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Reverse Osmosis Principles

Reverse osmosis is a demineralization process that relies on a semipermeable membrane to effect the separation of dissolved solids from a liquid. The semipermeable membrane allows liquid and some ions to pass, but retains the bulk of the dissolved solids. Although many liquids (solvents) may be used, the primary application of RO is water-based systems. Hence, all subsequent discussion and examples will be based on the use of water as the liquid solvent.

To understand how RO works, it is first necessary to understand the natural process of osmosis. This chapter covers the fundamentals of osmosis and reverse osmosis.

2.1 Osmosis

Osmosis is a natural process where water flows through a semipermeable membrane from a solution with a low concentration of dissolved solids to a solution with a high concentration of dissolved solids.

Picture a cell divided into 2 compartments by a semipermeable membrane, as shown in Figure 2.1. This membrane allows water and some ions to pass through it, but is impermeable to most dissolved solids. One compartment in the cell has a solution with a high concentration of dissolved solids while the other compartment has a solution with a low concentration of dissolved solids. Osmosis is the natural process where water will flow from the compartment with the low concentration of dissolved solids to the compartment with the high concentration of dissolved solids. Water will continue to flow through the membrane until the concentration is equalized on both sides of the membrane.

At equilibrium, the concentration of dissolved solids is the same in both compartments (Figure 2.2); there is no more net flow from one compartment to the other. However, the compartment that once contained the higher concentration solution now has a higher water level than the other compartment.

The difference in height between the 2 compartments corresponds to the osmotic pressure of the solution that is now at equilibrium.

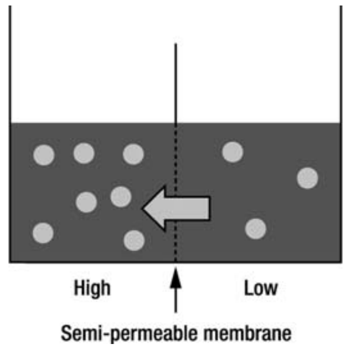

Figure 2.1 Cell divided into 2 compartments separated by a semipermeable membrane. Water moves by osmosis from the low-concentration solution in one compartment through the semipermeable membrane into the high-concentration solution in the other compartment.

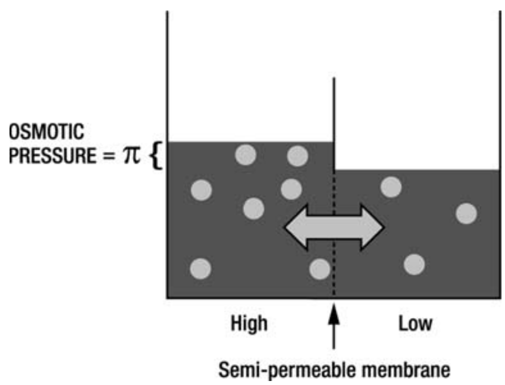

Figure 2.2 Concentration equilibrium. Difference in height corresponds to osmotic pressure of the solution.

Osmotic pressure (typically represented by π (pi)) is a function of the concentration of dissolved solids. It ranges from 0.6 to 1.1 psi for every 100 ppm total dissolved solids (TDS). For example, brackish water at 1,500 ppm TDS would have an osmotic pressure of about 15 psi. Seawater, at 35,000 ppm TDS, would have an osmotic pressure of about 350 psi.

2.2 Reverse Osmosis

Reverse osmosis is the process by which an applied pressure, greater than the osmotic pressure, is exerted on the compartment that

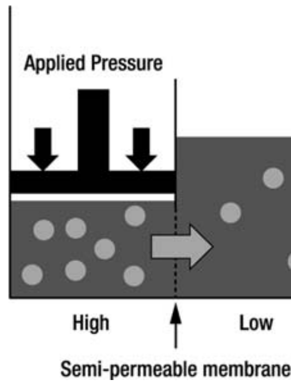

Figure 2.3 Reverse osmosis is the process by which an applied pressure, greater than the osmotic pressure, is exerted on the compartment that once contained the high-concentration solution, forcing water to move through the semipermeable membrane in the reverse direction of osmosis.

once contained the high-concentration solution (Figure 2.3). This pressure forces water to pass through the membrane in the direction reverse to that of osmosis. Water now moves from the compartment with the high-concentration solution to that with the low concentration solution. In this manner, relatively pure water passes through membrane into the one compartment while dissolved solids are retained in the other compartment. Hence, the water in the one compartment is purified or "demineralized," and the solids in the other compartment are concentrated or dewatered.

Due to the added resistance of the membrane, the applied pressures required to achieve reverse osmosis are significantly higher than the osmotic pressure. For example, for 1,500 ppm TDS brackish water, RO operating pressures can range from about 150 psi to 400 psi. For seawater at 35,000 ppm TDS, RO operating pressures as high as 1,500 psi may be required.

2.3 Dead-End Filtration

The type of filtration illustrated in Figures 2.1, 2.2, and 2.3 is called "dead end" ("end flow" or "direct flow") filtration. Dead end filtration involves all of the feed water passing through the membrane, leaving the solids behind on the membrane.

Consider a common coffee filter as shown in Figure 2.4. Feed water mixes with the coffee grounds on one side of the filter. The water then