A Review on Seawater Desalination Technology and Concentrating Solar Power

Vinod U.Patel[1], Soyeb Multani[2]

Assistant Professor, CGPIT Bardoli, Gujarat[1]

Assistant Professor, CGPIT Bardoli, Gujarat[2]

---***---

Abstract - *Concentrated Solar Power (CSP) technology is usually used for producing electricity by generating thermal energy and converting it to electricity by means of a thermodynamic cycle. However, the produced thermal energy can also be used directly in industrial processes requiring low-to-mid temperature levels. There are a large number of different desalination technologies available and applied worldwide. The purpose of this comparison was to select the most appropriate thermal and mechanical desalination method for the combination with CSP, and to find a plausible combination that could be representative for large scale dissemination. Comparing MSF and MED, it becomes clear that MED is more efficient in terms of primary energy and electricity consumption and has a lower cost. Moreover, the operating temperature of MED is lower, thus requiring steam at lower pressure if connected in co-generation to a steam cycle power plant. Thus, the combination of CSP with MED will be more effective than a combination of CSP and MSF desalination. Thermal vapour compression is often used to increase the efficiency of an MED process, but it requires steam at higher pressure if connected to a steam power cycle. Comparing the mechanical driven desalination options, reverse osmosis has a lower electricity consumption and cost per unit product water than the mechanical vapour compression method.*

***Key Words*: Desalination, Multi-stage flash desalination, Multi effect desalination (MED), Reverse Osmosis (RO), Thermal Vapour Compression (TVC), Mechanical Vapour Compression (MVC), concentrating solar power (CSP)**

1. INTRODUCTION

There are two main challenges for the world in the future; shortage of energy and shortage of fresh water both play a crucial role in the overall economic development of any country. These are thermal desalination methods that evaporate seawater by using heat from combustion or from the cold end of a power cycle, and mechanical methods using filtration through membranes. Vapour compression technologies are mainly used in combination with thermal distillation in order to increase volumes and efficiency of those processes.

2 SEAWATER DESALINATION TECHNOLOGIES

2.1 Multi-Stage Flash Desalination (MSF)

MSF is a thermal distillation process that involves condensation and evaporation of water. The condensation and evaporation steps are coupled to each other in many stages so that the latent heat of vaporization is recovered for reuse by preheating coming water (Figure 1). In the called brine heater, the coming feed water is heated to its maxi. Temperature by condensing saturated steam from the cold end of a steam cycle power plant the hot seawater then flows into the first evaporation stage where the pressure is set low. The sudden introduction of hot water into the chamber with lower pressure results it to boil very fast, almost flashing into steam. Only a small percentage of the water is converted to vapour, depending on the pressure maintained in this stage, since boiling will continue only till the water cools down to the equilibrium at the boiling stage. The vapour generated by flashing is condensed on surfaces of tubes of heat exchangers that run through the upper part of each stage. The tubes are cooled by the incoming feed water going to the brine heater, thus pre-heating that water this process is repeated in up to 45 stages, whereas mostly around 20 stages are employed. To maximize water and energy recovery, each stage of an MSF unit operates at lower pressure.

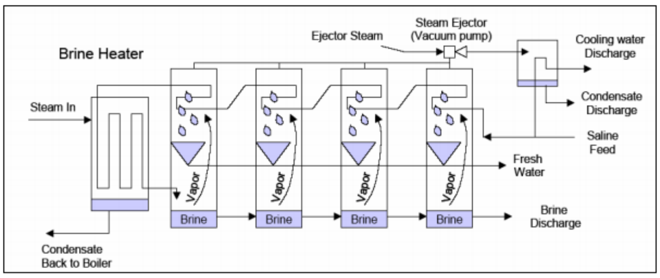

Figure 1: Multi-Stage Flash Desalination (MSF)

