# SOME PRACTICAL ASPECTS OF DESALINATION PROCESSES

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## Summary

Various types of evaporators used in MEB and their flow arrangements are described. Tube configurations and the general layout of MSF plants are discussed. Similarly, different arrangements of membrane systems in RO plants and pathway configurations in ED plants are given.

## 1. MEB Plants

In a multiple-effect boiling (MEB) plant, a series of evaporators are connected so that the vapor generated in an evaporator is used as the heating medium in the subsequent evaporator operating at a lower temperature and pressure. Thus, the heat evolved due to condensation of vapor from the first effect generates more vapor in the second effect. In this way, the MEB system improves the performance ratio (PR), which can just take a maximum value of less than unity in a single effect. The PR increases as more and more effects are used, but the total number of effects is limited by the total temperature range available and the minimum allowable temperature difference between the successive effects. The temperature range at the bottom end depends on the temperature of the coolant available and at the top end on the scaling potential of the brine as well as the temperature of the steam supply. The intereffect temperature difference cannot take a value below the boiling point elevation (BPE), since it represents the equilibrium condition and is made up of several contributions given by Eq. (15) in Section See: "Thermal Desalination Processes".

### Types of Evaporators

Any evaporator contains a heating surface through which heat is transferred from the heating medium to the boiling solution on the other side of the heating surface. Furthermore, the vapor generated is to be effectively separated from the residual liquid. How these features are implemented in practice is what distinguishes one type of evaporator from another. Basically, depending upon the nature of the boiling process, the evaporation of the liquid falls into three main categories, which are as follows.

(a) Pool boiling: the pool of liquid in the bulk boils as in a kettle or natural circulation thermosyphon reboiler.
(b) Convection heating: as in forced circulation evaporators.
(c) Film evaporation: the evaporation takes place from a thin film of liquid maintained on the heating surface.

The following paragraphs outline a few typical evaporators commonly used in industrial practice.

### 1.1. Forced Circulation Evaporator

Forced circulation evaporators (Figure 1) find the widest variety of applications. Their tube-side velocities are high (1.8-5.5 m $s^{-1}$) and, hence, higher heat transfer coefficients are obtained, requiring smaller heating surfaces. The tubes can be horizontal or vertical and boiling can either take place inside the tubes or be suppressed by the hydrostatic head maintained. In the latter case, the solution becomes superheated and flashes into a liquid-vapor mixture as shown in Figure 1. Because the material is pumped, fouling can be controlled easily. However, the operating and maintenance costs for the pumps are high. Corrosion and erosion can occur due to high velocities and plugging of the tubes can be a problem where salt deposits detach and settle at the bottom.

