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Commercial/Industrial Reverse Osmosis Systems: General Design Considerations

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The demand for Commercial/Industrial (C/I) Reverse Osmosis (RO) systems is growing at a phenomenal rate. C/I RO systems require a basic understanding of RO principles, RO design, and system requirements. This paper will serve as a basic road map and checklist for C/I RO selection.

Membrane Types & Applications

When discussing membrane technology, it is helpful to identify the three commonly recognized membrane types:

Reverse Osmosis

Most reverse osmosis elements are usually classified into two main groups: cellulose acetate and thin film. Most people know that cellulose acetate membranes are chlorine tolerant. This is appropriate since cellulose acetate is not resistant to bacteria and is, therefore, usually used in chlorinated feedwaters. The converse is true with thin films in that they are bacteria resistant but are not chlorine tolerant. Most commercial systems feature thin-film elements because they are capable of higher production rates and better dissolved solid rejection rates than cellulose acetate elements. Another consideration is the fact that thin-film elements can operate in a very wide pH range from 3 to 11.

Most RO systems are single-pass systems in that the product water is not passed through another membrane before being used. Double-pass systems are those where the product water is repressurized and sent through another set of membranes to produce ultra high quality water. The simple fact is the RO represents one of the most economical methods of high quality water. Depending on system design and feedwater, RO systems are definitely capable of rejecting more than 99.9% of bacteria, viruses, pyrogens, and more than 98% of the total dissolved solids in the feedwater.

Design considerations for RO mainly center around the feedwater composition, the desired product quality, production rate, and recovery rate. To do a complete treatment system design will require a working knowledge of pretreatment and postfilter systems. The service life of an RO membrane is very design dependent and is best left to your equipment manufacturer. However, failure to enact a proactive maintenance program can lead to system failure as well as a short membrane life.

Nanofiltration

Nanofiltration (NF) membrane applications seem to be growing at a fantastic rate. This may partially be due to the fact that people are pushing NF as just something new and different when, in fact, the user would be better served with RO. There are, however, some definite applications where NF may present a better option over traditional RO.

NF is generally referred to as a softening membrane (ie. they reject hardness constituents). While it is true that NF can "soften" water without the use of chemicals, or without raising the level of dissolved solids (salt), other applications are developing. Total Dissolved Solids (TDS) rejection is usually not expressed when discussing NF. This is because the NF membrane is "selective" in that it allows some types of solids to pass through at a higher rate than other types. Therefore, TDS rejection is entirely dependent on feedwater composition. Bacteria and viruses are easily rejected by the NF membrane solely on the basis of their size. Additionally, NF can usually remove color and organics; the foundation blocks trihalomethanes (THMs). These THMs, formed from water chlorination, can create carcinogens in the water.

Typically, nanofiltration elements are excellent in rejecting multivalent, or multi-charged anions. Although design and feedwater chemistry dependent, the divalent, or double charged ions, such as calcium (Ca^{++}) and carbonate ions ($CO_3^{=}$) are rejected fairly well. The range of rejection can be from 50 to 85%. Adding to NF's unique characteristics, monovalent ions, such as sodium (Na^+) and chloride (Cl^-), will have a higher passage rate, meaning a lower rejection rate, usually about 50%. The approximate molecular weight (MW) cut-off is 200 to 300 daltons. Like thin films, NF elements should usually not be exposed to oxidizers such as chlorine or ozone.

An important design note for NF membranes is since there is lower monovalent ion rejection, the osmotic pressure is usually less. This lowers the required operating pressures, usually in 100 to 200 psi (6.9 to 13.8 bars), as opposed to the standard RO equipped systems which usually operate above 200 psi (13.8 bars). System designers should, however, provide higher feed flow rate to compensate for the higher production rates of NF elements.

Ultrafiltration

UF utilizes the same membrane technology and processes identified with reverse osmosis elements. A simple way to define UF is that these membranes will reject dissolved solids but not ions. In terms of size, UF will reject particles of approximately 30 to 100 angstroms, or in other terms, particles whose molecular weights range between 10,000 and 120,000 daltons. UF elements have an obvious advantage over conventional cartridge filters as they can remove organics, pyrogens, and bacteria. The UF process operates at lower pressures than RO, usually requiring an operating feedwater pressure between 10 to 100 psi (0.7 to 6.9 bar).