Large MSF units are often coupled with steam power plants for best utilization of the fuel energy by combined generation. Steam produced at high temperature and pressure by the fuel is first expanded through a turbine to produce electricity. The low to moderate temperature steam exiting the turbine is then used to drive a thermal desalination process. In this case, the capacity of the low pressure stage of the steam turbine to produce electricity is reduced with increasing temperature of the extracted steam. Multi-Stage Flash plants are mostly coupled to the cold end of a steam cycle power plant, extracting steam at 90^{0}C - 120 °C from the turbine to feed the brine heater of the MSF unit. If the temperature is above the condensed water temperature at ambient pressure, special backpressure turbines are required for such a combined process. The reduction of power generation with respect to a conventional condensing steam turbine working at 35-40°C is considerable (Figure 2). On the other hand, an advantage of combined generation is that the condenser required for a conventional plant is substituted by the desalination unit. In this case, the feed water must include enough water for desalination and cooling.

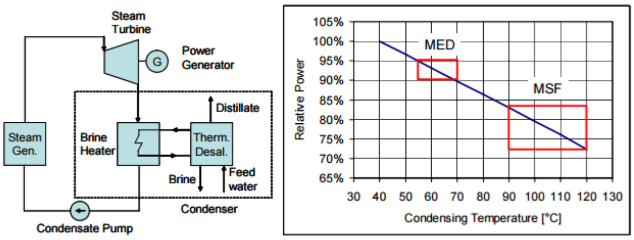

Figure 2: Principle of substituting the condenser of a steam cycle power plant by a thermal desalination unit (left) and typical reduction of steam turbine power capacity at increasing condensing temperature (right). The squares show the typical operating range of MED and MSF plants.

2 Multi-Effect Desalination (MED)

Multi-effect desalination (MED) is also a thermal distillation process (Figure 3). The feed water is sprayed distributed onto the surface of the evaporator surface of different type of chambers in a thin film to promote evaporation after it has been preheated in the upper section of individual chamber. The evaporator tubes in the initially effect are heated by steam extracted from a power cycle. The steam produced in the first effect is condensed inside the evaporator tubes of the next effect, where vapour is produced again. The surfaces of all the other effects are heated by the steam produced in every preceding effect. Each effect must have at lower pressure than the preceding one. This process is repeated within up to 18 effects. The steam produced in the last effect is condensed in a separate heat exchanger called the final condenser, which is cooled by the incoming sea water, which is then used as preheated feed water for the desalination process.

MED has gained attention due to the best performance by thermally compared to MSF. MED plants can be configured for low temperature or high temperature operation. Recently, they operate at top brine temperatures below 70°C to limit corrosion and scale formation. The top brine temperature can be as low as 55 °C which helps to reduce scaling and corrosion, and allows the use of low grade waste heat and corrosion. The top brine temperature can be as low as 55 °C which helps to reduce corrosion and scaling, and allows the use of low-grade waste heat.

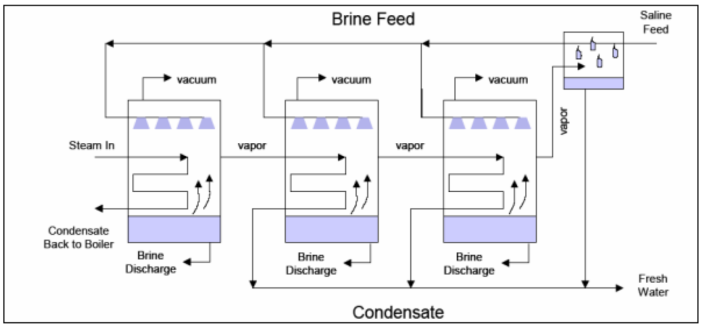

Figure 3: Principle of Multi Effect Desalination (MED)

