Introduction to Reverse Osmosis

Since their development as practical unit operations in the late 1950's and early 1960's, reverse osmosis (RO) and ultra filtration (UF) have been continually expanding the scope of their applications. Initially, reverse osmosis was applied to the desalination of seawater and brackish water. Increased demands on the industry to conserve water, reduce energy consumption, control pollution, and reclaim useful materials from waste streams, have made new applications economically attractive. In addition, advances in biotechnologies and pharmaceuticals, coupled with advances in membrane development are making membranes an important separation step; which, compared to distillation offers energy savings and does not lead to thermal degradation of the products.

How Reverse Osmosis Works

The phenomenon of osmosis occurs when pure water flows from a dilute saline solution through a membrane into a higher concentrated saline solution. The phenomenon of osmosis is illustrated in the figure below. A semi-permeable membrane is placed between two compartments. "Semi-permeable" means that the membrane is permeable to some species and not permeable to others. Assume that this membrane is permeable to water, but not to salt.

Then, place a salt solution in one compartment and pure water in the other compartment. The membrane will allow water to permeate through it to either side. But salt cannot pass through the membrane.

As a fundamental rule of nature, this system will try to reach equilibrium. That is, it will try to reach the same concentration on both sides of the membrane. The only possible way to reach equilibrium is for water to pass from the pure water compartment to the salt-containing compartment, to dilute the salt solution.

The drawing below also shows that osmosis can cause a rise in the height of the salt solution. This height will increase until the pressure of the column of water (salt solution) is so height that the force of this water column stops the water flow. The equilibrium point of this water column height in terms of water pressure against the membrane is called osmotic pressure.

If a force is applied to this column of water, the direction of water flow through the membrane can be reversed. This is the basis of the term reverse osmosis. Note that this reversed flow produces a pure water from the salt solution, since the membrane is not permeable to salt.

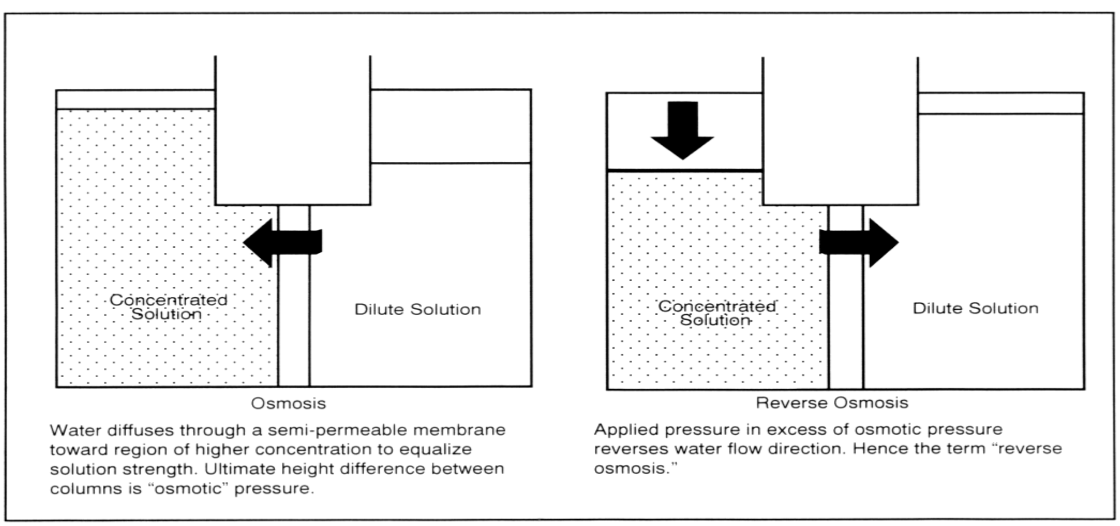
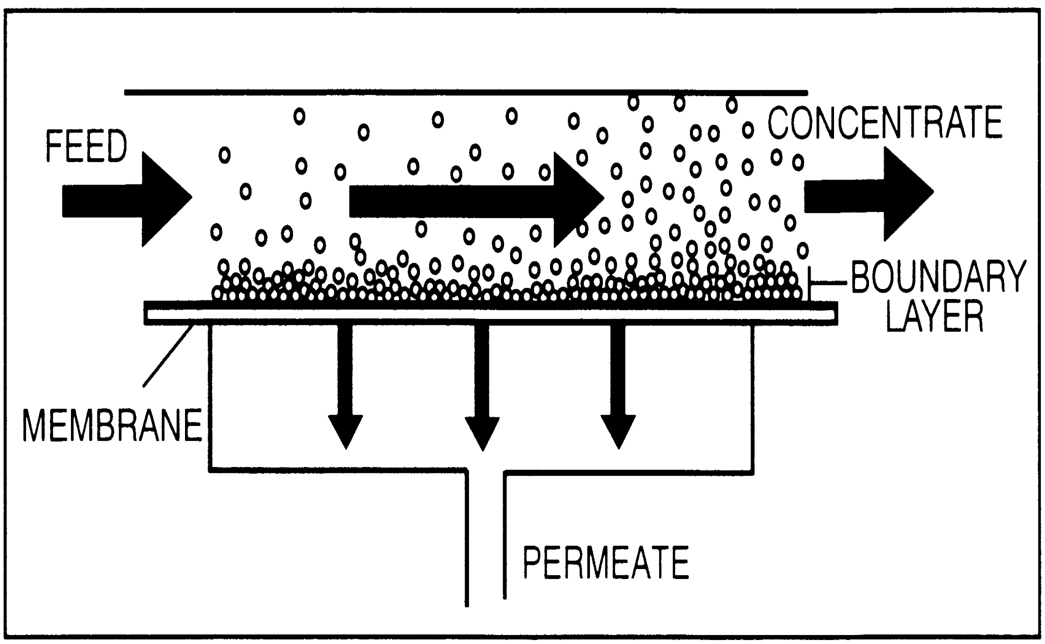


