18 Desalination technology

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18.1 The role of desalination in solving water scarcity problems

Currently about 470 million people live in regions with severe water shortages. The worst affected regions include northern China, northern Africa and the Middle East, northern India, parts of Mexico and the western United States. By 2025, the number of people living in water stressed countries is projected to climb to 3 billion – more than a six-fold increase (Cosgrove and Rijsberman, 2000).

Prudent use of available water resources can make them last longer, but countries with a per capita availability of less than 1000 m^3/year (i.e. the water scarce countries) will need technological solutions such as seawater desalination and reuse of reclaimed wastewater to augment fresh water supplies in the future. Desalination, along with water reuse and water importation, can provide a means of increasing the supply of fresh water. Some experts predict that desalinated seawater will become an important water source in this century, as 70% of the world's population lives within 50 miles of the sea. Given the almost unlimited availability of seawater, desalination could provide sustainable water supply to many municipalities and industry (Postel, 2000).

Driven by scarcity, competition for water between municipal users and irrigation may increase dramatically (Macoun, 2000). For domestic water supply in large cities, desalination will become a realistic alternative to conventional drinking water treatment, when costs are comparable. Industrial development demands large amounts of clean water and desalination may be the technology of choice to develop industry in regions of water scarcity in Asia, Africa and South America.

Desalination in the world's regions

By the end of 1999 a total desalination capacity of about 26 million m^3/d was installed or contracted worldwide, counting only plants with a capacity of more than 100 m^3/d (Wangnick, 2000). The leaders and pioneers of desalination are found in the Middle East region, followed by North America and Europe (table 18.1). Roughly half of the current desalination capacity is met by desalination of seawater while brackish water accounts for a quarter of the capacity. More than 80% of the total seawater desalting capacity is produced by some form of distillation process, i.e. multi-stage flash (MSF), multi-effect (ME) or vapour compression (VC) systems. However, in recent years a preference for membrane plants has developed outside the Middle East. About 50% of the newly installed seawater desalination capacity is based on reverse osmosis technology. The remarkable growth in seawater reverse osmosis is due to the lower energy consumption, lower specific investment costs, shorter plant construction time and easy capacity extension of membrane systems compared with distillation systems.

Table 18.1 Desalination in the world's regions

World's region	Desalination in 2000 Total capacity million m^3/d (%)	Seawater million m^3/d (%)
Australia & Pacific Islands	0.1 (0.4)	Negligible
Asia	3.2 (13.3)	1.2 (8.5)
The Middle East	11.3 (47.1)	9.5 (67.4)
Africa	1.2 (5.0)	0.8 (5.7)
Europe	3.1 (12.9)	1.7 (12.1)
North America	4.3 (17.9)	0.3 (2.1)
Central America & Caribbean	0.6 (2.5)	0.5 (3.5)
South America	0.2 (0.9)	< 0.1 (0.7)
TOTAL:	**24.0 (100)**	**14.1 (100)**

Source: Wangnick, 2000

18.2 Desalination methods

Definition of saline water

Saline water is water that contains a significant amount of total dissolved solids (TDS). It is divided into three categories. Freshwater generally covers water with a TDS up to 1000 mg/l, brackish water from 1000 to 10,000 and seawater above 35,000 mg/l. In certain cases brackish water may contain 10,000 to 35,000 mg/l TDS and it is then referred to as "difficult" brackish water (Buros,1980). Saline water also contains small amounts of organic matter and dissolved gases but the majority of dissolved materials are inorganic salts.

Desalination methods

Desalination technology can basically be divided in two types: thermal desalting technology and membrane desalting technology. Thermal desalting technology comprises multi-stage flash distillation (MSF), multi-effect distillation (MED) and vapour compression (VC), while membrane technology includes electrodialysis (ED) and reverse osmosis (RO). In all types of desalting technology, saline water is separated into two streams: a freshwater stream with a low salt concentration and a brine or concentrate stream with a high salt concentration. Both types of technology require energy to operate.

While both distillation (MSF, MED or VC) and membrane processes (RO) are widely used for seawater desalination, RO is also applied for brackish and low salinity water. ED is only suitable for fresh or brackish water. The energy consumption of membrane processes depends on the salinity of the raw water, whereas in distillation processes the (thermal) energy consumption is constant and does not depend on feed water salinity.

Energy consumption in RO and ED for brackish and low salinity water is much lower than in distillation processes. Recent innovations in seawater RO have reduced the energy consumption further. However, it is difficult to make a general statement that in seawater desalination one thermal or membrane process is better than another without in-depth information on site conditions and the specific application. In general, thermal systems are robust and have high tolerance for variable feedwater quality, while membrane systems have lower capital and energy costs but are sensitive to fouling.

