An Introduction to Reverse Osmosis Pre-Filtration

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RO filtration is used to remove the tiniest contaminants such as dissolved salts from water. For example, RO is used for desalination – to create fresh drinking water from sea-water, or to purify fresh water to remove trace contaminants and make drinking water even healthier. In industrial applications, RO is used to remove harmful scalants and damaging residues to minimize deposits in expensive boilers, or to recycle waste waters into water that can be re-used for washdown, irrigation or evaporative cooling , thus prolonging the availability of freshwater resources. Many of our customers and distributors have a lot more experience with traditional dead-end cartridge filters than with some of the more advanced forms of membrane filtration. For newcomers to water purification, any discussion of Reverse Osmosis can be intimidating at first, but this paper is intended to facilitate effective discussions about pre-filters between buyers and sellers.

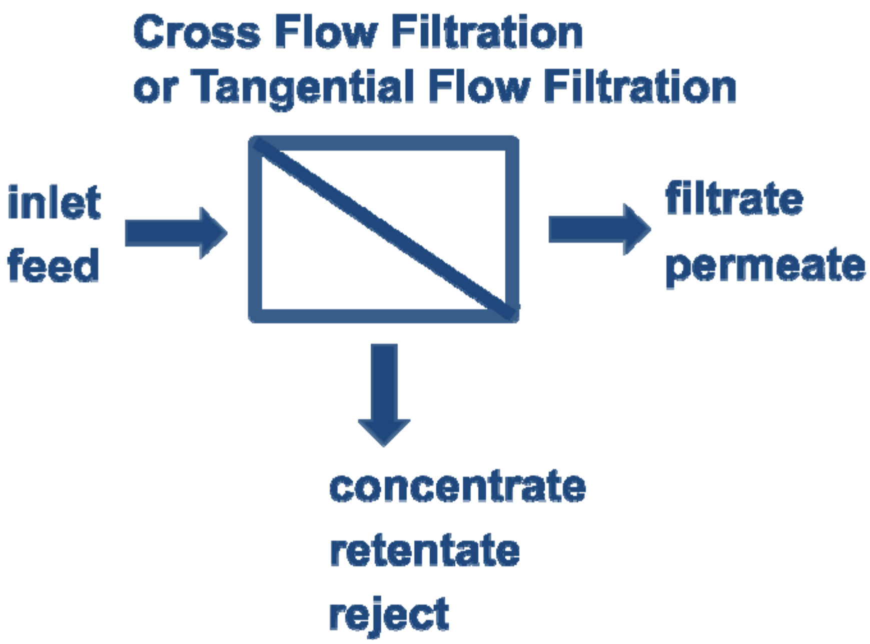

Figure 1: Cross Flow Filtration Schematic -An RO systems is a type of cross flow filtration system. Water flows tangentially along and across the RO membrane and helps to sweep the membrane clean, but pre-filtration is still needed.

"Dead end filtration" means that 100% of the water is directed through the cartridge filter, so that there is only one inlet and only one outlet. This is also sometimes called "direct flow filtration". On the other hand, RO Filtration has two types of "outlets". While RO filtration may be more complex than some other types of filtration, with a little effort it becomes easy to understand.

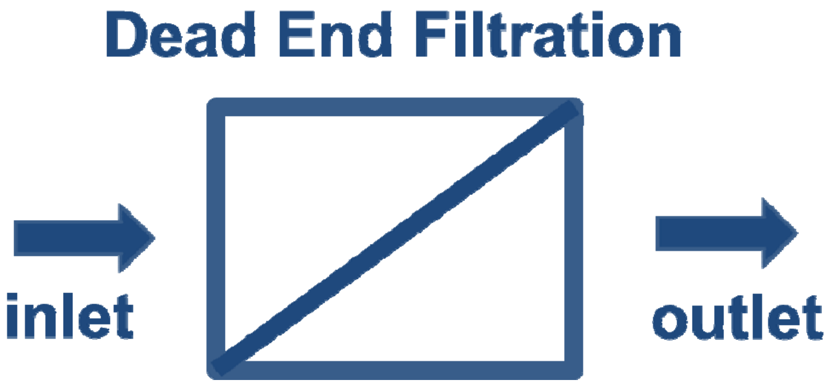

Figure 2 “Dead End Filtration” is commonly used for particulate filters, but is not used for Reverse Osmosis (RO). Dead end filtration has just one outlet, while RO filtration has two different kinds of “outlets”.

A key point is that Reverse Osmosis membrane (a material with tiny pores that excludes dissolved salts and molecules) is expensive, and it needs to be protected. Melt blown filters, string wound filters, and pleated filters (such as in a six-inch diameter “high flow” format) are commonly used to protect RO membranes – and that’s “RO Prefiltration 101”!

