SEPARATION PHENOMENA IN SOME DESALINATION PROCESSES

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Keywords : Solar Stills, Freeze, Hydrate Separation, Ion Exchange, Osmosis, Condensation, Solar evaporation

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Summary

An overview of all desalination processes for seawater and brackish water is presented. These include those when a change of phase is involved and those which depend on the selective flow of water through semi-permeable membranes.

1. Introduction

The separation of pure water from brine, seawater, or brackish water is based on two basic phenomena, as follows.

- Change of phase: liquid-vapor, liquid-solid and humidification-dehumidification.
- Selective flow of water through semipermeable membranes.

In the first category, the major processes involved are the evaporation and condensation of water, each characterized by the presence of a vapor-liquid interface. Beyond this interface, matter and energy are transferred due to the driving forces resulting from temperature, pressure, and concentration differences across the interface. Although a particular process may be designed to utilize one particular difference as its main independent variable, other differences may also be present. The water is made to evaporate from the brine either by a heating process under almost constant pressure or by an expansion process under almost adiabatic conditions. In the first type of process, water vapor is generated by boiling the liquid, while in the second type the vapor is released by flashing. Of course, evaporation can be affected by a combined heating/expansion process. Once the vapor is released from the brine, its condensation to pure water takes place at a more or less constant pressure.

Another process in the first category is the separation of pure water from the brine by freezing it to form ice crystals. In this case, a solid-liquid interface exists across which matter and energy are transferred. However, the freezing process has not gained as much popularity and application in large-scale desalination as the processes based on evaporation and condensation.

In humidification, water is transferred from the water stream or water surface to a gas stream such as air. The reverse process is dehumidification. Both the processes occur in solar stills, as outlined in the next section. When the rate of heat transfer to the water surface by convection is equal to the rate of mass transfer from the surface, a dynamic equilibrium is attained and the temperature of the water surface is known as the wet-bulb temperature.

The main processes belonging to the second category are reverse osmosis (RO) and electrodialysis (ED). In these, the product water and concentrate stream (brine) are separated by a physical barrier called a membrane, which allows the passage of only one material. Desalination is accomplished in RO by allowing the passage of pure water through the membrane and in ED the passage of charged ions through the membrane.

If a solution of non-volatile solute is separated from a pure solvent by a membrane which is permeable to the solvent but impermeable to the solute, a driving force known as osmotic pressure will arise (Figure 1a). This driving force causes the solvent to pass through the membrane into the solution to dilute it and the flow continues until the pressure on the solution side exceeds the pressure on the solvent side by the osmotic pressure. Desalination can be accomplished by reversing the above process. If a pressure greater than the osmotic pressure is applied to the brine side (Figure 1b), then the water passes through the membrane and away from the brine, thus producing a fresh water product. This is the basis of the RO process, which is characterized by high operating pressures (20 to 100 atm).