RO System Design Mechanical Basics

Basic System Components

Most RO units require the same basic system components:

- Prefilter
- Inlet Control Valve
- Pressure Pump
- Membrane Pressure Vessel
- Membrane
- Flow Control
- Check Valve (on most systems)
- Concentration Recirculation Control

Also required are a series of pressure indicators:

- Inlet Pressure
- Filter Pressure
- Pump Pressure
- Product Pressure

On larger RO systems, above 2000 GPD, it is recommended that the systems be equipped with:

- Product Flow Iindicator
- Concentrate Flow Indicator
- Recirculation Flow Meter
- TDS Monitor

Minimum System Requirements

One of the most important aspects of any membrane-based system is the system's minimum required feed flow rate and pressure. If

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the RO system will be equipped with a low pressure shut-down circuit, a low pressure switch is connected into the feedwater inlet line, usually after the prefilter and before the pump. This pressure switch ensures there is sufficient water pressure. This is an inexpensive device used to ensure there is indeed feedwater at the pump.

It is important to note that sufficient pressure does not always mean sufficient flow. The idea behind a pressure switch is that if the feed flow rate is less than the pump flow rate, the feed line will be sucked dry when the pump starts, consequently creating a low pressure situation and tripping the low pressure switch. Ideally, it is desired to be able to supply the pump with more water than it can pump. If adequate flow is not provided, cavitation occurs (bubbles form) within the pump which can cause the internal components to erode. The actual pressure at the pump inlet can be as low as 3-5 psi when there is sufficient water flow.

This will be covered later in our discussion of equipment integration. Any good design and/or installation requires this information to ensure satisfactory operation. Low flow is one of the most common problems and reasons for system failure.

Sediment prefilters in the range of 5 to 20 microns are usually found on RO systems. These filters are there to prevent sediment from reaching the system and membrane. When these filters load up with debris, they restrict water flow to the pump which will, in turn, trip the low pressure cut-out switch and shut the system down.

It is not recommended to use any type of carbon cartridge in the prefilter housing as the primary means of dechlorination. Typically, the flow rate of water through the cartridge makes the carbon filter ineffective. The feedwater flow rate may exceed the cartridge manufacturer's required maximum "contact flow" rate. The result will be the treated water may not be dechlorinated and membrane damage will occur. The second problem will be that the carbon prefilter will clog or collapse, resulting in the loss of feedwater flow rate. There may be severe pump damage in this case.

Generally, systems with production rates below 5,000 gallons per day will usually be equipped with positive displacement pumps such as the rotary vane pumps found in service with carbonated drink dispensers.

When sizing and installing systems, it is important to know the customer's electrical service. Small systems can usually be run economically on 120 V single-phase circuits. When motor size gets above ½ HP, it is advisable to run these on 240 V circuits. For systems with motors of 5 EP and above, three phase 240/480 V service is usually required. Circuits should be dedicated to the system when possible. As always, any type of electrical circuit used near water should be protected with a ground fault interrupter (GFI).

There are three basic types of pressure vessels used on membrane-based systems; namely, plastic, fiberglass, and stainless steel. Choice is dependent on a number of factors. Applications for PVC are usually those that are not favorable for stainless or fiberglass. An example might be in areas with high chloride levels in the water where stainless would corrode but fiberglass costs too much. Generally, these are used in smaller systems. Plastic, however, is much more susceptible to fatigue failure and has a much shorter service life. Stainless steel offers the excellent properties of high strength and corrosion resistance. Fiberglass is used in applications that have multi-element vessels. Although fiberglass has the highest cost in the smaller sizes, they become the most economical and feasible in the larger sizes.

The concentrate flow control on your system may be adjustable or fixed. Many flow control valves are made of stainless steel. This is also true of the concentrate recycle valves. Using the stainless steel components may present greater initial cost but yields longer lifetimes and higher performance.