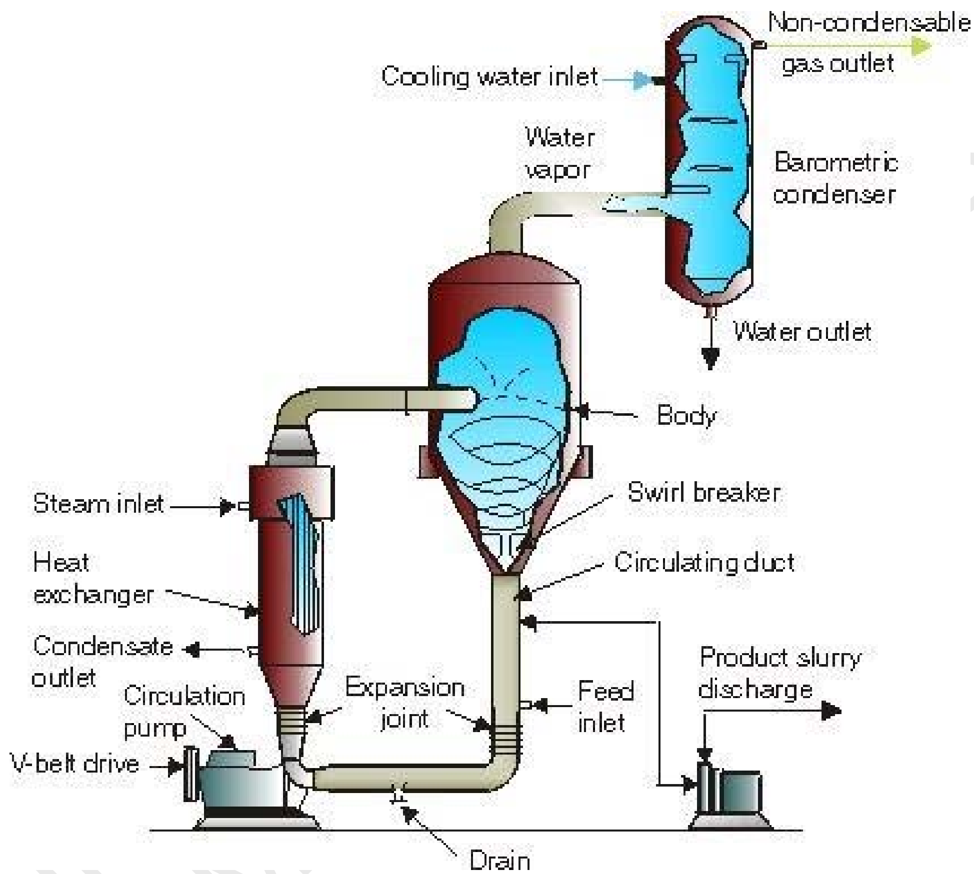


Figure 1. Forced circulation evaporator with a pump.

### 1.2. Rising Film Evaporator

This is a vertical long tube evaporator (Figure 2) in which steam condenses on the outside surface of the vertical tubes. The liquid inside the tube boils and the vapor generated occupies the core of the tube. A thinner and rapidly moving liquid film forms on the inside surface of the tubes as more vapor is generated, resulting in a higher central core velocity. Since the feed enters at the bottom, it is evenly distributed in all the tubes. This evaporator is more suitable for solutions having scaling tendencies; however, pressure drops are high.

