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The Official Journal of the PFI High Purity Water Conference & Seminar Series

Spring 2014

Basics of RO Troubleshooting

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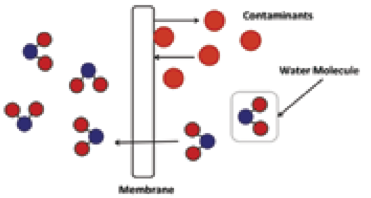
Reverse osmosis (RO) technology has been in widespread application for 30 to 40 years, and the industry's understanding and acceptance of this technology has grown significantly over this period. Process industry professionals now recognize the value that a reverse osmosis unit adds to a water system, in terms of both production quality and reduction in the recurring costs associated with ion exchange systems. It is surprising then, 40 years after its inception, how poorly many reverse osmosis systems are designed and operated. Any potential operational cost savings are thrown away by excessive cleaning and membrane replacement caused by unsound operation or design. This article is meant to provide a reverse osmosis operator or maintenance person with an overview of basic RO monitoring and troubleshooting techniques that can improve quality production, reduce downtime, and prevent costly RO membrane element destruction.

Reverse Osmosis Basics

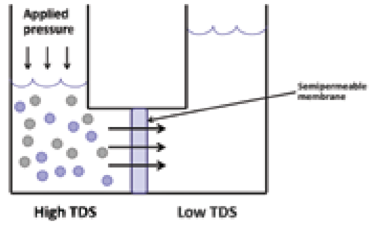
While this article is intended for someone who is already familiar with reverse osmosis units, a brief introduction may prove beneficial to the uninitiated. Osmosis is a naturally occurring phenomenon in which water has a tendency to pass through a semi-permeable membrane from a solution of low total dissolved solids (TDS) into a solution of high total dissolved solids. Flow of water through the membrane is dependent on the osmotic pressure of the solution, essentially a term describing the magnitude of a solution's tendency to pass water from one side of the membrane to the other.

A semipermeable membrane, true to its name, is a barrier through which certain components may pass while others are rejected. In the case of a reverse osmosis membrane, water is freely allowed to pass, while dissolved & suspended contaminants such as dirt, minerals or bacteria are mostly rejected.



Semipermeable Membrane

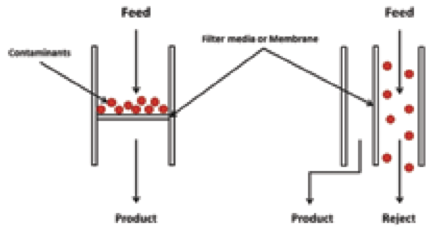
Reverse Osmosis then, is the reversal of the osmosis process: water passes from a solution of high TDS to low TDS. This means we can use membranes to remove dissolved solids from water by applied pressure. A high pressure pump is the driving force behind water production in every RO unit. There must be enough pressure applied to the feed water in order to overcome the osmotic pressure developed by the dissolved salts present. The more salts present in the water, the higher the osmotic pressure and the higher the required feed pressure for the RO unit.



Reverse Osmosis

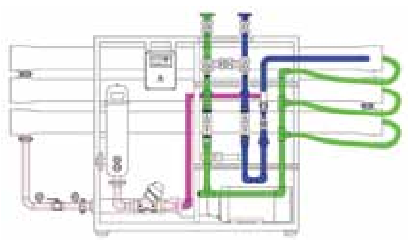
This explains the significant difference between RO units designed for use on city water or surface water, and RO units designed to desalinate seawater. The dissolved solids in seawater could be 100 times the dissolved solids present in a lake or a river.

The reverse osmosis process is an example of a cross flow filtration system. Typical media or cartridge filtration uses a full flow design, where all of the feed water passes through the filtration media and is collected as product. In a cross flow system, only a portion of the feed water is collected as product, and the rest is used to sweep away the dissolved solids that don't pass through the membrane. This cross flow prevents premature blockage of the membrane surface and failure of the water system.



Full Flow vs. Cross Flow

RO units consist of a number of membrane elements, housed in pressure vessels, a high pressure feed pump, valves, piping and instrumentation to control the various flows, monitor critical parameters and perform basic maintenance functions. Although units vary in size, materials of construction and controls capabilities, these are the common components found in different designs.



Green = Permeate **Blue = Concentrate**
Pink = Feed/Recycle

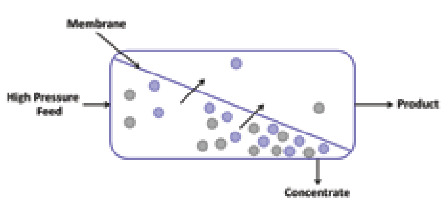
Scaling, Fouling & Chemical Attack

The issues that adversely affect RO system operation can almost always be grouped into three main categories:

- **Scaling**
- **Fouling**
- **Chemical Attack**

In order to produce water, an RO unit takes feed water with some amount of dissolved solids (salts) and splits it into two streams: a purified stream (product/permeate) and a dirty stream (concentrate/reject). Since the RO unit is rejecting the dissolved solids in the feed water, the concentrate stream has a significantly higher concentration than it did to start with. It is common to see about four times the amount of dissolved minerals in the concentrate stream as in the feed stream. How does this become an issue? Imagine pouring a tablespoon of salt into a glass of water. After some brief stirring action the glass of water would appear clear again, because the salt has been completely dissolved in the water. Now imagine what would happen if you poured five pounds of salt in the same glass. Some of the salt would dissolve as before, but after a certain point, it would stop, and you would see a glass full of solid salt crystals.