Table 18.2 Technology choices for seawater and brackish water desalination

Feedwater TDS (mg/l)	Type of water	Most suitable technology
< 1000	Freshwater	Membrane technology (RO/ED)
1000 – 10,000	Brackish Water	Membrane technology
> 35,000	Seawater	(RO/ED) Distillation (MSF/MED/VC) & membrane technology (RO)

18.3 Thermal desalting processes

Thermal desalting processes rely on the use of thermal energy to heat seawater to its boiling temperature. Water and dissolved gases volatilise and thus evaporate on continuous heating, while salts do not. Water vapour produced during evaporation is condensed on a cold surface and pure water is produced. Producing water by this process requires a large amount of energy, equivalent to about 9 USD/m^3 (at a crude oil price of 21 USD per barrel). These costs make the process very unattractive. That is why multi-effect distillation has been developed. In this process the heat of condensing steam is used to evaporate seawater. By repeating this process ten times or more, more distillate can be produced with the same amount of energy.

Multi-effect distillation (MED)

Although the installed capacity of MED is relatively small compared with MSF, a growth of 17% was recorded at the end of the 1990s. The complexity of MED plants and scaling problems hindered their real breakthrough. Since these problems have been solved by innovative design concepts and the use of very effective antiscalants, MED is gaining ground.

A schematic outline of an MED plant is presented in figure 18.1 and a plant in Mindelo, Cape Verde, is presented in figure 18.2. In the MED process, distillation takes place in a series of chambers (or effects) operating at progressively lower pressures, thus ensuring that the temperature at which seawater boils is lowered in each subsequent effect. The heat exchanger tubes in the first effect are heated by steam from a boiler or from a steam turbine in a power plant. Cold seawater is either sprayed or otherwise distributed over the surface of the evaporator tubes in a thin film to promote rapid boiling and evaporation. Steam flowing through the tubes condenses (inside the tubes) into pure water. The seawater film, on the outside of the tubes, boils as it absorbs heat from the steam inside the tubes. The steam from the seawater is introduced into the heat exchanger bundle (tubes) in the next effect (Buros, 2000). This process is usually repeated in 8-16 effects.

Scale formation needs to be avoided, since this phenomenon reduces the heat transfer, which in turn results in lower production capacity and higher energy consumption. Scale formation is controlled by (i) the degree to which seawater is concentrated in the plant; (ii) the top temperature of the plant (today 65°-80°C is commonly applied); or (iii) adding sulphuric acid and/or antiscalants. In the early days of MED the plants suffered severely from scaling. This was reason for the development of the MSF principle. MSF plants were much less vulnerable to scaling. Nowadays MED plants have solved these problems adequately.

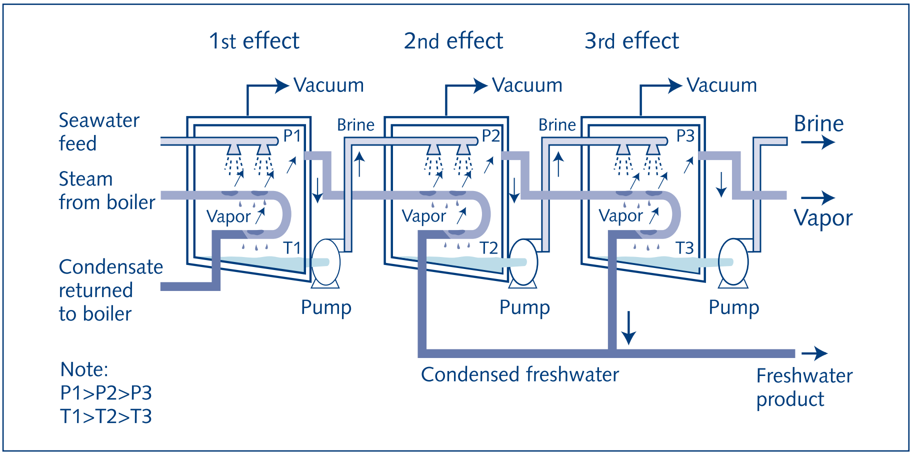

Fig. 18.1. Schematic diagram of a multi-effect distillation (MED) unit
Source: Buros, O.K , 1980

In the MED process up to 15 tonnes of distillate can be produced per tonne of steam. To achieve this high thermal efficiency or *performance ratio* a relative large number of effects (chambers) and large heat exchangers are needed, resulting in higher investment costs.

Multi-stage flash distillation (MSF)

In the MSF process water is heated up to 110°C (max.), and flows subsequently through chambers (stages) of decreasing pressure (Fig. 18.3). As a result, the water flashes off to produce vapour. The vapour is condensed through a heat exchange with feed water. In this way the evaporation (condensation) heat is recovered. In practice about nine tonnes of distillate is produced with one tonne of steam. Scaling problems were drastically less than with MED since water was evaporated in chambers and not at the hot surface of the heat exchangers. Higher performance ratios can be achieved when more chambers (stages) and more heat exchanger surface area are installed. Scaling is controlled by addition of sulphuric acid and/or antiscalant.

