DESALINATION

J. M. Jordaan
Water Utilisation Division, University of Pretoria, South Africa

Keywords: desalination**,** distillation, evaporation, potable water, reverse osmosis, sea water conversion

Contents

Summary

The various desalination processes for converting saline water (seawater or brackish water) into potable water are briefly described. Some examples are given of the present state-of-the-art, where life-support systems have been based on potable water resources recovered on large and small scales from saline water, worldwide.

1. Introduction

The conversion of saline water into fresh potable water and water for industrial purposes has been practiced worldwide over the last forty to fifty years of the twentieth century. It is a technique of providing and augmenting freshwater supplies in areas deficient therein, such as arid regions close to the ocean, or to other saline water bodies.

Seawater conversion is commonly known as desalination or desalting. The processes by which this is accomplished may vary according to the available power source, which can range from solar energy to thermal and electrical energy, to nuclear power. The cheaper the power source, the more attractive and economical would be the prospect of seawater desalination for extending potable water supplies.

2. Categories of Desalination Processes

A large number of variations, several dozen, of the main categories of desalination processes have been developed over the decades, mainly for the conversion of seawater. There are three main categories of desalination processes, namely, those based on evaporation, freezing and diffusion principles. Each of these categories will first be described briefly, naming the various subcomponents. Thereafter, more detailed descriptions and discussions of the more common processes will be given.

2.1 Evaporation

Under this category is designated those processes where the saline feed water is evaporated, boiled or flashed, by heat addition, and the evaporate condensed by heat extraction into the distillate as pure (desalinated) product water, with brine as a waste product. The following evaporation processes are commonly used:

- solar (direct still) desalination, (solar heating and distillation);
- multistage flash distillation (MSF) (boiling and condensing);
- vertical-tube evaporation (VTE) (boiling and condensing);
- horizontal-tube multieffect evaporation (HTME) (boiling and condensing);
- cross-flow or longitudinal flow evaporation; and
- vapor recompression (VP).

Power sources for all these processes involve heating, with some degree of waste heat utilization, as a source of power recovery. These processes require large amounts of thermal energy and are favored in places where surplus power is freely available, or where thermal energy is cheap. Brine, as a by-product, may either be disposed of, or be used for salt recovery.

2.2 Freezing

Freezing processes are those where heat is extracted from the saline feed water until part of it becomes crystallized into pure water-ice granules, which are then separated from the residual brine, and melted into fresh product water. Some of the heat extracted in the freezing cycle may be recovered and utilized in the melting stage.

The following freezing processes are available:

- Direct-contact freezing (DCF), where chilled surfaces are drawn through the saline feed water so that clear ice is formed, which is then heated and melted down into product water.
- Indirect or secondary refrigerant freezing (SRF), which is essentially a frosting-defrosting action, yielding fresh product water and leaving brine behind.

The heat exchange required in the freezing/melting process per unit volume of product water is about four times less than the heat exchange in the evaporation processes, per unit volume of product water, due to the smaller latent heat of melting compared with that of evaporation (flashing). Consequently, where power is expensive, these freezing processes would be favored over evaporation processes.

2.3 Diffusion

Under diffusion, those processes are considered whereby the fresh product water is separated from the saline feed water by means of a hydrophobic or semipermeable membrane. The feed water, as a result of the extraction of freshwater, is gradually converted into brine. The separation is done either by electrical means (electrodialysis) or by reverse osmotic pressure (reverse osmosis). The diffusion processes briefly involve the following principles:

- Electrodialysis (ED). In the electrodialysis process ionic components of a solution are separated by the use of semipermeable ion-selective membranes. Application of a potential between the two electrodes, situated on each side of the membranes, causes an electric current to pass through the saline fluid, which in turn, causes a migration of cations towards the negative electrode, and a migration of anions towards the positive electrode. Because of the selective action of cation- and anion-permeable membranes, cells of different concentration are formed on each side of the membranes.

  The anodes and cathodes, each separated by a semipermeable membrane from the feed water, attract the negative and positive ions respectively (anions and cations, e.g., Cl^- and Na^+) from the saline feed water stream, thereby reducing its salinity to form product water (partially desalinated) and leaving brine as a waste product.

- Reverse osmosis (RO), also known as hyperfiltration. Reverse osmosis is a process whereby pure water is separated from feed water containing dissolved solids (salts in solution) by being filtered through a semipermeable membrane across which a high ambient pressure differential is applied in order to overcome the existing osmotic pressure differential towards the dissolved salts in the saline feed water. The saline feed water is therefore subjected to a high pressure (of several hundred atmospheres), and circulated to have external contact around micropored tubular membranes contained in cylindrical elements. The pressure causes the freshwater molecules to be diffused through these semipermeable membranes while the saline ions remain behind, yielding fresh product water on the inside of the micropored tubes and leaving brine as a waste product on the outside. The freshwater is then collected by means of a manifold, while the brine (still under pressure) is discarded.

Existing membrane technology, with associated equipment, has been developed to a high degree of sophistication for operating pressures up to 6900 kN/m² (69 bar or 690 m head). Reverse osmosis has the advantage of removing dissolved organic materials that are less selectively removed by other demineralizing processes. The primary limitations of reverse osmosis are its high cost and the lack of experience existing in the treatment of domestic waste water. It also requires careful pretreatment of the feed water to prevent clogging of the micropores in the tubular membranes.