Another type of filter that is often used for RO pre-filtration is a type of cross flow filtration called ultrafiltration or microfiltration – these are more open than RO, but are still cross flow filters rated in microns for MF or molecular weight for UF. Note: a pre-filter is a less expensive filter that is installed before the RO membrane and extends the life of the more expensive RO membrane, thereby reducing the client’s overall operating cost.

What do we mean when we talk about the “life” of RO membrane? Several undesirable things can happen to an RO membrane, and when these things happen, the life of the membrane is cut short.

Undesirable Things That Can Happen to an RO Membrane

1) The membrane can “foul” – load up with debris or biological growth so it is much more difficult to push water through it. When this happens, the system needs to be cleaned using a regimen of cleaning chemicals pumped through the RO system under specified conditions. This takes the membrane out of service and costs the customer in down time.
2) The membrane can need more frequent cleanings – this results in less water throughput and use of more cleaning chemicals. More frequent cleanings by themselves can de crease RO membrane life.
3) The membrane can become “permanently” fouled – so that chemical cleaning no longer helps and the membrane needs to be replaced.
4) The RO membrane’s upstream side can become “plugged” or occluded by debris and physically plug the face of the membrane. Cross flow velocity needed to sweep the RO membrane surface is reduced – this reduced flow causes the module to become irreversibly plugged. This plugging can also cause excessive pressure on the module face and in severe cases cause “telescoping” from excessive differential pressure (ΔP).

5) RO membranes are also subject to chemical attack, compromising the membrane surface so that salts and contaminants get through. (Note: chlorine, which is present in many water systems, can damage some types of RO membrane, and for that reason activated carbon filters can be included as part of a pre-filter protection regime. The absence of chlorine can accelerate bio-fouling of a membrane. The type of membrane can limit the type of cleaning chemicals that can be used, or the concentrations and cumulative numbers of cleanings with certain chemicals.)[i]

An operator of an RO system will often monitor the quality of the water between the pre-filters and the RO membrane with a "turbidity meter", or a particle counter. If the turbidity of the water (or particle count) is lower than that specified for the process then the pre-filters are doing a good job in removing contaminants. Many conversations within a plant, and between operators and suppliers, will involve actual turbidity values (or particle counts) vs. specified limits. Most manufacturers of RO elements will suggest a maximum SDI (silt density index) such as 5 (I have come across recommendations ranging from 3 to 5) or a turbidity value of less than 1 NTU.

RO membrane systems operate in "tangential flow" or "cross flow" mode – "tangential flow" and "cross flow" are synonyms. These terms signify that some percentage of the water goes "through" the filter membrane while the remaining percentage goes "across" the filter membrane. The <u>percentage</u> of water that gets filtered is called the "recovery". For example, if the recovery is 25%, then 25% of the feed water gets filtered and 75% is rejected. If the recover y is 75%, then 75% of the feedwater is filtered and 25% is rejected.

A dead-end filter system has one inlet and one outlet (and essentially 100% of feedwater water is filtered), but an RO system has two "outlets". One outlet is for the water that is filtered, and one outlet is for the water that was not filtered. The water that does not pass through the membrane but instead flows across the membrane helps to "sweep the membrane clean" and helps to prevent it from fouling – but not in a perfect way, so <u>pre-filtration is always necessary</u>.

The term "rejection" relates to the amount of a given contaminant that is "rejected" or retained by the membrane. Rejection is never a perfect 100%, and the percentage of a salt or species rejected can vary based on conditions such as concentration and temperature. Also, RO membrane manufacturers make different grades of RO membrane with different degrees of rejection – a tighter RO membrane will provide more rejection with the trade-off of lower production rates or requirement for more energy

The RO system inlet is also called the "feed". The water that gets filtered is called either the "filtrate" or the "permeate". The water that flows across the membrane and then exits the system without ever getting filtered has concentrated salts and contaminants in it and is called the "concentrate", "retentate" , "reject", "discharge" or "brine". This "concentrate" water can sometimes pose an environmental challenge because of the high levels of salts or the types of contaminants present.

The predominant format for RO membrane modules (elements) is the spiral wound type .[ii] "Spiral wound" means that the module's construction incudes several materials used in layers that are rolled up. Let's think about this construction in terms of how the pre-filtration upstream of RO module could be important.

Flow goes through many of these materials "the long way". That is, the water is not merely flowing through the thickness of the fabric of these materials, it is traveling along the full length of the fabric – for example, it could be a one meter (3 ft) long flow path.

