WHY YOUR RO MEMBRANE CLEANING MAY NOT BE EFFECTIVE. THE BENEFITS OF REVERSE CLEANING

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SUMMARY

Historically, RO (Reverse Osmosis) membrane cleanings have been performed in a forward direction, with the cleaning solution being introduced into the feed end of the pressure vessels. This results in the cleaning flow going through the RO membranes in the same direction as normal operation. This works well for many types of cleanings, but there are specific instances when the foulant is concentrated in the front end of the lead RO membranes. Some examples of this might be biofouling, colloidal fouling, or deposition of particulates. Cleaning in a forward direction can prove to have minimal effect at removing these front end foulants, and it actually can make matters worse by pushing foulant and/or debris further into the lead membranes. In these cases, it has been shown that reversing the direction of the cleaning flow can be beneficial in removing the foulant and returning the RO system to normal performance. Some of the major RO membrane manufacturers strongly discourage reverse cleaning due to concerns about telescoping the RO elements, since there is no support structure at the feed end of the pressure vessels. This paper will discuss the precautions that should be implemented to perform reverse cleaning safely, along with studies showing the effectiveness of reverse cleaning. This paper will look at some of the major desalination plants that have implemented the method, and we will look at how some of the larger desalination plants were able to convert their cleaning systems to be able to reverse clean simply. Finally, we will look at alternatives to reverse cleaning, such as reverse flushing, and rotations of lead and tail elements.

Keywords: Reverse Cleaning, Biofouling

INTRODUCTION

Reverse cleaning has not become an accepted industry practice due to concerns that damage may occur to the RO elements when cleaning is done in a reverse direction. Indeed, some RO element manufacturers strictly prohibit the use of reverse flow cleaning. Much of this is due to the history of RO elements, which used to be rolled by hand and contained much less membrane area than today. With the automated tensioning that is used today during the automated membrane rolling process, the membranes have much higher structural integrity than in years past. In addition, the RO elements generally contain much more membrane area than during the early years of RO. This results in an element that is much less likely to experience telescoping or feed spacer migration than in years past. Telescoping is when the outer membrane layers of the element unravel and extend downstream past the remaining layers[1]. Feed spacer migration is when the feed spacer netting becomes plugged with foulant and can move in the feed direction until it begins to protrude out the brine end of the element. With proper precautions in place, reverse cleaning can be done safely.

METHODS

When the author started in the RO membrane business over 35 years ago, Hydranautics was involved in the construction of many municipal desalination plants. Most of these plants had portable CIP (Clean-in-Place) skids which used hoses to connect the CIP skid to the train that was to be cleaned. In certain cases where we had fouling or contaminants in the lead membranes, we would simply switch the hoses to reverse the flow. This worked very well in cases where sand, carbon fines, ion exchange resins, etc. would get into the lead membranes. As time went on and larger and larger desalination plants were built, the piping connections became permanent and the ability to reverse clean was lost. But when biofouling in the lead membranes became a major issue at one of the NEWater plants (NEWater is a municipal water recycling program in Singapore) in 2007, we were able to implement reverse flushing to help control the very high differential pressure. This same system has now been converted to be able to perform reverse cleaning on a regular basis. The difference between reverse cleaning and reverse flushing is that reverse cleaning uses a cleaning pump (and chemicals) with a higher velocity for more effective cleaning, while reverse flushing uses flushing pumps (and lower velocities) with permeate only.

Biofouling is a common problem at many wastewater and seawater RO plants. There is a common misperception that if there is Microfiltration (MF) or Ultrafiltration (UF) pretreatment ahead of the RO system, then there should not be any RO membrane fouling. While MF and UF are proven to remove most colloidal matter and generally will give excellent SDI (Silt Density Index) results, we find that biofouling can present problems at many WWRO (Wastewater Reverse Osmosis) and SWRO (Seawater Reverse Osmosis) plants that use MF/UF. Biofouling usually forms at the very front of the lead membrane (see Photo 1), and can be minimal after the first 10 – 20 centimeters of the lead membrane. This is the reason that reverse cleaning is beneficial in such cases, since it is a physical process of “pushing” the foulant back out of the end of the membrane where the fouling has accumulated. A forward cleaning would involve having to break up the foulant and pass this foulant through all of the other membranes in the pressure vessel. Many times the biofoulant will “catch” some of the colloidal or other matter that may get into the RO elements, and this can make cleaning much more difficult. In these cases, reverse cleaning has been shown to be especially useful [2].