Figure 1: Overview of Osmosis / Reverse Osmosis

MEMBRANE ELEMENTS

The most typical operating span of these four major desalination processes is shown in the figure below. The various filtration technologies, which currently exist, can be categorized on the basis of the size of particles removed from a feed stream. Conventional macrofiltration of suspended solids is accomplished by passing a feed solution through the filter media in a perpendicular direction. The entire solution passes through the media, creating only one exit stream. Examples of such filtration devices include cartridge filters, bag filters, sand filters, and multimedia filters. Macrofiltration separation capabilities are generally limited to undissolved particles greater than 1 micron.

For the removal of small particles and dissolved salts, membrane separation systems are utilized which use a different method than conventional particle filtration. As shown in the figure below, termed crossflow membrane filtration uses a pressurized feed stream which flows parallel to the membrane surface. A portion of this stream passes through the membrane, leaving behind the rejected particles in the concentrated remainder of the stream. Since there is a continuous flow across the membrane surface, the rejected particles do not accumulate but instead are swept away by the concentrate stream. Thus, one feed stream is separated into two exit streams: the solution passing through the membrane surface (permeate) and the remaining concentrate stream.

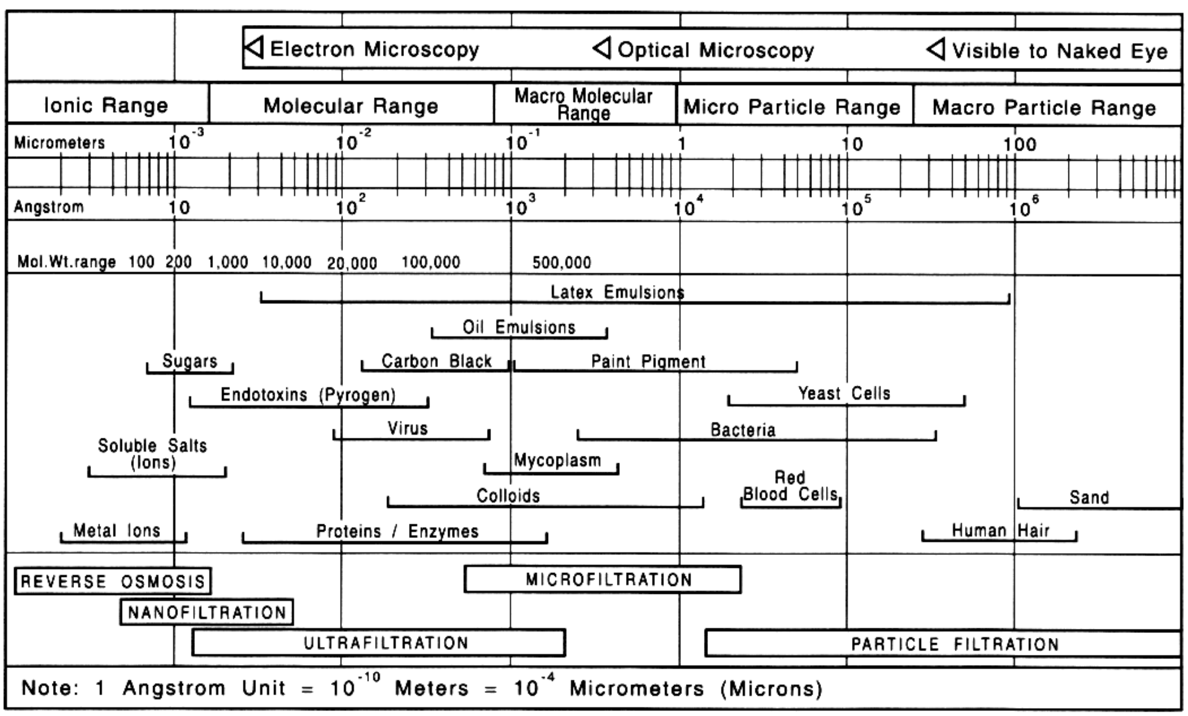


Applications for Reverse Osmosis

