# A Comparative Study of Sea Water Desalination Technologies Driven By Solar Power

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***Abstract: Desalination refers to the process which involves removal of salts and other minerals from seawater. The process require significant amount of energy for separating salts from seawater and dependence of conventional desalination plants on fossil fuels result in high consumption of fossil fuels (which is not desirable because of their limited amount) and considerable environmental pollution. So, there is a need to employ energy resources which are clean, environmentally-friendly and more importantly unlimited i.e. renewable energy sources. This paper describes various approaches that exist for desalination, in particular, techniques that could be coupled with solar energy and comparison between several desalination technologies is also presented in the paper.***

***Keywords: Desalination, Solar thermal desalination, MED, MSF, RO, ED.***

## 1. INTRODUCTION

Water is vital for all forms of life that exist on earth. About 72% of the earth's surface has water cover and about 97% of this available water is brackish in nature .The salinity of seawater on an average is around 35% and may change depending on geographical location and climate of that area. Thus, as such it is not fit for human ingestion or agriculture and only 3% is fresh water in the form of snow cover (in the poles), ground water, rivers, lakes and soil moisture. Less than one percent of fresh water is actually within human reach [1].

Fresh water availability depends upon geographical area and season prevalent at that location. Thus, oceans seem to be the only unlimited pockets containing water but water present in oceans has high salt content. So, a sensible approach to solve the fresh water-scarcity problem is with sea water desalination driven by renewable energy systems. Currently, a number of desalination plants have been in operation and they utilize various renewable energy means to produce fresh water. A detailed explanation of various techniques used for seawater desalination which could run using solar power is presented in this paper.

## 2. SOLAR THERMAL DESALINATION

Desalination systems are grouped into direct and indirect collection systems [2] depending upon how solar energy is being used for desalinating sea water.

***Direct collection systems***

These systems utilize solar energy (heat) directly for the purpose of distillation in the solar collector. This method is particularly suitable for regions where demand for freshwater is below 200 $m^3$/day [3].

The oldest solar still is of basin type and the basic components it comprises are a basin, glass cover, supporting structure, a distillate trough/rack and insulation.

The basin encloses the brackish water that will undergo desalination. Glazing cover is mounted over the basin and is the most important element of any solar still. It must have transmittance so as to allow short wave energy of solar radiation to pass through and should not allow long wave radiations to escape so that heat energy is trapped inside. The distillate trough is positioned at the base of the slanted glazing, the purpose of which is to collect the condensed water and direct it toward storage. The covered area of the trough is made small to avoid shading the basin. Insulation is used to retard the flow of heat from a solar still and is placed beneath the basin so as to minimize the heat loss through the basin. Solar energy enters the device through the glass cover and heat the basin of salt water. The temperature of the water increases and it evaporates, rises up and then condenses on the cooler glass plate. The condensed droplets run down because of the slope of the glazing cover and are collected in distillate trough as shown in Fig. 1.

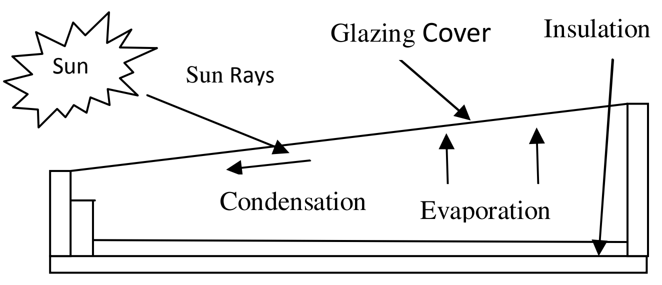


**Fig. 1 A basic still**

The efficiency of a solar still is generally less than 50% [4]. Being less efficient, it is thus essential to use very inexpensive materials for the construction of a solar still to minimize capital costs incurred. An improvement in the efficiency of a basin still is possible by employing numerous passive and active methods.

In active solar stills, the solar still can be incorporated with external equipment which can supply extra-thermal energy and is delivered to the basin of solar still so as to increase the evaporation rate of brackish water. The external equipment may be a collector/concentrator panel [5], waste thermal energy from any chemical/industrial plant [6] or conventional boiler. Concentrating solar power plants with unit capacities of upto 80 MW are presently being operational in USA and are being built in Spain.