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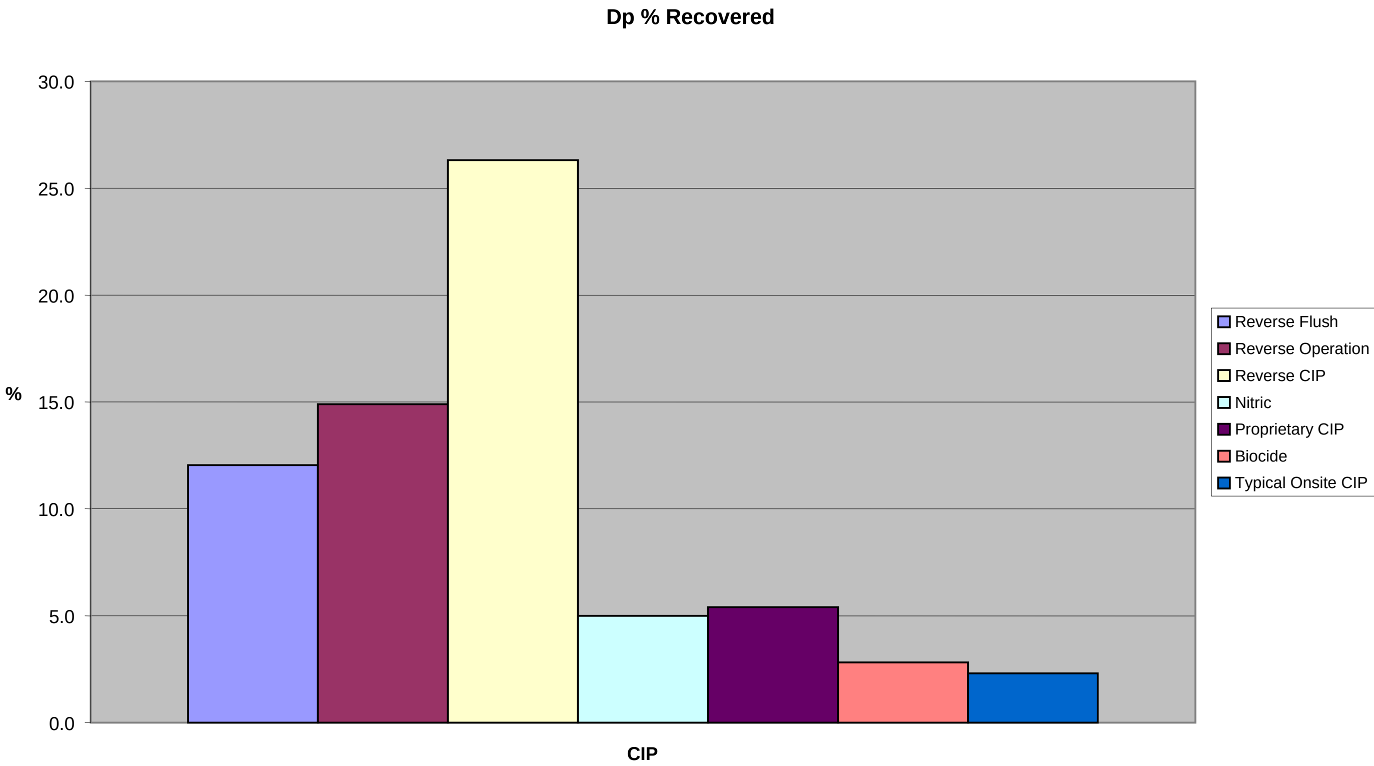
Photo 1 - Biofouling Formation at Feed End of RO Element

