REVERSE OSMOSIS ROUGHING DEMINERALIZATION

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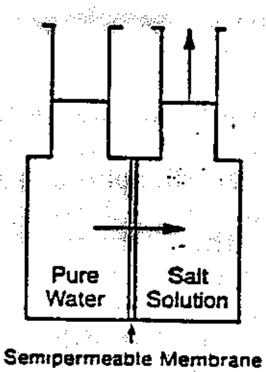
As industries need for purified water has increase and Florida's water quality deteriorated, the need for advanced water treatment methods has become more apparent. Reverse osmosis is one such method, becoming increasingly popular due to recent advances in reverse osmosis membrane development. Of particular interest is the application of reverse osmosis in high pressure boiler feed systems. In this application reverse osmosis is used as a roughing demineralizer, dramatically decreasing the operating costs of downstream ion exchange units and often decreasing the total cost of producing boiler makeup water. Such equipment can often pay for itself in ion exchange regenerant chemical savings alone.

This paper will cover the fundamentals of reverse osmosis theory and unit design, a brief history of RO membrane development, and the factors which influence economic feasibility of reverse osmosis for boiler feed applications.

Osmosis vs Reverse Osmosis

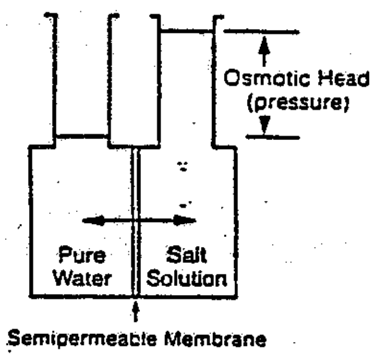
Understanding the process of reverse osmosis can best be gained by first understanding the process of osmosis. A simple osmosis system is shown in figure 1 below.



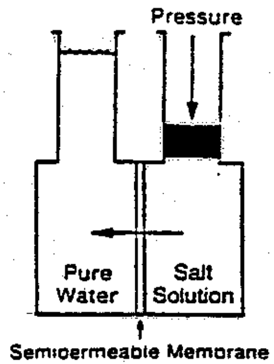
Natural osmosis takes place when water passes from a less concentrated solution to a more concentrated solution through a semi-permeable membrane. The semi-permeable membrane is one that will pass the water molecules but will not pass a great percentage of the solute (dissolved material). Most of this material is rejected.

A certain amount of potential energy exists between the two solutions on either side of the semi-permeable membrane, with the more dilute solution exhibiting the higher potential level. Hence the water, like everything else in nature, will flow from the solution with the higher potential energy level to the solution with the lower potential energy level. The highest energy level for water is pure water and as solutes are added the potential energy is reduced.

Water will flow through the membrane until the system has reached a state of equilibrium. Equilibrium will be reached when the differential head is equivalent to the apparent or differential osmonic pressure. (See figure 2.)



Reverse osmosis can then be defined as the separation of one component of a solution from another by means of pressure exerted on the solution. This usually means a separation of dissolved solids (solute) from water (solvent). Referring to figure 3, the addition of pressure to the more concentrated solution will stop the transport of water through the membrane when the head pressure equals the differential osmonic pressure of the system. As more pressure is applied, the water will flow from the concentrated solution to the dilute solution. This is logical because the additional pressure has increased the energy level of the more concentrated solution to more than the energy level of the less concentrated solution. Again water flows from a higher energy level to a lower energy level, in this case the more concentrated to the less concentrated. The rate of water transport is a function of: 1) the pressure applied, 2) the apparent or differential osmonic pressure of the system, 3) the temperature of the solution, 4) the specific characteristics of the semi-permeable membrane. (See figure 3.)