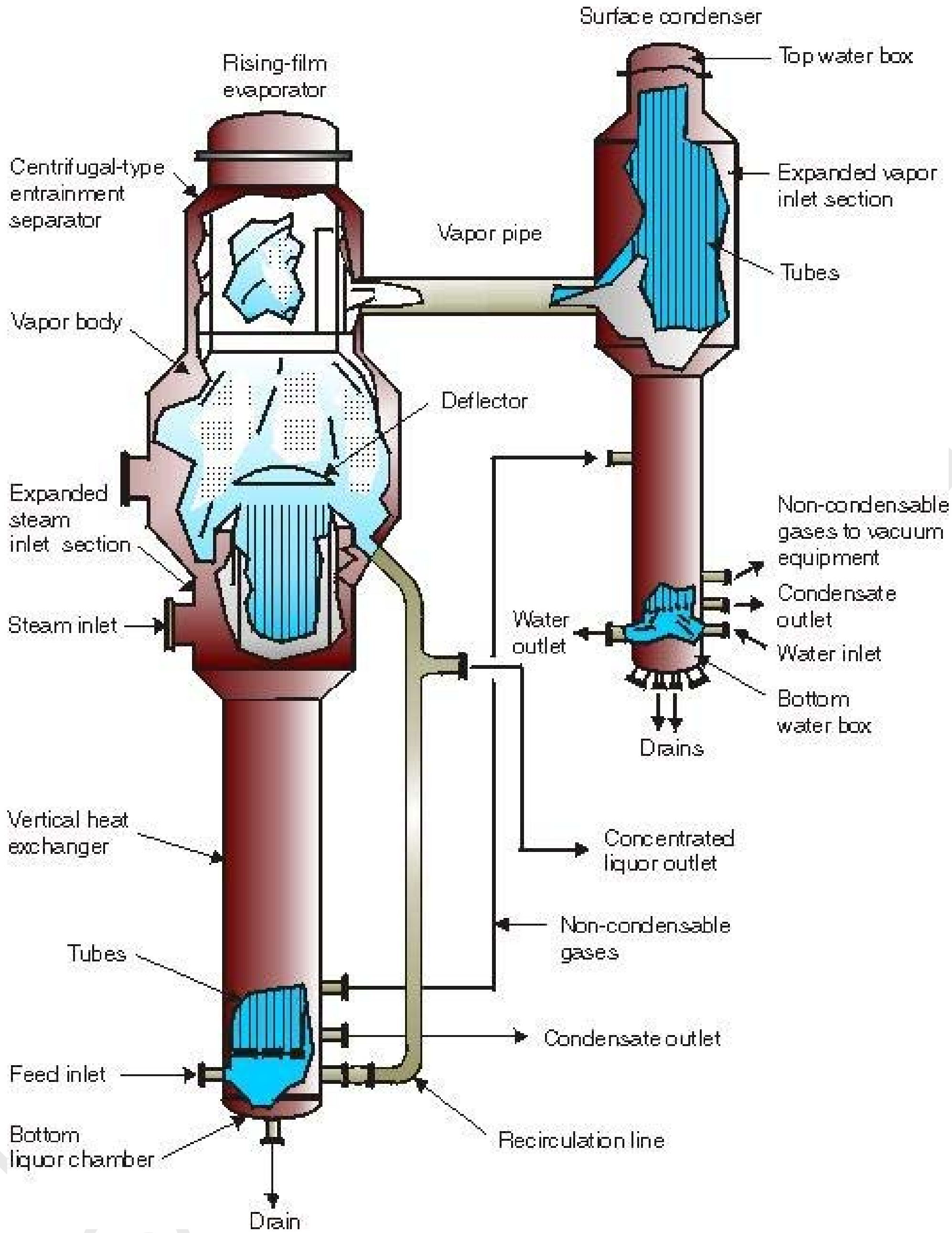


Figure 2. Rising film evaporator.

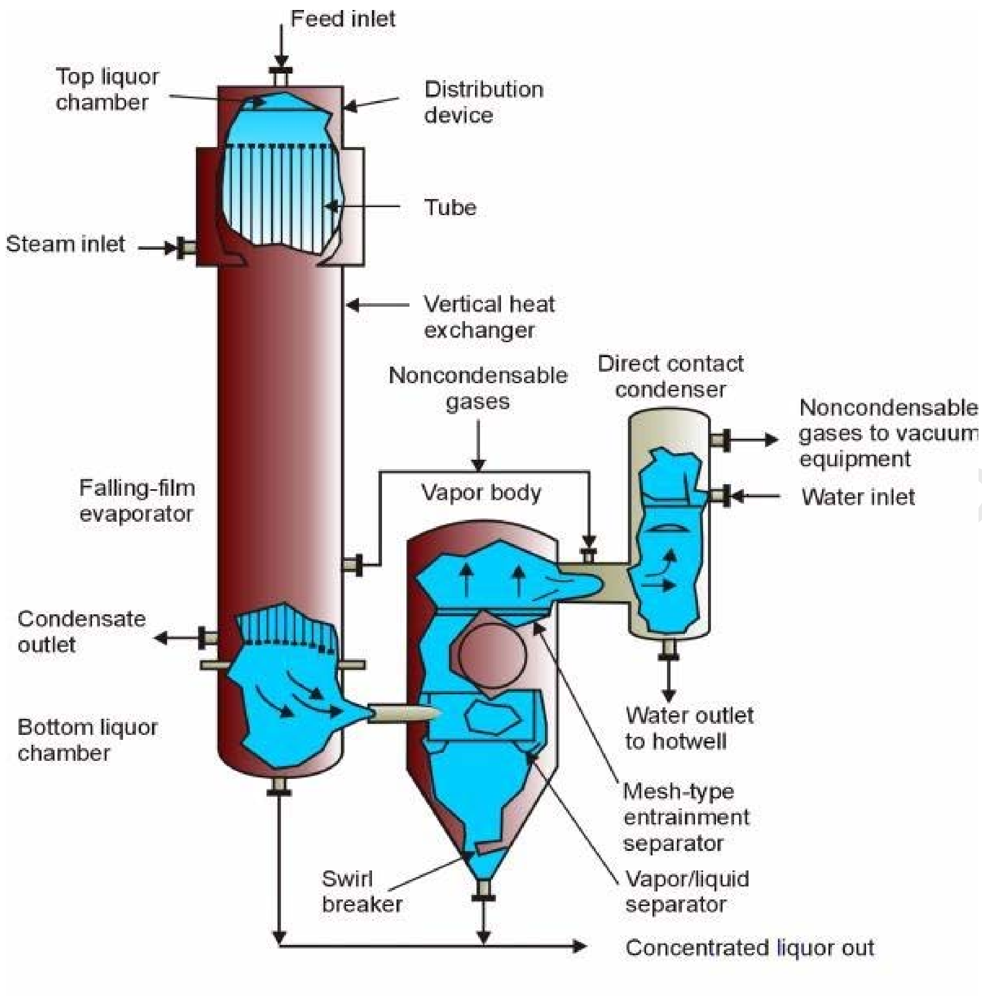


Figure 3. Falling film vertical evaporator.