No external equipment is being used in passive solar still. A passive solar still possess certain advantages that process can be made self-operating, of simple construction and relatively maintenance free. These advantages are however counter-balanced by the low throughput i.e. little amounts of freshwater produced, approximately 2 L/m$^2$ for the simple basin type solar still [7] and there is also requirement of regular flushing of collected salts.

Though the yield of solar stills is on lower side, however, their use may prove to be economically feasible for those arid/remote areas, where saline water is the only water available, power is inadequate, and demand for fresh water is less than 200 m$^3$/day [8].

***Indirect collection systems***

It employs two separate units; one for collecting solar energy called solar collection array and one for distillation of brackish water.

Solar desalination technologies under indirect collection systems can be broadly classified into two groups. One is Thermal desalination and second is Membrane desalination.

Thermal desalination uses heat to vaporize saline water leaving behind a solution rich in salt content, called the brine. Freshwater is then obtained from condensation of the vapor. Multi stage flash (MSF) and Multi effect distillation (MED) belong to this category.

In the second approach i.e. membrane desalination, high pressurized saline or brackish water is forced through a porous or semi-permeable membrane which results in separation of fresh water from seawater. The two major processes of this type are reverse osmosis (RO), and electro dialysis (ED).

***Multi stage flash distillation***

This process is employed for producing fresh water from sea water wherein evaporation is achieved by reducing its pressure as it flows through various stages of the plant.

The feed seawater enters into the condenser tubes of last stage and its temperature increases progressively as it flows from last stage towards first stage as shown in Fig. 2. Low pressure steam, supplied externally, is used for heating seawater to the desired brine temperature in the brine heater. Then the heated sea water flows through a series of stages. In each stage, the ambient pressure is kept lower than the saturation vapour pressure which causes immediate flashing of seawater at the bottom of the stages. The steam thus produced is condensed on tubes of heat exchanger that are arranged across the width of the evaporator. The feed water flows through these tubes. So, as the vapour gives off its heat during condensation, the feed water temperature is increased thus requiring lesser thermal energy to reach to desired brine temperature in the brain heater. An MSF plant has 10 to 30 stages [9] and usually operates at top brine temperatures of 90–120°C.

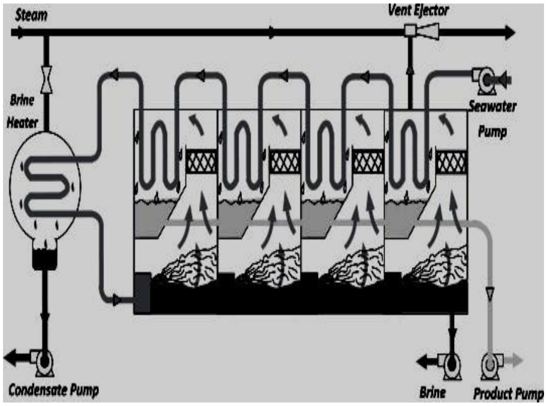


**Fig. 2. Multi-stage flash distillation**

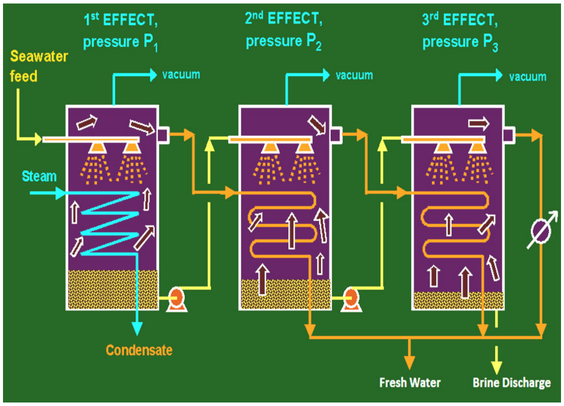


**Fig. 3. Multi Effect Distillation**

The thermal energy required for generating steam can be extracted from solar collector unit. The secondary fluid flows in tubes placed along focal point of parabolic troughs or compound parabolic collectors can be used as source of heat which through a heat exchanger can supply required amount of heat for steam generation in brine heater.