History of Membrane Development

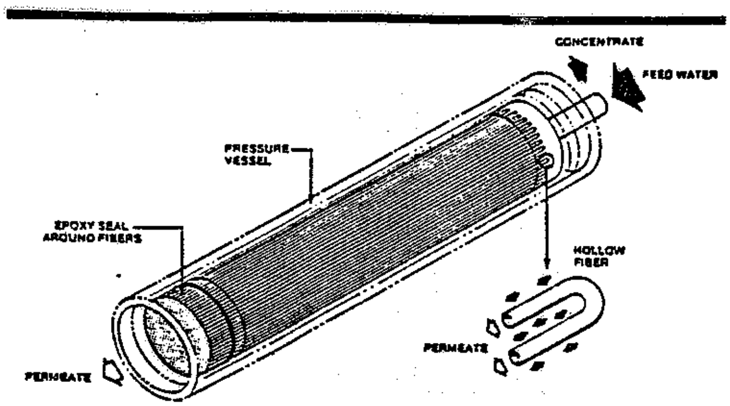
Although the natural process of osmosis has been known for over 200 years, the development of reverse osmosis has occurred in just the past thirty years.

The first reverse osmosis membranes were developed at the University of Florida in the late 1950's. These first membranes were constructed of cellulose acetate and demonstrated only a modest salt rejection and low flux at a relatively high pressure. Further development of the cellulose acetate membrane was carried out at UCLA, resulting in an asymetric flat sheet membrane which exhibited both higher flux and higher salt rejection than previously thought possible.

The first commercial RO systems used the flat sheet cellulose acetate membrane in a plate and frame device. By the mid 1960's a tubular device had also been developed using this same cellulose acetate membrane. Both of these devices are still used today, but only for process applications due to their cumbersome size and limited hydraulic capabilities.

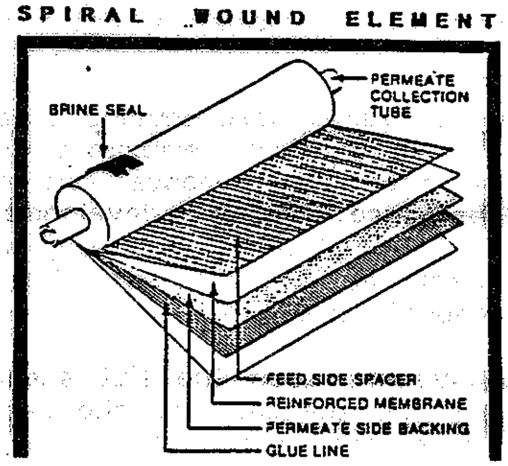
Further developments in the late 1960's and early 1970's resulted in the two devices and/or packages we now see today. The first and least commonly used membrane device is the hollow fiber permeator. The permeator utilizes thousands of fibers with diameters smaller than human hair packaged in convenient bundles (figure 4).

HOLLOW FINE FIBER ELEMENT



he second and more commonly used membrane device is the spiral wound membrane element. The spiral wound element is actually a flat sheet of membrane rolled up around a hollow product tube, much like a window shade (figure 5).

SPIRAL WOUND ELEMENT

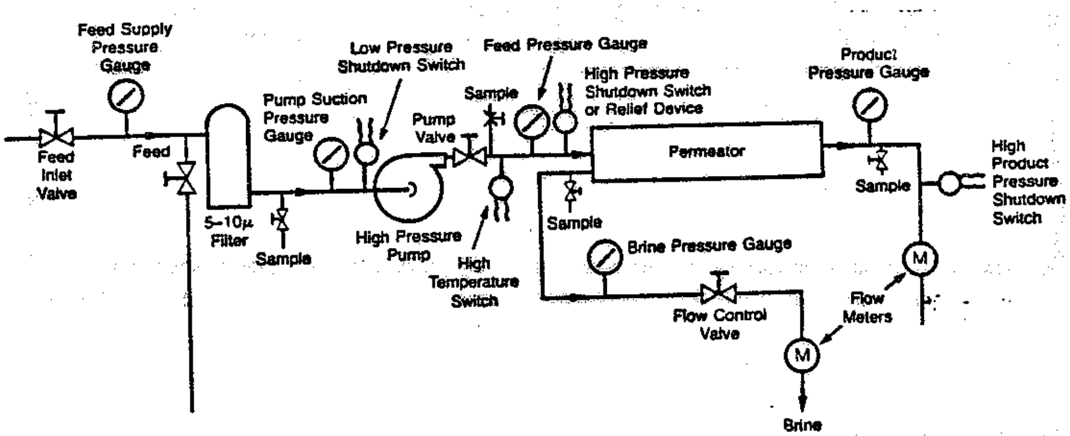


Today a variety of membrane polymer types are used in the spiral wound configuration. The list includes polyamides, polysulfones and blended cellulose acetates.