Every compound has a limit to the amount that can be dissolved in water before crystalline solids start to form. Some compounds have a very high limit and some compounds have a very low limit. The compounds that have a low limit are the ones that are most troublesome. These solid crystalline salts can cause issues with RO operation. The membranes only operate effectively when the surface is kept clean. If there are solids blocking the surface, there is less area to make water. When dissolved solids are precipitating on the surface of the membrane it is referred to as **scaling**. The two most common scaling compounds are calcium carbonate and calcium sulfate.



Feed Water Concentration

Fouling is another common issue that can affect membrane performance. Fouling is a general term used to describe any suspended solids that accumulate on the membrane surface or in the membrane feed channel and reduce water production. Fouling can be caused by dirt, sand, silt, clay, bacteria or any other small suspended solids. Fouling caused by bacteria or living organisms is often called "biofouling" to distinguish it from fouling caused by inorganic compounds. Biofouling is often one of the trickiest problems to diagnose and treat in an RO unit. The main difference between scaling and fouling is in the type of constituents in the water that are creating the problem. Fouling is caused by suspended solids (typically greater than 0.01 microns), while scaling is caused by dissolved solids (salts) exceeding their solubility.

Scaling and fouling are both fundamentally the same type of issue, particulate plugging the membrane surface resulting in reduced flow. The third category, **chemical attack**, refers to chemical destruction of the membrane surface. The membrane is a composite of several layers of different types of material designed to give it the unique salt rejecting properties. The top layer is extremely thin and fragile, and certain chemicals can destroy it. As damage accumulates the quality of the product water declines. Oxidizing agents such as free chlorine or high concentrations of disinfectants or cleaning chemicals can produce this effect. While scaling and fouling can both be remediated with proper chemical cleaning, chemical attack is irreversible, and replacing membrane elements is the only way to return the system to start-up quality.

Monitoring

Monitoring, recording system data and trending selected parameters on an RO unit is one of the most effective tools for identifying problems. The following items, at a minimum, should be measured and logged on a daily basis.

- **Conductivity (Quality measurement)**
  - Feed water
  - Permeate (product water)
- **Pressures**
  - Membrane Feed (housing inlet piping)
  - Interstage (between housings)
  - Concentrate (housing outlet piping)
- **Flows**
  - Feed flow
  - Permeate flow
  - Concentrate flow
- **Temperature**
  - Feed water temperature

The above parameters provide enough data to compute the three critical operational indicators for an RO unit. These indicators are:

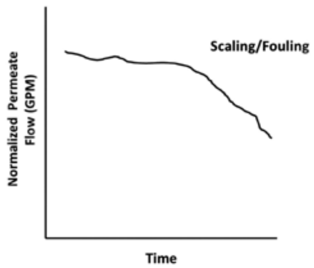
- **Normalized permeate flow**
- **Pressure drop per stage**
- **Normalized salt rejection**

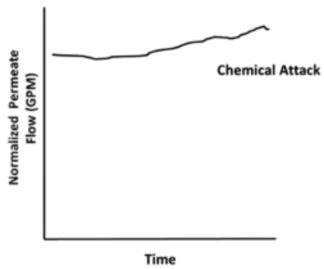
Normalized permeate flow is a calculated value. This parameter must be normalized because there are several factors that influence permeate flow: feed pressure, feed conductivity and feed temperature. A higher feed pressure increases the amount of water produced. This applied pressure is the force that is overcoming the osmotic pressure and pushing water through the membrane. It makes sense that a stronger push causes more water to flow through. Higher feed water conductivity reduces the amount of water produced. The osmotic pressure counteracts the applied pressure so a greater feed conductivity = higher osmotic pressure = less water production. Temperature also affects permeate production. A higher water temperature lowers the viscosity of the water, which reduces the required feed pressure to produce a given amount of permeate. All of these variables must be taken into account when normalizing the permeate flow rate. Otherwise it would be difficult to tell whether the production of an RO unit is declining due to a problem, or to a decrease in the feed water temperature. Normalized permeate flow then can be determined as follows:

$$\text{Normalized Permeate Flow} = \frac{\text{Net driving pressure original}}{\text{Net driving pressure current}} \times \text{Temperature Correction Factor} \times \text{Permeate Flow}$$

When the membrane is brand new and completely free of any dissolved or suspended contaminants the normalized permeate flow is at its maximum. Over time, as contaminants begin to plug the membrane surface, more pressure is required to produce the same amount of product water. The normalized permeate flow declines.

