1 MEMBRANE PROCESSES

1.1 Types of Membrane Processes

These are Microfiltration, Ultrafiltration, Nanofiltration and Reverse Osmosis, all of which use permeable membranes to achieve the desired separation between solute and solvent and are based on the principle of cross-flow, although dead-end operation may sometimes be used. The membrane may be viewed as a specialized filter, which allows the passage of solvent under pressure, while retaining solutes to different degrees, depending on the membrane type. By definition, reverse osmosis ideally allows passage only to water, while retaining all solutes. Nanofiltration and ultrafiltration, on the other hand, retain suspended solids as well as dissolved macromolecules, separating them on the basis of their physical size. Micro- and Ultrafiltration are intended to retain suspended solids in the micron and sub-micron ranges.

The membranes may be visualized to work on a "sieve filtration" mechanism. The difference in filtration characteristics is shown in Figure 1.1.1.

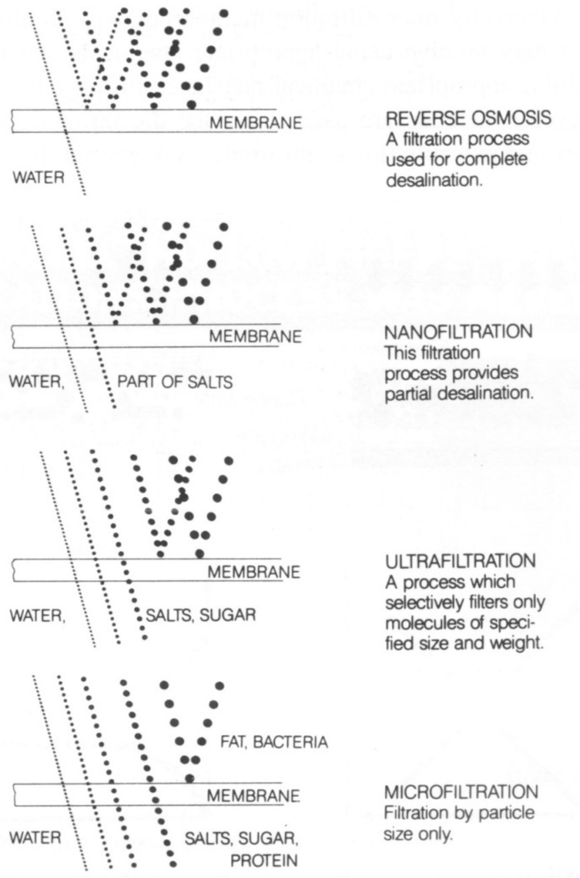


Figure 1.1.1: Difference in Filtration Characteristics between RO, NF, UF and MF

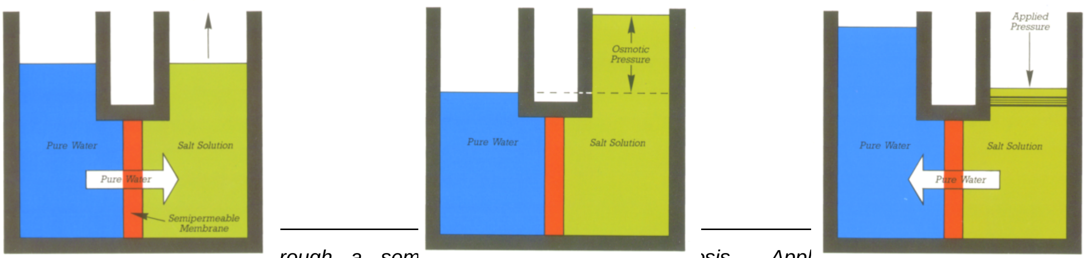
1.2 Reverse Osmosis

Reverse osmosis uses polymeric membranes in tubular, spiral and hollow-fiber configurations in the removal of dissolved ionic species from solution. As such, reverse osmosis is widely used in the desalination of brackish and seawater, as well as in the treatment of industrial effluents. Reverse osmosis is the unit operation by which the natural osmotic process is reversed to effect the removal of dissolved salts and organic compounds from an aqueous solution. This is achieved with the aid of a semi-permeable membrane and the application of a pressure, higher than the osmotic pressure, on the feed water. The membrane allows passage of pure water only, resulting in the concentration of salts and organics in the feed water. Typical operating pressures range from 15–40 bar for brackish feed waters and 60–70 bar for seawater.