The applications for RO are numerous and varied, and include desalination of sea water or brackish water for drinking purposes, wastewater recovery, food and beverage processing, biomedical separations, purification of home drinking water and industrial process water. Also, RO is often used in the production of ultrapure water for use in the semiconductor industry, power industry (boiler feed water), and medical/laboratory applications. Utilizing RO prior to Ion Exchange(IX) dramatically reduces operating costs and regeneration frequency of the IX systems.

Transmembrane pressures for RO typically range from 14 bar (200 PS) for brackish water to 69 bar (1,000 PSI) for seawater.

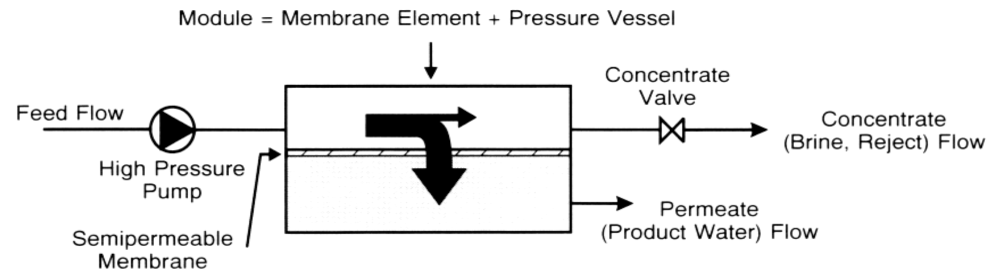
The normal range of filtration processes is shown in the figure below.



Ranges of Filtration Processes

How To Use Reverse Osmosis In Practice

The simplified reverse osmosis process is shown in the figure below.



$$\text{Recovery (\%)} = \frac{\text{Permeate Flow} \cdot 100}{\text{Feed Flow}}$$

$$\text{Salt Passage (\%)} = \frac{\text{Permeate Salt Concentration} \cdot 100}{\text{Feed Salt Concentration}}$$

$$\text{Salt Rejection (\%)} = 100 - \text{Salt Passage}$$

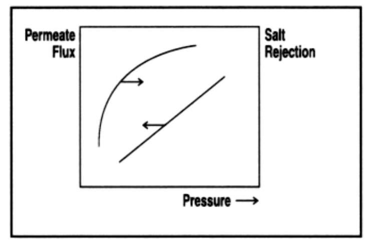
Figure 2: Reverse Osmosis Process

Factors Influencing Reverse Osmosis

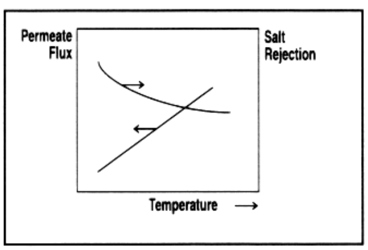
Permeate flow through unit membrane area and salt rejection are the key performance parameters of a reverse osmosis process. They are mainly influenced by variable parameters, which are as follows:

Pressure

With increasing effective feed pressure, the permeate TDS will decrease while the permeate flux will increase as shown here.