Fig. 18.2. Multi-effect distillation plant with vapour compression (MED +VC) in Mindelo, Cape Verde (capacity: 2400m^3/day) (photograph by Jan C. Schippers)

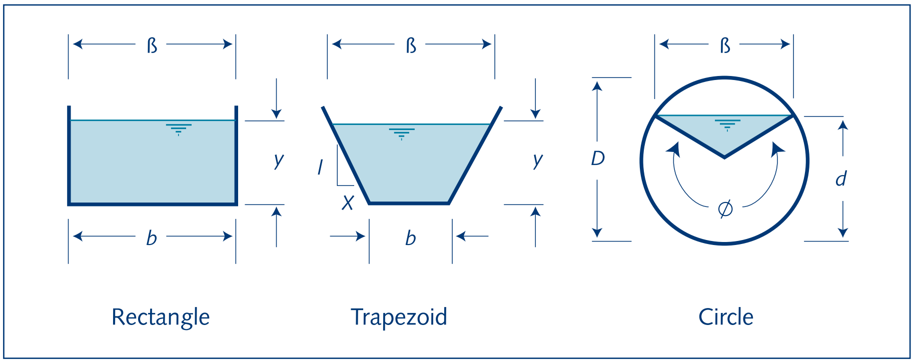

Fig. 18.3. Schematic diagram of a multi-stage flash (MSF) unit Source: Buros, O.K., The U.S.A.I.D. Desalination Manual, 1980

MSF distillation systems were introduced in the early 1960s and dominated the seawater desalination market for several decades. However, gradually MED and in particular seawater RO are increasing their market share. An MSF plant in Las Palmas, Gran Canaria (Spain) is shown in figure 18.4. MSF and MED technology are commonly combined with power generation (dual purpose plants). This combination reduces investment and energy costs because no separate steam boiler is needed and low-grade steam from the steam turbines can be utilised.

Fig. 18.4. Multi stage flash (MSF) distillation plant, Las Palmas, Gran Canaria (capacity: 2x 9,000m^3/day; commissioned in 1980) (photograph by Jose M. Veza)

Vapour compression distillation (VC)

Two types of vapour compression distillation are currently in use: mechanical vapour compression (MVC) and thermal vapour compression (TVC). The commonly applied mechanical vapour compression makes use of electrical power only, so no external steam is needed. The heat to evaporate the water comes from the compression of the vapour.

In an MVC system (Fig. 18.5), seawater, preheated in a heat exchanger by the outgoing streams of concentrate and fresh water, is sprayed onto the heat exchanger tubes. The seawater boils and partially vaporises. The vapour produced is drawn up into the compressor where it is compressed, a process that raises the saturation temperature. The vapour condenses inside the heat exchanger tubes and releases its condensation heat to evaporate the preheated and recycled seawater outside. The heart of any vapour compression system is the compressor. Mechanical vapour compressors are simple and robust, but the electrical energy consumption is relatively high. The capacity of vapour compression plants is limited by the size of the compressors. These units are typically used for small-scale application in remote locations. A mechanical vapour compression plant in Praia, Cape Verde is shown in figure 18.6. The specific energy consumption of the MVC is between 6.5 and 11 kWh/m^3.

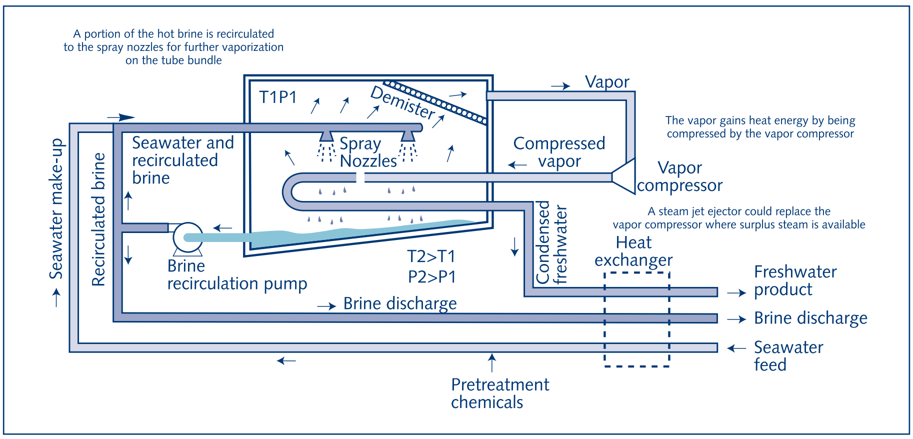

Fig. 18.5. Schematic diagram of a vapour compression (VC) unit
Source: Buros, O.K.,1980

Fig. 18.6. Mechanical vapour compression (MVC) plant in Praia, Cape Verde (capacity: 2 x 1250 m^3/day) (photograph by Jan C. Schippers)

18.4 Membrane desalting processes

Electrodialysis

Electrodialysis (ED) became a commercial process in the 1970s and currently many small and medium-sized plants are operating all around the world. ED is considered to be a very suitable process for desalting brackish water. A major advantage of ED over reverse osmosis is the high recovery rate that can be achieved (up to 95%), which strongly reduces the volume of concentrate/brine that has to be disposed. For this reason, ED is very suitable for the desalination of inland brackish water sources, where the disposal of brine can be a serious environmental issue (IWACO, 2000).