When using pressurized storage tanks, a check valve must be used on the product water outlet of the system to prevent backflow through the membrane. A check valve is also recommended in atmospheric tank installations where the product line is above the height of the RO unit.

Pressure indicators are used extensively throughout a system for initial set-up, troubleshooting, as well as for daily monitoring of the system's performance As system size increases, flow indicators are used to help facilitate flow measurements. Common places for flow indicators are in the product, concentrate, and recirculation lines. Continuous TDS monitors give indication on how well the system is rejecting solids. Some monitors/indicators have built-in alarms which can be interlocked to shut the system off or can simply give an audible or visual indication. In some applications, these alarms can be tied to interfacing systems which send alarms to remote locations via computer modems.

Membrane Design Consideration

Beyond the mechanical plumbing of the systems, the RO designer must meet the customer's needs and the requirements of the RO membranes themselves. In typical RO design, the membrane vessel, depending on length, can hold up to six elements. The vessels can be plumbed, in parallel, to form a stage. The stages then can be arranged in series so the cross flow is maximized and the concentrate flow can be minimized. In most designs, the first stage's concentrate will feed the next stage. Depending on the required product flow rate, and the recovery desired, there may be several stages. The arrangement of these stages is called the array. Tapering the array will help ensure proper cross flow rates throughout the system.

The general rule is 50% maximum recovery for single-stage systems, up to 75% with two stages, and 90% recovery with three stages. Before system design work can start, a water analysis is required. Certain feedwater chemistries, high TDS, and high recovery rates can require some special design considerations. In some cases, interstage pumping may be needed to insure proper flow and that velocities are met.

Stages	Maximum Recommend Recovery
1	50%
2	75%
3	90%

In designing the system, consult with the membrane manufacturer to obtain maximum flux rates, operating pressures, and other pertinent information. Many membrane manufacturers offer computer projections or have RO design consultation staffs to aid in the proper application and implementation of their RO elements. Be careful of do-it-yourself computer programs supplied by manufacturers. While they can be extremely helpful, they are somewhat sophisticated and beyond the technical capabilities of the average installer or sales person. Erroneous information input into these programs can result in erroneous outputs.

One other option to consider in the system is a recirculation of the concentrate. In some cases, this can help maintain the required cross flow rate and decrease the total number of the elements or stages. While maintaining acceptable recovery, there are minimum cross flow rates. Check with the membrane manufacturer.

Membrane Element Size	Minimum Concentrate, GPM
8" x 40"	16
4" x 40"	4
2.5" x 40"	1.6
2.5" x 25"	1.3

Equipment Sizing

Specifying Pretreatment

The basic requirement of any application is the water analysis. This report will give all of the information required to ensure system performance. If the customer does not provide one, advise them of the requirement to obtain the report and present them with the option of paying only for the test if the system is subsequently not purchased. The SDI, or Silt Density Index, number is helpful. Usually, feedwater with a SDI of 3 or less is preferred.

Once the information is in hand, the process of putting together all of the necessary pretreatment can begin. There are many manufacturers who can provide all the components of the system. There may be advantages in selecting components from different manufacturers. The main requirement is that the system flow together correctly. Beyond the water analysis, also know the available feedwater flow rate and pressure, water temperature, whether the feedwater is chlorinated, and to what concentration (ppm) the chlorine is maintained.

Multimedia Filtration

This filtration is used for the reduction of suspended solids and for colloidal materials. Average flow rates are seven gallons per minute per cubic foot of bed area. A properly designed system should remove particles that are 10 microns and above. Follow control valve manufacturer's recommendations on flow rates, backwash flow rates, and pressure drops.

Carbon Filtration

For the removal of organics and chlorine, use a high quality granular activated carbon (GAC) filter. The recommended type GAC is an acid washed, bituminous coal with an Iodine Number of 300 or higher. Average flow rates are 3 GPM per cubic foot. Follow control valve manufacturer's recommendations on flow rates, backwash flow rates, and pressure drops.

Water Softener

For the removal of hardness elements, a water softener is recommended but is required for hardness levels above 28 to 30 grains per gallon.

