LENNTECH bv
info@lenntech.com
www.lenntech.com
Tel. +31-15-261.09.00
Fax. +31-15-261.62.89

Pretreatment

MEMBRANE FOULING CONSIDERATIONS

The feed water, depending on its source, may contain various concentrations of suspended solids and dissolved matter. Suspended solids may consist of inorganic particles, colloids and biological debris such as microorganisms and algae. Dissolved matter may consists of highly soluble salts, such as chlorides, and sparingly soluble salts, such as carbonates, sulfates, and silica. During the RO process, the volume of feed water decreases, and the concentration of suspended particles and dissolved ions increases. Suspended particles may settle on the membrane surface, thus blocking feed channels and increasing friction losses (pressure drop) across the system. Sparingly soluble salts may precipitate from the concentrate stream, create scale on the membrane surface, and result in lower water permeability through the RO membranes (flux decline). This process of formation of a deposited layer on a membrane surface is called membrane fouling and results in performance decline of the RO system. The objective of the feed water pretreatment process is to improve the quality of the feed water to the level which would result in reliable operation of the RO membranes.

The quality of the feed water is defined in terms of concentration of suspended particles and saturation levels of the sparingly soluble salts. The common indicators of suspended particles used in the RO industry are turbidity and Silt Density Index (SDI). The maximum limits are: turbidity of 1 NTU and SDI of 4. Continuous operation of an RO system with feed water which has turbidity or SDI values near the limits of these values may result in significant membrane fouling. For long-term, reliable operation of the RO unit, the average values of turbidity and SDI in the feed water should not exceed 0.5 NTU and 2.5 SDI units, respectively.

The indicators of saturation levels of sparingly soluble salts in the concentrate stream are the Langelier Saturation Index (LSI) and the saturation ratios. The LSI provides an indication of the calcium carbonate saturation. Negative values of LSI indicate that the water is aggressive and that it will have a tendency to dissolve calcium carbonate. Positive values of LSI indicate the possibility of calcium carbonate precipitation. The LSI was originally developed by Langelier for potable water of a low salinity. For high salinity water encountered in RO

applications, the LSI is an approximate indicator only. The saturation ratio is the ratio of the product of the actual concentration of the ions in the concentrate stream to the theoretical solubilities of the salts at a given conditions of temperature and ionic strength. These ratios are applicable mainly to sparingly soluble sulfates of calcium, barium and strontium. Silica could be also a potential scale forming constituent. Other potential scale forming salts, such as calcium fluoride or phosphate which may be present in RO feed, seldom represent a problem.

Depending on the raw water quality, the pretreatment process may consists of all or some of the following treatment steps:

- Removal of large particles using a coarse strainer.
- Water disinfection with chlorine.
- Clarification with or without flocculation.
- Clarification and hardness reduction using lime treatment.
- Media filtration.
- Reduction of alkalinity by pH adjustment.
- Addition of scale inhibitor.
- Reduction of free chlorine using sodium bisulfite or activated carbon filters.
- Water sterilization using UV radiation.
- Final removal of suspended particles using cartridge filters.

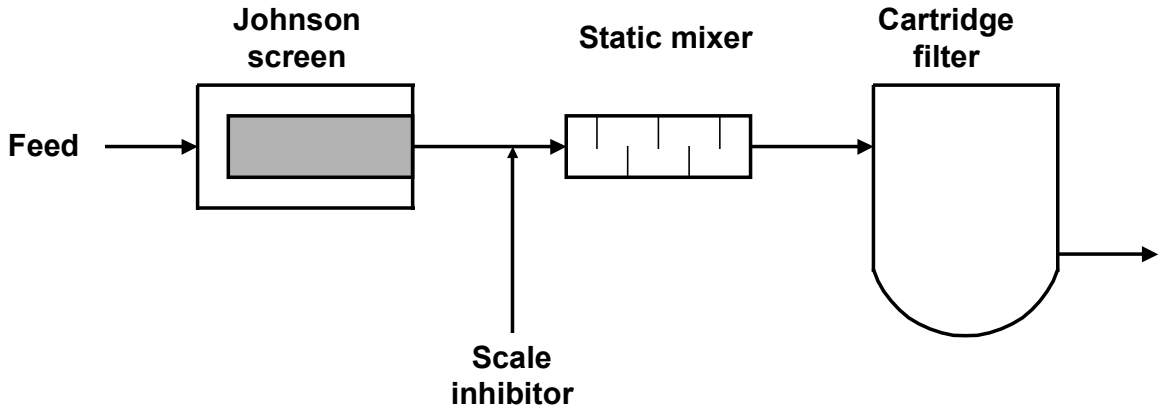
The initial removal of large particles from the feed water is accomplished using mesh strainers or traveling screens. Mesh strainers are used in well water supply systems to stop and remove sand particles which may be pumped from the well. Traveling screens are used mainly for surface water sources, which typically have large concentrations of biological debris.

It is common practice to disinfect surface feed water in order to control biological activity. Biological activity in a well water is usually very low, and in majority of cases, well water does not require chlorination. In some cases, chlorination is used to oxidize iron and manganese in the well water before filtration. Well water containing hydrogen sulfide should not be chlorinated or exposed to air. In presence of an oxidant, the sulfide ion can oxidize to elemental sulfur which eventually may plug membrane elements.

Settling of surface water in a detention tank results in some reduction of suspended particles. Addition of flocculants, such as iron or aluminum salts, results in formation of corresponding hydroxides; these hydroxides neutralize surface charges of colloidal particles, aggregate, and adsorb to floating particles before settling at the lower part of the clarifier. To increase the size and strength of the flock, a long chain organic polymer can be added to the water to bind flock particles together. Use of lime results in increase of pH, formation of calcium