WATERCORPORATION STUDY

When the WaterCorporation in Perth, Western Australia had problems with biofouling in the Beenyup demonstration plant, they continued to do high pH, high temperature cleanings with minimal success at restoring dP's (dP is the pressure differential across a membrane which indicates the level of "plugging" of the RO feed spacer) to baseline levels. After one year of operation, the RO membranes needed to be replaced due to the aggressive cleanings. The biofouling was heavily concentrated in the lead membranes, and the lead membranes were then "flipped" around so that the brine end of the element became the feed end, and the brine seal was moved to the new feed side of the element. These elements were weighed (after 30 minutes of drain time) and then placed in tail positions at the back of the 2nd stage and operated as normal. After several days of operation, these tail elements were removed and weighed again after 30 minutes of drain time. Each of the elements was now several kilograms lighter, due to the biofoulant material being pushed out of the RO membranes during operation. This test showed that "flipping" the elements could reduce dP's, but it would involve a lot of manual labor. The WaterCorporation then ran a series of tests to determine the most effective way to remove the biofouling. Their results showed conclusively the benefits of reverse cleaning (see Graph 1). 4 of the cleaning methods were done in a forward direction, while 3 of the cleaning methods were done in a reverse direction. All 3 reverse flow methods were better at removing the foulants than any of the forward flow methods. This led to the WaterCorporation modifying the demonstration plant to be able to reverse clean. Based upon the results of reverse cleaning at the Demonstration plant, the full scale Beenyup Wastewater treatment plant was built with the ability to reverse clean the RO elements and commissioned in 2016 (with the capacity doubled in 2019).



Graph 1 – WaterCorporation Study of Cleaning Results

It is important to note that RO plants should be designed to be able to clean the membranes in both directions, not just in reverse direction only. Fouling of the RO membranes usually starts at either the front of the RO system, or at the tail end of the RO system (usually due to scaling). It then tends to spread towards the middle of the RO system if left unchecked. On a two-stage system, only the first stage needs to be designed to be able to reverse clean. There is usually no additional benefit to be able to clean the second stage in reverse direction, since foulant accumulation is rare at the front of the 2nd stage. In fact, if any scalant is present at the tail end of the RO system, reverse cleaning may allow any sharp, crystalline, scaling particles (see Photo 2) that are present to damage membranes towards the front of the pressure vessel. For this reason, cleaning (in a forward direction) should be done first to remove any possible scalant. An illustration of forward (normal) versus reverse direction cleaning is shown in Figure 1.

