Reverse Osmosis System Design Guidelines

The methodology of designing a reverse osmosis (RO) system is a fairly uniform process across the water treatment industry. A RO system is inherently a modular design with the "building blocks" being the membrane elements and the pressure vessels (that house the elements). For commercial and industrial applications, the elements and pressure vessels come in standard sizes that are common amongst suppliers. A key advantage of a modular design is that the system can be scaled to size by combining these building blocks in a manner that meets the water production needs of the application.

Designing a RO system is principally an exercise on selecting the most efficient membrane for the specific application and then determining the size and quantity of membrane elements necessary to produce the desired volume of permeate, as well as arranging the elements in parallel and/or series to balance and optimize the flow and recovery across the entire system.

Since the RO elements are modular, a broad range of production rates from 1 gallon per minute (gpm) to 500,000 gpm (and beyond) can be accommodated by selecting from pre-engineered RO skids based on the feed water source and quality, as well as and the desired product water flow and quality. The requirements of many commercial and industrial applications are often met using pre-engineered RO skids; thereby reducing the cost of the system and shortening the lead time. Specialized applications such as ultrapure water and larger systems such as municipal treatment; however, typically require more customized systems.

There are different types of membranes used to treat tap water, brackish water, seawater and wastewater. Regardless of the specific type of membrane, the performance of a membrane is specified and compared based on its rate of water production (permeability) and the percent of total salts it retains (rejection). In theory, the selection of the "ideal" membrane for a given application is the highest water production rate with the highest salt rejection at the lowest feed pump pressure (i.e. low operating cost.)

Reverse osmosis projection design software can be used to model the setup the system and the operating parameters. Information entered into the projection software includes the feed water chemistry (water analysis), feed water temperature, type of membrane, number of membranes per vessel, number of vessels and vessel plumbing configuration.

General guidelines for modeling an RO system to take into consideration are the silt density index (SDI) measurement of the feed water after pretreatment. Derived from experience, limits on permeate flux and element recovery for different types of waters are based on correlation of the SDI value with membrane fouling and mineral content with element recovery, respectfully, for different types of waters. These general limits shown in Table 1 below serve as boundary conditions when designing a RO system. A system designed with high permeate flux rates for example is likely to experience higher fouling rates and more frequent chemical cleanings. Due to high salinity (>36,000 ppm TDS), seawater system designs are further limited by the osmotic pressure and durability of the membrane elements.

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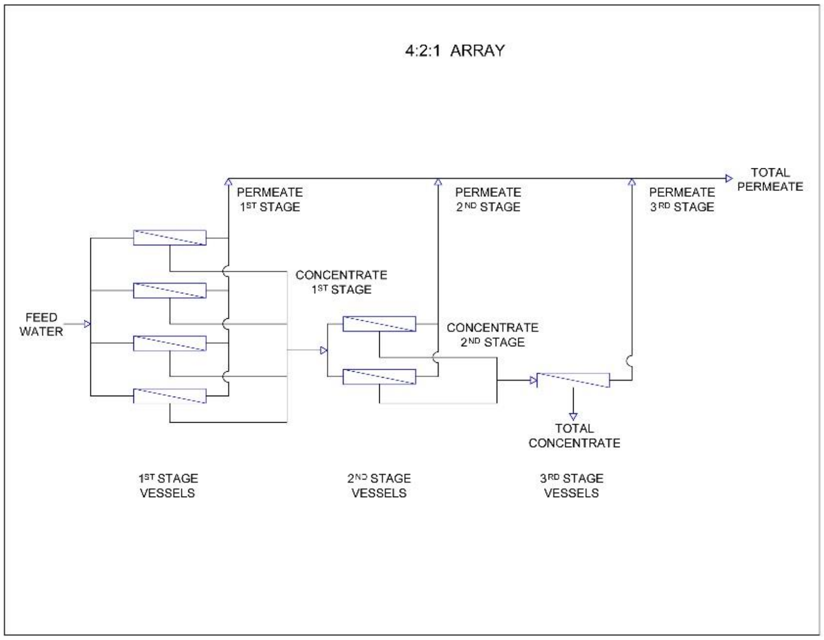
Feed Source		Tap Water	Well Water	Surface Water	Sea Water
Feed SDI		< 3	< 3	< 5	< 5
Maximum Element Recovery (%)		19	17	15	13
Average System Flux (gfd)		20	17	13	10
Max Feed Flow Rate per Element (gpm)	2.5" Diameter	6	6	6	6
	4" Diameter	14	14	14	14
	8" Diameter	75	70	55	60
Min. Concentrate Flow Rate per Element (gpm)	2.5" Diameter	1	1	1	1
	4" Diameter	3	3	3	3
	8" Diameter	14	14	14	14