1.2.1 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 Figure 1.1.4. 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.



...rough a sem... membrane toward a region of higher concentration to equalize solution strength. Ultimate height difference between columns is "osmotic pressure".	*...sis – Appl... osmotic pressure reverses water flow direction. Hence the term "reverse osmosis"*

Figure 1.1.4: Overview of Osmosis / Reverse Osmosis

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.

Figure 1.1.4 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 high 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 Reverse Osmosis. Note that this reversed flow produces pure water from the salt solution, since the membrane is not permeable to salt.

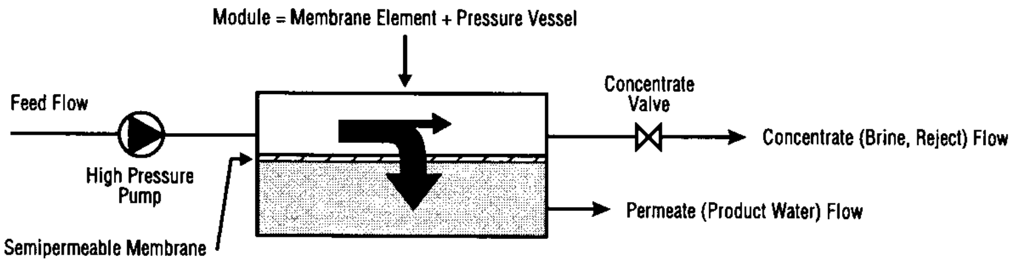
1.2.2 How to Use Reverse Osmosis In Practice

The simplified reverse osmosis process is shown in Figure 1.1.5, while Figure 1.1.6 illustrates the relationship between feed, concentrate and permeate in cross-flow operation.

With a high pressure pump, pressurized saline feed water is continuously pumped to the module system. Within the module, consisting of a pressure vessel (housing) and a membrane element, the feed water will be split in a low saline product called permeate and a high saline brine called concentrate or reject.

A flow regulating valve called concentrate valve, controls the percentage of feed water that is going to the concentrate stream and the permeate which will be obtained from the feed.

Figure 1.1.5: Reverse Osmosis Process



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

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

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

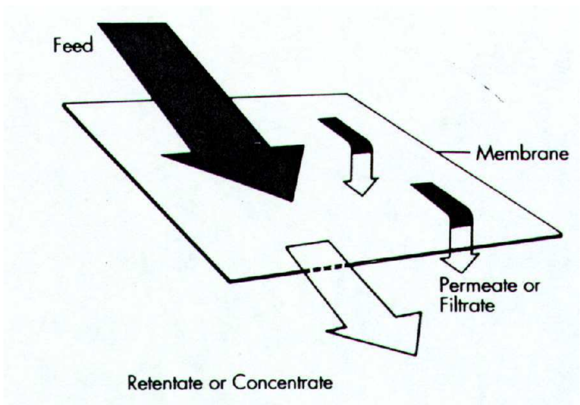


Figure 1.1.6: Principle of Cross-flow filtration showing relationship between Feed, Brine and Filtrate.

1.2.3 Spiral Wound Membrane Configuration

The spiral wound membrane assembly normally consists of several spiral membrane cartridges, which are connected together and placed in a cylindrical pressure vessel (Figure 1.1.7).