- 28.0 Grains per Gallon Removal/cubic feet @ 9 lbs salt with automatic controller;
- 32.0 Grains per Gallon Removal/cubic feet @ 15 lbs. salt with exchange tank;
- Average flow rate per cubic foot is 7 to 9 GPM.

Follow control valve manufacturer's recommendations on flow rate and backwash requirements. Size your softener with minimum 24-hour regeneration intervals. Salt usage and brine discharges are always considerations.

There are other types of pretreatment, such as chemical injection, which may be used for pH adjustment, membrane protection, and dechlorination. These require a more in-depth discussion, which is beyond the scope of this text. If you feel your application needs such chemical treatment, seek the advice of the membrane manufacturer.

The single most important thing to consider is the relationship of all the flow rates, working pressures, and pressure drops of all the equipment included in the system as they have a direct effect on the RO system. Remember, you have a minimum flow rate and pressure to maintain to the RO pump. A booster pump may be needed or an alternative pretreatment course may have to be taken if the feedwater doesn't meet the minimum flow and pressure requirements.

RO System Sizing

Previously, RO system design was discussed. Knowing what size system the application should have is equally important. Using the water analysis, the customer's production requirements, and the desired system recovery, the size of the RO system can be determined. In sizing the RO system, the feedwater temperature becomes very important. Most membrane performance is rated at 77°F (25°C) which, of course, is not always available. The product flow rate will decrease approximately 3% per degree below 77°F (25°C). On larger systems, feedwater heating may be considered. Feedwater temperature above 77°F (25°C) will increase product flow. However, membranes operated at elevated temperatures will have an increased salt passage and reduced life spans.

Other factors to consider may include the biofouling rate, storage tank size, and post treatment system. There will be some normal loss decrease in production due to element aging. As with any equipment, it may be desirable to factor in a reserve capacity. In most cases, the maximum recovery is desired, but can be damaging to the membrane. In discussing the array earlier, we found that by using two or more stages, the recovery was maximized.

The most efficient array is 4:2:1. A recommended two-stage array is 4:2 The highest efficiency is achieved by the use of a tapered array. Most light Commercial/Industrial systems operate at 33 to 50% recovery. While 50% recovery is possible, a single-vessel system should not operate above 33%. Consult membrane manufacturers if the system will operate outside the guidelines above.

Recommended Vessel Array Ratios

Stages	Ratios
2	4:2
3	4:2:1

Once all the factors are known, system sizing and design become a matter of making all the pieces fit together. If it is impossible to obtain all of the sizing information, there are some general guidelines which manufacturers use to size systems for general applications. Most of these application guidelines are commonplace in the light C/I marketplace. The type of storage tank and repressurization system used play important roles in the choice of light C/I equipment selection. Many times, storage can be increased to minimize the required RO production flow rate. On the other hand, if storage is at a premium, the storage can be minimized with the use of a larger RO system.

Final Notes

Membranes have a finite life, even in the well-designed systems. Normal operation of the system over time will lead to degradation of the membrane's performance. Most system operators will opt to clean elements, especially when there are a large number of elements in the system. In these larger systems, it is a good idea to have a built-in cleaning system.

The basic cleaning system would be self-contained, having chemical solution mixing tanks, heater, recirculation pump, interconnecting tubing, and provisions for drain connections. The cleaning operation will include a chemical cleaning agent. Consult with the membrane manufacturer on what types of cleaning agents are acceptable for their elements. Cleaning is generally recommended when the flux flow rate is decreased by 10%. An interval of three months or more between cleanings can be considered normal. If cleaning is needed more often, it is a good idea to look at the pretreatment system and ensure that it is operating correctly.

Summary

Although the principle of RO is understood by most, many do not understand the mechanics of system design or operation. When feedwater quality drops off, a whole system approach is recommended to ensure proper operation. A basic, working understanding of RO systems will aid in the sizing, set-up, and operation of the RO unit. When selecting a system, having strong supplier support is most desirable. The cost of an incomplete or poorly-designed system will never be recovered.

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