System recovery is defined as the percentage of permeate water produced from the feed flow. Recovery is limited by factors as solubility of the salts in the concentrate stream (scaling), flow across the membrane surface (crossflow) and (as mentioned in the case of seawater) osmotic pressure. In general terms, a brackish water RO skid is designed to target 60 to 85% recovery and a seawater RO skid is designed to target 30 to 60% recovery.



Flux is calculated by dividing the permeate production by total active membrane area and is measured as GFD (Gallons per Square Foot Membrane Area per Day). For example, a system producing 40,000 gallons per day with 2500 square feet of total active membrane area would have an average system flux of 16 GFD. Flux is limited by feed water type (fouling), temperature and salt concentration.

In order to calculate the number of membrane elements required for the application, the desired permeate production rate is divided by the average system flux rate taken from Table 1 and the membrane surface area of the selected element. For example, if the application requires 81,600 gallons per day to be produced from well water, 17 GFD was the design flux, and an 8” element with 400 SF of membrane area was chosen, then 12 membrane elements are needed.

The number of pressure vessels required is found by dividing the total quantity of membrane elements needed by the number of elements inside each pressure vessel. Large brackish systems typically use pressure vessels designed to hold either 6 or 7 elements. Large seawater systems use pressure vessels designed to hold either 7 or 8 elements. For smaller systems, however, a compact footprint is often desired and shorter vessel sizes are used. In the example where 12 membrane elements are needed and the vessel type was 4-elements per vessel, then 3 pressure vessels would be required.

Next, the pressure vessels need to be arranged in an array. An array is the order of stages and the number of pressure vessels in each stage. For example, a 4:2:1 array identifies there are 3 stages with 4 vessels in the first stage, followed by 2 vessels in the second stage and 1 vessel in the third stage. The figure below illustrates a 5:3 array using 4-element pressure vessels.

The number of stages in an array is generally determined by the system recovery. For a recovery of up to 50%, one stage is used. For a recovery of up to 75%, two stages are used. Beyond that, three stages are used.   These are not absolutes and the projection software is used to optimize the array.

After determining the number of stages in the array, the next step is to calculate the number of vessels in each stage. Within each stage, the vessels are plumbed in parallel as illustrated in the figure. The stages themselves are connected together in series with the concentrate of the first stage feeding the second stage. The ideal design is to operate each stage at a similar recovery and flux rate, while ensuring that the maximum feed flow rate and permeate flow rate of the first element in the first stage are not exceeded and that the minimum concentrate rate exiting the last stage does not drop below the minimum concentrate flow rate. If an individual element exceeds the maximum recovery limit, the maximum feed flow rate is exceeded and/or the minimum concentrate flow rate is not met, then the array is rearranged, stages are added or subtracted, etc. This is done to satisfy the design guidelines and optimize the performance of the system. The reality is that the flow rate of the tail elements in the last stage will normally be less than that of the feed elements in the first stage due to pressure drop across the system and the increasing osmotic pressure of the brine in the concentrate.

To determine the performance of the RO system, the projection software uses an iterative process to derive the required feed pump pressure and the total permeate quality.   The program calculates feed flow rates, permeate flow rates and salt concentration on an element by element basis across the entire system with the feed pressures and salt concentration for each element as the feed to the following element.