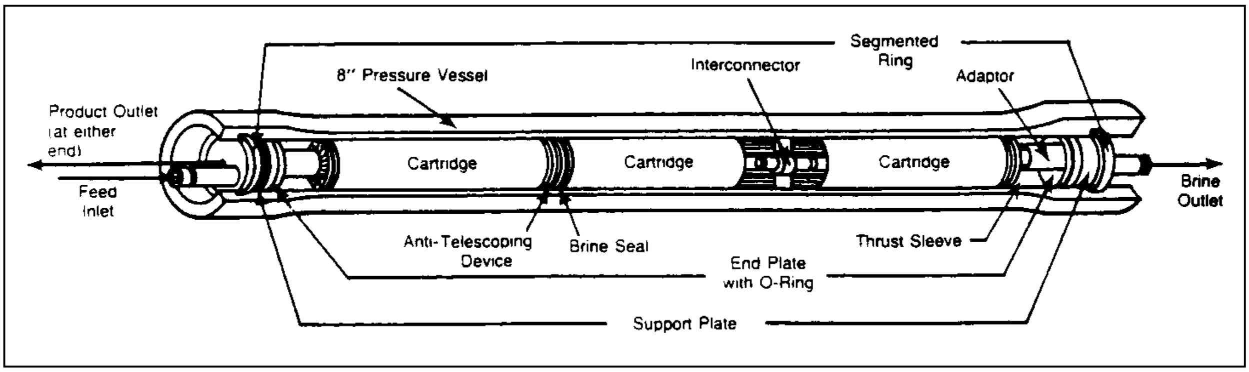


Figure 1.1.7: Spiral Wound Membrane Assembly

Each spiral cartridge is produced independently (see Figure 1.1.8). Two sheets of membranes are placed on both sides of a fabric spacer. The three pieces are then sealed on three sides to form an envelope. The remaining open side is attached to a perforated product water collection tube. A woven plastic sheet serves as a spacer and is laid on one side of the membrane envelope. The membrane envelope and spacer sheet is then rolled up into a cylindrical bundle.

Up to six membrane cartridges are connected together within a pressure vessel. Pressurized feed water enters the pressure vessel shell and flows through the channels between the spiral windings of the first cartridge. Some of the feed water permeates through the membrane and travels a spiral path to the product water collection tube at the center of the membrane cartridge. The remaining feed continues through the spiral layers, the length of the cartridge. It then encounters the next membrane in the vessel and the process is repeated. The product from each membrane cartridge exits from the common product tube in the pressure vessel. The feed water becomes more concentrated as it passes through each membrane cartridge and exits from the pressure vessel as brine.

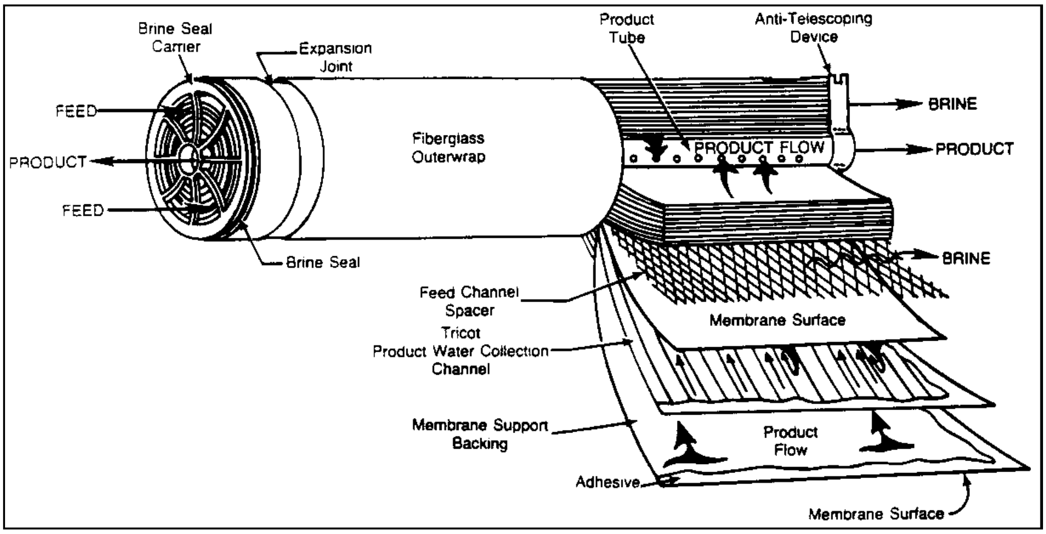


Figure 1.1.8: The Spiral Wound Membrane