The membrane of choice for most boiler feed applications is a thin film composite (TFC) type membrane. The TFC membrane exhibits a very high total salt rejection, lower operating pressure and high total silica rejection. These features have led to the wide spread use of the TFC membrane in pre D.I. applications such as boiler feed. Silica rejection is of particular concern in areas such as Florida where feed water silica levels are often high. Lower operating pressure and resulting lower electrical cost of a TFC membrane system has also led to its popularity.

Basic Machine Design

The figure below illustrates a simplified one element reverse osmosis system.



Please note the following components on the above system and their function.

-Prefilter, used to remove suspended solids from the feedwater.

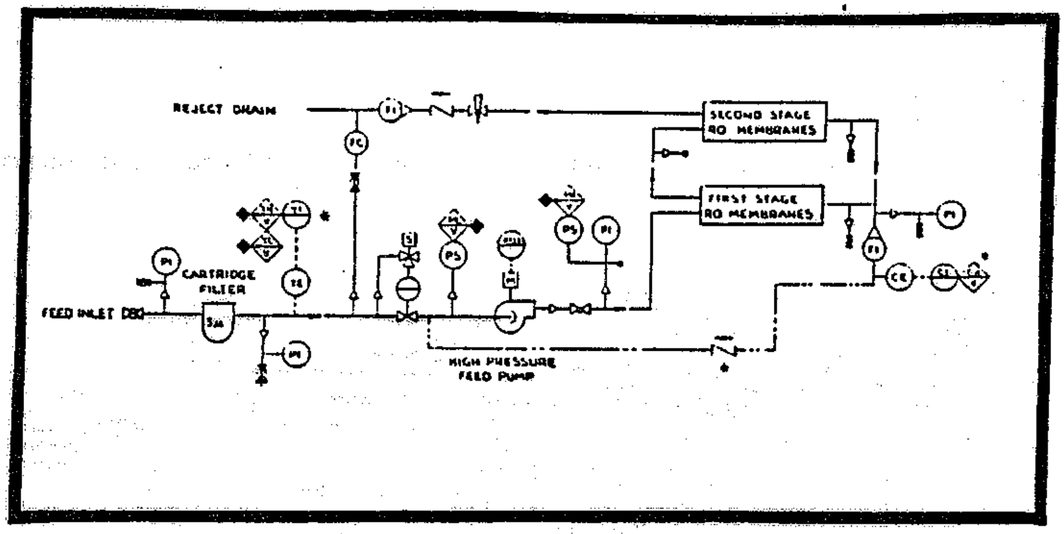
-High pressure, single or multi-staged centrifugal pump used to develop the pressure necessary to drive the RO process (200-400 psi).

-RO elements, splits feedwater into product and concentrate.

-Concentrate valve, used to set the concentrate flow rate of the system.

Also please note that the ratio of the product flow to concentrate flow is termed <u>percent recovery</u>. Typical commercial RO systems operate at a recovery between 60 and 80 percent by using several membrane elements in series. Recovery for a single element system (as above) will be approximately 10-15%. The figure below illustrates how membrane elements are arrayed in parallel to balance hydraulic flow in series to achieve the percent recovery desired.
(figure 7)

MITCO TYPICAL R.O. AND P & I DIAGRAM



Boiler Feed Applications

Electric utilities and industries, which generate their own power, require very good quality water for their high pressure steam boilers. Exact water quality is dictated by a number of factors including the operating pressure of the boiler and the percentage of condensate return for the boiler system. The specifications for makeup water quality often include total dissolved solids or conductivity of makeup water, ppm of hardness, ppm of silica, ppm of chloride and total organic carbon.