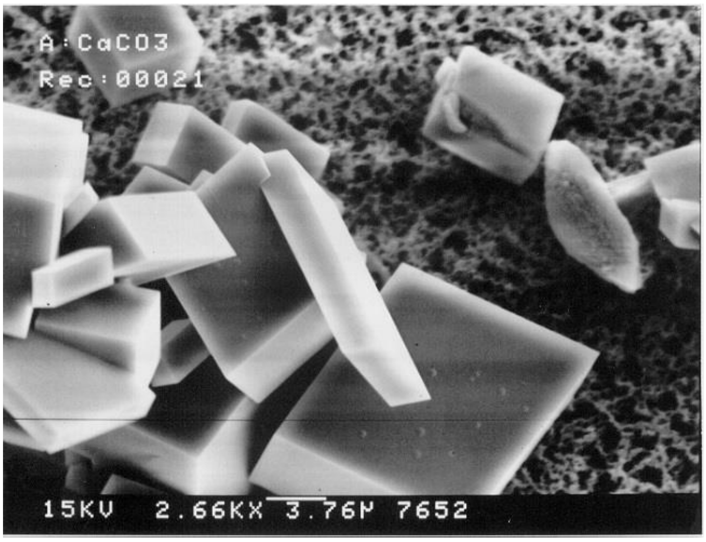


Photo 2 - Calcium Carbonate Scaling

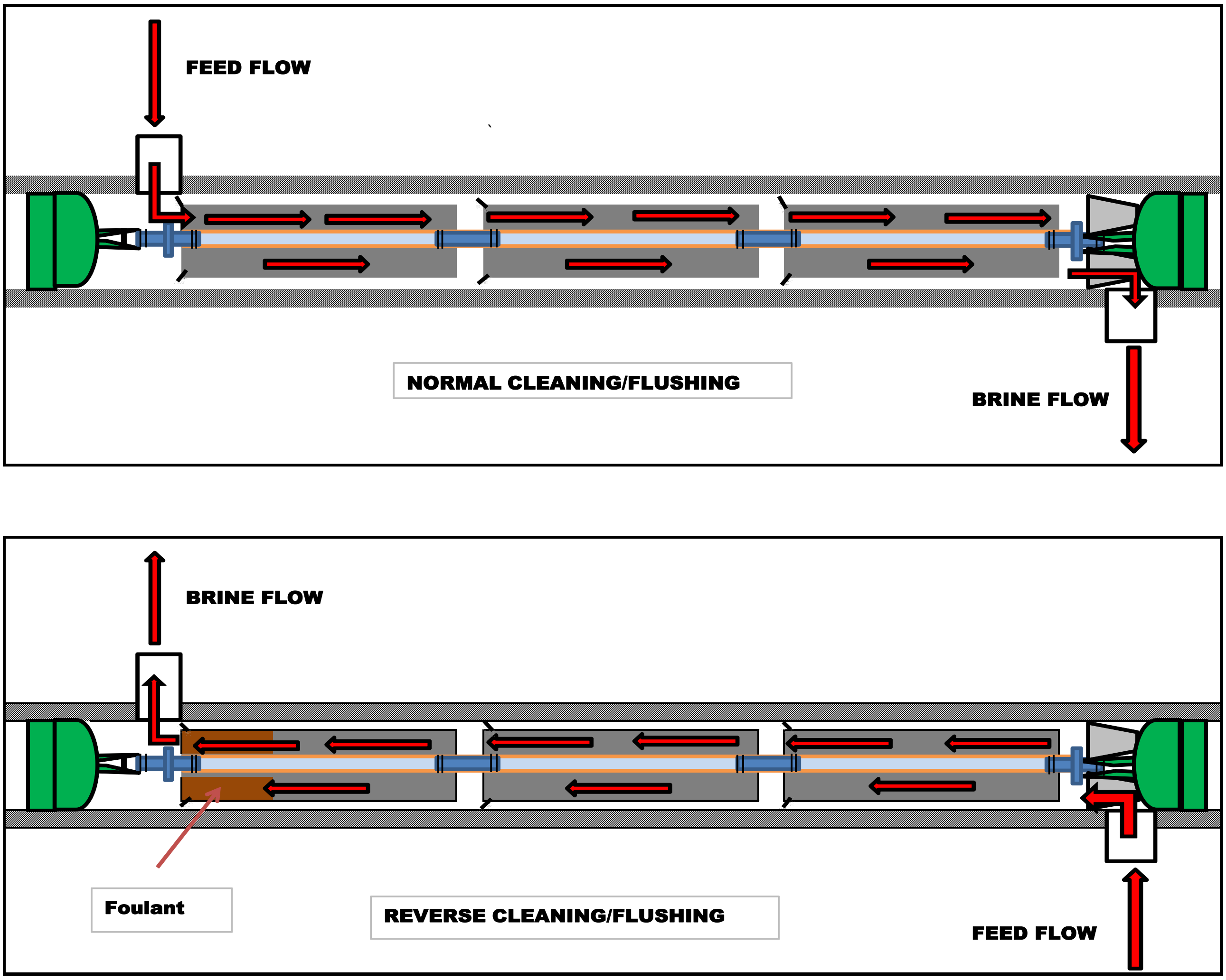


Figure 1 - Illustration of Normal Cleaning versus Reverse Cleaning

LIST OF PLANTS WITH THE ABILITYTO REVERSE CLEAN OR FLUSH

Below is a list of some of the major desalination plants that were either built to be able to reverse clean or flush, or have been modified to reverse clean or flush:

