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Recent Situation and Actual Possibilities in Development of Sea Water Desalination Equipment

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A number of seawater desalination technologies have been developed during the last several decades to augment the supply of water in arid regions of the world. Beyond the recent situation in sea water desalination equipment, paper presents also actual information from development of new feature desalination unit based on MSF principle. The paper presents a review of many types of desalination technologies such as thermal, membrane and hybrid.

1. Introduction

Water is an important resource for mankind. It is necessary for industrial and agricultural growth, as well as for supporting growing populations. Population require a safe drinking water supply. Water is an natural resource that covers three quarters of the earth's surface. However, only about 3 % of all water sources are potable. We find 97 % of all water in oceans, 2 % in glaciers, and the rest in lakes, rivers and underground. Natural resources cannot satisfy the growing demand for fresh water with the increasing worldwide demand for supplies of drinking water. This has forced mankind to search for another source of water. Desalination techniques are capable of providing the solution. Desalination is water treatment process which has emerged as an important source of fresh water by removing salt from saline water. Desalination has already become an acceptable alternative to conventional water resources. The importance of desalinated water will no doubt increase, because natural fresh water resources are depleted and the need for diversification of national fresh water income increases. About 25 % of worlds' population does not have access to satisfactory quality and/or quantity of freshwater and more than 80 countries face severe water problems. Worldwide drought and desertification are expected to sharpen the problem. Countries that nowadays haven't water shortages may have to tackle the problem of fresh water scarcity in the near future.

2. Desalination technologies

The desalination process represents the step in which dissolved solutes are substantially removed from the feedwater to create the desired product water. A number of technologies exist. The commercial used desalination technologies can be divided into two main categories: thermal distillation (MSF and ME) and membrane separation (RO) (AMTA, 2007). Also, on the market are hybrids plants which integrate thermal and membrane technologies (Hamed, 2005) and other technologies. Other commercial technologies have less application due to their small units' size such as solar distillation (SD) (Qiblawey and Banat, 2005), vapor compression (VC) or their application of low salinity such as

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electro dialysis (ED). Moreover, there are different emerging technologies which are still under research and development, including forward osmosis (FO), membrane distillation (MD), capacitance deionization (CDI), and gas hydrates (GH), freezing, humidification dehumidification (HDH) and solar stills. Other supporting technologies include micro/ultra/nano/ionic filtration (MF/UF/NF/IF respectively) (JWR&DTF, 2005).
A seawater desalination process separates saline seawater into two streams: a fresh water stream containing a low concentration of dissolved salts and a concentrated brine stream. This process requires some form of energy to desalinate, and utilizes several different technologies for separation.
There is no single "best" method of desalination. Globally, thermal and membrane technologies are both used widely for seawater desalination. Both processes require energy to effect separation of salts, and various energy sources can be used.

