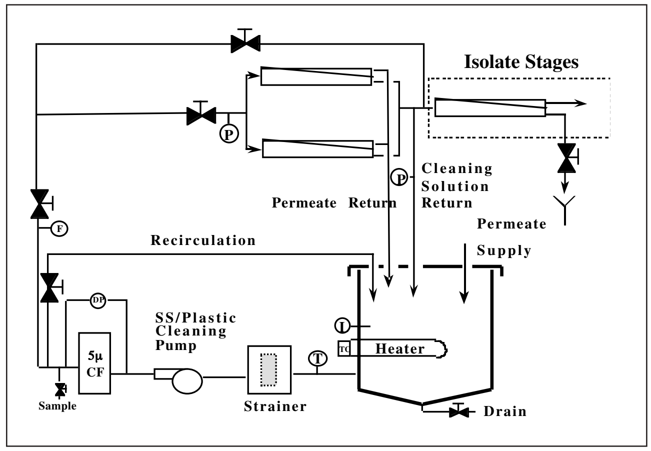


**Figure 3 — *Cleaning Skid***

Cleaning will be much better if very turbulent flow conditions can be created.

Start the cleaning solution flow slowly. You will always reach the maximum pressure drop of about 10 psi per membrane element before you reach the maximum desired flow rate. Position the pressure gauges as close to the inlet and outlet of the stage as possible.

Always heat the cleaning solutions. The reaction rate doubles for about every 10°F in temperature.

Always change out the cartridge filter elements and clean out the filter housing with every cleaning.

Consider the purchase of a single element cleaning and testing stand. Often, only one or two lead elements are fouled. Cleaning the entire stage only pushes this crud through downstream elements that are clean. A single element cleaning and testing stand allows you to clean only those elements that are dirty and to do some tricks like clean backwards to prevent front end crud from going through the entire element. The stand also allows you to test the performance of each element.

## OUTSOURCING

Many of the cleaning services described above can be contracted out to various suppliers. In fact, the purchase and operation of the whole pretreatment system can be outsourced. The economic and business factors that make outsourcing an attractive option are very site specific. However, whenever you are thinking about installing a reverse osmosis system in your industrial plant, you must include outsourcing as one of the options that needs to be seriously considered.

## CONCLUSION

There is a lot to think about when thinking about installing a reverse osmosis system in your industrial plant. Put a project champion in charge and give them the time to extensively learn about the process. Consider all technologies that will provide the quantity and quality of water necessary. Remember to include non-economic factors in your decision concerning the chosen system. Don't forget to consider outsourcing the system as one potential option.

If reverse osmosis remains the system of choice, run a pilot plant study for several months. This study will help train operators in the new technology and prevent many potentially costly problems once the system is built.

There will always be startup problems but hopefully costly errors can be avoided by improving your knowledge of this technology, both its advantages and its potential disadvantages.

## REFERENCES


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2. Glanz, D. and Herring, J., Proc. 57th International Water Conf., IWC-96-19, 153-161, (1996).