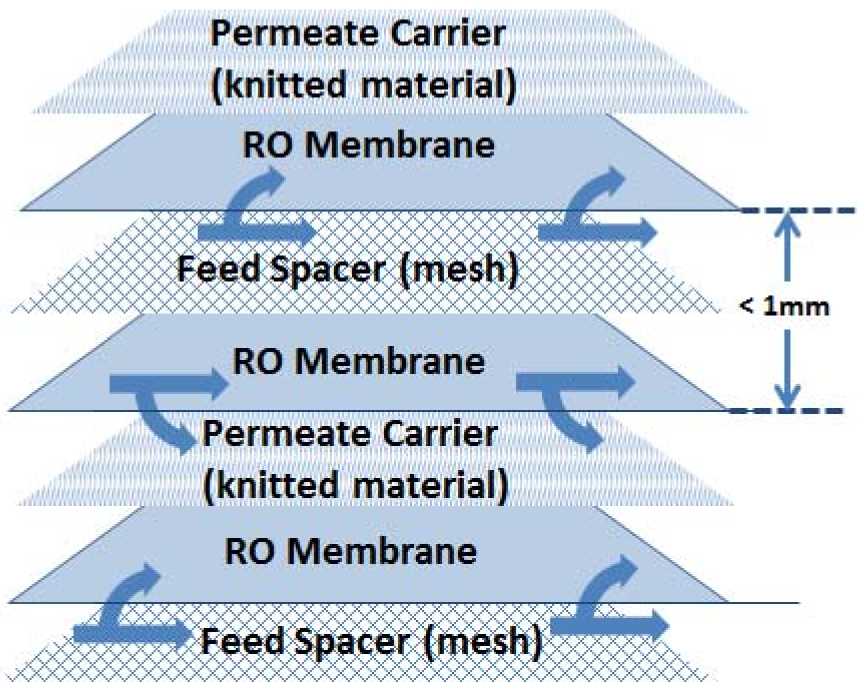

Figure 3 An RO filter module contains layers of feed spacer, RO membrane, and permeate carrier. The feed spacer creates a narrow channel subject to fouling.

The permeate water, once filtered by the RO membrane, flows into and along a material called a "permeate carrier" (sometimes called a "permeate spacer") – this can be a type of knitted or "tricot weave" polyester material. The permeate carrier is welded to a perforated core called a permeate collection tube (or permeate tube). This permeate carrier is sandwiched between RO membrane above and below it, and the sandwich is sealed on three edges by glue or ultrasonically to form a "membrane leaf." By the time the water passes through the membrane and goes into the permeate carrier it would be very clean, so it is hard to imagine the permeate carrier getting loaded up with debris – so we are not usually so worried about fouling this material. A separator material – a kind of (usually polypropylene) mesh – called a "feed spacer" separates the membrane-leaf layers which are rolled up or "spiraled". The feed spacer forms a feed channel that, for water applications, is usually less than one millimeter high, and this channel, as its name suggests, accepts water from the inlet or feed. The feed spacer mesh also helps to create turbulence that helps the feed-water clean the upstream surface of the membrane.

Finally, the mesh helps to mix the upstream feed-water, and this mixing is important because as the feedwater is "dewatered" at the membrane surface, it develops a boundary-layer of extra-high salt concentration, exaggerating 'concentration polarization', and this exaggeration of 'concentration polarization' negatively impacts salt rejection and osmotic pressure. Mixing lessens the concentration polarization at the membrane surface.

It is important to note that the openings within the feed spacer mesh will be a fraction of millimeter and these can become plugged if the feed water is not pre-filtered properly, or if cleaning is not performed as needed. Membrane module manufacturers make membranes with different feed channel heights – a larger feed channel can be better for challenging applications in order to help prevent fouling. A common type of fouling of the feed spacer is "bio-fouling."

The membrane itself is a material subject to much research, innovation and potential evolution because of developments in material science. A typical membrane these days might have three layers: a support, a substrate, and the "skin" which forms the actual barrier layer. For example, the support can be polyester (120 microns thick, for example), the substrate can be polysulfone (40 micron thick, for example), and the skin or barrier layer can be polyamide (perhaps 0.2 microns thick).[iii] The side with barrier-layer skin is often called the "top" (it is the upstream side), and the other side that is glued is called the "back" (and it is the downstream side.)

Membrane manufacturers will recommend appropriate cleaning chemicals, and the type of cleaning chemical recommended will depend on the type of foulant. It might be a caustic for bio-fouling, and an acid for removing scale, or both in sequence with the caustic step usually occurring first.[iv] The cumulative exposure of membrane to cleaning chemicals can reduce its life. In addition, cleaning may restore a membrane to most of its previous performance, but not completely restore it, so degradation of performance will be experienced over time. Cleaning also necessitates a temporary stoppage of water production and expenditures for cleaning chemicals. Therefore, extra-cleaning is an un-satisfactory remedy to inadequate pre-filtration. Chlorine bleach (sodium hypochlorite), a chemical frequently desired for disinfection and cleaning, is typically not permitted to be used for Clean in Place (CIP) of RO membranes.