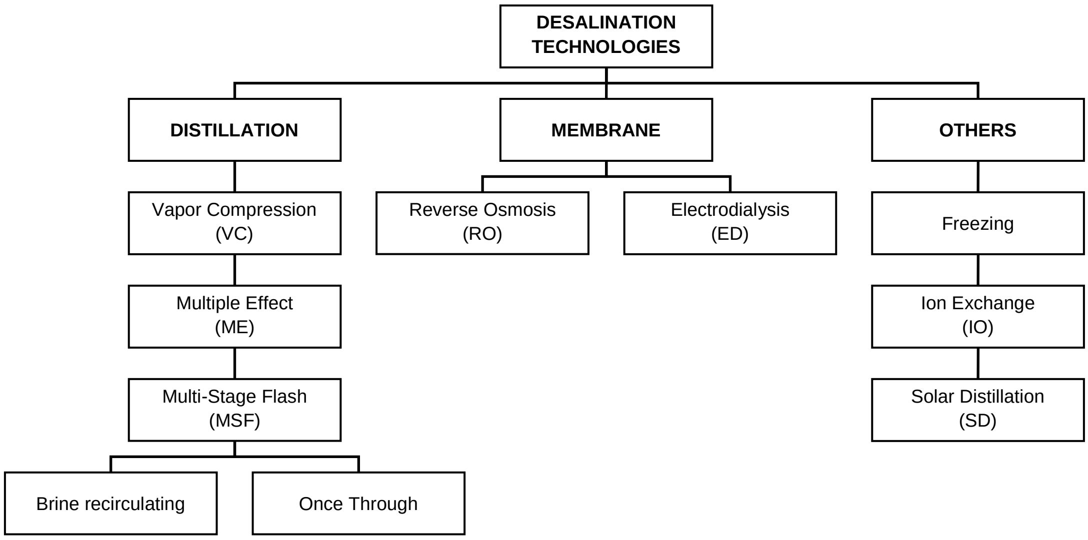

Figure 1: Classification of desalinating processes

2.1 Thermal technologies

The major commercial thermal desalination technologies are MSF and ME. In the past, thermal technologies have dominated the desalination market, particularly in the Middle East, where the low energy costs and large scale cogeneration plants have guaranteed the ascendance of thermal processes. These thermal processes mimic the natural water cycle of evaporation and condensation and produce output water with very low salt concentration.
Thermal processes are generally used in the following applications:

- to treat highly saline waters (predominantly seawater)
- where large volumes of products water are required
- in locations where energy costs are low or where a waste heat source is available.

Thermal distillation is based on to heat a saline solution to generate water vapor. If this vapor is directed toward a cool surface, it can be condensed to liquid water containing very little of the original salt. Thermal processes are usually designed to boil water in a series of vessels operating at successively lower temperatures and pressures. At one-quarter of normal atmospheric pressure, water will boil at 65 °C, and it will boil at only 45 °C if the pressure is decreased to one-tenth normal atmospheric pressure (Wagner and Kretzschmar, 2008). Thermal processes, such multistage flash (MSF), multiple effect distillation (MED), and mechanical vapor compression (MVC), account for 43 % of the online capacity for desalination worldwide.

Multi-Stage Flash (MSF)
The MSF process involves boiling seawater and condensing the vapor to produce distilled water. It works on the principle that seawater will evaporate as it is introduced into the first evaporator (flash chamber). Chambers are maintained at lower pressure in comparison to atmospheric pressure so that the sudden introduction of heated feedwater into these vessels causes rapid boiling, or “flashing”. It then condenses and cools down to a saturation temperature equivalent to the chamber pressure. The heat of condensation released by the condensing water vapor at each stage gradually raises the temperature of the incoming seawater (feedwater). The tubes of condenser are cooled down by incoming feedwater on its way to the brine heater. Feedwater is then heated in a heat exchanger, called the brine heater, before being allowed to flow into a series of chambers, called as “stages”, which constitute the “evaporator” in the MSF unit. This has the effect of warming up the feedwater such that the amount of thermal energy needed to raise its temperature in the brine heater is reduced. Freshwater flowing from stage to stage is taken out as product water from the last stage. The MSF plant consists of heat input, heat recovery, and heat rejection sections.

Multiple-Effect (ME)
The multiple effect processes are being used with increasing frequency when thermal evaporation is preferred or required, due to its reduced pumping requirements and thus its lower power use compared to MSF.
The ME distillation process takes place in a series of vessels or effects and is based on the principle of evaporation and condensation at reduced ambient pressures. The plant designs for ME distillation can be various in process details. The feedwater after being preheated in the final condenser is led in first effect. The evaporator surfaces in the first effect are heated by hot water inside the tubes from the engines or steam from the steam turbines of a power plant or boiler. The vapor from the first effect is used to heat the surfaces of the succeeding effects. The vapor produced in the last effect is condensed in the final condenser – cooled by incoming seawater (feedwater). Not all of the water is converted to vapor. In each effect, the remaining water forms the brine solution. Brine is led to the input of the next effect. ME equipments employ a separate vacuum system for maintaining different ambient pressures in different vessels.

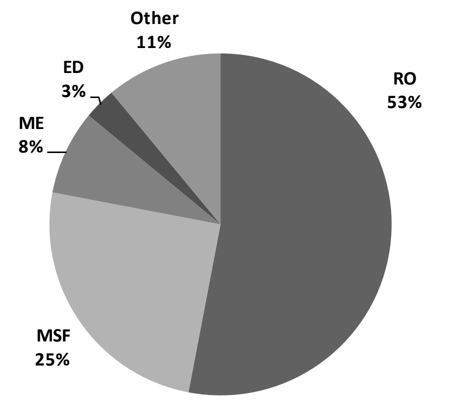

Figure 2: Global desalination capacity by process (ESCWA, 2009)