### APPENDIX 1 — SYSTEM SAMPLING GUIDE

| Sample Point | Monitor & Record | Sampling Frequency | Comments |
|---|---|---|---|
| RO Feed | Conductivity | Continuous | Used to determine % rejection. |
| | Flow Rate | Continuous | Used to determine Normalized Permeate Flow. Also total the feed flow. |
| | Pressure | Continuous | Used to determine the Net Differential Pressure across the RO machine. |
| | Temperature | Continuous | Required for normalization calculations. |
| | pH | Continuous | Required when pH adjustment is being used. |
| | Biocide | Each Shift | Use a Chlorine or ORP monitor to test for residual oxidants or a sulfite residual test for excess scavenger. |
| | Silt Density Index (SDI) | Daily | Needed to maintain warranty and insure membrane life expectancy. |
| RO Permeate | Conductivity | Continuous | Used to determine % rejection. |
| | Flow Rate | Continuous | Used to determine Normalized Permeate Flow. |
| | Pressure | Continuous | Permeate pressure should always be very low. |
| RO Concentrate | Conductivity | Continuous | Used to determine % recovery. |
| | Flow Rate | Continuous | Used for mass balance calculations in troubleshooting procedures. |
| | Pressure | Continuous | Used for differential pressure calculations. |
| Between Stages | Pressure | Continuous | Determines differential pressure of the first stage. |
| Pressure Vessel Permeate | Conductivity | As Necessary | Required sample point for troubleshooting a bad seal or membrane element. |
| Cartridge Filter | Influent Pressure<br>Effluent Pressure | Daily<br>Daily | Required for differential pressure calculation.<br>Required for differential pressure calculation. |
| Calculated Data | Cartridge Filter Differential Pressure | Daily | Determines the frequency of cartridge filter element replacement. |
| | Percent Rejection | Daily | Determines the condition of the membranes |
| | Net Driving Pressure | Daily | Effects the permeate flow. If the permeate pressure doesn't vary, sample frequency can be extended. |
| Pressure | System Differential | Daily | Measures hydraulic pressure losses through the membrane elements. Also should be calculated for the individual stages. |
| Normalized | Permeate Flow Rate | Daily | The most sensitive indicator of a problem. Clean if a change of 10% occurs. |
| | Percent Recovery | Daily | Must be held constant at all times to accurately compare differential pressure readings. |


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# Monitoring Reverse Osmosis Systems

What are the important operating parameters that should be monitored when RO systems are in place? The three most important parameters to be monitored daily are normalized permeate flow, differential pressure, and percent rejection.

The need for high purity boiler feed-water is basic to all industry, whether it is the chemical processing industry, the pulp and paper industry, or the refining industry. In order to provide this high purity water and at the same time cut the regeneration costs for the demineralizer systems, more and more plants are installing reverse osmosis (RO) systems. With these systems come the problems of preventing fouling and scaling to keep the system running smoothly.

What are the important operating parameters that should be monitored when RO systems are in place? The three most important parameters to be monitored daily are normalized permeate flow, differential pressure, and percent rejection. They indicate the extent of fouling and/or scaling, two major causes of premature membrane element replacement.

Normalized permeate flow is one of the most sensitive forecasters of trouble in an RO system. Fouling can reduce the permeate flow rate; however, just measuring the permeate flow rate is not sufficient because it varies with the feedwater temperature, feed pressure, permeate pressure, and feed-water TDS (total dissolved solids). A simple calculation corrects for temperature and pressure variations. The calculation, known as normalized permeate flow, adjusts the daily data readings to what they would be if the system were operating at start-up pressure and 25 °C. This allows for daily comparisons of RO performance. Seasonal feedwater temperature variations can make fouling trends difficult to detect if the normalized permeate flow calculation is not used. For example, during the springtime, the RO feedwater derived from surface sources becomes warmer. This increase in feedwater temperature affects membrane performance by increasing the permeate flow rate. If the membrane elements are fouling at the same time (fouling causes a decrease in permeate flow rate), it is unlikely that this will be noticed until a change in seasons. At this time, the membrane elements may be severely fouled, with the permeate flow rate severely restricted.

## The normalized permeate flow rate calculation requires the following data:

***Net Driving Pressure at Start-Up:*** This is the driving pressure delivered by the RO pump when the existing membranes were first put into use. (See Figure 1.) It is calculated by subtracting the permeate pressure at start-up from the feed pressure at start-up. If the permeate pressure does not vary in the system (i.e., the permeate flows directly into a degasifier or storage tank), this

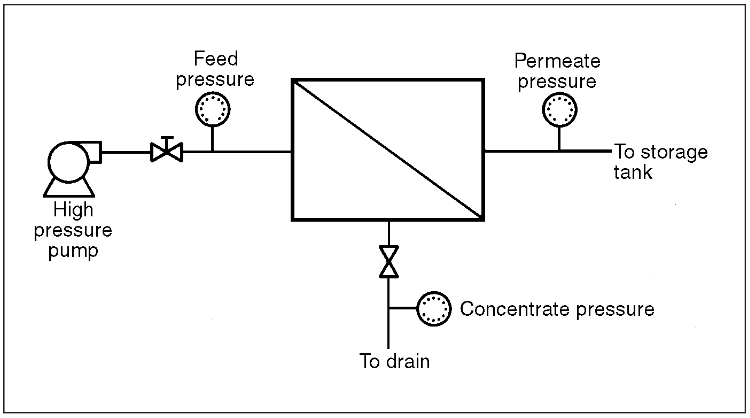


**Figure 1 —** *The key pressures to monitor in an RO system are feed pressure, concentrate pressure, differential pressure, and permeate pressure.*