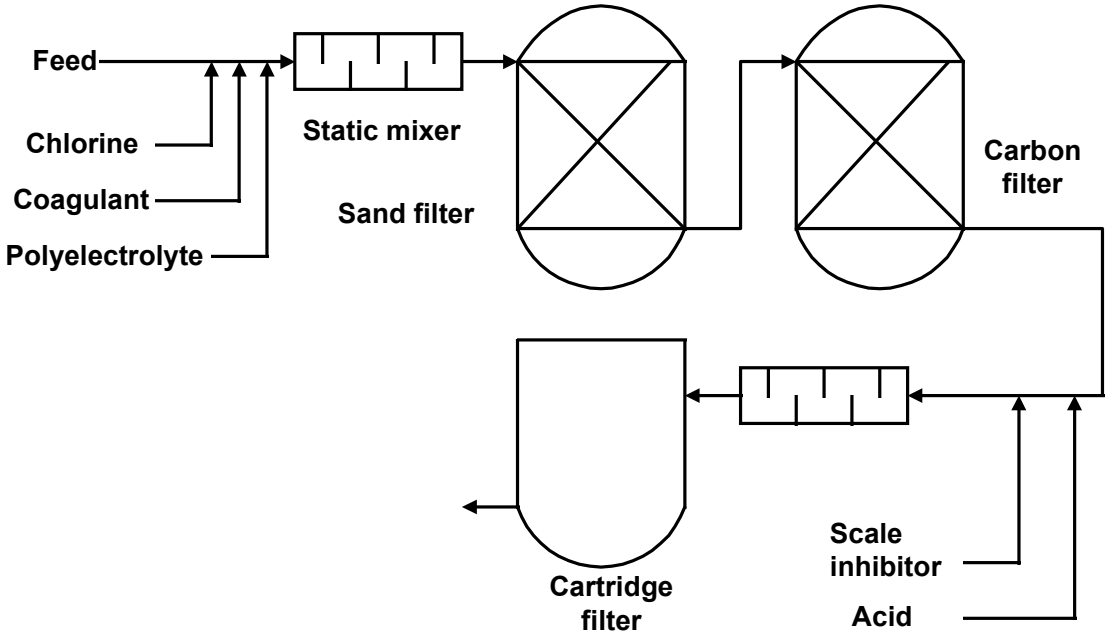
carbonate and magnesium hydroxide particles. Lime clarification results in reduction of hardness and alkalinity, and the clarification of treated water.

Well water usually contains low concentrations of suspended particles, due to the filtration effect of the aquifer. The pretreatment of well water is usually limited to screening of sand, addition of scale inhibitor to the feed water, and cartridge filtration.



Pretreatment system for well water source

Surface water may contain various concentrations of suspended particles, which are either of inorganic or biological origin. Surface water usually requires disinfection to control biological activity and removal of suspended particles by media filtration. The efficiency of filtration process can be increased by adding filtration aids, such as flocculants and organic polymers. Some surface water may contain high concentrations of dissolved organics. Those can be removed by passing feed water through an activated carbon filter. Depending on composition of the water, acidification and addition scale inhibitor may be required. The flow diagram of pretreatment system for surface water is shown below.



Pretreatment system for surface water source

Cartridge filters, almost universally used in all RO systems prior to the high pressure pump, serve as the final barrier to water born particles. The nominal rating commonly used in RO applications is in the range of 5 - 15 microns. Some systems use cartridges with micron ratings as low as 1 micron. There seems to be little benefit from lower micron rated filters as such filters require a high replacement rate with relatively small improvement in the final feed water quality.

Recently, new pretreatment equipment has been introduced to the RO market. It consists of backwashable capillary microfiltration and ultrafiltration membrane modules. This new equipment can operate reliably at a very high recovery rates and low feed pressure. The new capillary systems can provide better feed water quality than a number of conventional filtration steps operating in series. The cost of this new equipment is still very high compared to the cost of an RO unit.

LENNTECH bv
info@lenntech.com
www.lenntech.com
Tel. +31-15-261.09.00
Fax. +31-15-261.62.89

Reducing the Fouling Rate of Surface and Waste Water RO Systems

Keywords: fouling, reverse osmosis, membranes, surface water, waste water, biocides

Summary: This paper discusses technical advances to reduce the rate of fouling due to organic, colloidal and biological foulants. These advances will focus on a new low fouling composite polyamide RO membrane with a neutral surface charge and the institution of biological control programs.

INTRODUCTION

This paper will focus on recent technical advances on how to reduce the rate of organic, colloidal and biological fouling of Reverse Osmosis (RO) systems for notoriously difficult feed water sources. Market applications of RO technology will become more accessible for the treatment of surface waters, municipal secondary or tertiary waste waters, landfill leachate, laundry gray water, and industrial process waste waters. Areas of discussion include:

- A review of critical RO system design and operating considerations.
- The use of a new low fouling composite polyamide RO membrane that has a neutral surface charge for reduced organic fouling.
- A review of RO pretreatment for reduced colloidal and biological fouling.

It has been observed that the use of a neutrally charged Low Fouling Composite (LFC) polyamide membrane reduces the rate of attraction of charged organic and colloidal material from the feed water. This is the same observation seen in the past when a neutrally charged Cellulose Acetate (CA) membrane operated on difficult feed waters. A significant reduction in fouling rate and improved cleanability has been observed using this LFC membrane, without sacrificing the advantages of higher salt rejection, lower feed pressure, higher flux, and a broader pH range associated with commercially existing negatively charged Composite Polyamide (PA) membranes.

Biological control programs will be discussed in conjunction with the use of this new LFC membrane. The LFC membrane has a similar chlorine tolerance level as existing PA membrane and have to be protected from biological fouling.

RO SYSTEM DESIGN AND OPERATING CONSIDERATIONS

A conservative, carefully planned out total system design is required for an RO system treating difficult waters. Competent application engineering comprised of a series of sound engineering decisions and proper on-site operations will increase the chances of a successful application. The following criteria must be addressed :

1. **Feed Water Characterization: The importance of a detailed water analysis showing minimum, maximum and average levels of ions and potential foulants cannot be over emphasized, especially when the feed source can experience seasonal or process fluctuations. A pilot plant may be prudent for the development of the optimal pretreatment scheme and RO design parameters.**

2. **RO Pretreatment: The most important design consideration is proper pretreatment for the removal and control of foulants. When dealing with difficult feed waters, the engineer must make a decision as to whether to use conventional pretreatment techniques or to use crossflow MF or UF systems to minimize RO fouling due to colloidal, organic and biological foulants. Included in this is the need for a carefully planned biological control program to minimize the rate of biological fouling for biologically active feed waters.**

3. **RO Element Selection: .A large number of choices exist when selecting an RO element. This includes evaluation of membrane type, membrane surface charge, fouling resistance, active membrane area in the element, feed pressure requirements and rejection levels of dissolved ions and organics.**

4. **Flux Rate: The rate of membrane surface fouling is a function of the permeate flux rate, measured as GFD (Gallons per square Foot of membrane area per Day). The lower the flux rate, the lower the rate of fouling. The relationship of fouling rate to the flux has been demonstrated both during laboratory tests and in field operation. The most recent university research work was reported by Elimelech [1,2] from the University of California, Los Angeles. This report concluded the increase in fouling rate with higher flux is a result of higher concentration of organics at the membrane surface and a higher drag force perpendicular to the membrane surface**