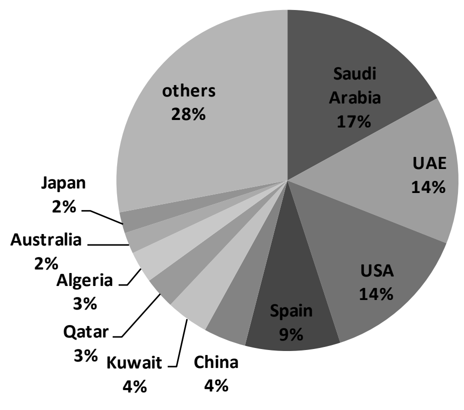

Figure 3: Top 10 desalination countries (ESCWA, 2009)

2.2 Membrane technologies
The two most important membrane processes are reverse osmosis (RO) and electrodialysis (ED). Each process uses the ability of the membranes to differentiate and selectively separate salts and water. However, the membranes are used differently for each of these processes.

Other commercially available membrane technologies include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and electrodialisys reverse (EDR). For the salt separation from the seawater, RO, MF, UF and NF use hydraulic pressure, whereas ED and EDR are electrically driven membrane process. Membrane technologies can be used not only for desalting brackish water and seawater sources but also for treating wastewater in reuse and recycling applications, because of their ability to provide removal of nonsalinity contaminants.

Reverse Osmosis (RO)

Reverse osmosis is the major commercial membrane process. RO is used for both brackish and sea water. RO is a pressure-driven process which uses membranes for saline water separation. The RO process uses semipermeable membranes and a driving force of hydraulic pressure, in the range of about 10 to 83 bar. The saline water is pumped at high pressure into a closed (high pressure) vessel against a membrane; pure water permeates through the membrane whereas the brine left behind is discharged as reject. An RO system requires a pretreatment process, high-pressure pump, membrane assembly, and post treatment process.

Formulations of RO membrane include cellulose acetates, polyamides, polyetheramides, and polyethersulfones. Nowadays most widely used membrane material is a thin-film composite polymer combining a microporous polysulfone support layer with a thin polyamide layer (Committee on Advancing Desalination Technology, 2008).

Most modern reverse osmosis plants have an energy recovery system. The brine discharge is usually at very high pressure whereas the fresh water is at low pressure. The pressure energy in the brine is fed back to the feedwater using pressure exchangers.

Electrodialysis (ED)

Electrodialysis or electrodialysis reverse is an electricity-driven process; it uses electrical energy to move salts ions selectively, through a membrane leaving fresh water behind. Pretreated water is pumped between electrodialysis cells under the influence of low voltage direct current (DC) electrical filed.

2.3 Hybrid technologies

Hybrid desalination configurations include combinations of processes designed to improve process efficiency or reduce energy costs. Hybrid desalination systems combine both thermal and membrane processes to add economical and technical features of the integrated system. Some of the advantages of these hybrid technologies include flexibility in operation, less specific energy consumption, low intake/out fall construction cost, high plant availability and better power and water matching (Hamed, 2005). Normally MSF-RO and MED-RO combination are used in commercial applications.

Table 1: Quality categories for water salinity (Banat, 2007)

Use	Rating	Approximate salinity [ppm]
Human consumption	Excellent	<100
Human consumption	Good to fair	100-1.000
Human consumption	Poor	1.000-1.200
Human consumption	Unacceptable	>1.200
Irrigation	Maximum for healthy grow	3.500

Table 2: Salinity in vary seas

Sea	Approximate salinity [ppm]
Red Sea	40.000
Mediterranean Sea	38.000
Average sea-water	35.000
Black Sea	18.000
Baltic Sea	8.000

2.4 Other desalination technologies

Vapour compression (VC)

Vapour compression is a thermal process in which the external heating energy comes from compression of part of the produced vapor. The VC method is simple, reliable and high efficient process. Its efficiency comes largely from a low energy requirement and its basic design that uses the "heat pump" principle of continuously recycling the latent heat exchanged in the evaporation-condensation process.

Freezing

The basis of freeze desalination technologies is to change the phase of water from liquid to solid. When salty water freezes, the ice crystallizes from pure water leaving the dissolved organic and inorganic solids (e.g., salt) in liquid pockets of high salinity brine. Traditional freezing processes involve five steps: precooking of the feed water, crystallization of ice into a slush, separation of ice from the brine, washing the ice, and melting the ice (U.S. Congress, 1988). Although freshwater can be obtained quite easily from ice where seawater freezes naturally. The engineering involved in constructing and operating a freeze desalination plant is quite complicated.

This approach seeks to take advantage of the relatively low enthalpy of phase change – the freezing of water at atmospheric conditions (334 kJ/kg) – whereas evaporation would require 2,326 kJ/kg (Committee on Advancing Desalination Technology, 2008).