The membrane + spacer materials sandwich is placed within a fiberglass shell, and end caps are assembled to each end. The end caps have a lot of holes on each end to allow feedwater into the feed spacers. The end caps have O-rings, called brine seals, on their rims, and these seal to the inside of a pressure vessel when the module elements are pushed into them. Without brine seals the feed water would have a direct path to concentrate side , completely bypassing the membrane. The endcaps also allow modules to seal together end-to-end within the pressure vessel . A module can be shipped dry, or it can be shipped pre-wet with a preservative in it.[v] After all the modules are installed into the pressure vessel, end-connectors are added to the assemblies.

When we see a large industrial RO system, we see banks of long horizontal tubes, and these are the RO pressure vessels, and each pressure vessel holds many RO modules inside of it place end-to end.   Near this bank of filter vessels, there can be another bank with around ½ as many vessels, and next to that, perhaps another bank with ½ as many vessels as the previous one. Having three different banks as I just described is called 3-stage RO, and when each stage has fewer vessels than the previous stage, it is called a pyramid. We will explain what a “stage” is later.

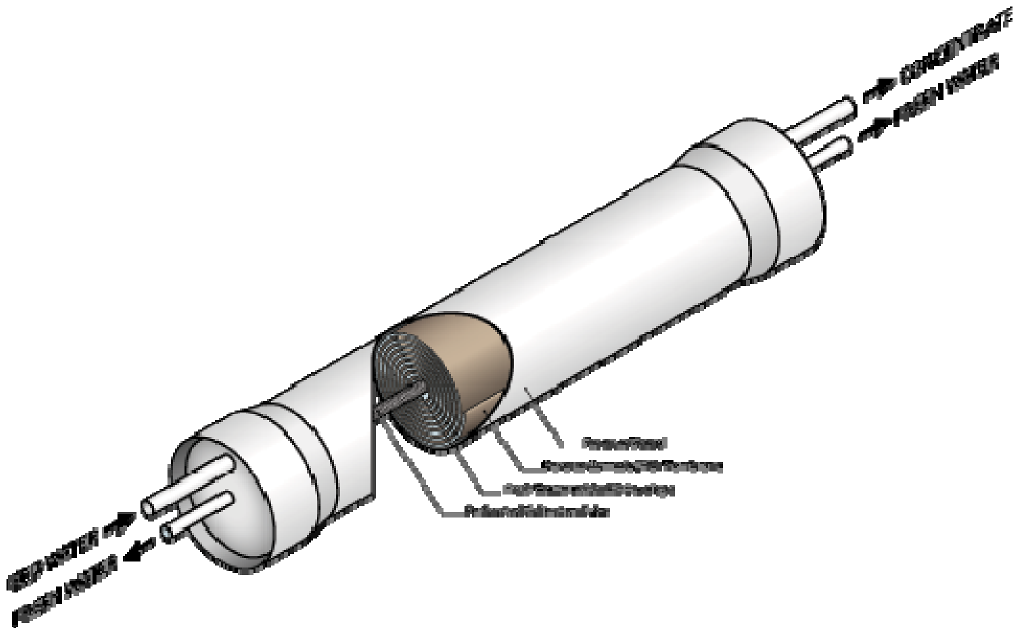

Figure 4 RO Membrane Modules are Generally “Spiral Wound” type. Feed spacer mesh forms a very narrow channel between membrane layers.

What does the term ‘Reverse Osmosis’ itself mean? If we think back to high school chemistry, we might remember that water and salts tend to move about to form an equilibrium in concentration – for example, if we were to place some salt water into a large tank of fresh water, the dissolved salts would migrate (via a process called diffusion) so as to even out the concentrations in every section of the tank. This natural migration of dissolved salts and water molecules to create “sameness of concentration”, when it occurs across semi-permeable barriers (such as a membrane) is called osmosis. With RO filtration, we are not allowing equilibrium of salt concentrations, rather are creating a large imbalance – we are using energy in the form of water-pressure to separate salt water into fresh water and super-salty brine water, for example. This is the “reverse” of osmosis, hence “reverse osmosis.”