1. Ulu Pandan Wastewater Reclamation Plant – Singapore
2. Beenyup Wastewater Reclamation Plant – Perth, Australia
3. Changi 2 Wastewater Reclamation Plant – Singapore
4. Melbourne SWRO plant – Melbourne, Australia
5. Adelaide SWRO plant – Adelaide, Australia
6. Gold Coast SWRO plant – Gold Coast, Australia
7. Tuas 3 SWRO plant - Singapore

MODIFYING EXISTING CLEANING SYSTEMS TO BE ABLE TO REVERSE CLEAN

The best method to employ reverse cleaning is for the system to be built with the capability. Plants that are not initially designed and built to allow reverse cleaning and flushing can be modified. A simple (but less effective method) is to change the direction of the permeate flush pumps. This is called reverse flushing (as seen as the first bar in Graph 1). Reverse flushing is helpful in removing front end foulants, but since the flow velocity is usually much less than what cleaning pumps can supply, along with the fact that no chemicals are used, it is usually less effective than reverse cleaning.

There are certain factors that can make modifying an existing CIP system a much simpler task than many people imagine. RO membrane cleaning is generally done at pressures lower than 4 bar due to the fact that the cleaning solution is required to flow across the surface of the RO membrane and lift the foulants off of the membrane surface. If too much pressure is applied, it can cause the creation of permeate and prevent removal of the foulants from the membrane surface. Since the cleaning is done at such low pressures, it is common for the pipework of CIP systems to be made of plastics or fiberglass (even in SWRO systems). This makes modifications much easier, and the ideal point for the modifications is where the lines leave from (and return to) the CIP system. A “cross” can be installed, utilizing valving such that you can choose the direction of flow in the pipework. The 300 MLD Adelaide SWRO plant is one such plant that has made this modification (see Photo 3 and Figure 2, 3, 4 below). There are 10 SWRO trains in each of the two 150 MLD halves of the SWRO plant, and there is one CIP system that is used to clean the 10 SWRO trains of each half. By modifying the pipework near the CIP system, the operators are able to choose either direction for the flow through the seawater RO membranes during cleaning.

Photo 3 - Adelaide CIP line before modification (courtesy of Acciona)