Ion-Exchange

Ion-exchange process uses resins to remove undesirable ions in water. Ion exchange is mainly used for water softening and demineralization, and applications of ion exchange at the municipal level are limited.

Solar Distillation

Solar desalination can either be direct - use solar energy to produce distillate directly in the solar collector, or indirect - combining conventional desalination techniques, such as multistage flash desalination (MSF), vapor compression (VC), reverse osmosis (RO), membrane distillation (MD) and electrodialysis, with solar collectors for heat generation (Qiblawey and Banat, 2005).

3. Possibilities in development

Space for development is still in thermal desalination methods. The way for further development in thermal methods may be the development of small units for medium customers, which will use waste heat from the customer’s technology.

Distillation unit based on MSF principle is featured by several advantages. First of all, such unit can be designed as modular systems. A module consists several, for example, of four stages (see Figure 4 placed on the next side). There is important that capacity increases with the number of modules and heat consumption decreases with number of modules. These units can be used for marine, on-shore and off-shore installations. Principal flow diagram of a desalination unit is shown in Figure 4.

First, the sea water is preheated by flowing as cooling medium through condensing part of equipment. After leaving the condenser the sea water flows through the brine heater where the heat input to the plant causes a further temperature increase. The sea water is then directed into the first stage of the unit which is at pressure below boiling pressure. In order to return to a state of equilibrium, part of the sea water flashes off such the saturation temperature corresponds to the pressure in the stage. The distillation process operates from low vacuum in the first stage to high vacuum in last stage, with stage to stage pressure and temperature differential being the key to the repeated flashing. The flashed vapor is drawn to the condenser where it is condensed and collected as distillate. The fresh water is continuously measured. If the salinity exceeds the adjustable limit the distillate is automatically dumped into the recirculation brine as indicated by dashed line in Figure 4.

4. Conclusion

The selection of a desalination technology depends on many factors, such as location, energy costs, economics, energy requirement, feed water salt content and dependence on fresh water quality. The last few decades have been the most widely desalination method used thermal method. In the recent era the membrane methods are in a large increase. Reverse osmosis has progressed a lot in the recent time due to improvements in membranes.

Space for development is, however, still in thermal desalination methods. The way for further development in thermal methods may be the development of small units for medium customers, which will use waste heat from the customer's technology. An example of such development possibility is an introduced modular desalination unit based on MSF principle (see Figure 4) featured by several discussed advantages.

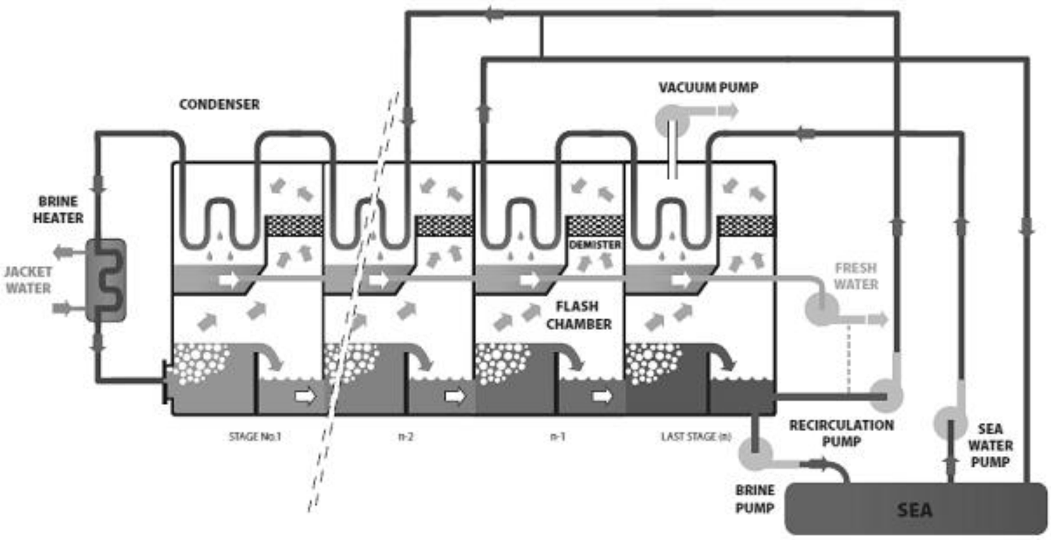

Figure 4: Flow diagram of a new desalination unit

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