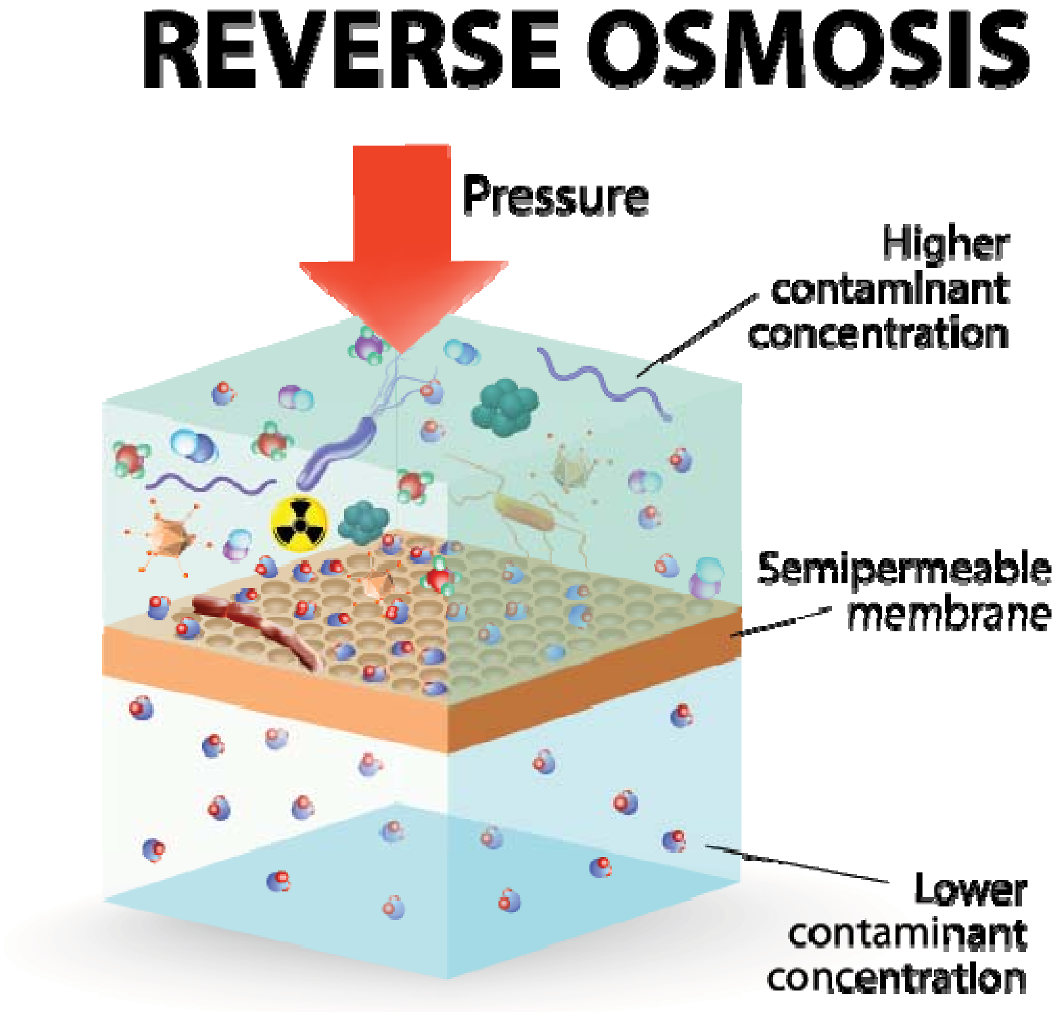

Figure 5- Reverse osmosis uses pressure to concentrate salts and dissolved molecules on the "concentrate" side of the membrane, and to push fresh water though to the "permeate" side of the RO membrane.

While pre-filtration systems for reverse osmosis commonly use cartridge filters of the “dead end filtration” type, pre-filtration systems can also be of the cross-flow type. Microfiltration cross flow filtration (MF) is used to remove contaminants the size of bacteria and microscopic particles, and ultrafiltration cross flow filtration (UF) is used to remove contaminants the size of very large molecules, viruses and bacteria. Bacteria, viruses, and other small micro-organisms or tiny bio-matter are sometimes collectively called “organics”.

There are many other types of water filtration and pre-treatment that can be used upstream of an RO system, but each RO system clearly requires prefiltration for reasons defined above. The type of pre-filtration used will depend on the type of water being fed to the RO system. Water system designers take variable water source parameters into consideration when designing pretreatment for RO systems. These can vary, but need to be accounted for because overall operating costs must be balanced with the overall capital cost of the system. There is always a demand for innovative, effective prefiltration , because prefiltration is such a critical aspect of protecting a client's investment in their expensive RO membranes should last for years when well taken care of.

Regardless of the type of filter used in a pre-filtration step, the amount of energy needed for pre-filtration is a lot less than the amount of energy needed to drive Reverse Osmosis (RO). This makes sense, because the "pores" in the RO membrane are a lot smaller than the pores in the prefilters. We think of the RO membrane as "tight", with high pressure required to overcome osmotic pressure and push water through these fine membranes. This is one reason why engineers will usually not simply call out RO technology for a water treatment system, but instead they will generally only use it if it is really needed to meet the required water quality.