## 1.3. Falling Film Evaporator

In a falling film vertical tube evaporator (Figure 3) the feed enters at the top and flows down the tube wall as a thin film which is fast-moving under gravity. The heat transfer coefficient is high and the contact time is low. The temperature driving force is not affected by any static head, which allows the evaporator to operate under a lower temperature difference in the film regime.

The flow of vapor and liquid can be arranged either co-current or countercurrent. In the former case, the two phases are separated at the bottom, while in the latter case liquid is withdrawn from the bottom and vapor from the top. In the co-current flow, shear forces increase the liquid film thickness and if the vapor flow is high it may lead to flooding of the tubes, resulting in poor performance and unstable operation.

A common phenomenon in the falling film evaporator is dry patch formation, which may be due to either insufficient liquid flow rate failing to keep a continuous liquid film or due to the evaporator not being installed vertically. Moreover, the feed liquid must be uniformly distributed around the periphery of each tube so that the flow is uniform in all the tubes. A variety of distributors such as perforated plates, spray nozzles, and weirs have been developed for proper liquid distribution.

A rising or falling film evaporator combines the advantages of both types. Vapor-Liquid separation takes place at the bottom and the flow of both phases is co-current.

### 1.4. Horizontal Spray Film Evaporator

As shown in Figure 4, the heating medium (steam or vapor) condenses inside the tubes of a horizontal tube bundle over which the feed liquor is sprayed, which falls by gravity from tube to tube. Thus, the sprayed liquid redistributes on each tube, while the vapor generated disengages and flows upwards without excessive entrainment.

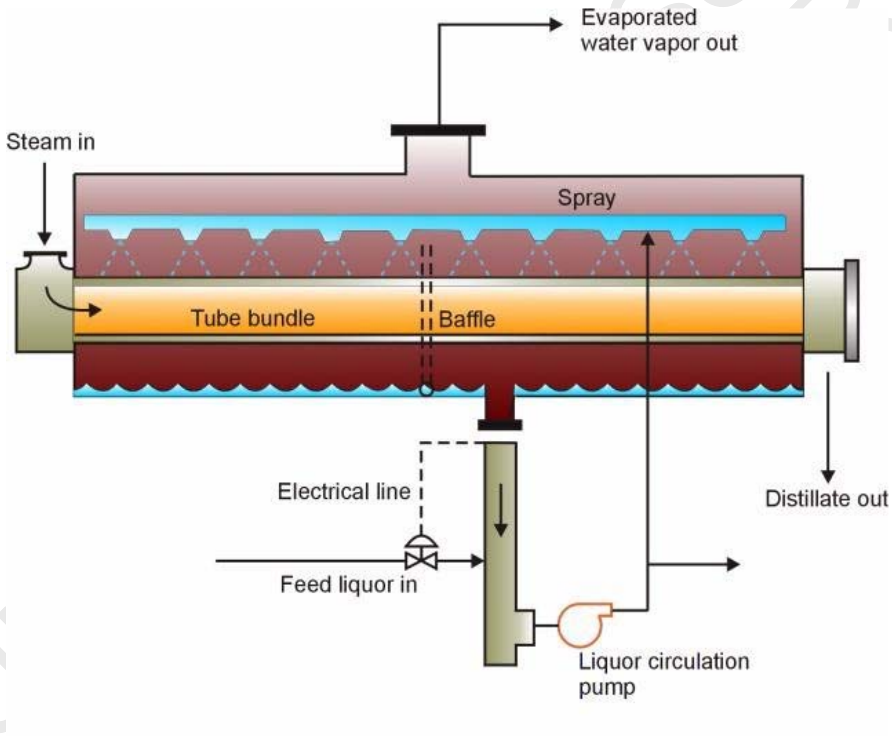


Figure 4. Horizontal spray film evaporator.

Because of high wetting rates and positive liquid distribution, this evaporator is more suitable for handling scaling liquor. Dry patch formation or liquor maldistribution are totally absent. High heat transfer coefficients are obtained due to positive venting and disengagement of the vapor and inerts. The square or rectangular tube layout allows easy and thorough cleaning of the tubes by mechanical or chemical means. However, a larger floor space is required.