The principle of electrodialysis

Electrodialysis is a process in which solutions are desalted by an electric current. Salts in water dissociate into positively and negatively charged ions. When electrodes connected to an external source of direct current (e.g. a battery) are placed in a container of salt water, electrical current is carried through the solution by the charged species (ions). The ions in solution tend to migrate to the electrode of opposite charge (i.e. positively charged ions (cations) such as Na^+, $Mg2^+$ migrate to the negatively charged electrode and vice versa). On its own this process is not very effective, due to back diffusion of the ions into the bulk. To overcome this problem, semi-permeable membranes are placed between the electrodes (Fig. 18.7).
When the raw water contains suspended/colloidal matter, then pre-treatment is applied to prevent clogging of the membranes.

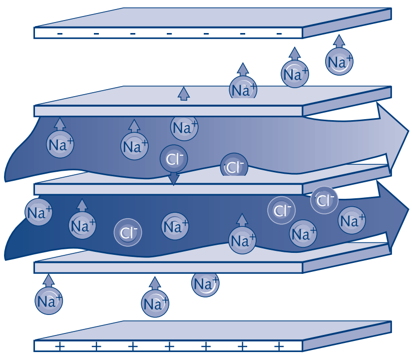

Fig. 18.7. The electrodialysis process
Source: www.ionics.com

Electrodialysis reversal (EDR)

One of the problems in all desalting processes is that the membrane and other active surfaces tend to become "scaled" over time due to the precipitation of sparingly soluble salts present in the feed water. The electrodialysis reversal (EDR) process was developed to prevent scaling and to reduce the addition of acid and antiscalant in electrolysis systems. By reversing the electrical current and exchanging the fresh (product) water and the concentrate (brine) streams within the membrane stack several times per hour, fouling and scaling constituents that build up on the ED membranes in one cycle are washed out in the next cycle. The reversal process is useful in breaking up and flushing out scale, slime and other deposits before they harden on the membrane. EDR is less vulnerable to fouling and scaling than RO.

Reverse osmosis

Reverse osmosis membrane technology is a more recent development than thermal distillation processes. Today reverse osmosis represents the fastest growing segment of the desalination market. For the first time, in 1998, more membrane plants (particularly RO) were contracted/built than distillation units and in 2000, 65% of all new plants were membrane systems (Pankratz, 2000). The strong growth in the membrane market is due to the lower energy consumption, lower specific investments costs, shorter plant construction time and easy capacity extension of membrane systems compared with distillation systems.

Principle of reverse osmosis

The heart of any RO system is a semi-permeable membrane that allows the fluid that is being purified to pass through it, while rejecting a high percentage of unwanted constituents. Reverse osmosis membranes are capable of rejecting bacteria, salts, sugars, proteins, particles and dyes. In the case of desalination of seawater and brackish water, the membrane is permeable to water but not to molecules of dissolved salt. An osmotic pressure difference exists when solutions of different concentration are separated by a membrane permeable to the solvent (water) but not to the solute (salt). The pure water passes through the membrane to the salt water side in an attempt to dilute the salt water. The diffusion of pure water through a membrane continues until equilibrium is reached – a process known as *osmosis*.

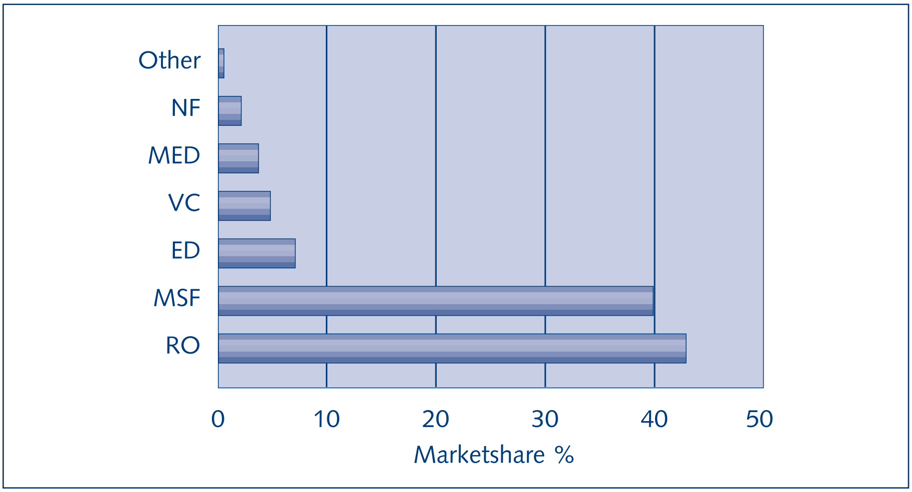

Fig. 18.8. Market share of thermal and membrane processes for desalination plants in operation
Source: Pankratz, T., 2000

Since the aim of most desalination systems is to recover fresh water from salt water, the natural osmotic flow has to be reversed by forcing the salt water through the membrane in the reverse direction. This can be achieved by applying a pressure to the salt water as it is fed to the system, creating a condition known as reverse osmosis. In reverse osmosis systems the dynamic pressure difference must be greater than the osmotic pressure in order to reverse the flow and force the water from the seawater side through the membrane to the pure water side. The permeate water flow through the membrane is proportional to the difference between the applied dynamic pressure difference across the membrane and the osmotic pressure difference, and proportional to the membrane permeability coefficient. Pressures range from 5-25 bar in the case of brackish water desalination and 50-90 bar for seawater.