5. **Cross Flow Velocity: The higher the cross flow velocity parallel to the membrane surface, the lower the rate of fouling. Foulants are flushed away from the membrane surface by the higher shearing action. Higher area membrane elements allow for the use of fewer pressure vessels and higher feed and concentrate flows.**

6. **System Flushes and Shutdown: The biological fouling rate can increase dramatically when the system is idle and no water is flowing. The system should be flushed to remove foulants on shutdown, startup, and even intermittently during standby. The best low-pressure flushes are performed at high crossflow velocities using RO permeate quality water. A RO soaked with permeate quality water can help loosen existing foulants.**

7. **Normalize Data: To understand how the RO is operating when process variables fluctuate, the operator logged data must be normalized to determine the rate of system fouling. Normalization programs have been developed that calculates and charts normalized feed-to-reject pressure drop, normalized permeate flow and normalized per cent salt passage. These normalized parameters are calculated by comparing current conditions to those in the first day of operation with adjustments made for changes in major variables such as temperature, feed TDS, recovery and pressures.**

8. **Proper Cleaning Operation: Operators must be instructed to run the RO system properly by cleaning when mildly fouled, not severely fouled. The RO should be cleaned whenever the normalized pressure drop increases by 15%, the normalized permeate flow decreases by 15%, or the normalized per cent salt passage increases by 15%. A well**

designed cleaning operation includes the ability to clean stages separately to achieve optimal crossflow velocities.

A LOWER FOULING RO MEMBRANE

The best RO element to reduce fouling rates is one that has a neutrally charged surface to minimize the attachment of charged foulants, can be used with a biocide to control biological fouling, and has a high surface area to decrease flux and increase cross-flow velocity. In the past, the cellulose acetate (CA) membrane with its neutral surface charge and a resistance to biocidal chlorine up to 1 ppm or 26,280 ppm-hours, exhibited the best fouling resistance for difficult water applications. However, the CA membrane had pH limitations, higher feed pressure requirements, and higher salt passage when compared to the popular negatively charged composite polyamide (PA) membranes. Today, a new generation of Low Fouling Composite polyamide (LFC) membrane is available. The LFC membrane has the unique advantages of equivalent rejection and feed pressure requirements of a durable PA membrane and the neutral surface charge of the CA membrane (see Figure 1). A limitation to the LFC membrane is that being a polyamide membrane it has a chlorine tolerance level similar to PA membranes of approximately 1,000 ppm-hours.

Figure 1: Comparison of RO Membranes

	LFC	PA	CA
Membrane polymer	Polyamide	Polyamide	Cellulose acetate
Surface charge	Neutral	Negative	Neutral
NaCl rejection	99%	99 to 99.7%	95 to 98%
Organic rejection	Similar	Similar	Lower
Test Pressure	225 psi	225 psi	420 psi
Specific flux (gfd per 100 psi of NDP)	13	13	5 to 6
Feed pH range	3 to 10	3 to 10	4 to 6
Temperature limit	113 F (45 C)	113 F (45 C)	104 F (40 C)
Chlorine tolerance	1000 ppm-hr	1000 ppm-hr	26,280 ppm-hr
Hydrophilicity	47° angle	62° angle	50° angle

The reduced fouling capability of the LFC membrane is the result of new membrane chemistry. The membrane is permanently modified during the casting process to produce a neutral surface charge and a more hydrophilic membrane surface. The combination of a neutral surface charge and increased hydrophilicity minimizes the adsorption of hydrophobic organic foulants (e.g. humic matter) onto the membrane surface. Flux degradation due to the build up of foulants that are organic in nature, hydrophobic metal gels (e.g. iron), and charged colloidal material is minimized. Just as important for long term operational stability is the enhanced ability to remove foulants and restore the system flux with periodic flushings and/or chemical cleanings.

The LFC membrane can operate with either acidic or basic feed waters and still maintain its neutral surface charge. The surface charge of three membranes over a pH range of 3 to 10 were analyzed quantitatively by measuring the Zeta Potential using Laser-Doppler electrophoresis equipment. The LFC membrane maintained a relatively neutral surface charge of –3 to +5 millivolts (mV). The conventional PA membrane has a negative charge of –5 to –21 mV between a pH of 4 to 10 due to the disassociation of the carboxylic groups in the polyamide chain. Interestingly, the PA membrane at a pH less than 4 actually exhibits a positive charge due to the disassociation state of the amine groups in the polyamide chain. [3] (See Figure 2).

The LFC membrane, in the same fashion as the CA membrane, can operate with foulants of varying charges with minimal or no loss of flux. The conventional negatively charged (anionic) PA membranes are notorious for a dramatic irreversible loss of flux when exposed to cationic (positively charged), amphoteric (either positively or negatively charged based on pH conditions) and neutral polyelectrolytes which are so popular as potential pretreatment and cleaning chemicals (e.g. coagulants, flocculants, surfactants, detergents). Figure 3 depicts the excellent flux stability of the LFC membrane when challenged with cationic, anionic, amphoteric and neutral surfactants. [3]

The LFC membrane is being operated on a tertiary municipal effluent at the waste water treatment plant at San Pasqual, Ca USA. The pretreatment prior to the RO consists of capillary ultrafiltration. The LFC membrane is being compared to an ESPA membrane, a low-pressure negatively-charged composite

polyamide membrane. The system is operated at a flux rate of 10 gfd (17 l/m²hr). Figure 3 shows the ESPA membrane starts at 25% less feed pressure when clean due to its lower specific flux. However, within days the LFC operates at lower feed pressure due to organic fouling of the negatively charged ESPA membrane. Both membranes have established stabilized fluxes, but the LFC operates at 30-35% less feed pressure. The salt rejection for both membranes after 2000 hours of operation have stayed above 99%. [3]

RO PRETREATMENT SYSTEMS

Any paper on the use of RO membranes for difficult water sources would be remiss without a discussion on critical pretreatment requirements. In general terms, the application engineer should design the pretreatment for LFC to the same standards as if a conventional PA membrane was being used.

Organic Fouling: The LFC membrane offers significant advantages in long term and recoverable flux stability when compared to conventional PA membranes when the foulant is an organic. This capability makes removal of organics in the pretreatment less of an issue than in the past. Though no definitive level of acceptable organic content in a RO feed water exists, an alert level for the designer to consider LFC over a PA membrane could be considered to be 3 ppm TOC (Total Organic Carbon as C), 6 ppm BOD (Biological Oxygen Demand as O_2) or 8 ppm COD (Chemical Oxygen Demand as O_2).