3. General Comments Regarding Process Considerations

As desalination technology developed, the evaporative processes, principally multistage flash, were perfected at first for the conversion of seawater into totally pure water. Only later were the diffusion processes, electrodialysis and reverse osmosis, developed, mainly for reducing the salinity of brackish waters, only marginally at first, but eventually more completely. Modern technology also includes the complete conversion of seawater, by reverse osmosis.

The following desalination processes are available, and are in common use:

- Solar energy (direct stills), or as a supplementary heat source for evaporative distillation by other means, has only been cost-effective for very small water outputs in isolated places, due to the extremely large insolation (solar energy collection) surfaces required.

- Horizontal-tube multieffect evaporation processes require heating to about 70°C, and are thermally more efficient than multistage flash for the desalination of seawater. This technique is used mainly to provide potable water for large urban complexes in freshwater scarce areas situated close to the ocean.

- Cross-flow and long-flow versions of MSF (referring to the direction the feed water flows with respect to the heating elements) are further options that are available. These systems are highly suitable for the desalination of seawater on a large scale.

- Diffusion. The following two diffusion processes, electrodialysis and reverse osmosis, have become practically useful under special circumstances:

    - Electrodialysis is not suitable for the conversion of seawater, but is only useful for marginally improving the freshness of brackish water.
    - Reverse osmosis systems are highly suitable for the conversion of both seawater and brackish water to potable water, and for numerous industrial applications. Reverse osmosis applied to brackish water permits a blended product water flow of greater output than the feed water input (by diluting the partly saline source water with the desalinated product water).

The following are considerations regarding the applicability of various processes. Factors that may influence the selection of desalination processes are listed below:

Bibliography

Harris M. and Habenicht, H. (1999). *Desalination for the Central Namib Area*. 8 pp. Fourth Biennial Congress of the International Association for Hydraulic Engineering and Research (IAHR), on: Conserving and Sharing Water in a Water-scarce Environment; Windhoek, Namibia: Lund [Kai] Associates. [Presents a detailed analysis and proposals for a sea-water desalination plant for a semi-arid region.]

International Desalination Association (1999). 25 Years Electro-dialysis Experience *Desalination and Water Reuse* Volume 9/2 August/September. [Summaries of selected papers on desalination presented at the International Desalination Association (IDA) World Congress on Desalination and Water Sciences, 1997, Madrid.]

Jordaan J. M. (1999). *Icebergs as a Potential Water Source for Namibia?* 6 pp. Fourth Biennial Congress of the International Association for Hydraulic Engineering and Research (IAHR), on: Conserving and Sharing Water in a Water-scarce Environment, Windhoek, Namibia: Lund [Kai] Associates. [Gives an objective review of the state-of-the-art of potential Antarctic iceberg harvesting, as compared to other more readily at hand resources such as desalination, and the pro's and con's for limited applications.]

Schmidt H. U. and Hendry B. (1976). *Sea Water Conversion Project* Interim Report June 16, ~150 pp. Windhoek, Namibia: Department of Water Affairs (Namwater). (Unpublished, unnumbered report). [A state-of-the-art review of desalination processes available at the time, concentrating on reverse osmosis.]

Schutte C. F. (1983). *Desalination: A South African Prospective*, 111 pp. Pretoria, South Africa: Water Research Commission. [Presents an overview of the practicability of the full scale application of various desalination processes for converting sea water and brackish water to potable water and for the treatment and reclamation of industrial and mining effluents.]

UK Atomic Energy Authority (AEA) (1967). *Desalination and its Role in Water Supply*. "Water for Peace" Conference, Washington, DC USA. New York British Information Services. 103 pp. London: HM Stationery Office. [A comprehensive review of desalination methods, with reference to the traditional methods of water supply and irrigation. It includes a survey of research and development, contains clear schematic diagrams of seven desalination processes, including evaporation/distillation, electro-dialysis, reverse osmosis and refrigerant techniques. A presentation of British achievements in this field is included.]

US Naval Civil Engineering Laboratory (1965). *Guide to NCEL Technical Documents.* US NCEL, Port Hueneme CA, USA, Reports Nos. R-045, R-182, R-245 (Waste Heat), N-332 Sea Water Ionics), N-342 (Brackish Water Ionics), R-407 (Waste Heat Sea Water Conversion). Washington DC, USA: The Superintendent of Documents. [Reporting pilot test results on sea water conversion processes and small installations for potable water production purposes on shipboard and in remote oceanic locations.]

Biographical Sketch

Jan Jordaan is a retired professor of civil engineering and professional engineer in civil engineering hydraulics. He graduated from the University of the Witwatersrand (B.Sc. Eng.) and obtained the degrees M.S. (Wisconsin), Civil Engineer (MIT) and Sc.D. (MIT). He lectured at the Universities of Hawaii, Delaware and Pretoria. His professional career included hydraulic and coastal engineering research with the Council for Scientific and Industrial Research in Pretoria, South Africa, and the US Naval Civil Engineering Laboratory, Port Hueneme CA, USA. He specialized in hydraulic engineering practice for a period of twenty-eight years with the Department of Water Affairs in South Africa and Namibia, and was active as Technical Assessor for the proposed Misicuni Multiple Purpose Hydroelectric and Water Project, Cochabamba, Bolivia, South America. He was involved in investigations for water sources for Namibia from 1974 to 1981 as Chief Engineer Investigations in the Department of Water Affairs, Windhoek, Namibia, and helped in directing the pilot plant reverse osmosis desalination project at Swakopmund in that country. He also made a study of other desalination processes on a European Technical Study visit and previously participated in ocean-related research programs at the US Naval Civil Engineering Laboratory at Port Hueneme.