Pre-treatment requirements in reverse osmosis systems

Pre-treatment of feed water is necessary to avoid fouling and/or scaling, which result in a lower permeability of the membrane and higher pressures required. When the applied pressure exceeds a maximum allowable level, chemical cleaning is needed. For greater operational efficiency, suspended and colloidal material must be removed and the water pre-treated to prevent particulate fouling, precipitation of salts (scaling) and growth of micro-organisms (biological fouling) on the membrane surface. Typically pre-treatment consists of filtration to remove suspended solids and dosing with acid or acid/antiscalant to prevent precipitation. The need to remove suspended/colloidal matter, algae and biodegradable organic matter (biofouling) depends on the location.

Membrane devices and systems

The main component of any RO system is the membrane. RO desalination membranes are made from a variety of polymeric materials, e.g. aromatic polyamides, cellulose acetate and cellulose acetate derivatives. RO membranes are manufactured in two different element configurations - spiral-wound (fig 18.10) and hollow fibre.

A pump is used to pressurise the feed water; the operating pressure of the feed pump must be at least the osmotic pressure of the water. In practice the feed pressure is usually 2-3 times greater than the osmotic pressure. Typical feed pressures range from 8-25 bar for brackish water and 50-90 bar for seawater (Fig. 18.11).

An important parameter in the design of a reverse osmosis system is the recovery rate, defined as the ratio of permeate flow to feed flow. RO membranes plug instantly unless they are run in *cross flow* mode. Unlike traditional filtration, all the influent does not pass through the media. Rather it is split into a *permeate* (filtrate) stream and a *concentrate* stream, the latter flowing parallel to the membrane. Thus, cross flow splits the feed stream into two effluents: a purified stream and a stream more concentrated in solutes too large to pass through the pores of the RO membrane. During operation the feed solution becomes more and more concentrated and the osmotic pressure (and the salt concentration) increases as pure water permeates the membranes. In addition, the flow velocity at the feed side of the membrane is reduced due to the permeation of (pure) water through the membrane.

The possibility of membrane fouling and scaling is increased when the solute (salt) concentration increases and the flow on the feed side of the membrane is then reduced. Scaling of reverse osmosis membranes can occur during operation, particularly if the design recovery rate is set too high. Knowing the solubility of a given compound (salt), the maximum safe recovery rate (R) can be calculated to avoid scaling of the membrane during operation. The most likely components to scale RO membranes during operation are salts with a very low solubility, e.g. $CaCO_3$, $BaSO_4$, $CaSO_4$ and CaF_2. Besides scaling, fouling of the membrane by colloids and other particles is also exacerbated by high recovery rates, as rejected material (colloids, etc.) may accumulate on or close to the membrane surface and eventually foul the membrane.

Generally, all membrane processes show a decrease in membrane flux (15-20% over a three-year period) and an increase in solute (salt) passage with time. To combat the unavoidable flux decline, RO systems are designed so that the operating pressure can be increased during operation to maintain the design flux of the system. The operating pressure is usually increased (over a period of 1-3 months) until the operating pressure reaches the maximum design pressure of the system. At this point water production is stopped and part of the RO installation is cleaned using chemical cleaning solutions to restore the permeability of the membranes. This procedure is repeated until the entire installation is cleaned.

Table 18.3 Design parameters of seawater and brackish water reverse osmosis plants

Design parameter	Units	Typical value for dea water RO plant	Typical value for brackish water RO plant
Flux (Jw)	$l/m^2.hr$	9-16	20-31
Salt rejection (R)	%	98-99.8	93-98
Recovery rate (Y)	%	30-60	75-90
Operating pressure (P)	Bar	8-25	80-90

Source: IWACO, 2000

Fig. 18.11. Reverse osmosis (RO) racks and pump turbine system in La Aldea, Gran Canaria (capacity: 5000 m^3/day; commissioned in 2001) (photograph by Jose M. Veza)

18.5 Energy consumption in desalination systems

Thermal desalination processes produce very high quality fresh water, but large amounts of thermal energy in the form of steam, and electrical energy (2-4 kWh/m^3) are required in these plants. Thermal distillation plants are usually coupled to power plants where steam, used to drive turbines generating electricity, is available to provide thermal energy to evaporate seawater in the desalination process. The combination of distillation (MSF or MED) and power generation (dual purpose plant) is attractive from an energy point of view, as it can yield substantial savings in energy, provided there is a market for the electricity. In addition, no separate boiler is needed to produce steam, which reduces the investment costs.

From table 18.3 it can be seen that thermal energy consumption is roughly 16 times lower in a dual purpose (co-generation) plant than in a single stage MSF or MED plant. Nevertheless, the total energy consumption of distillation systems is still high compared with RO systems because thermal energy is not required in RO systems and the electrical energy requirement (3-6.5 kWh/m^3) is similar to that of distillation systems (table 18.3). Significant improvements in energy recovery and in RO membranes have decreased the energy consumption to about 2.5-3 kWh/m^3 in new RO plants and further reductions to about 2 kWh/m^3 are expected in the future.