Performance vs. Pressure



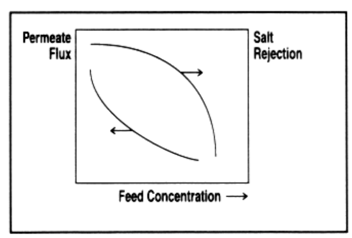
Performance vs. Temperature

Temperature

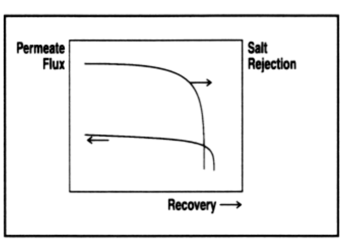
If the temperature increases and all other parameters are kept constant, the permeate flux and the salt passage will increase as shown.

Feedwater Salt Concentration

The figure to the left shows the impact of the feedwater salt concentration on the permeate flux and the salt rejection.



Performance vs. Feedwater Salt Concentration



Performance vs. Recovery

Recovery

The recovery is the ratio of permeate flow to feed flow. In the case of increasing recovery, the permeate flux will decrease and stop if the salt concentration reaches a value where the osmotic pressure of the concentrate is as high as the applied feed pressure. The salt rejection will drop with increasing recovery as pictured here.

Membrane Composition

The membrane is defined as a thin film composite membrane consisting of three layers: a polyester support web, a microporous polysulfone interlayer, and an ultra thin barrier layer on the top surface. A schematic diagram of the membrane is shown below.

The major structural support is provided by the non-woven web, which has been calendered to produce a hard, smooth surface free of loose fibers. Since the polyester web is too irregular and porous to provide a proper substrate for the salt barrier layer, a microporous layer of engineering plastic (polysulfone) is cast onto the surface of the web.

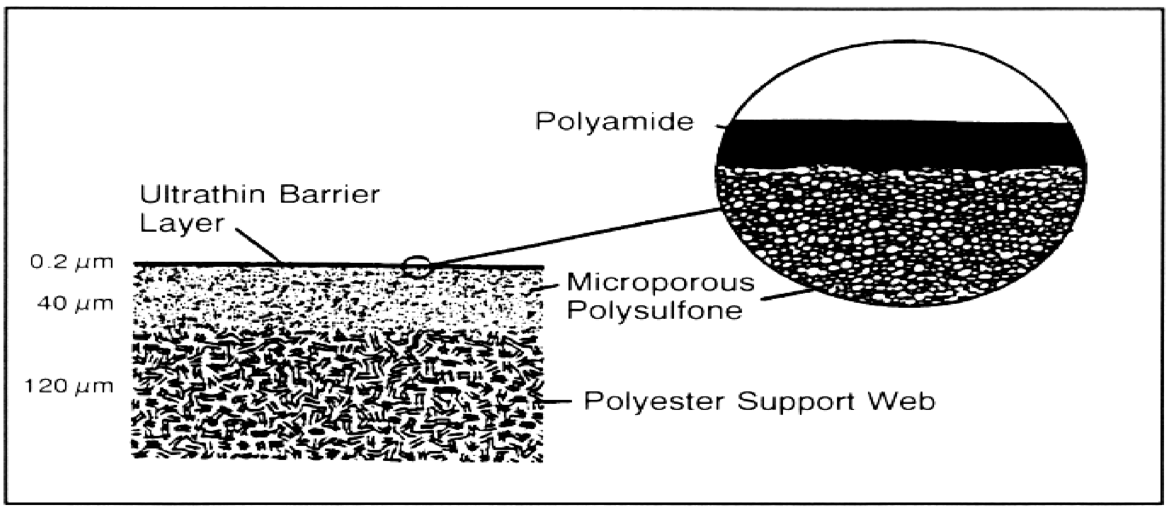


Figure 2: Schematic Cross-Section of Thin Film Composite Reverse Osmosis Membrane