In some instances , a slightly looser kind of RO called nanofiltration (NF) can reduce costs of a project and the costs of operation. Just to be clear, nanotechnologies that remove nanometer-sized contaminants (e.g., the size of small viruses) are NOT called nanofiltration (NF), they are called ultrafiltration (UF). Nanofiltration (NF) removes many di-valent salts and is somewhat similar to RO, but it is coarser than RO – NF does not reject <u>all</u> the salts that RO rejects, and allows a percentage of the mono-valent ions like Na+ & Cl- to pass through. Selecting NF instead of RO can be a way to reduce costs – capital costs, membrane costs, construction costs, and energy costs, but only when a lesser water quality is needed or required. NF, like RO, requires pre-filtration.

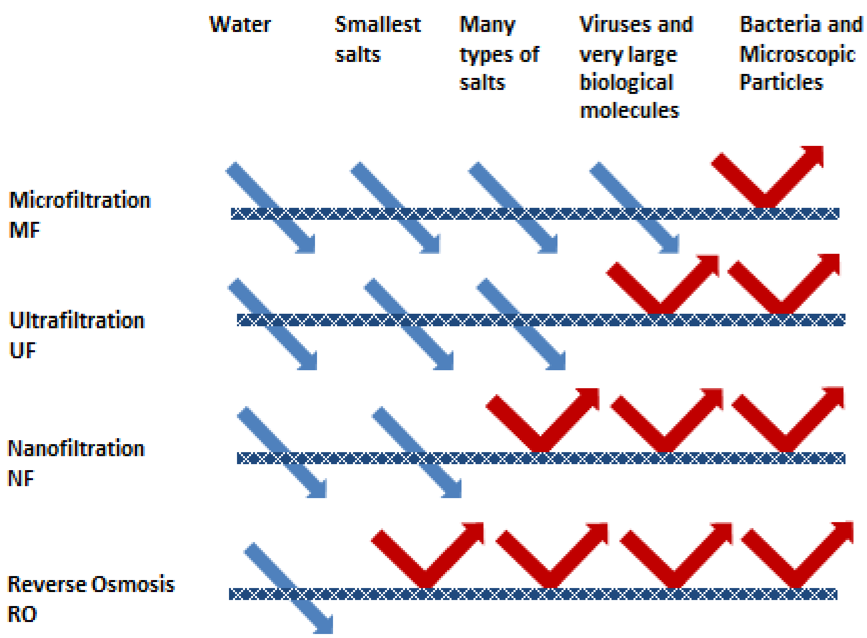

Figure 6 MF, UF, NF, and RO membranes differ in what they allow to filter through, and what they "reject". Rejected species are represented by bent (red) arrows, while species that filter though the membrane are represented by straight (blue) arrows. Note that RO removes the tiniest salts, and that removal of nanometer-scale viruses is not nanofiltration (NF) but instead is called ultrafiltration (UF). The arrows are not meant to indicate 100% of anything, but represent the general result.

Traditionally, a molecule or particle that passes through a filter is called “filterable”. Water is called filterable because it passes through the filter. For example, a “filterable virus” is one that passes through the filter material (membrane) and not removed. Filterable is the <u>opposite</u> of “removed-by-filtration” or “filter-out-able”.

Words like “filterable” and “nano-filtration” are terms that even engineers and scientist use incorrectly from time to time. Since people can occasionally mis-use terminology, it is often a good idea to ask clarifying questions or confirm information with alternative words.

Trick question: in an RO system, are viruses filterable? The answer is NO, because viruses are removed to a large extent by RO (see figure 3) and a very large percentage of them will not get through the RO membrane. (Remember that if they get through, they are filterable.)

Here is another trick question. Will RO remove <u>all</u> bacteria from water? The answer is no, because RO membranes are not perfectly leak-tight. Although they are so tight that they will exclude the vast majority of salts, they are not without ‘defects’ (I do not mean “quality defects”, but rather minute imperfections or tiny leaks that are a normal and expected part of the RO module) and some bacteria can get through. It can be puzzling to some that a “coarser” filter can be installed downstream of RO, but this is an example of why that can be the case.

We talked about RO membranes being very tight and the need for energy in order to create the pressures to drive water through the RO membrane. The saltier the water the more pressure is needed and desalination of seawater can sometimes employ a feed pressure in excess of 1,000 psig (6,900 kPa). For the highest pressure systems, the stream called “concentrate” or “retentate” or “reject water” will have a lot of pressure too, but there is often no good reason why the concentrate stream needs all that “left over” pressure. An “energy recovery device” (ERD) takes the energy from the RO concentrate and transfers a lot of that energy elsewhere – for example, a lot of the pressure energy from the concentrate can be given back to the feed. I would encourage curious readers to watch online videos that show how these RO system “energy recovery devices” work.