Table 18.4 Thermal and electrical energy consumption in distillation and membrane systems

Energy	Distillation technology		Membrane Technology (RO)
	MSF	MED	
Energy – Heat, MJ/m^3			
• Single stage/effect system	2600	2600	-
• *Multi stage/effect system	290	290	-
• Co-generation power production	160	160	-
Energy – Electrical power (kWh/m^3)	3.6	2.3	6.5-3.01

* Performance ratio = 9 in MSF & MED

The energy consumption of thermal and membrane desalination systems is compared in table 18.4. The electrical energy requirement of RO systems is converted into thermal energy in order to compare the energy consumption of RO with the MSF and MED processes. The thermal energy consumption in a dual purpose (co-generation) plant was used, which is lower than for a single or multiple stage distillation plant (table 18.3). Assumptions were made regarding the price of energy and the efficiency of converting electrical energy into heat energy (see footnote).

Table 18.5 A comparison of energy consumption of distillation and membrane (RO) systems

Energy	Distillation technology		Membrane Technology (RO)
	MSF	MED	
Energy – heat, MJ/m^3 • co-generation • electrical energy	 160 25	 160 16	 heat energy not required 45-21
Total energy consumption (MJ/m^3)	**185**	**176**	**45-21**
Cost primary energy (USD/m^3)	**0.65**	**0.61**	**0.16-0.07**

Assumptions: 1 kWh = 7 MJ (50% efficiency), Energy price: 3.5 USD /GJ (ca. 21 USD barrel of oil; 1 barrel = 160 L)

18.6 Desalinated water costs

The difference between the cost of desalinated water and that of conventional supplies narrowed dramatically in the 1990s. The drastic price drop caused the desalination market to explode – a 49% growth was recorded in seawater desalination in a three-year period at the end of the Millennium. Prices quoted for desalinated brackish water range from 0.2 to 0.35 USD/m^3. (Wilf and Klinko, 1998) (Wade et al., 1999). While prices quoted for desalinated seawater are significantly higher, in the mid-1990s they have decreased to 0.5-0.8 USD/m^3 for large membrane desalination systems (capacity ca. 40,000 m^3/day) and 0.7-1.2 USD/m^3 for large distillation systems. The costs are higher for small membrane desalination systems (e.g. $<$ 100 m^3/day) and range from 1.5 to 2.8 USD/m^3 with and without energy recovery, respectively (Desalination & Water Reuse, Editorial, 1999).

Desalinated water costs are made up of energy, depreciation, monitoring and maintenance (particularly high for distillation systems), membrane replacement (reverse osmosis systems only), spare parts and process chemicals (Buros, 1980). Energy and depreciation (capital costs) are responsible for about 70-80% of the costs of thermal and membrane distillation systems (table 18.5).

The recent decrease in the selling price of desalinated water is due in no small part to the advent of large-scale privatised desalination projects where financing and/or operating tasks are delegated to private enterprises (Pankratz, 2000). Technological improvements in energy recovery have dramatically reduced energy utilisation (from 5-2.5 kWh/m^3) in seawater reverse osmosis (SWRO) systems. Membrane costs have also fallen in recent years while salt rejection and productivity (flux) have increased. Other factors such as lower specific investment costs, shorter plant construction time and easy extension of plant capacity of membrane systems have also helped to reduce costs. A new advancement in thermal desalination technology is the use of low-grade waste heat from industry to provide the thermal energy for desalination in Multi-effect distillation (MED) systems. In future, alternative energy sources (wind, solar) and hybrid plants using both thermal and membrane technology may increase the efficiency and flexibility of thermal plants and further reduce costs.

Table 18.6 Operational costs of distillation and membrane desalination systems (price level of 2000)

Cost component	MSF (USD/m^3)[1]	MED (USD/m^3)[2]	RO (USD/m^3)[3]
Energy – heat	0.24	0.24	-
– power	0.11	0.07	0.25
Operation & maintenance	0.13	0.13	0.06
Spare parts	0.08	0.08	-
Membranes	-	-	0.05
Chemicals	0.02	0.02	0.06
Capital	0.62	0.60	0.32
TOTAL COST (USD/m^3)	**1.20,**	**1.14**	**0.74**

1 Electrical energy = 0.03 USD/kWh, Thermal energy = 1.5 USD/GJ, Plant lifetime = 25 years, Interest rate = 8%

2 Electrical energy = 0.03 USD/kWh, Thermal energy = 1.5 USD/GJ, Plant lifetime = 25 years, Interest rate = 8%

3 Energy requirement = 4.2 kWh/m^3, Electrical energy = 0.06 USD/kWh, Plant Recovery = 45%

18.7 Small community water supply applications

Appropriate technology modifications using the principles of thermal and membrane desalting technologies have been developed in several countries. However, the small treatment plants are usually very inefficient in operation. Capital investments are very high, while production volumes are low. The economies of scale and the use of dual purpose plants, as applied in larger thermal desalting installations, do not often apply in rural and small town situations.