The traditional means of producing high purity boiler feedwater is through twin bed and/or mixed bed demineralization.

As most of you probably know, the process of ion exchange demineralization is accomplished through the use of specialized polymer resin beads having chemical binding sites for cations or anions existing in water. By its very nature the ion exchange process is up and down, requiring periodic regeneration of the resin when all the binding sites are full. This regeneration process is traditionally accomplished through the use of acid (either HCL or H_2SO_4) for the cation resins and sodium hydroxide for anion resins. In turn, the major part of the operating cost for an ion exchange demineralizer is associated with the cost of regenerant chemicals.

Several inherent limitations of the ion exchange demineralization process have lead to the use of roughing demineralization, a type of ion exchange pretreatment. These include:

- -The preferential binding of specific cations and anions to the repective ion exchange resin types. This creates a phenomenon known as leakage. (Sodium leakage for cation resin and silica leakage for anion resins).

- -The loss of capacity in anion resins due to organic fouling.

- -Operating cost for ion exchange demineralization increases, on a linear basis, as feedwater total dissolved solids (TDS) increases. This is particularly evident in areas where salt water intrusion takes place on a well, used to provide feedwater to an ion exchange system.

- -The cyclic nature of the ion exchange process, going from service to regeneration combined with a variety of potential problems which may occur during the regeneration process create an element of risk. The risk of not being able to produce acceptable water due to poor regeneration.

Reverse osmosis is particularly effective as a roughing demineralizer because of the way it dampens the impact caused by these limitations of ion exchange demineralization. For example, the leakage phenomenon is of great concern in Florida due to the characteristicly high sodium and silica levels of of our ground water. In response, ion exchange systems must be designed with particular attention to the resin capacities for these specific ions and the regenerant procedures required to constantly return the resin to these capacity levels. Reverse osmosis roughing demineralization using high rejection TFC membrane elements, reduces this excess loading on ion exchange beds by a factor up to 95%. The net effect is a smoother operating demineralizer system and better overall water quality.

Organic fouling of anion resin is also of major concern in many area's through out the state of Florida. Reverse osmosis is quite effective in removal of 99t% of all organics over 150 molecular weight, including the humic and tannic acids which taint our waters. By removing the organic foulant through roughing demineralization, reverse osmosis will help to extend the operational life of anion resin and eliminate the need for the brine treatments often employed in attempts to clean up fouled anion resin beds.

The impact of reverse osmosis roughing demineralization on the <u>cost</u> of producing boiler make-up water is tied to it's relative operating cost when compared to the cost of ion exchange. The graph below illustrates the cost per 1000 gallons of demineralized water produced using straight twin bed/mixed bed ion exchange vs reverse osmosis/ion exchange. (See figure). The operating cost for both processes is plotted against feedwater TDS. Looking at the graph, two things should jump out at you. 1) As feedwater TDS gets higher the savings available through RO roughing demineralization grow greater. 2) Operating cost saving are seen from feed water TDS values as low as 75ppm. The cost saving are due to extended IX runtimes and a resulting lower regenerant chemical cost.

This brings up another point regarding our list of the limitations of ion exchange. If you are making plans for the future and you know that salt water intrusion is taking place on the well used for demineralizer feedwater. Reverse osmosis has got to look awful good in terms of stabilizing the future cost for boiler make-up water.

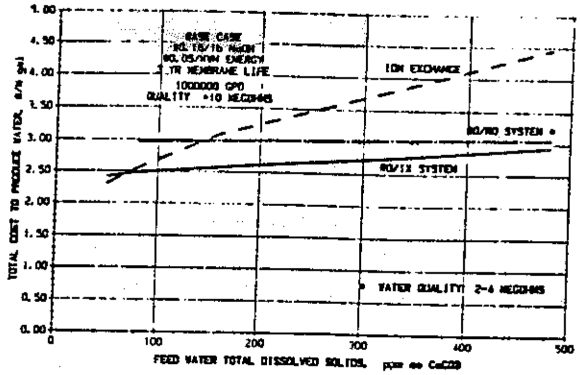
But what if your well isn't experiencing salt water intrusion? Well then, it all depends on the feedwater TDS, just how much money you can save today by installing a RO system. Most of us in Florida have a TDS of 250 to 400 ppm regardless if you have your own wells or are buying water from the city. These feedwater TDS values translate into savings of $0.75 to 1.25 per 1000 gallons if RO roughing demineralization is used.