3 Reverse Osmosis (RO)

Reverse osmosis (RO) is a membrane separation process that regains water from a saline solution pressurized to a point greater than the osmotic pressure of the solution (Figure 4). In essence, membrane filters hold back the salt ions from the pressurized solution, allowing only the water to pass. RO membranes are sensitive to oxidizers, pH, and a wide range of organics, algae, bacteria, and depositions of particulates and fouling. Therefore, pre-treatment of the feed water is an important process step and can have a significant impact on the cost and energy consumption of RO, especially since all the feed water, even the amount that will eventually to be discharged, must be pre-treated before passed to the membrane. Recently, ultra, micro and nano-filtration has been proposed as an alternative to the chemical pre-treatment of raw water in order to avoid contamination of the seawater by the additives in the surrounding of the plants. RO post-treatment includes removing carbon dioxide and stabilizing the pH value via the addition of Na or Ca salts, and the removal of dangerous substances from the brine. Pressurizing the saline water accounts for most of the energy consumed by RO. Since the osmotic pressure, and so the pressure required to perform the separation is directly related to the salt concentration, RO is often the method of choice for brackish water, where only low to intermediate pressures are needed. The operating pressure for brackish water systems ranges from 10 to 15 bar and for seawater systems from 50 to 80 bar (the osmotic pressure of seawater with a salinity of 35 g/kg at 25 bar).

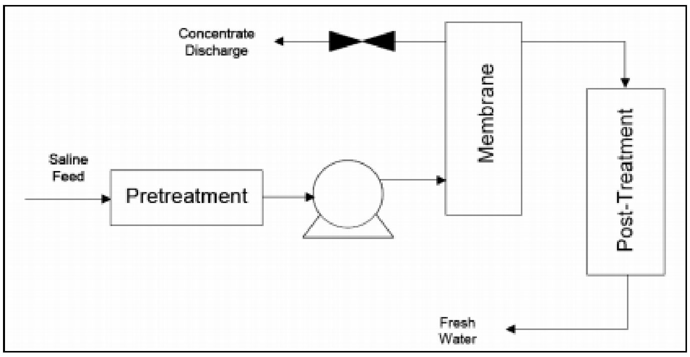

Figure 4: Principle of Desalination by Reverse Osmosis (RO)

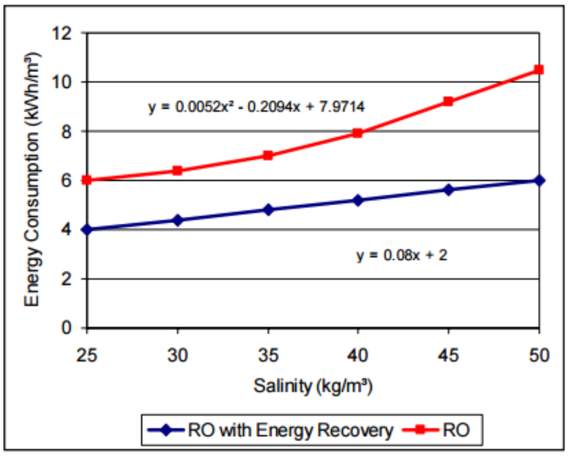

Figure 5: Specific electricity consumption of reverse osmosis plants with and without energy recovery system as function of raw water salinity

4 Thermal Vapour Compression

Vapour compression is added to a multi-effect distiller in order to improve efficiency. Vapour compression processes rely on the reuse of vapour produced in the distiller as heating steam after re-compression. The vapour produced in one stage is partially re-compressed in a compressor and used to heat the first cell. The vapour is compressed either with a mechanical compressor. For thermal vapour compression, motive steam at higher pressure is withdrawn from next process, e.g. or industrial process steam or a steam power cycle.