Another concept that needs to be grasped is that of differential pressure, delta P, or ΔP. In a dead end flow system there is only one kind of differential pressure: the difference between the inlet and outlet pressures. In cross flow systems such as RO, there are two kinds of differential pressure. The first one, actually called the “differential pressure” or ΔP, is the difference in pressure of the feed and the concentrate streams (“in” and “out” across the module). The second is called the “trans membrane pressure” or TMP. That pressure is the average of the feed and concentrate pressures, minus the permeate pressure. The terms “differential pressure” and ΔP can be thrown around imprecisely, and it is often helpful to ask clarifying questions .

There is an important kind of pressure called “net driving pressure” or NDP. Basically, you have pump pressure pushing the water through the membrane, but you have an osmotic pressure which wants the fresh water to come back to the salty concentrate side. The osmotic pressure is saying “oh no, you don’t!” and that osmotic pressure has to be netted out. For many cross flow applications (such as for

MF) there is not any consequential osmotic effect, but for RO desalination of seawater it is important. The symbol π is used for osmotic pressure.

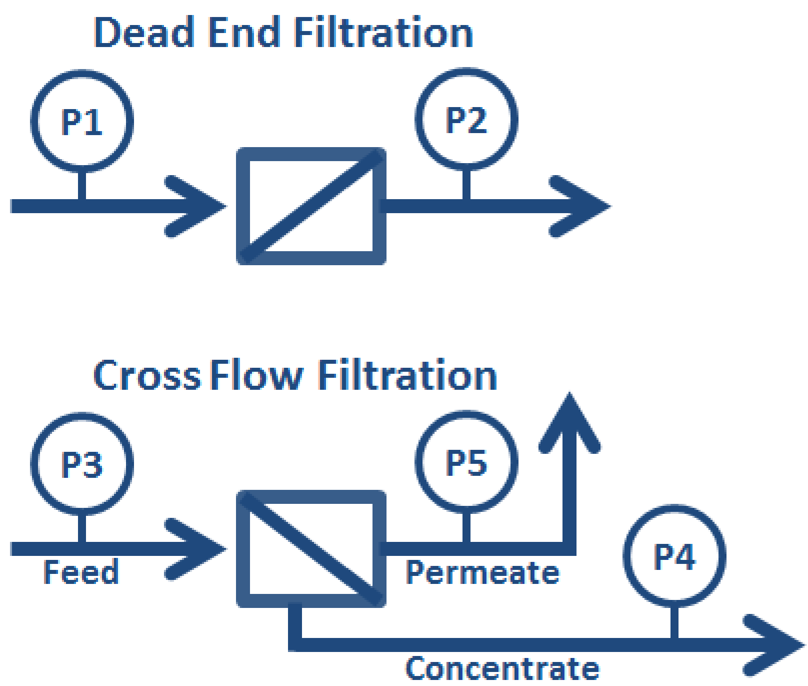

Figure 7 In this figure, the differential pressure for the dead end filtration system is P1-P2. The differential pressure for the cross flow filtration is P4–P3. The Trans-Membrane-Pressure (TMP) for the cross flow filtrations system is (P3+P4)/2 – P5.

It is important to know the terms "stage" and "pass" if working with RO or serving RO system clients. After water leaves an RO step, it can be fed to another RO step to get extra treatment. The extra step is either called a "stage" or a "pass" depending on what is being done.

If we send the "concentrate" to another RO step, we can squeeze out more fresh, purified water and increase our recovery percentage and reduce waste water. One way to further treat the concentrate is to send some of it back to the feed – this is called recirculation, or more specifically "concentrate recirculation". Another way to post treat the concentrate is to add more RO vessels, and in this case the terminology that is used is multi-***stage*** RO.

If we post-treat the permeate with another RO step, we can make the water even more pure, and remove even more trace amounts of salts and contaminants. In that case, we send the permeate to the next ***pass*****.** (Remember the the double Ps - "*pass* is for permeate. Another *pass* makes the water more pure.") A *stage* is for concentrate. So "two ***stage*** RO" has an extra RO step for the first stage's *concentrate*, while "two ***pass*** RO" has an extra RO step for the first pass's *permeate*.

Figure 8 The RO pressure vessels in this industrial water system are placed horizontally, and vertically-oriented stainless steel pre-filter housings are in the foreground.

Is it the Pre-Filter's Fault?