calculation may be eliminated and simply substitute the feed pressure in place of the net driving pressure. If start-up data is unavailable, substitute the design feed pressure from the original vendor.

***Net Driving Pressure:*** This is calculated each day by subtracting the permeate pressure from the feed pressure. (See Figure 1.) It has a direct influence on the permeate flow rate. This calculation can be eliminated if the permeate pressure does not vary; simply use the daily RO feed pressure in place of the net driving pressure.

***Temperature Correction Factor:*** This is a conversion factor for a given feedwater temperature that adjusts the daily permeate flow rate to what it would be at 25 °C (77 °F). Contact the membrane manufacturer or your Nalco representative for the temperature correction factor.

***Permeate Flow Rate:*** This is the direct reading from the permeate flow meter.

Normalized permeate flow rate =

$$\frac{\text{Start-up net driving pressure}}{\text{Daily net driving pressure}} \times \frac{\text{Temp. corr. factor}}{} \times \frac{\text{Permeate flow rate}}{}$$

## Differential Pressure

The differential pressure is the difference between the feed pressure and the concentrate pressure. (See Figure 1.) It is a measure of the hydraulic pressure losses through the RO membrane elements and the manifold piping. When the flow channels become clogged, the differential pressure also depends on the feed flow rate and the percent recovery.

Feed flow rate = Permeate flow rate + Concentrate flow rate

$$\text{Percent recovery} = \frac{\text{Permeate flow rate}}{\text{Feed flow rate}} \times 100$$

**Note:** To accurately compare differential pressure readings taken at different times, make sure that the RO is adjusted to the same percent recovery and feed flow rate.

## Percent Rejection

Percent rejection refers to the percentage of total dissolved solids (TDS) that are rejected by the RO. When the RO membranes are in trouble, percent rejection usually decreases; however, certain foulants can plug up the membrane and increase the percent rejection reading. It can be calculated by using the following formula:

Percent rejection =

$$\frac{\text{Feed TDS} - \text{Permeate TDS}}{\text{Feed TDS}} \times 100$$

A drop in percent rejection may be a sign of a leaking "O" ring, fouling, scaling, membrane hydrolysis, improper pH, too high a recovery rate, too low a feed pressure, or a change in composition of the feedwater source.

Other suggested parameters are listed as follows. Keep in mind, however, that because each system is unique, additions to this list can be made to optimize the monitoring program. A TRENDCHECK® data management program can be extremely beneficial in keep track of all important parameters.

- Date
- Operator's initials
- Elapsed hours or gallonage reading
- Feedwater pH
- Silt Density Index
- Concentrate flow rate
- Feedwater temperature
- Feed pressure
- Concentrate pressure
- Feedwater TDS
- Permeate TDS
- Percent rejection
- Differential pressure
- Net driving pressure
- Permeate pressure
- Permeate flow rate
- Percent recovery
- Feedwater temperature correction factor
- Normalized permeate flow rate

Here are some practical tips to keep in mind when monitoring an RO system.

- Allow the RO to run uninterrupted for 20 minutes before taking any readings.
- When the early warning system indicates a loss in performance, first check the calibration of the instruments for accuracy.
- Always record and compare complete sets of the RO data immediately before and after cleaning the RO.
- Monitor each array of the RO as a separate system.
- Utilize TRENDCHECK to track performance on all important monitoring parameters.
- Monitor the RO pretreatment system as closely as you would the RO system itself.
- Clean the RO when the corrected permeate flow rate decreases by 10% and/or when a 10 to 20% increase in differential pressure is observed.

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