Nevertheless, small desalination package plants or simple desalination technologies may be considered in situations where sufficient fresh water cannot be found and water has to be supplied by trunk lines or tankers from far away. In such situations, desalinated water may be cheaper than what people presently pay for their scarce fresh water. To make the technology and service sustainable, the private sector will usually be involved in the investment, management and distribution. Before deciding to opt for desalination technology, all other water source options should be reviewed for long-term feasibility and sustainability. These possible options should include piped water from outside the area; tankering; rainwater harvesting; fog collection; using deep, fossil water; and mixing fresh water with saline water.

Membrane desalting technologies are not common in small community water supplies because of the required mechanical parts (pumps) and sensitive membranes. Recent membrane improvements and reduced unit prices may mean that the more reliable technology will become attractive for small systems. Hybrid RO systems have been developed using photovoltaic arrays or wind energy to drive the pumps and solar energy to heat up the water to reach a higher efficiency.

Thermal desalting systems are commonly based on solar power to raise the temperature of the saline water. Several different technologies have been developed, including

- Solar stills
- Hybrid solar stills
- Wood-fuelled stills

Solar stills

The Mexican Still is the most common solar still (Fig. 18.12). Solar energy is concentrated through (stainless steel) reflectors and magnifying glasses mounted around a distillation tank. This causes the saline water to boil (Ryan, 1996). It is a durable system, easy to construct but with a low production efficiency. The production ranges from 4-17 l/m^2. Investment costs are relatively high and, as the still is covered by glass sheets (better than plastic), it is prone to breakage.

In many countries with arid and semi-arid regions, modifications have been made to this principle, resulting in creative but not always efficient technical solutions.

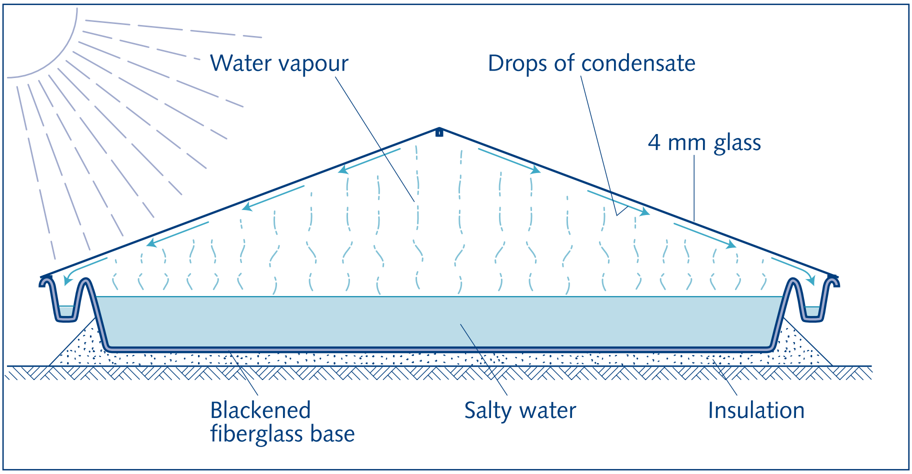

Fig. 18.12. Mexican Still
Source: Yates, Woto and Tlhage, 1990

Hybrid solar stills

Hybrid solar stills make use of the sun's energy to heat up the water and have a distillation tank in which the pressure is lowered through vacuum pumps driven by wind energy, photovoltaic arrays, diesel engines or electric motors.

Wood-fuelled stills

The most direct and simple but also the most inefficient desalting technique is the wood-fuelled still. Figure 18.13 shows three systems producing different volumes of water per hour. The Kudu-horn system has a production of about 0.7 l/h while the Ghanzi still produces about 33 l/h. (Yates et al., 1990). A major environmental concern is that saline water is common in arid and semi-arid areas where the availability of firewood is very limited.