Yet another thing to consider is the effect on operating cost of increases in regenerant chemical cost. Figure 9 shows the effect of caustic pricing on the respective costs for producing boiler makeup water with ion exchange vs RO/ion exchange.

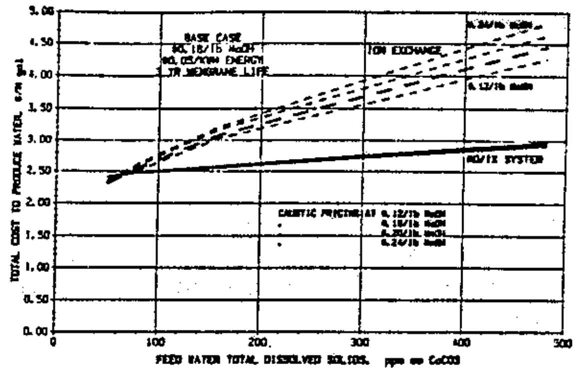
On the other hand figure 10 shows the effect of an increased power price. Power is by far the largest single cost associated in the reverse osmosis process just as caustic is to ion exchange.

The bottom line for someone with an existing ion exchange system is <u>Pay back</u>. This is illustrated in figure 11 plotting payback in years vs <u>TDS of feedwater</u>. The three lines on the graph represent the effect of RO capital cost. Capital cost for a complete RO system is typically between $1.00 and $1.50 per daily gallon of water which the RO system is designed to produce. This graph should help each of you to determine the payback in each of your applications.

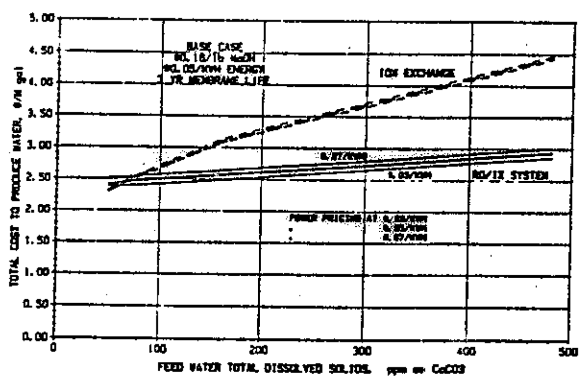
I would like to thank you Mr. John Wing for having the foresight of seeing the potential of reverse osmosis roughing demineralization and Ms. Sharon Whipple of Dow Chemical for her assistance in my preparation of this paper.



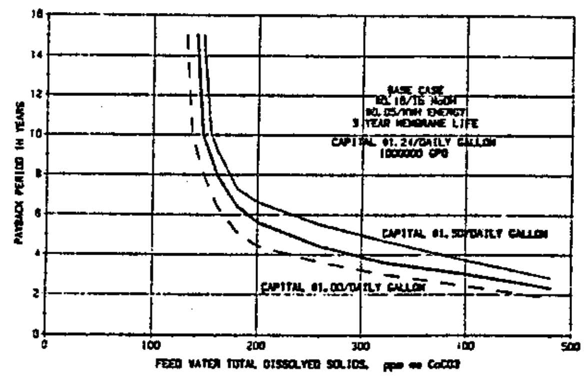
The economics of reverse osmosis and ion exchange - base cases.



The economics of reverse osmosis and ion exchange - effect of caustic pricing.



The economics of reverse osmosis and ion exchange - effect of power pricing.



The economics of reverse osmosis and ion exchange - payback for RO retrofit of an ion exchange plant to an RO/IEX plant.