A MSF desalination plant in Kuwait showed a production rate of 10 $m^3$ /day [10] for a surface parabolic trough collector of 220 m² and a 12-stage MSF desalination system. The output of the system is reported to be over 10 times the output of solar stills for the same solar collector area.

An experimental solar desalination plant in Tripoli, Libya has shown capacity in the range from 1238-1570 $m^3$ /day for a solar pond temperature ranging from 65-106°C with pond size 70,000 $m^2$ with maximum GOR (gained output ratio) of 10[11].

***Multi-effect distillation***

This system in principle is analogous to MSF except that feed water is heated by steam in the tubes in the first stage and the resulting vapour is used in subsequent stages to evaporate the water. As shown in Fig. 3, feed water enters into the first stage called first effect where it is heated by steam that may be generated by a boiler or from turbines of power plants or by steam transformer. A part of feed water evaporates by extracting thermal energy from steam and vapour thus produced in first vessel (effect) is used to heat the liquid that enters from first effect to next vessel. Flashing of liquid take place as it enters into the second effect because of lower ambient pressure. Thus, in MED, vapour is generated by flashing as well by evaporation but major part of distillate is produced by evaporation. The number of effects range from 4 to 14 in an MED plant and the performance ratio is around 10– 18 [12]. MED consumes less power as compared to MSF and it also has a better performance ratio [13].

The input energy required for generating steam in MED can be extracted from solar energy by different means (solar tower, heliostats, parabolic troughs, CPC etc.) [14].The cost of producing fresh water from sea feed water in an MED plant coupled with solar technology has been found to be dependent on plant capacity: for large plants (5000 $m^3$/day), cost is around 2 US $/$m^3$ and is mounting up to 3.2 US$/$m^3$ for smaller plants (500 $m^3$/day) [15]. Abu Dhabi plant [16] where evacuated-tube solar collectors are used has freshwater output of about 85 $m^3$/day.

***Reverse osmosis***

Reverse osmosis, often abbreviated to RO, is reverse of osmosis in which sea feed water, rich in salt content, is forced to pass through a semi-permeable membrane. Only water molecules pass through the membrane to the other side i.e. low pressure side while the undesirable components i.e. salts and other dissolved elements and/or microorganisms, micro-algae, harmful bacteria are retained by the membrane filter on the high pressure side. No thermal energy is required for this separation but the main energy consumption in this process is pressurization of the feedwater. Also, this process requires preliminary treatment of feedwater (to avoid fouling, scaling and degradation of membrane) as well post treatment of fresh water being produced (to remove any dissolved gases and to stabilize the pH level). The percentage of water that is recovered from the feed as permeate in reverse osmosis units range from 35-60% depending upon number of passes and total dissolved salts in feed water.

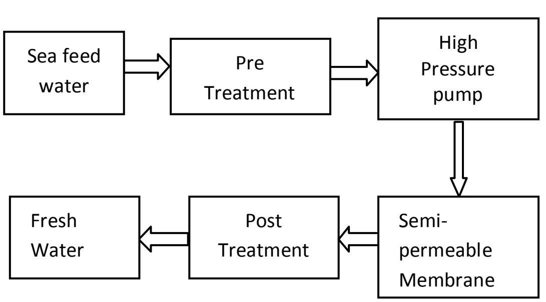


**Fig. 4. Flowchart of RO process**

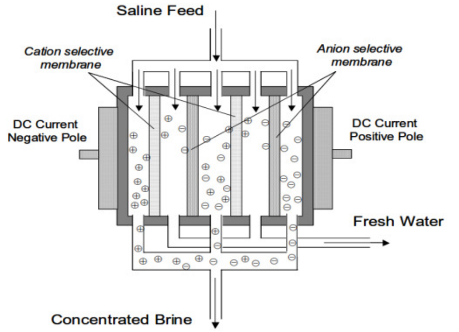


**Fig. 5. Electrodialysis Process**

Solar power extraction source can act a prime mover driving the pumps used in RO systems for pressurizing the feed water [17] or solar energy can be converted to electrical energy using PV panels [18].Many demonstration plants have been put up in recent past coupling RO systems with solar PV arrays and results have been encouraging. Battery banks are also added to the system to provide steady operating voltage required to operate the pump during the night and low light periods. Investment cost of a solar coupled RO plant is higher than conventional RO, but is also dependent on other parameters like location of the plant, quality of saline water available at that particular region and capacity of the plant.