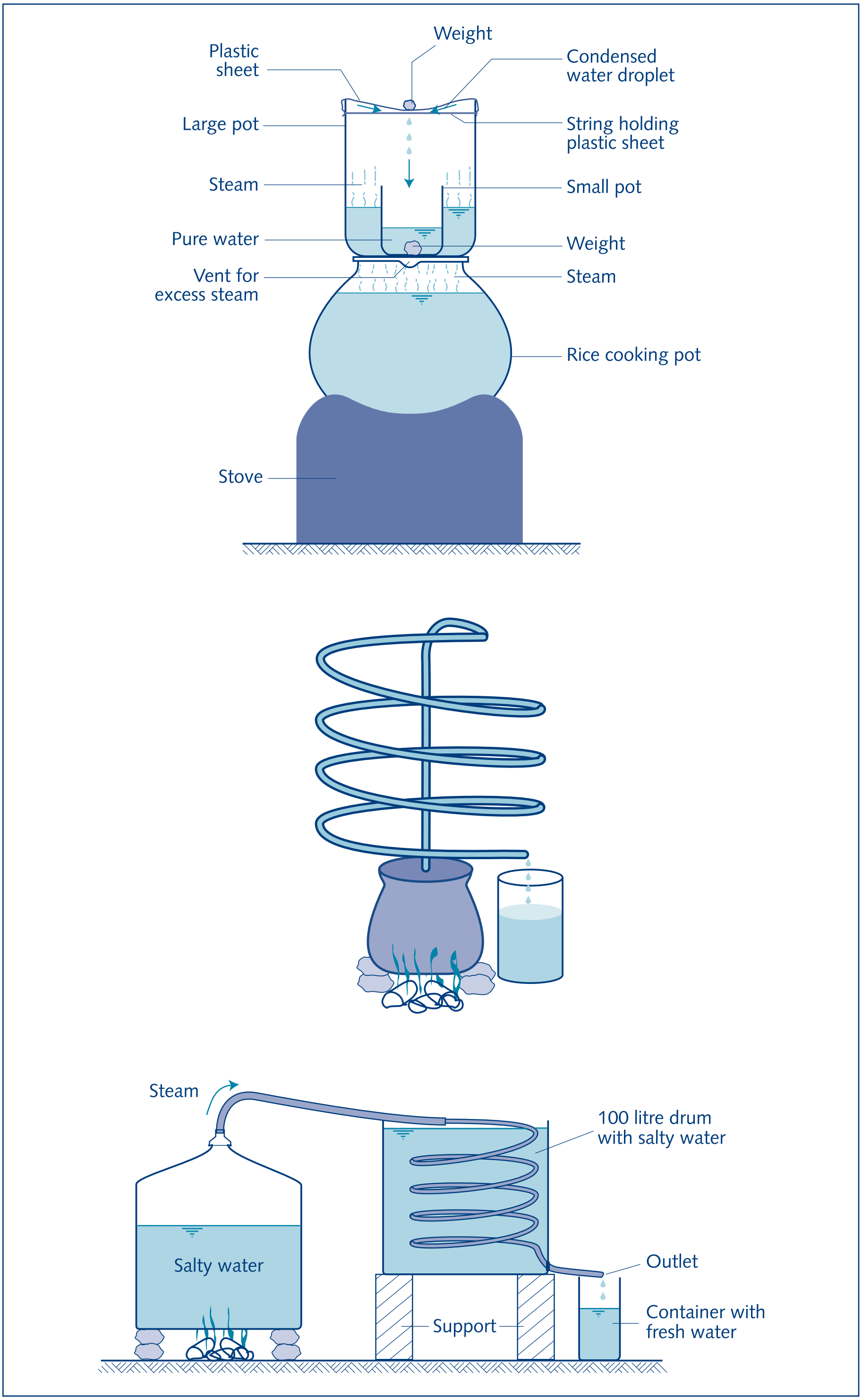

Fig. 18.13. Three wood-fuelled stills
Sources: Ryan, 1996 and Yates et al., 1990

Bibliography

Buros, O.K. et al. (1980). *The U.S.A.I.D. desalination manual.* Englewood, NJ, USA, IDEA Publications.

Buros, O.K. (2000). *The ABC's of desalting.* 2nd ed. S.l., International Desalination Association.

Cosgrove, W.J. and Rijsberman, F.R. (2000). *World water vision: making water everybody's business*. London, UK, Earthscan.
http://watervision.cdinet.com/visioncontents.html

Editorial desalination & water reuse, 9/3 (1999). p. 33-41.

Fontana, S. (2000). 'Seawater in a kettle'. In: *Hydroplus,* March, p. 28-33.

IWACO (2000). *Desalination techniques: state of the art and current developments.* Rotterdam, The Netherlands, IWACO.

Macoun, A. (2000). *Desalination & water reuse 10/2*. p.14-20.

Pankratz, T. (2000). 'Large scale desalination plants: a drought-proof water supply'. In: *IDA News,* vol 9, no. March/April, p. 3-4.

Postel, S. (1999). *Pillar of sand: can the irrigation miracle last?.* New York, NY, USA, W.W. Norton.

Ryan, F. (1996). 'Domestsic desalination of water'. In: *Pickford, J. (ed.). Reaching the unreached: challenges for the 21st century: proceedings of the 22nd WEDC conference, New Delhi, India, 9-13 September 1996*. Loughborough, UK, WEDC, Loughborough University of Technology.
http://info.lboro.ac.uk/departments/cv/wedc/conferences/22contents.htm

Sommer, B. (1997). 'Desalination at household level: results of a literature review'. In: *SANDEC news,* no. 3, p. 11-14.

Wangnick Consulting (2000). *IDA worldwide desalting plants inventory.* (Report; no. 16). Gnarrenburg, Germany, Wangnick Consulting.

Wilf, M. and Klinko, K. (1998). *Desalination*, vol. 117, p. 323-331.

Wade, N.; Willis, J. and McSorely, J. (1999). *Desalination*, vol. 125, p. 191-201.

Woto, T.; Yates, R. and Tlhage, J.T. (1990). *Solar-powered desalination: a case study from Botswana.* (Technical study; no. 65e). Ottawa, Ont, Canada, International Development Research Centre (IDRC).

Web sites

International Desalination Association http://www.ida.bm/

University of Hawaii: http://www.hawaii.edu

Desalintation Directory, International Science Services: http://www.desline.com

The Middle East Research Center: http://medrc.org.om

IONICS: http://www.ionics.com

DOW: http://www.dow.com