Plants using horizontal tube film evaporators (HTFEs) are designed in two ways, namely stacked or horizontal. The stacked plants have the obvious advantage of being compact in terms of occupying a smaller area, but are used for smaller outputs. In a stacked-type solar evaporator for desalination, solar energy obtained through solar collectors is utilized as the heating medium. To make use of the gravity flow and reduce pumping as much as possible, such plants are usually designed with the high temperature on top. Both the brine and the distillate flow down the plant unaided from effect to effect, with simultaneous flashing in each effect. For large plants, the stacked arrangement becomes unwieldy for maintenance. Therefore, horizontally arranged effects are used, as shown in Figure 4.

### 1.5. Submerged Tube Evaporators

In these evaporators, heating vapor condenses inside the tubes which are submerged in the liquid to boil. In the earlier plants, the flat, spiral, or helical coils were used to promote the circulation of brine. As the plant size increased, the coils were replaced by the full-length horizontal cylindrical shells.

Several factors limit the performance of the submerged tube evaporators. Most important is the limitation imposed on the maximum brine temperature due to scale formation. A brine temperature of not more than 120°C is necessary to prevent sulfate scale, which would be very difficult to remove in the absence of softer scale components. Sulfuric acid pre-treatment of brine permits a higher maximum temperature than polyphosphate chemical pre-treatment; in the latter case, the upper limit is only 85°C. The last effect temperature must not be allowed to fall too low, since the heat transfer coefficient of a natural circulation submerged tube evaporator drops appreciably below 55°C. Lower temperature differences in the effects are unsatisfactory because of a considerable fall in the rate of heat transfer. Moreover, the loss in temperature differences due to the hydrostatic head becomes significant under submerged conditions.

### 1.6. Vapor Compression Evaporators

These are widely used for desalting brackish water or even seawater. Vapor compression is accomplished by using either a mechanical compressor or a steam jet ejector, depending upon the volume of the vapor to be handled and the pressure level required. Generally, such compressors are quite large and expensive; the choice is limited to centrifugal or axial flow compressors. Comparatively, steam jet ejectors offer many advantages being simple in construction and having no moving parts. Any corrosion-resistant material can be used for their construction and maintenance is low. They can handle large volumes of vapor at low operating pressures. However, the major disadvantage of the steam ejectors is that they operate at maximum efficiency under only one load condition.

Figure 5 shows a single-effect evaporator in which the process vapor is compressed to a higher pressure to increase its saturation temperature so that it can be used as the heating medium in the same effect. Typically, a single-effect evaporator with vapor compression provides a steam economy of 1.7, approximately equal to that of a double-effect unit.

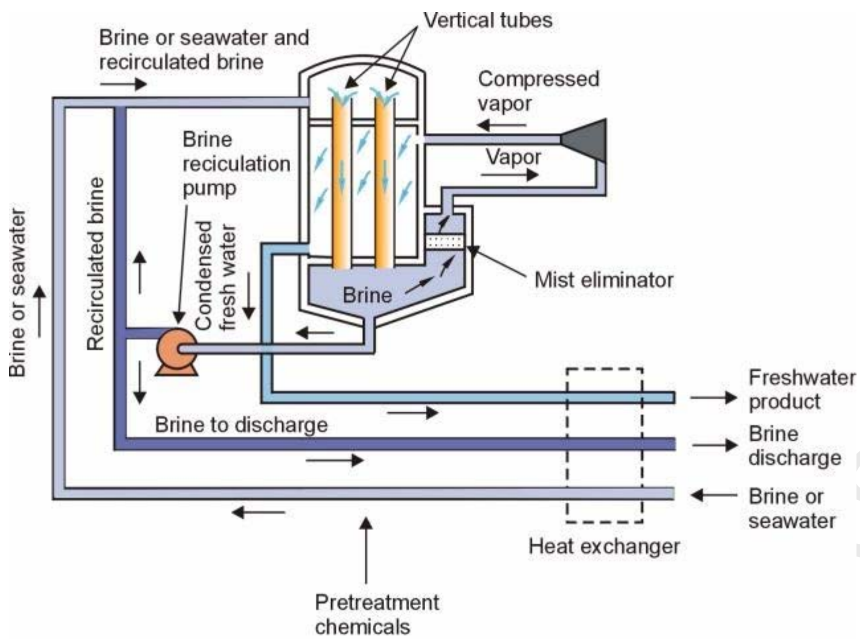


Figure 5. Single-effect evaporator with vapor compression.