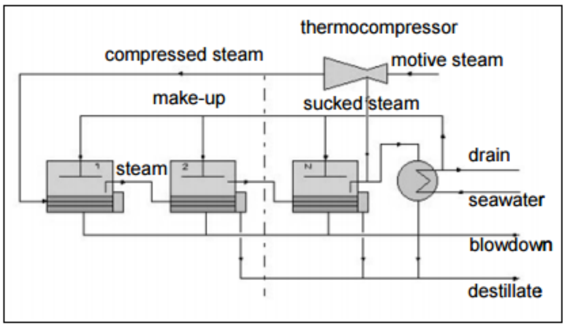

Figure 6: Thermal Vapour Compression

5 Mechanical Vapour Compressions

Mechanical vapour compression processes are particularly useful for small to medium plant. MVC units range in size up to about 3,000 m^3 per day while TVC units may range in size to 36,000 m^3 per day. MVC systems have between one and three stages, many of them have a single stage, while TVC systems have several stages. This difference arises from the fact that the pressure and temperature increase by the mechanical compressor and its capacity are limited.

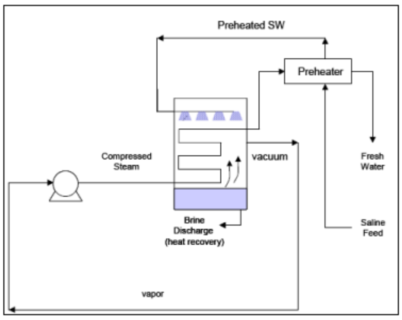

Figure 7: Single stage mechanical vapour compression desalination process

6 Solar power concentrations

The results for water desalination experiment showed that water with initial concentration of salt of 35 g/l gave fresh water with salinity of 0.5 g/l, also, the HD system could totally eliminate copper ion from contaminated feed water with initial concentration of 100 mg/l. The maximum water flow rate obtained was 2.65 l/h at inlet water temperature of 850C. The energy consumption per litre of fresh water is calculated at 85oC to be 45.3 KWhr/m^3, which is higher than energy required for desalination by reverse osmosis system [2.5-7 KWh/m^3]. The temperature of miscarried water is high enough to be introduced to a second stage of the humidification system [15690 KJ/hr with miscarried water in case of T= 56°C]. Also, the condenser efficiency is 23% and additional condensation steps are required to maximize the yield of fresh water from this unit.

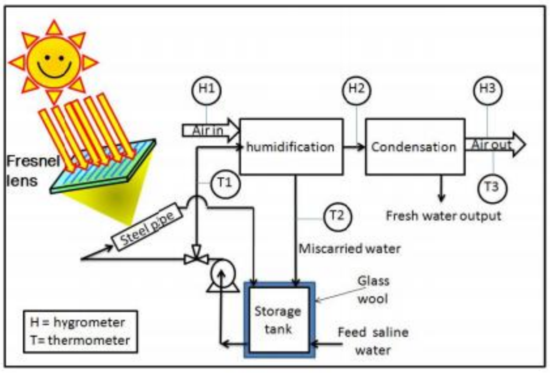

Figure 8 Utilization of Fresnel lens solar collector in water heating for desalination by humidification-dehumidification process

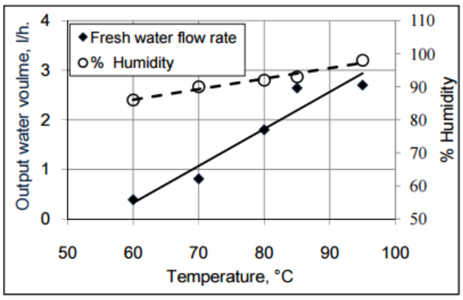

Figure: 9 Effect of inlet water temperature on the percentage of humidity of carrier air and on the output freshwater volumetric flow rate at sprayer speed of 2200 rpm.