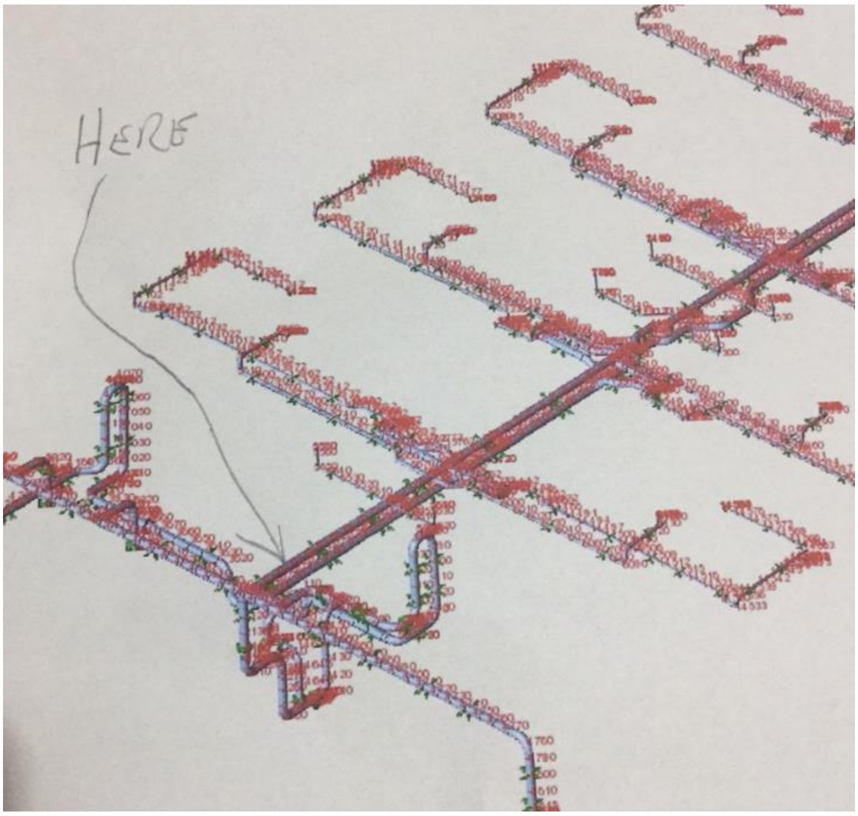


Figure 2 – Diagram of Adelaide CIP system layout to each train. The point labelled "Here" is where the CIP system has been modified to allow reverse cleaning. This allows reverse cleaning to each "branch" which is a SWRO train.

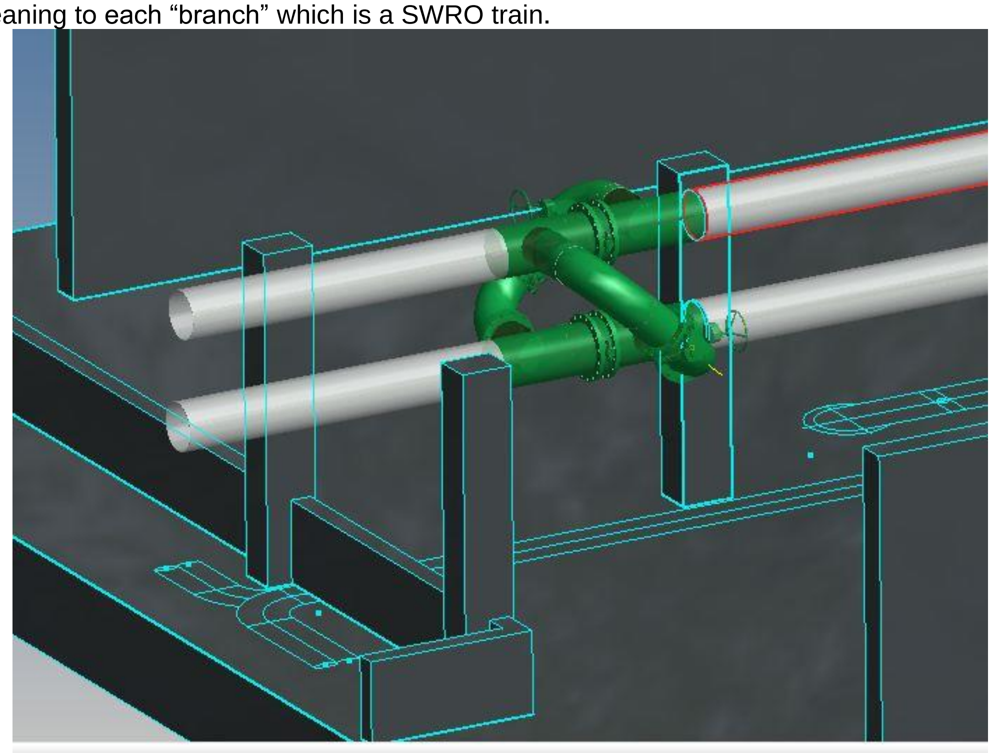


Figure 3 - Drawing of crossover pipework (courtesy of Acciona)