Colloidal and Suspended Fouling: This pretreatment requirement includes the filtration of colloidal and suspended particles to turbidities of less than 1.0 NTU and a 15-minute SDI (Silt Density Index) value of less than 4.0. Excessive volumes of colloidal and suspended material will plug the RO element feed path, regardless of the membrane type.

Conventional pretreatment schemes in the past have utilized a myriad of technologies such as clarifiers, lime softeners, sand filters, carbon filters, iron filters, multimedia filters, and chemical feeds to flocculate and coagulate. In the last few years, there has been a greater acceptance in the industry to the use of cross-flow microfiltration (MF) and ultrafiltration (UF) membrane systems. The increased use of MF and UF have been driven by a number of factors. Capillary membrane technology has always produced RO feed water of significantly better and predictable quality than conventional pretreatment systems, but now is being recognized as being both cost-effective and capable of stable operation.

Biological Fouling: This pretreatment requirement is difficult to characterize or quantify in the design phase of an RO system. It can be expected that in RO systems where biological activity results in slimy biofilm formations, the problem can be found in the pretreatment system back to the point where no biocide is present and in the RO. This type of fouling process will plug the RO element feed path, irrespective of the membrane type. Permeate flux will decrease and the feed-to-concentrate pressure drop will increase. Excessive pressure drop may result in mechanical damage of the RO elements. Design wise, minimizing piping dead-legs and avoiding the use of carbon filters can minimize biological fouling. Operationally, sanitizing the RO pretreatment equipment and RO equipment prior to loading RO elements and continuous running of the RO system after start up is important in minimizing the build up of the biofilm.

The long-term answer in controlling biological fouling lies in the institution of a “biological control program”. The program has two major parts:

- Control biological fouling during the service and offline modes using a continuous or periodic introduction of a biocide.
- Establish an effective sanitization and clean

up regiment after the RO becomes biologically fouled.

To date, there is no "perfect" biocide for use with the LFC or PA membrane. The "perfect" biocide for these membranes would have the following properties:

- Does not damage the membrane.
- Controls and kills all strains of bacteria and biofilms
- Physically breaks up existing biofilms
- Compatible with all system components
- Non-toxic and easy to handle
- Easily disposed of and bio-degradable
- Easily monitored and injected
- Disinfects the permeate side of the membrane
- Inexpensive

Chlorine: The LFC membrane, like the PA membrane, has limited chlorine tolerance of approximately 1,000 ppm hours and requires that the RO feed be dechlorinated to less than 0.1 ppm. Normally, membrane life is defined as three years and/or when salt passage doubles. Chlorine tolerance is further reduced by the presence of insoluble iron, which acts as a catalyst in the oxidative attack of chlorine. Chlorine damage of the membrane is easily identifiable by decreased salt rejection, increased flux, and by a factory dye test. Presence of chlorine damage will effectively void the membrane warranty. However, in recent years there have been some field experiments using continuous and intermittent chlorination during the service mode by end-users who have experienced severe bio-fouling problems. These end-users have had to assess and assume the risks mentioned above versus the benefits of chlorine as a biocide. The benefits of chlorine is that it is an effective biocide, inexpensive, controls the volume of the biofilm mass, a portion of it passes through the membrane to sanitize the permeate side, it could extend the useful life of the membrane by sparing it from harsh cleanings and irreversible fouling conditions, or at least reduce the hassles of frequent cleanings and sanitizations. One train of thought for systems with a biofilm suggests that by controlling the chlorine dosing, the amount of chlorine that actually makes it to the membrane can be minimal as the chlorine is consumed by the biofilm. One end-user has reported that a "chemotherapy" approach of chlorine shock dosing at 0.25 ppm for four hours per day has reduced his cleanings by a factor of ten over a period of 15 months, with no reportable loss of salt rejection when compared to a test train that had no chlorine introduced. [4] The passage of chlorine into the permeate will vary by system, but has been observed at 20 to 50% of the feed level.

Chloramines: The use of non-oxidizing chloramines as a continuously fed biocide has gained interest recently. Typically, LFC and PA membranes can have a chloramine tolerance of 150,000 to 300,000 ppm-hours before a noticeable increase in salt passage. The 300,000 ppm-hours level correlates to a chloramine level of 11.4 ppm for an operating period of 3 years. RO designers are cautioned that it has been observed in a few applications that this chloramine tolerance can be much lower due to the catalytic effects of high temperature, low pH, or presence of transition metals. Chloramines are produced by adding ammonia to chlorinated water. If the mix is not perfect, there can be either residual free chlorine or ammonia. The residual free chlorine would require dechlorination using a sodium bisulfite feed or carbon filtration, but this can also result in dechloramination with a resulting increase in ammonia gas or ammonium ion levels. Caution is required in that the increased presence of sodium bisulfite or ammonia or ammonium can invite biofilm growth if all the chloramines were removed. Ammonia is known to be corrosive to any downstream non-stainless steel metal fixtures. The passage of chloramines into the permeate is relatively high, and has been observed at up to 80% of the feed level. The passage of ammonia into the permeate is 100% since it is a gas. Since ammonium is a monovalent cation, it is well

rejected.

Isothiazalon: The use of non-oxidizing isothiazalon as a continuously or intermittently fed biocide (or slimicide) has also gained interest recently as it is causes no degradation of the LFC or PA membrane. Isothiazalon is available under the Rohm & Haas brand name Kathon, Betz brand name Slimicide C-68, or Argo brand name Rogun 781. This biocide is hazardous, so special handling precautions are warranted and should not be used for systems producing potable water. Typical dosing on a continuous basis can be 3 to 5 ppm of active ingredient, but actual dosing should be based on achieving a near zero residual in the reject stream. Intermittent shock dosing levels of 15 to 25 ppm for at least a couple of hours can be effective, but rapid regrowth of the biofilm is possible if conditions are proper. There is basically no passage of this biocide into the permeate due to its large molecular weight. This biocide is expensive to buy, but the savings in reduced cleanings, longer membrane life and more stable operation of the RO over time should result in a justifiable payback.

Hydrogen Peroxide/Paracetic Acid: The use an oxidizing type biocide solution of hydrogen peroxide and paracetic acid for offline sanitizations has been popular since the 1980's for PA membranes, especially for RO systems having to meet FDA or potable drinking water requirements. Hydrogen peroxide alone could be used as a biocide at a 2,000 ppm dosage, but the addition of 450 ppm of paracetic acid dramatically improves its rate of bacterial disinfection to less than one hour and breaks down a biofilm in about four hours. Temperature has to be maintained between 20 and 25 °C for an effective disinfection while protecting the membrane. Special care must be taken that transition metals (e.g. iron or manganese) are not present in the feed water and the membrane surface is cleaned of these metals as they can catalyze an oxidative attack of the membrane.