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**Bibliography and Suggestions for further study**

Al-Sahali Mohammad, Hisham Ettouney, (2007)Developments in thermal desalination processes: Design, energy, and costing aspects, *Desalination* 214, 227–240

Awerbuch Leon (2009), Future Directions in Integration of Desalination, Energy and the Environment, A seminar sponsored by American Nuclear Society - Student Chapter and Department of Nuclear Science and Engineering Massachusetts Institute of Technology.

Awerbuch, L. (2004), "The status of desalination in today's world." In S. Nicklin (editor) *Desalination and Water Re-Use*. Tudor Rose, United Kingdom.

Billet R (1989) *Evaporation Technology*. Weinheim: VCH Publishers.

Borsani Roberto , Silvio Rebagliati, (2005), Fundamentals and costing of MSF desalination plants and comparison with other technologies, Desalination,182, 29–37

Borsani, R. and Ghiazza, E., (2001), MSF desalination units over 15 MIGD is becoming a reality and start a new age for the old technology, Proc. of IDA, World Congress, Bahrain.

Bower, A. S., Hunt, H. D., and Price, J. F.(2000). Character and dynamics of the Red Sea and Persian Gulf outflows, *J. Geophys. Res*., 105(C3), 6387–6414

Coats J and Pressburg B S (1960) How heat transfer occurs in evaporators. *Chemical Engineering Feb 22* 139-144.

DAR (1996) *Multi-effect Evaporation in Seawater Desalination*, Hydrabad, India: DAR Water Science and Technology Pvt. Ltd.

Durand M I A A (1996) A shortcut for designing evaporators. *Chemical Engineering*.

Fane T (1994) *Workshop papers on Membrane Technology*. Perth, West Australia: Murdoch University.

Hanbury W T and Hodgkiess T (1995) *Desalination Technology 95. An Intensive Workshop and Course*. Lenzie, Glasgow: Porthan Ltd Easter Auchinloch.

J.S.Park,H.J.Lee,S.J.Choi,K.E.Geckeler,J.Cho,S.H.Moon (2003),Fouling mitigation of anion exchange membrane by zeta potential control,J.Colloid Interface Sci.259 .293

K.S. Speigler Y.M. El-Sayed (1994 ) A Desalination Primer ,Balaban Publishers

M. Wilf (2007), TheThe Guidebook to Membrane Desalination Technology. L'Aquila Italy:Balaban Desalination Publications,

Maurel A (1986) Paper presented at the Department Formation Continue ICPI, Lyon, France, 13-17 October.

Mehra D K (1986) Selecting evaporators. *Chemical Engineering* 93(3), 56-72.

Morin O J (1995) Desalination - state of the art - 1961 Part 1. *Desalination and Water Reuse* 4/3.

Murdoch University (1994) A course in Desalination Technology Part 4, Membrane Process for Desalination. West Australia: Murdoch University Perth.

Ophir A., Gendel A.(2005), Advanced MED process for most economical sea water desalination, *Desalination* 182, 187-198

Parekh B S (1988) *Reverse Osmosis Technology*. Marcel Dekker, New York.

Ramakrishna R (1987) Estimate optimum number of effects for multi-effect evaporation. *Chemical Engineering* 11, 82.

Soteris, Kalogirou A. (2005), Seawater desalination using renewable energy sources, *Desalination* 31,242-281

Spiegler K S and Laird A D K (1980) *Principles of Desalination*, Part A, 2nd edn. New York: Academic Press.

Spiegler K. S. (1980) *Principles of Desalination* (Part A and Part B) 2nd edn. New York: Academic Press.

Taylor et al. (1994) Simplified modelling of diffusion controlled membrane systems. *Journal of Water SRT - Aqua* 43, 238-245.

Tonners, J. (2008), Barriers to Thermal Desalination in the United States, Desalination and Water Purification Research and Development Program Report No. 144,U.S. Department of the Interior Bureau of Reclamation, http://ausra.com/news/releases/071105.html.

UNEP/ROWA (2008), Desalination Resource and Guidance Manual for Environmental Impact Assessments

World Health Organization (WHO) (2009), Boron in Drinking-water, Guidelines for Drinking-water Quality, WHO/HSE/WSH/09.01/2