Normalized permeate flow (NPF) is the single most effective measure for scaling or fouling. NPF can also be used to identify chemical attack. If the surface of the membrane is deteriorating, the water can pass through easier. In this situation it is possible to see normalized permeate flow *increase*, which should not occur under normal conditions. If a significant increase in normalized permeate flow is observed, then tests for potentially oxidizing substances should be performed on the concentrate water. If left un-checked, the product quality will eventually deteriorate to a point where membranes must be replaced.



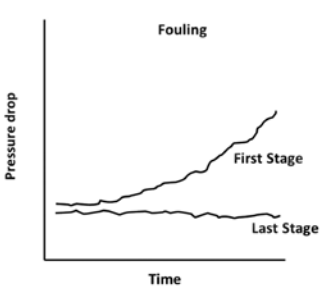


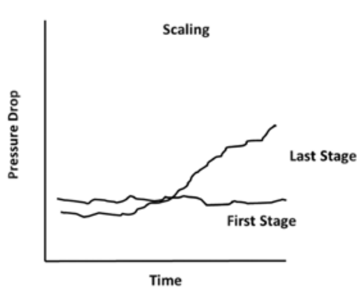
Pressure drop can also be used for monitoring & troubleshooting an RO system. Pressure drop is determined by taking the inlet pressure & subtracting the reject outlet pressure:

Pressure drop = Inlet pressure - Reject outlet pressure

In a unit with new elements, the pressure drop is due to the friction and energy loss of the water as it flows through the feed water spacer, vessel, pipe and valves. Every unit has a normal amount of pressure drop which should be recorded at start-up. As the feed water channel becomes plugged with scaling or fouling material, the pressure drop rises. As the spaces through which the water must pass become more constrained, more friction and energy loss results, which presents itself as a higher pressure drop in the unit.

It is especially useful to measure pressure drop across each stage independently. A decline in normalized permeate flow is enough to indicate a problem but it doesn't necessarily point to whether the problem is scaling or fouling. Fouling almost always occurs first at the lead end of an RO unit. The housings in the first stage are more likely to foul before the last stage. Scaling however is more likely to occur at the back end of an RO unit. This is where the highest concentration of dissolved solids occurs, so exceeding the saturation limit in the last stage is much more probable. If a decline in normalized permeate flow is observed and a pressure drop increase occurs across the first stage, but not the second, the problem is likely some sort of fouling. On the other side, if the NPF is going down and an increase in pressure drop across the second stage occurs but not the first stage, then scaling is most likely the issue.





The third critical operation parameter is **percent salt rejection**. This value indicates how well membranes are rejecting the dissolved solids in the feed stream. It can be approximated as follows:

$$\%\ \text{Salt Rejection} = \frac{\text{Feed Conductivity} - \text{Permeate Conductivity}}{\text{Feed Conductivity}} \times 100$$

This parameter is especially useful for identifying scaling or chemical attack problems. If the membrane is being oxidized by free chlorine for instance, the salt rejection decreases. As the rejecting layer is damaged, more salt passes through. Similarly, if the membranes are heavily scaled, a decline in salt rejection is observed. This decline can be explained by two factors. First, an accumulation of crystalline salt material on the membrane surface creates localized high concentration spots that increase salt diffusion through the membrane. This can be attributed to a phenomenon called concentration polarization. There is a very thin layer (only a few microns) at the surface of the membrane where the crossflow is much lower than in the rest of the feed channel. This layer is referred to as a boundary layer. The rate of dissolved solids diffusion into the boundary layer is higher than the rate of diffusion. This results in a localized concentration increase typically between 10 and 20 percent. This in turn increases the salt diffusion *through* the membrane and compromises the salt rejection. Secondly, it is possible that sharp crystalline scale could scratch the extremely thin membrane surface, opening up holes for more dissolved solids to pass through.

The following table summarizes the expected indicators to help diagnose a problem.

PROBLEM	SYMPTOM
Scaling	Decrease in normalized permeate flow Increase in pressure drop across last stage Decline in % salt rejection
Fouling	Decrease in normalized permeate flow Increase in pressure drop across last stage Little to no effect on % salt rejection
Chemical Attack	Increase in normalized permeate flow Little to no effect in pressure drop Decline in % salt rejection

This article is meant to provide basic troubleshooting techniques needed to properly operate and maintain a reverse osmosis system. These techniques do not require costly instrumentation or software packages, and they can be applied to RO systems of any size or type. There are a variety of advanced techniques not discussed in this article, including membrane autopsies, element probing and housing profiling, but the information presented covers the majority of problems encountered when operating an RO unit. The most crucial part of maintaining a system in proper operation is consistent monitoring and collection of data. Analyzing the data collected is the easy part.

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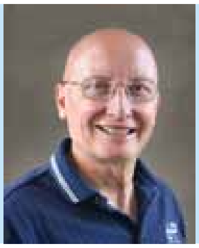

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Humility

True humility is not thinking less of yourself; it is thinking of yourself less.

- C.S. Lewis

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