PRE-SELECTION OF DESALINATION TECHNOLOGIES

Table 1 shows some of the characteristics of the four leading desalination technologies. The purpose of this comparison was to select the most appropriate thermal and mechanical desalination method for the combination with CSP, and to find a plausible combination that could be representative for large scale dissemination. Comparing MED and MSF, it becomes clear that MED is more efficient in terms of electricity consumption and primary energy and has a low cost. The operating temperature of MED is lower, thus requiring steam at low pressure if connected in co-generation to a steam power plant cycle. So the combination of CSP with MED will become more efficient than a combination of MSF and CSP desalination. Thermal vapour compression is mostly used to increase the efficiency of an MED process, but it requires steam at high pressure if connected to a steam power cycle. Comparing the mechanical driven desalination options, reverse osmosis has a lower electricity consumption and cost per unit product water than the mechanical vapour compression system. The much lower primary energy consumption of RO and the slightly lower cost compared to MED suggests that RO might be the preferred desalination technology anyway. However, if MED is coupled to a power plant, it replaces the cost of the condensation unit of the steam cycle and partially uses waste heat from power generation for the desalination process. In this case, not all the primary energy used must be accounted for the desalination process, but only the portion that is equivalent to a reduction of the amount of electricity generated in the plant when compared to conventional cooling at lower temperature, and of course the direct power consumption of the MED process. Processes combining thermal and mechanical desalination may lead to more efficient future desalination systems /MEDRC 2001/. However for simplicity, only separated processes have been used for our comparison. For further more detailed analysis of a combination with CSP under different environmental and economic site.

Table1

Energy used	Thermal		Mechanical	
Process	MSF	MED/TVC	MVC	RO
Worldwide capacity	13	2	0.6	6
Heat consumption(KJ/kg)	250-330	145-390		
Electricity consumption(kWh/m³)	3-5	1.5-2.5	8-15	2.5-7
Production unit capacity(m³/day)	<76000	<36000	<3000	<20000
Conversion Freshwater/seawater	10-25%	23-33%	23-41%	20-50%
Max. Top Brine temperature(°C)	90-120	55-70	70	45
Product water quality (ppm)	<10	<10	<10	200-500

3. CONCLUSION

The purpose of this comparison was to select the most appropriate thermal and mechanical desalination method for the combination with CSP, and to find a plausible combination that could be representative for large scale dissemination. . Comparing MED and MSF, it becomes clear that MED is more efficient in terms of electricity consumption and primary energy and has a low cost. The operating temperature of MED is lower, thus requiring steam at low pressure if connected in co-generation to a steam power plant cycle. So the combination of CSP with MED will become more efficient than a combination of MSF and CSP desalination. Thermal vapour compression is mostly used to increase the efficiency of an MED process, but it requires steam at high pressure if connected to a steam power cycle. Comparing the mechanical driven desalination options, reverse osmosis has a lower electricity consumption and cost per unit product water than the mechanical vapour compression system. one of CSP technologies called Fresnel Reflector (LFR) technology is particularly suitable for process heat, mainly due to its direct steam generation capacity, low cost and low land occupancy. LFR produces both saturated and superheated steam, with temperatures ranging between 120°C and 500°C, from 6 bar to 100 bar.

REFERENCES

[1] Y.B.Karhe, Dr. P.V.WalkeA Solar Desalination System Using Humidification-Dehumidification Process- A Review of Recent Research , International Journal of Modern Engineering Research (IJMER) Vol.3, Issue.2, 2013 pp-962-969.

[2] S. Hobeikaa,*, B. Alexandera Case study: Linear Fresnel Reflectors (LFR) solar systems for industrial applications, International Conference on Concentrating Solar Power and Chemical Energy Systems, SolarPACES 2014

[3] R. Mohamed Salah Mahmoud1, Asma Abd El-Sattar Mohamed1 Utilization of Fresnel lens solar collector in water
heating for desalination by humidification-dehumidification process, Fifteenth International Water Technology Conference, IWTC-15 2011, Alexandria, Egypt.

[4] WP 1: Review of CSP and Desalination Technology

[5] Solar Euromed SAS. (2014). http://www.solareuromed.com/en, (n.d.).

[6] S. Benmarraze, P. Lecuillier, R. Olivés, M. Benmarraze, Life cycle assessment of solar collector Fresnel module and parabolic trough assemblies, in: 2010.