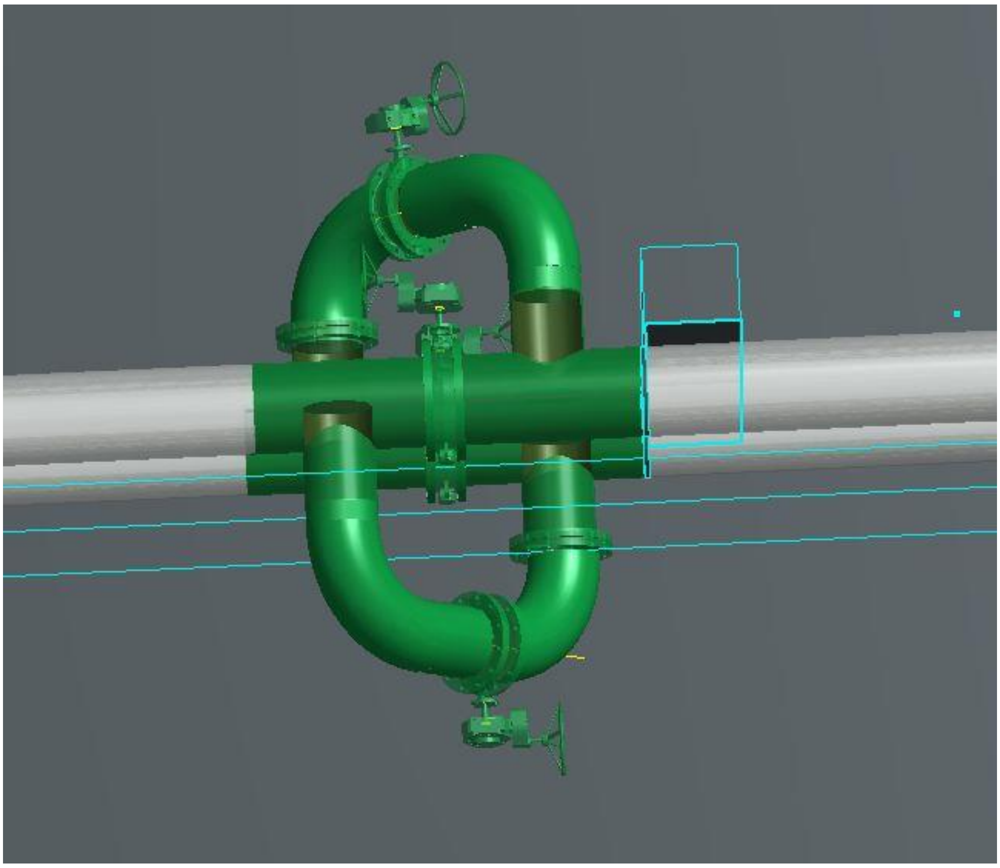


Figure 4 - Closeup drawing of crossover pipework (courtesy of Acciona)

There are other large seawater plants that utilize reverse flushing in a unique manner. The Gold Coast SWRO plant [3] has large permeate suckback tanks mounted mid-level relative to the height of the trains. When one of the trains shuts down, the high salinity seawater will pull in the permeate from these tanks through osmosis, since the low salinity permeate will want to dilute the high salinity seawater. This is akin to a backwash of a MF or UF filter, except that it will not cause permeate backpressure damage to the RO elements. It helps lift the foulants off the membrane surface. Permeate suckback tanks are quite common in areas where the power supply is unreliable, as they allow permeate flushing when the power is shut down. The Gold Coast plant has a unique operating feature, upon shutdown of each train, the reject valves are closed and dump valves are opened at the front end of each train. This results in a reverse flush on each shutdown. This is truly an innovative design and the RO membranes (now 11 years old) have only been cleaned twice during this period.