Other biocides and biological cleaning chemicals: The industry's best hope in developing better "biological control programs" resides with specialty RO chemical suppliers. The development of new biocide products (e.g. enzyme based slimicides) and their proper application will be important in operating LFC and PA membrane systems on difficult water sources.

CONCLUSION

As the water treatment industry enters the new millennium, the ability to treat difficult surface and waste waters that are notorious for having high organic, colloidal and biological fouling potential using membrane technology will open a number of new markets. The introduction of LFC, the first neutrally charged polyamide RO membrane, addresses the issue of how to accommodate organic foulants. The increased popularity of capillary MF or UF membranes addresses the issue of how to accommodate colloidal foulants. Advancements are being made in the development of biological control programs using biocides of different types to accommodate biological foulants.

References:

1. X. Zhu and M. Elimelech. "Fouling of Reverse Osmosis Membranes by Aluminum Oxide Colloids". Journal of Environmental Engineering, December 1995, 884-892.
2. S Hong and M. Elimelech. "Fouling of Nanofiltration Membranes by Natural Organic Matter", proceedings of 1996 ADA Conference, Monterey, Ca. USA, August 1996, 717-727.
3. R. Gerard, H. Hachisuka, M. Hirose. "New Membrane Developments Expanding the Horizon for Application of Reverse Osmosis Technology", proceedings of 1997 Aquatech 98 in Amsterdam, the Netherlands.

4. B. Karnaugh, J. Jaminet, B. Shelton. "Biofouling Management of the TIME DI Water RO Plant by Direct Periodic Chlorination", Ultrapure Water July/August 1998.

Figure 2: pH Effects on Membrane Surface Charge

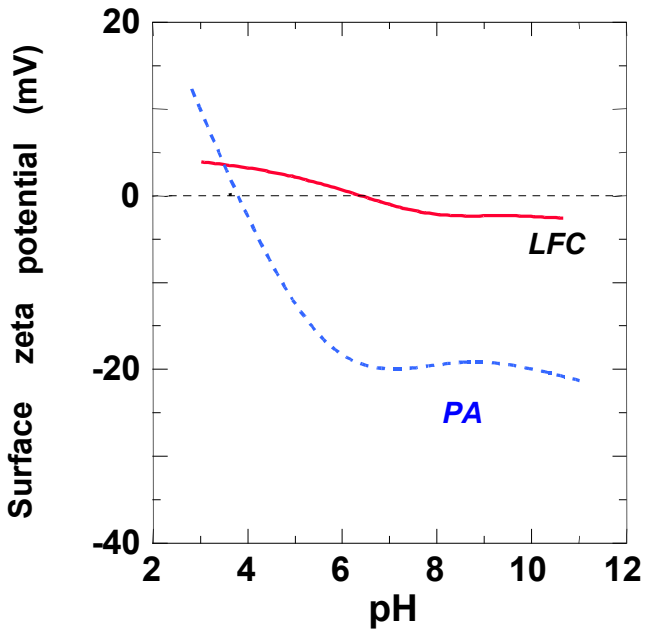


Figure 3: Membrane Exposure to Surfactants

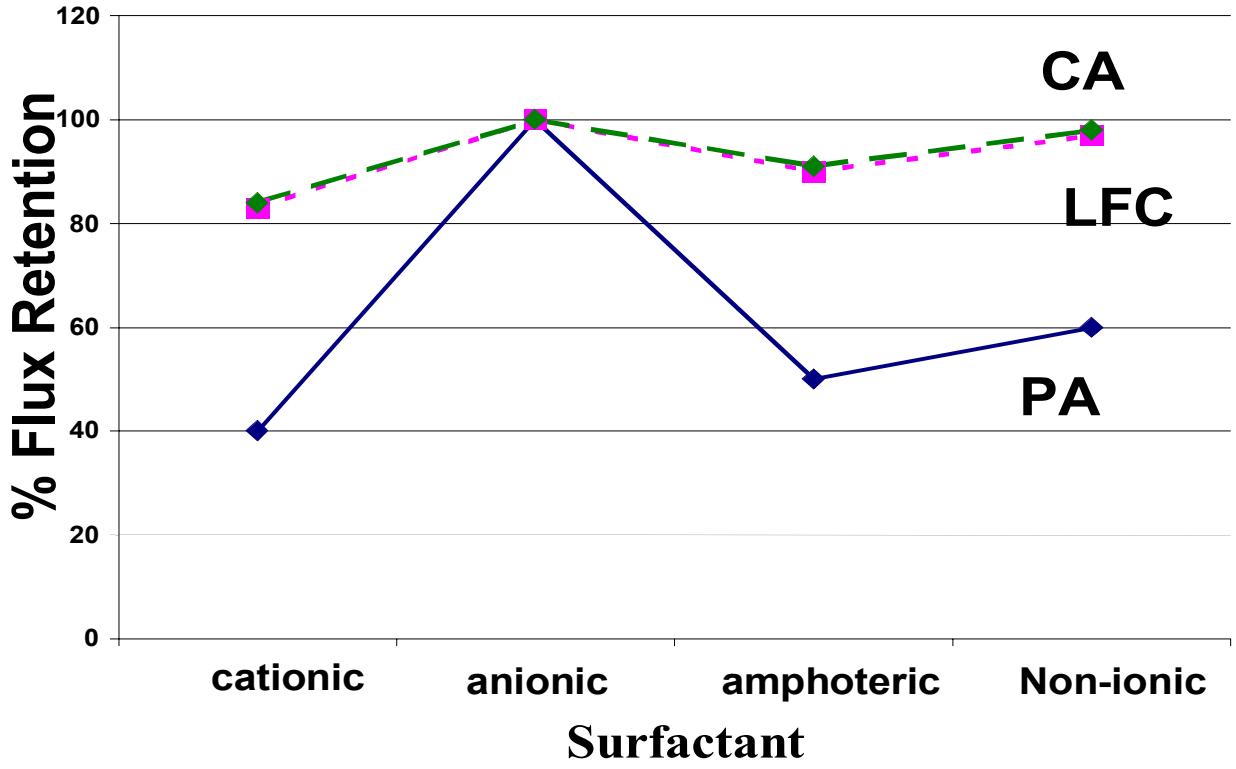


Figure 4: LFC Flux Stability at San Pasqual

LENNTECH bv
info@lenntech.com
www.lenntech.com
Tel. +31-15-261.09.00
Fax. +31-15-261.62.89

Cleaning

Over time, membrane systems can become fouled with any of a number of foulants such as colloids, organic matter, metallic scales, and biological constituents. (See Pretreatment). These materials can build up on the membrane surface and in the feed brine channel. If left uncorrected, the accumulation of these foulants can cause a severe loss of performance in the system: pressure requirements increase to maintain flow, pressure drops increase, and salt rejection can suffer. If the system is not cleaned and the system continues to build up foulants, the elements may "telescope," or shear internally, causing the integrity of the membrane surface to be compromised and rendering the membrane irreversibly damaged.