An PV-RO plant at RasEjder, Libya with PV capacity of 50kW and solar radiation intensity of 5.24 $kWh/m^2/day$ has been in operation with capacity of 300 $m^3/day$ [19].

***Electrodialysis***

Electro-dialysis is an electrochemical process wherein application of electric potential results in transportation of ions through semi permeable membranes [20]. The electro dialysis unit consists of stack of alternate anion and cation exchange membranes with electrodes on outer side so that electric potential can be applied across the membrane stack. A cation exchange membrane allow cations to pass through and block the passage of anions through them while anion exchange membrane permit anions and block positive ions(cations). Feedwater enters into flow conduits and passes through the cells where under the influence of electric current, separation of brine from feedwater takes place as shown in Fig. 5. The feedwater must be pretreated to prevent suspended solids or organic compounds from entering the membrane stack otherwise that could that could damage the surface of ion exchange membranes. Electro dialysis is more cost effective than RO when used on brackish water containing total dissolved solids (TDS) levels less than 3000 mg/l.

Since the unit require DC power for its operation, so it can be directly coupled with solar PV panels for supply of required electric potential. A comparison between different desalination technologies based on various parameters is presented in Table 1[21].

| **Parameter** | **MSF** | **MED** | **RO** | **ED** |
|---|---|---|---|---|
| Principle | Flash Evaporation | Flash + Evaporation | Solution-diffusion | Ion separation |
| Energy consumption | Electrical: 2.5-5.0 $kWh/m^3$ Thermal: 40-120 $kWh/m^3$ | Electrical: 1.0-2.5 $kWh/m^3$ Thermal: 40-120 $kWh/m^3$ | Electrical: 2.8-5 $kWh/m^3$ Thermal: None | Electrical: 4-4.5 $kWh/m^3$ Thermal: None |
| Maximum top brine | ~ 120°C | ~ 100°C | ~ 35°C | ~ 35°C |

| | | | | |
|---|---|---|---|---|
| temperature | | | | |
| Product water quality (ppm TDS) | 5-50 | 5-50 | 250-350 | 250-350 |
| Recovery | 10-20% | 25-45% | 30-50% | 80-90% |
| Pretreatment requirement | low | low | high | high |
| Scale problem | High | Low-Medium | Low | Medium |
| Installation Cost ($/m$^3$) | 1000-2100 | 900-1000 | 700-900 | |
| Reliability | very high | very high | moderate | high |
| Production Unit Capacity (m$^3$/d) | < 76000 | < 36000 | < 20000 | |

## 3. CONCLUSION

In this paper, a number of seawater desalination technologies which could be coupled with solar energy extraction source have been reviewed. Thermal technologies were the only viable option in the past and MSF was recognized as the established and proven technology. But, because of the lower power consumption and better performance ratio, MED is now the state-of the-art thermal technology. With recent growth in membrane technology, RO surpassed MSF and should now be considered as baseline desalination technology.

The use of solar power for desalination purpose is one of the most promising applications of the renewable energy. Active research and development is required in both solar power and desalination technologies to constantly improve the technologies and reduce the cost of renewable energy driven desalination plants compared to conventional power plants. Apart from solar energy, other renewable energy means such as wind, geothermal etc. could be used in combination with solar so as to improve the efficiency and effectiveness of the whole system. For small scale plants, solar driven desalination seems to attractive and if the same could be extended for large-scale desalination plants at a reasonable cost and with higher efficiency, this possibly will mean a solution to one of the most pressing environmental issues of today and the near future.

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