Reverse Osmosis

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Osmosis is a phenomenon which regulates many biological functions in plants and animals. That the plants stand upright, or the water reaches the tip of every leaf of a plant is due to osmotic pressure. The fact that we cannot survive by drinking seawater is also linked to this same phenomenon. J H van 't Hoff showed in 1886 that osmotic pressure is related to concentration and temperature of the solution by a law that is similar to the gas law. An understanding of this phenomenon paved the way not only in explaining the biological functions which depend on osmosis, but also in creating conditions for reversing it known as 'reverse osmosis'. Reverse osmosis has many applications, one of which is desalination of seawater. The inaugural Nobel Prize in Chemistry was awarded in 1901 to van 't Hoff for his seminal work in this area. The present article explains the principle of osmosis and reverse osmosis.

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Osmosis and Reverse Osmosis

As the name suggests, reverse osmosis is the opposite phenomenon of osmosis. Osmosis describes the spontaneous flow of water from a dilute to a more concentrated solution, when separated from each other by a suitable membrane. These membranes allow the free passage of water but not of dissolved substances and van't Hoff suggested the adjective 'semi-permeable' to describe this property. During osmosis, when water moves away from low concentration areas, it causes these areas to become more concentrated. On the other side, when water moves into areas of high concentration, solute concentration in these areas decreases. The tendency for water to flow through the membrane can be expressed as 'osmotic pressure (symbol, π)', since it is similar to water flow caused by a pressure differential.

Keywords
Osmosis, reverse osmosis, desalinatiion, seawater, water purification.

Solution Concentration (NaCl)	Osmotic pressure* (kPa)
0.05 M	248
0.1 M	496
0.4 M	1983
1.0 M	4959
4.0 M	19835

*from equation (1) at 25°C

Table 1. Osmotic pressures of sodium chloride solutions.

Calculation of Osmotic Pressure

Osmotic pressure of a solution is related to its dissolved solute concentration and is calculated from van 't Hoff equation:

$$\pi = iMR, \tag{1}$$

where π is the osmotic pressure (kPa) of the solution, R is universal gas constant, T is absolute temperature (K), M is molarity of the dissolved salts in the solution and i is the van't Hoff factor. The van 't Hoff factor is introduced to cover deviations from ideal solution behaviour that include finite volume occupied by solute molecules and their mutual attraction as in van der Waals attraction. Equation (1) is sometimes known as Morse's equation as it was proposed empirically by H N Morse as a modification of van 't Hoff equation. It allows calculation of osmotic pressures of salt solutions. The van 't Hoff factor (i) for sodium chloride salt is two. Inserting the other values in (1) gives us the osmotic pressures of sodium chloride solutions of varying concentrations as illustrated in *Table* 1.

Development of Osmotic Pressure Differentials

Figure 1 illustrates the development of osmotic pressure differential across a semi- permeable membrane.Here dilute salt solution with an osmotic pressure of π_1 is in contact with concentrated salt solution of osmotic pressure π_2 through a semi-permeable

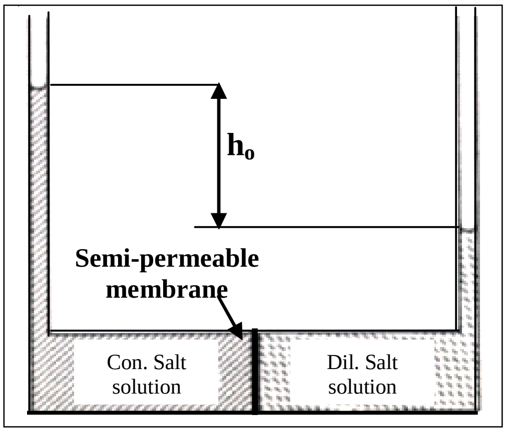

Figure 1. Development of an osmotic pressure gradient across a semi-permeable membrane; h_0 is the pressure differential generated between two chambers because of chemical concentration gradients.

membrane, which allows water molecules but not the dissolved salt molecules to flow through.

This induces an osmotic pressure difference ($\Delta\pi = \pi_2 - \pi_1$) between the two chambers. The osmotic pressure difference between the two chambers is dissipated by the flow of water (termed osmotic flow) from the dilute side to the concentrated solution chamber till the dissolved salt concentration in both chambers becomes equal. The ability of the semi-permeable membrane to allow only passage of water and not dissolved salt molecules is defined by the term osmotic efficiency, ω and is given by a number between zero and one. If $\omega = 0$, then the membrane does not interfere with the movement of dissolved salt molecules at all. In this case there is no osmotic flow. If $\omega = 1$ then the semi-permeable membrane is perfect and dissolved salts cannot flow through the membrane, that is, the membrane totally prevents the flow of solute down its chemical potential gradient.

The osmotic pressure difference between the two chambers is dissipated by the flow of water (termed osmotic flow) from the dilute side to the concentrated solution chamber till the dissolved salt concentration in both chambers becomes equal.

Referring to *Figure* 1, assume that the concentrated salt solution chamber contains seawater having a salinity of 35,000 mg/l and the dilute salt solution chamber contains distilled water. To simplify calculations, it is assumed that the seawater is essentially composed of sodium chloride salt. The dissolved sodium chloride concentration of 35,000 mg/l represents a molar concentration of 0.6 M and such a salt solution is characterized by osmotic pressure of approximately 2975 kPa according to equation (1). Since distilled water has osmotic pressure of zero (as dissolved salt concentration = 0), it means that an osmotic pressure differential of 2975 kPa is generated when 35,000 mg/l salt water is separated from distilled water by a perfect (ω=1) semi-permeable membrane.

How Reverse Osmosis Works

Instead of water flowing from distilled water chamber to concentrated salt solution chamber, if water is forced from a region of hiher salt concentration (concentrated salt solution chamber) through a semi-permeable membrane to a region of low solute concentration (dilute solution chamber) by applying a pressure in excess of the osmotic pressure differential, the process is reverse of the nor-mal osmosis process and is therefore termed as reverse osmosis.

The membranes used for reverse osmosis have a dense barrier layer in the polymer matrix where most separation occurs. In most cases the membrane is designed to allow only water to pass through this dense layer while preventing the passage of solutes (such as salt ions). This process requires that a high pressure be applied on the high concentration side of the membrane, usually 2–17 bar for fresh and brackish water, and 40–70 bar for seawater, which has around 30 bar natural osmotic pressure which must be overcome.

Some Applications of Reverse Osmosis

As may be evident by now, the reverse osmosis process is best known for its use in desalination (removing the salt from sea water to get fresh water), but also to get purified naturally occurring water for medical, industrial process and other rinsing applications. In the production of bottled mineral water, the water passes through a reverse osmosis water processor to remove pollutants and microorganisms. Rain water collected from sewer drains is purified with reverse osmosis water processors and used as tap water in Los Angeles and other cities, in case of water shortages. In industry, reverse osmosis is used to remove minerals from boiler water. It also finds application in cleaning effluent and brackish groundwater.

Suggested Reading

[1] S Glasstone, *Textbook of Physical Chemistry*, Macmillan India, New Delhi, 1974.

[2] http://en.wikipedia.org/wiki/Seawater

[3] http://en.wikipedia.org/wiki/Osmotic_pressure

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