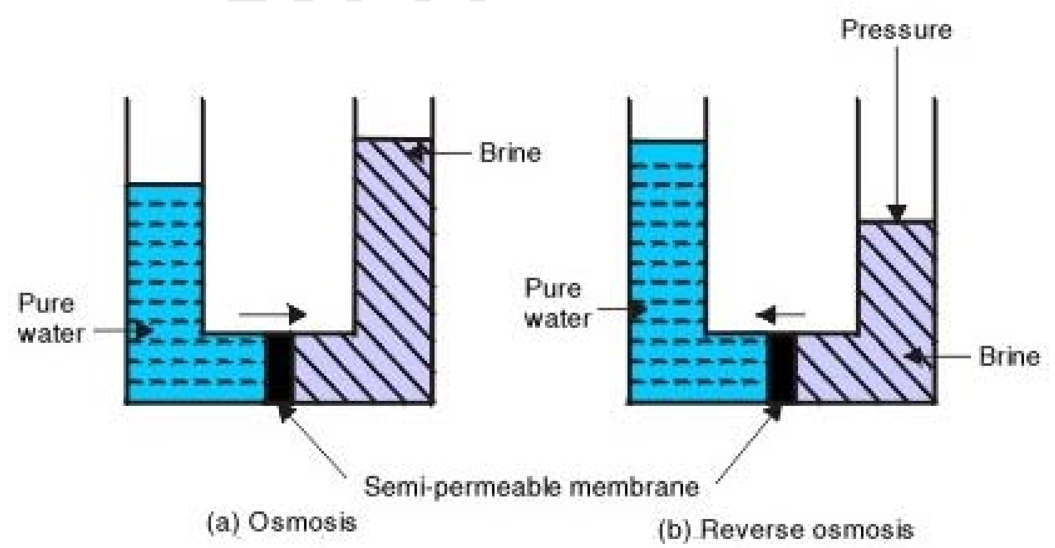

Figure 1. Osmosis and reverse osmosis.

Most of the salts in saline water are present as charged ions and not as molecules. If a direct electric current is passed through an ionic solution, the positively charged cations migrate toward the cathode while the negatively charged anions move toward the anode. Now, if pairs of membranes which are alternatively permeable to cations and anions, as shown in Figure 2, are placed in between the anode and the cathode, a region of low salinity is formed between the membranes (compartments 2, 4, and 6). This is the ED principle, which is widely used in brackish water desalination.

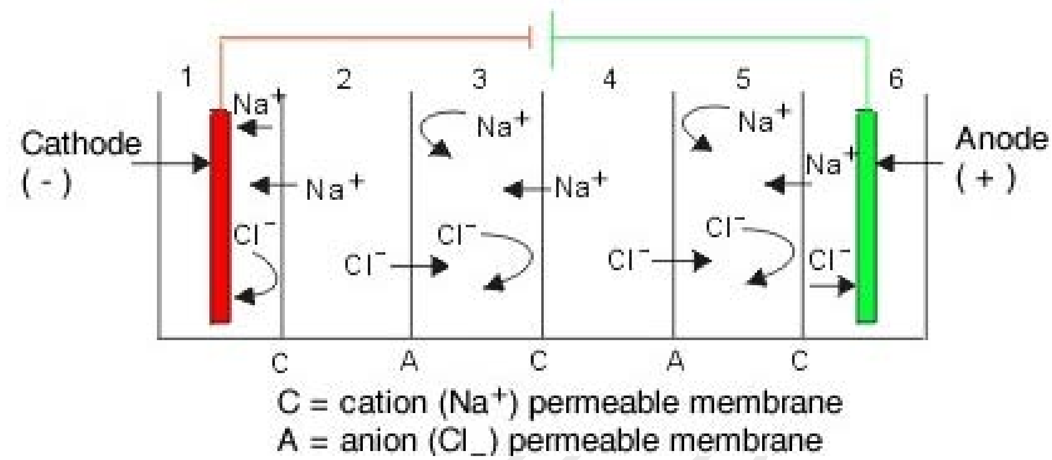

Figure 2. An ED cell.

In addition, there are membrane filtration processes that have their own ranges of operating pressures, membrane pore sizes, and applications. These are summarized in Table 1.

Process	**Membrane pores**	**Pressure (atm)**	**Typical applications**
Nanofiltration	2-5 nm	7-30	50% NaCl and 98% $MgSO_4$ retention
Ultrafiltration	5-20 nm	1-10	Retains fine colloids, macromolecules, and microorganisms
Microfiltration	50 nm-1 micron	0.5-5	Retains colloids, microorganisms, and suspended solids
Pervaporation	Dense membrane	Vacuum	Organics dewatering
Vapor permeation	Dense membrane	Feed vapor phase	Species transferred due to higher solubility and/or diffusivity in the membrane phase

Table 1. Characteristics of membrane processes

Ion exchangers are solid materials containing certain loosely bonded ions. When these materials come into contact with brine containing other type of dissolved ions, an exchange of ions takes place. As a result, the unwanted dissolved ions are absorbed by the exchanger material while the inoffensive ions from the material go into the solution.

Although in this process the nature of the chemical content of the solution is changed, the content of the total dissolved solids remains the same. In the case of a softening process, ions in the exchanger material are generally highly soluble such as that of sodium. However, with the objective of desalting, the ions in the exchanger material must be water-forming ions, i.e. hydrogen and hydroxide ions or, alternatively, ions which can be separated from the solution by either precipitation or gasification.

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