This section will cover several points related to cleaning. The first part will concern itself with data collection and symptoms of membrane fouling. The second part will define the components of a cleaning system and provide guidelines for building and operating a cleaning skid. Finally, directions and guidelines for performing a cleaning will be given; the reader is encouraged to double click on topics related to specific procedures for cleaning specific membrane elements.

DATA Monitoring

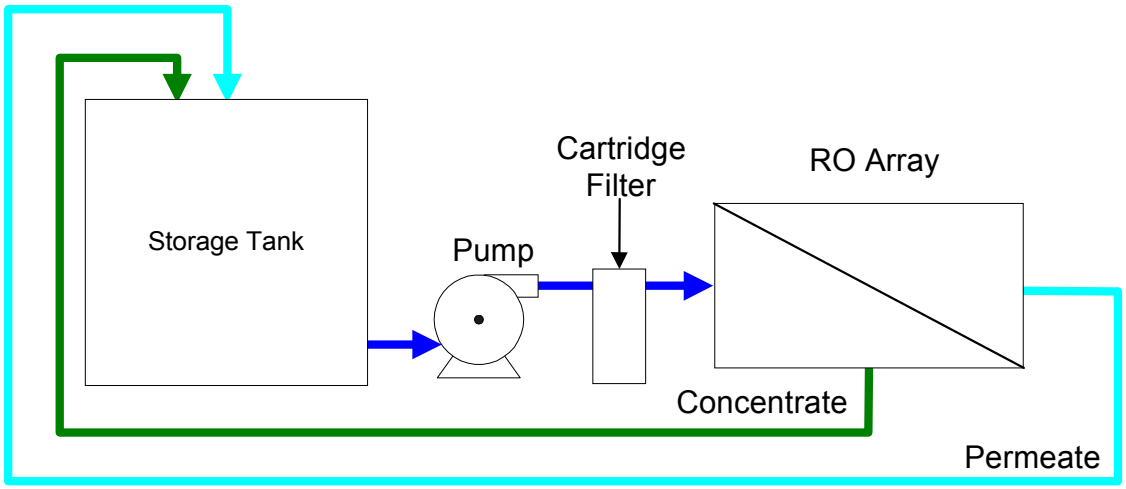
Good monitoring of the performance of a system can alert the user to possible fouling before the situation becomes severe. The practice of entering operational data several times a week into a normalization program can provide the means to track performance over time. Symptoms of fouling would include one or all of the following conditions:

- Normalized water flow has decreased by 10-15% from start-up (reference) conditions.
- Delta P, or pressure drop over a stage or the system, has increased by 10-15%.
- Salt rejection has decreased (ie permeate TDS has increased) significantly over time.

Note that it is important to use normalized data. Normalized data corrects for temperature effects on system performance. For instance, if the temperature drops, it is expected to require more pressure to achieve the same flow. Loss of flow due solely to a reduction in temperature does not mean the system is fouled.

Cleaning System Specifications

The following diagram gives the basic parts of an RO cleaning skid. Cleaning solution is pumped from a storage tank through a cartridge filter to the RO array. Solution is then recycled back to the tank. The volume of solution should be adequate to fill the volume of the vessels, filters and piping. The diagram below shows no instrumentation, however, it may be adviseable to add a low level switch to the tank to prevent the pump from running dry. Additionally, a temperature controller and heater/cooler unit may be added to maintain solution at the optimum temperature range.



Volume requirements:

To figure the volume of solution required for a system consisting of six 8" vessels with six elements per vessel and 40 feet of 4 inch pipe (3.82 " ID), figure the volume of the vessels and add it to the volume of the piping to obtain the total volume. For example:

Volume of the vessels:

The calculation is made where Vv is the volume of one vessel, Pi = 3.14, and R is the radius of the vessel or pipe. US units are given on the left, SI units on the right

Vv = Pi*(R*R)*length

= 3.14 * (4in * 4in) * 20ft / (144 in2/ft2)	= 3.14*(.10m*.10m)*6.1m
= 6.98 ft3	= 0.196 m^3
= 6.98 ft3 * 7.48 gal/ ft^3	
= 52 gal/vessel	= 196 liters/vessel

Total vessel volume = 6 vessels * 52.2 gal/vessel = 313.2 gal
= 6 vessels * 196 liters/vessel = 1176 liters

Volume of piping:

Vp = Pi* (R*R) * length

= 3.14 * (1.91in*1.91in) *40 ft/(144 in2/ ft2)	= 3.14*(.049m*.049m)*12.2m
= 3.18 ft3	= 0.09 m^3
= 3.18 ft3 * 7.48 gal / ft^3	
= 23.8 gal	= 90 liters

Total required volume = 313.2 gal + 23.8 gal = 337 gal
= 1176 liters + 90 liters = 1266 liters

The tank for this system should hold a minimum of 340 gallons or 1270 liters of cleaning solution.

Materials/components:

Materials for the skid should be the following:

Tank:	Fiberglass reinforced plasitc (FRP) or polypropylene.
Piping:	PVC schedule 80 or Nylon reinforced flex hose.
Victaulics:	Stainless Steel
Valves:	Stainless Steel
Pump	Stainless Steel or Non-metallic composite polyesters.

Pump should be a centrifugal type able to attain the flows and pressures listed in table 1of the next section. Cartridge filters should be 5 micron rating string wound modules. Valves should be installed appropriately to control flow. Tank should have a removable cover. All components should be able to withstand extremes in pH, temperatures up to 113 F (45 C), and electrical sources/switches should be protected and well grounded.

Cleaning Procedures

Generally, low pH solutions are used to clean metallic scales while alkaline solutions are used to clean biological and organic fouling. Relatively high flow (governed by the size of the element) with low pressure is recommended. (Do not, however, exceed maximum flow limits for the elements). Table 1 provides guidelines for pressures and flows per vessel for a range of element diameters.