PRECAUTIONS FOR REVERSE CLEANING

As discussed in the introduction, many RO membrane element manufacturers prohibit reverse cleaning or flushing. This is due to the fact that each pressure vessel has a thrust ring device installed at the downstream end which is designed to support the column of elements and prevent them from telescoping (these thrust rings are also known as anti-telescoping supports). But there is no thrust ring installed on the feed side of each pressure vessel, and if one were installed on the feed side it would not be able to sufficiently support the column since the feed side of the pressure vessel is where shimming take place. Shimming is the done by adding plastic spacers to the front of each vessel, which act to take up excess slack and to help secure the membranes in place and prevent o-rings from rolling). To help prevent damage from occurring during reverse cleaning, we recommend the following best practices [4]:

Removal of tail end scaling

Cleaning in the forward direction is always recommended if scaling is present. Scaling occurs when soluble salts precipitate and fall out of solution at the tail end of RO systems. These salts must be removed before doing any reverse direction cleaning. The crystals that form during scaling can have very sharp edges that can damage the membrane surface, and reverse direction cleaning can potentially cause greater damage than normal cleaning if these crystals are not removed first.

Limitation of Cleaning Flow Rates

As explained previously, since the column of RO elements in not supported by a thrust ring while cleaning in a reverse direction, we recommend limiting the reverse cleaning flow rates, at least initially, until the dP is reduced. Normal cleaning flow rates for standard 8-inch diameter elements are 36 – 48 gallons per minute (136 – 182 liters per minute) per pressure vessel. We recommend limiting the reverse cleaning flow rates to 2/3 of the normal cleaning flow rates. This corresponds to 24 – 32 gallons per minute (91 – 121 liters per minute). In cases of high fouling and very high dP's (where the dP has doubled from baseline values), we recommend reducing the flow rates further to 1/3 of the normal cleaning flow rates (12 – 16 gallons per minute or 45 – 61 liters per minute) to reduce the chance of telescoping the elements. For 8-inch elements which have a thicker feed spacer (34 mil) than standard elements, the cleaning flow rates are generally about 10% higher. It is always recommended to start cleaning with low flow and increase it slowly in steps according to actual dP values. The flow rates can then be slowly raised as the foulant is removed and dP reduced, with the reverse CIP being done at normal (forward) cleaning flow rates as the final step. Most membrane manufacturers recommend cleaning when the dP's have risen to 10 – 15 % above baseline values.

Preventing Permeate Backpressure Damage

Never clean the RO elements from the permeate side. This can lead to permeate backpressure of the elements which will irreversibly damage the RO membrane elements. Always ensure that any permeate that is produced during cleaning is not restricted and is allowed to flow back to the CIP tank.

ALTERNATIVE METHODS TO REVERSE CLEANINGS

Many times, plant operators want to know whether reverse cleaning will work for them before they make any expensive modifications to their RO CIP systems. Of course, they can send elements off for cleaning analysis, but many times cleaning of elements in a lab may not give the same results as when performed in place. One simple method for diagnosis is to remove a lead element that is heavily fouled and swap it with a tail element. When installing the lead element into the tail position, it should be "flipped" 180° and the brine seal should be moved to the other side of the element so that it is now on the new feed side with the brine seal facing forward. The element should be drained of water for 30 minutes and then weighed. After several days of operation, the element can be removed, drained for 30 minutes, and then weighed again. If the element has lost significant weight (sometimes several kilograms), then reverse cleaning may be beneficial for you.

Another helpful option is to use permeate only with a reverse cleaning system to reduce chemical consumption, reduce downtime, and extend times between cleanings. An added benefit is that it extends the RO membrane life. Many RO plants use permeate in their CIP tanks and do a reverse flush (but at a higher velocity using their CIP pumps) to lower their dP's and remove front end foulants. They may do this for only 15 to 20 minutes, and then they can go back online right away, since no chemicals are being used. While this does not bring dP's back down to baseline levels, it has allowed many plants to go much longer between cleanings, and to help maintain manageable dP levels.

CONCLUSIONS

Reverse cleaning has been shown to be very helpful at removing front end fouling at many wastewater and seawater reverse osmosis plants. Modifications to enable reverse cleanings can be performed quite simply at many plants, depending on the layout and pipework of the plant. An increasing number of large plants are being built with the ability to reverse clean. Many of these plants are using permeate water only (no chemicals) in reverse direction to maintain low dP levels. This results in cost savings from less chemical use, less downtime, and longer RO membrane life.

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