Should an RO membrane suffer a reduction in permeate flow, higher TMPs, higher ΔP, or encounter premature fouling, it is natural to review the performance of the pre-filters. Changes in source water quality can result in changes in pre-filter life and effectiveness of pre-filtration that can necessitate review of the pre-filter selection. Two common types of pre-filtration performance improvements sometimes sought are a) better pre-filter life and b) increased particulate-removal efficiencies. Pre-filters with greater surface area and/or or with multiple filtration zones have been shown to increase pre-filter life in many situations. Tighter pre-filters, such as selection of 1 micron filters instead of 5 micron filters, may be justified in some situations to improve RO membrane protection. Above and beyond those technical improvements, RO plant operators may seek other logistic and commercial improvements such as delivery time reduction.

Many times pre-filters can be upgraded in order to improve RO membrane performance. Changes in RO membrane performance are not always a consequence of having the wrong kind of pre-filter, however. The following are some examples of other causes of system issues.

Why Perceived “Membrane Issues” Are Not Always the Pre-Filter’s Fault

1) Effectiveness of cleaning regimens can affect membrane performance.
2) Changes in temperature can result in changes in RO membrane performance.
3) Changes in incoming water salinity can result in changes in RO membrane performance.
4) RO systems can foul with precipitates and scale that form on the membrane, and these would not yet exist as removable particles at the time they pass through the pre-filter.
5) Improper installation of pre-filters can result in pre-filter bypass
6) Operation, settings, or failures of other system equipment such as pumps, control valves, brine seals, module couplers, etc. can affect membrane system performance.

It is a good idea for filter users to flush pre-filters before they are put on line. It is preferable that the flush water itself be pre-filtered if possible. This applies to both sediment-removal filters and chlorine removal (activated carbon) filters. Industrial filters are usually not made in clean rooms, and many filter factory operations such as cutting can produce debris. In addition, most industrial filters are not pre-flushed at the filter factory because pre-flushing and subsequent drying can tremendously increase the costs and prices of the filters. Many filter users will flush any new pre-filter by diverting the downstream water to drain for up to several minutes immediately after installation. Some filter users have a separate flush-station where they pre-treat the filter and afterwards transfer the flushed filters to the process filter housing. Once the pre-filters have been flushed, the water can be allowed to feed the RO modules.

Summary: Pre-filtration is essential for maintaining RO membrane system performance and for increasing the life of the membrane. Some key terms explained in this paper that a newcomer can learn to become more conversant with suppliers or customers are: Reverse Osmosis (RO), cross flow filtration, feed, concentrate, permeate, pre-filtration, dead-end-filtration, recovery, rejection, energy recovery device, differential pressure, trans membrane pressure, RO feed monitoring, membrane fouling, membrane cleaning, multi-stage RO, and multi-pass RO.

If you would like help with RO pre-filtration please contact Delta Pure Filtration.

Delta Pure
Reliable Filtration

www.DeltaPure.com
800-785-9450

Epilogue

Delta Pure Filtration offers several RO pre-filtration products.

DMB Series Melt Blown Filters: Melt blown filters, either 1 micron or 5 micron rated, are very commonly used for RO pre-filtration in many industrial and commercial applications.

DMC Series Melt Blown Filters: Melt blown filters on rigid polypropylene cores for greater strength, either 1 micron or 5 micron rated, are very commonly used for RO pre-filtration in many industrial and commercial applications.

DW Series String Wound Filters: 1 micron string wound filters are used for RO pre-filtration in many seawater desalination plants.

FUSION DWMC Series melt blown + stringwound dual stage filters: These filters are currently undergoing trials in various applications, and one customer has reported > 5x pre-filter life and excellent water quality as compared to the traditional melt blown filters that had been used.

DHF High Flow pleated cartridges: These pleated filters offer extra surface area for long life, and extra flow capacity for reduced footprint. The 60" long filters can often be placed in smaller diameter filter vessels to reduce capital equipment cost, and in horizontal housings which facilitate change-out. Highly efficient cartridges serve to protect and reduce fouling of RO membrane.

DWCC Series Activated Carbon Filters – These activated carbon filter cartridges are often used in small commercial and residual RO systems to remove chlorine upstream of RO membrane. Chlorine can damage some types of RO membrane.

CCB Series Activated Carbon Block Filters – These filters offer higher chlorine capacity but lower flow rates as compared to our DWCC and DWCF series carbon filters. These activated carbon block filter cartridges are often used in small commercial and residual RO systems to remove chlorine upstream of RO membrane. Chlorine can damage some types of RO membrane.

If you would like help with RO pre-filtration please contact us.

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[i] "FILMTEC Membranes Troubleshooting: Symptoms of Trouble, Causes and Corrective Measures", http://msdssearch.dow.com/PublishedLiteratureDOWCOM/dh_0060/0901b80380060418.pdf?filepath=liquidseps/pdfs/noreg/609-02122.pdf&fromPage=GetDoc

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