Table 1: Pressures and Flows for Elements

Element diameter inches (cm)	Feed Pressure psi (bar)	Feed Flow/vessel GPM (lpm)
2.5 (6.4)	20-60 (1.4-4.1)	3-5 (11-20)
4 (10.1)	20-60 (1.4-4.1)	8-10 (30-40)
6 (15.2)	20-60 (1.4-4.1)	16-20 (60-75)
8 (20.2)	20-60 (1.4-4.1)	30-40 (115-150)

To clean a system, follow these six basic steps:

1. Prepare the cleaning solution per the instructions found in the appropriate TSB.
2. Displace the solution in the vessels either by flushing with permeate water or by pumping cleaning solution at a low pressure and low flow. To prevent dilution of the cleaning solution, the process water can be dumped to drain until the cleaning solution has filled the vessels.
3. Recycle the solution through the elements and back to the tank.
4. Soak the elements for 1 hour. (For heavy fouling, overnight soaking may be required).
5. Recycle at the flow rates listed in Table 1 for an hour. The turbulence created in this high flow regime will help to displace the foulants from the membrane. Do not exceed 10 psi pressure drop per element; if the pressure drop is too great, reduce the flow.
6. Flush the system with clean permeate water or pre-filtered raw water.

List of TSB's

TSB 100: RO Membrane Foulants and Their Removal from Cellulose Acetate Blend (CAB) RO Membrane

TSB 102: RO Membrane Foulants and Their Removal from Polyvinyl Derivative (PVD) RO Membrane Elements

TSB 107: RO Membrane Foulants and Their Removal from Composite Polyamide (ESPA, ESNA, CPA, LFC, and SWC) RO Membrane Elements

TSB 111: Cleaning Procedure for Ultrafiltration Membranes used for Oily Water Separations

TSB 112: Cleaning Procedure for Ultrafiltration Membranes used for E-Coat Paint Applications

In general, the steps and solutions listed in the above TSB's are similiar. However, it is worthwhile emphasizing the following points:

- Use of chlorine or other strong oxidants on polyamide membranes can cause irreversible damage to the membrane.
- Warm water, ie 90 F - 100 F (32 C - 37 C), gives significantly better cleaning than lower temperature solutions.
- If the pH of an acid solution increases during recirculation, add more acid to return the pH back to the target value. What is occurring is that acid is being consumed as it dissolves inorganic scale.
- Do not use sulfuric acid for low pH solutions as this creates a risk of creating sulfate scale.

- Permeate water is preferred for mixing solutions.
- Use of filtered tap water for high pH solutions can result in carbonate fouling if the water is hard.
- Flush the membranes with permeate water following cleaning to remove the cleaning solutions.
- Under severe fouling conditions, it may be necessary to soak overnight.

Storage TSB's

If elements are to be out of service for more than 24 hours, please refer to the following TSB's for storage instructions:

TSB 101: General Storage Procedures for Cellulose Acetate Blend (CAB) RO Membrane Elements

TSB 108: General Storage Procedures for Composite Polyamide (ESPA, ESNA, CPA, LFC, and SWC) and Polyvinyl Derivative (PVD) RO Membrane Elements

LENNTECH bv
info@lenntech.com
www.lenntech.com
Tel. +31-15-261.09.00
Fax. +31-15-261.62.89

Troubleshooting Your RO

Summary: There can be many reasons why a RO system suffers a loss in performance, and is unable to produce the proper quantity and/or quality of permeate water. Similar to a doctor attempting to make a diagnosis, you must identify as many symptoms as possible before you can derive an educated guess as to what the disease is.

INTRODUCTION

The focus of this paper is how to troubleshoot a RO system on-site. Many of the techniques assume the equipment has been designed with instrumentation and sampling points to allow troubleshooting and for on-site cleanings, which is common for "industrial quality" systems, but not necessarily for "residential or light commercial" equipment. The capital cost for small RO to include troubleshooting instruments and sample valves is prohibitive for their market niches, relative to the minimal cost of replacing RO elements on a more frequent basis. As RO systems reach a certain size (say 15 gpm or larger), the cost of replacing RO elements on a frequent basis becomes prohibitive versus the initial capital cost of adding instruments, sample valves and on-site cleaning equipment.

HOW TO AVOID TROUBLE

The best way to stay out of trouble with a RO system is to avoid it initially. A few RO design tips are:

- Design the RO system with access to a complete water analysis. If there are seasonal variations (which are common for surface sources) or varying sources (which are common with municipal sources), get all the analyses you can and be sure they are recent.

- Perform 15 minute SDI (Silt Density Index) tests. This on-site testing helps to determine the potential for colloidal silt fouling. Refer to TSB113.
- Invest in the appropriate pretreatment. If you want to sleep well at night, make sure the system design has adequate pretreatment to the RO.
- Design the RO system flux rate conservatively, especially if the potential for fouling exists. A RO with a clean well water source can be designed more aggressively than one for a surface water source. A reduced rate of permeate water flow for a given area of membrane reduces the convective deposition of foulants at the membrane surface. Fluxes for surface waters should range from 8 to 14 gfd (gallons per square foot of membrane area per day) and 14 to 18 gfd for well sources.
- Design the RO recovery rate conservatively. A conservative per cent recovery of the feed water minimizes the concentration of foulants.
- Maximize the cross flow velocity in the elements. A conservative design maximizes the cross-flow velocity of the feed and concentrate streams. A higher cross-flow velocity reduces the concentration of salts and foulants at the membrane surface by increasing their diffusion back into bulk feed stream above the membrane surface.
- Select the right membrane for the application. Sometimes a neutrally charged CAB (cellulose acetate blend) or LFC (Low Fouling Composite) RO element is a better choice than a negatively charged CPA (Composite PolyAmide) RO element for difficult surface or waste water sources.

IDENTIFYING A PROBLEM

Verify that you really have RO system fouling. Changes in system operating parameters do have an effect on performance. For instance, an increase in feed TDS (total dissolved solids) will increase feed pressure requirements by approximately 1 psig for every 100 ppm TDS increase due to increased osmotic pressure and it will also increase permeate conductivity since the RO will always reject a fixed percentage of the salts. A 10^{o} F increase in feed water temperature will decrease the feed pump pressure requirement by 15%. An increase in the per cent recovery of the system will increase the reject TDS which in turn will increase permeate conductivity. (Concentrate TDS due to concentration of the feed water is 2 times higher at 50% recovery, 4 times higher at 75% recovery and 10 times higher at 90% recovery). Finally, a reduction in the permeate flow

will result in higher conductivity if the same recovery is maintained because the passage of salts through the membrane is independent of the passage of water through the membrane, which results in less permeate water to dilute the salts that have passed through.

It is recommended that you "normalize" your logged operating data to determine if you have a problem with your system. "Normalization" computer programs, such as RODATA, graphically represent normalized permeate flow, per cent salt rejection and feed-to-reject pressure drop. These normalized parameters are calculated by comparing a particular day's operations to the first day of operation. Adjustments are made for changes in major operating variables such as temperature, feed TDS, recovery, and pressures. In this way, performance declines unrelated to operating parameters can be identified and treated.

Questions to ask yourself…

Loss in performance is generally divided into two categories: loss of flow, and loss of rejection. The following lists of questions help to identify possible root causes for either of these problems.

Loss of Flow

Attributable to fouling, these questions can help pinpoint the problem. Certain foulants impact the front end of the system while others impact the back end of the system. Use the RO Troubleshooting Matrix (at the end of this document) to help determine the nature of the foulant.

- Did you shut down the RO system properly? In some instances, the reject water from the Service operation should be flushed out of the system upon shutdown. If not, inorganic foulants can precipitate onto the surface of the membrane. The best flush water source is RO permeate.
- Did you store the RO system properly? Improperly stored systems (especially under warm conditions) can produce a severe biofilm problem. (Refer to TSB's 101, 103, 108, and 110 for more information).
- If you acidify to lower feed pH or add scale inhibitor (SI) for the control of calcium carbonate (lime) scale, are you meeting your target pH or SI concentration? If not, you may need to do an acid clean. (TSB's 100, 102, 107)

- Has your pressure drop between the feed and reject lines increased greater than 15%? Increasing pressure drop indicates that fouling of the feed path and a restriction of flow over the membrane surface is occurring. Monitoring pressure drops across stages gives you the advantage of determining if the fouling is limited to a particular stage, which can help identify the potential foulant.
- In seawater systems, are you flushing with permeate water at shut-down? Flushing removes high concentrations of ions that could precipitate out of solution. At a minimum, feedwater can be used, but it is recommended to use permeate water for the flush.
- Are the cartridge filters fouling? Inspect the RO feed cartridge filter for foulants as this is relatively easy.

Loss of Rejection

Loss of rejection displays itself as a higher permeate conductivity. It may be due either to fouling, degradation of the membrane surface, or an o-ring leak. The following questions can help you pinpoint the source of this problem. Verify that the permeate conductivity has not increased greater than 15%.

- Do all the vessels in a stage have nearly the same conductivity permeate? Measure permeate quality by stage and by pressure vessel if possible. One vessel having a significantly higher permeate conductivity probably has a faulty o-ring, a disconnect, or a damaged membrane. (See TSB's related to vessel shimming (TSB 109) and vessel probing (TSB 114) to determine the point of the leak).
- Have your composite membranes been exposed to chlorine or any other strong oxidant? The exposure may have damaged the membranes.
- Have your cellulose acetate (CAB) membranes been exposed to pH extremes? The exposure may have damaged the membranes. Likely causes of pH extremes are faulty metering pumps, acid tanks that have gone dry, loss of prime to the metering pump, or flushing/storage in non-acidified water.
- Is the instrumentation accurate? Verify that all of your instruments are calibrated properly.

- Do the elements look discolored or damaged? Inspect the RO elements for foulants or physical damage.
- How do the actual conductivity and temperature of the feedwater compare to the design criteria? If the actual feedwater has higher TDS or is warmer than the design, this may account for the discrepancy. Sample and obtain detailed water analyses of the RO feed, concentrate and permeate. Compare the results of the analyses to the RO design projections of the element manufacturer.
- Can there be times when the permeate pressure exceeds the feed pressure? If the permeate is pumped to an elevated position, and there are no check valves on the permeate lines, at shut down, the permeate pressure can exceed the feed pressure. This can cause the membrane envelopes to expand and rupture.
- Are your o-rings in good condition? O-rings can flatten or crack with age. The result is that leaks can develop. Replacement of o-rings periodically is a good, cost-effective preventive maintenance step. Alternatively, vessels may be probed (TSB 114) to find faulty o-rings.

IF you still think there is a problem…

- Once you have ruled out any mechanical failures as the source of your RO problem, then you need to determine what your suspected foulant or foulants are and perform a cleaning or series of cleanings.
- The cleaning solution can be collected and analyzed for the foulants removed, color change or pH change. The effectiveness of the cleaning can be verified by placing the RO back into Service.
- If you don't know what your foulants are and don't want to experiment on site as to what cleaning solution(s) are required and what the proper cleaning procedures should be, their are companies who specialize in the supply of proprietary cleaning chemicals and off-site evaluations of RO elements. These services can be invaluable, especially the first time around in cleaning a RO.
- If all else fails in determining what fouled the RO element, a destructive autopsy can be performed. The RO element is cut open and unrolled with analytical tests run on the membrane and the foulant to determine the problem.

Hydranautics can perform analytical testing of foulants at our labs, as well as perform Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray analysis to help determine the cause of fouling. TSB 116, Returned Goods Authorization (RGA) Procedure, provides a list of services and costs.

Summary

This list of questions should help in troubleshooting most RO problems. Attached is a table to help determine some of the most common problems from the given systems.

If further assistance is required, contact the Technical Service Group at Hydranautics by e:mail or at 1-800-CPA-PURE (1-800-272-7873)

RO Troubleshooting Matrix

Possible Cause	Possible Location	Normalized Pressure Drop	Normalized Permeate Flow	Normalized Salt Passage
Metal Oxide	**1st stage**	**Normal to Increased**	**Decreased**	**Normal to Increased**
Colloidal Fouling	**1st stage**	**Normal to Increased**	**Decreased**	**Normal to Increased**
Scaling	**Last stage**	**Increased**	**Decreased**	**Increased**
Biological Fouling	**Any stage**	**Normal to Increased**	**Decreased**	**Normal to Increased**
Organic Fouling	**All stages**	**Normal**	**Decreased**	**Decreased or Increased**
Oxidant (e.g. Cl_2)	**1st stage most severe**	**Normal to Decreased**	**Increased**	**Increased**
Abrasion (carbon, silt)	**1st stage most severe**	**Normal**	**Increased**	**Increased**
O-ring or glue leaks	**Random**	**Normal to decreased**	**Normal to Increased**	**Increased**
Recovery too high	**All stages**	**Decreased**	**Normal to Decreased**	**Increased**

Hydranautics are the most common Membranes.
Go for more information to:

http://www.lenntech.com/products/membrane/hydranautics/hydronautics-membranes.htm

LENNTECH bv
Rotterdamseweg 402m
2629HH Delft
The Netherlands
info@lenntech.com
www.lenntech.com
Tel. +31-15-261.09.00
Fax. +31-15-261.62.89