TECHNICAL SEMINAR REPORT ON

SOLAR ENERGY FOR WATER DESALINATION

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CERTIFICATE

This is to certify that the technical seminar report entitled

SOLAR ENERGY FOR WATER DESALINATION

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In the Partial fulfillment of requirements for the award of BACHELOR OF TECHNOLOGY to JNTU, Hyderabad**.** This report is a bonafide work carried out by the student under my supervision.

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ABSTRACT

Desalination is one of the most traditional processes to generate potable Water. With the rise in demand for potable water and paucity of fresh water resources, this process has gained special importance. Conventional thermal desalination processes involves evaporative methods such as multi-stage flash and solar distils, which are found to be energy intensive, whereas reverse osmosis based systems have high operating and maintenance costs.

This Report presents the different solutions to the most commonly used desalination process, and solar energy production technology compatible with desalination. The goal is to assess the feasibility and profitability of the substitution of fuel energy used for desalination plants with renewable energy. A review of various technologies will define broadly features associated to each technology and range of cost that are expected. Finally, a review of various projects will detail the practical aspects of floor space and actual production costs of fresh water. The world-wide availability of renewable energies and the availability of mature technologies in this field make it possible to consider the coupling of desalination plants with renewable energy production processes in order to ensure the production of water in a sustainable and environmentally friendly scheme for the regions concerned.

Solar desalination is used by nature to produce rain which is the main source of fresh water on earth. All available man-made distillation systems are duplication on a small scale of this natural process. Recently, considerable attention has been given to the use of renewable energy as sources for desalination, especially in remote areas and islands, because of the high costs of fossil fuels, difficulties in obtaining it, attempts to conserve fossil fuels, interest in reducing air pollution, and the lack of electrical power in remote areas.

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1. INTRODUCTION

1.1 DEFINATION

Desalination means the process that removes the excess salt and other minerals from water in order to obtain fresh water suitable for Human consumption or irrigation. Sometimes the process produces table salt as a by-product.

1.2 NEED OF RENEWABLE ENERGY FOR DESALINATION

The origin and continuation of mankind is based on water. Water is one of the most abundant resources on earth, covering three-fourths of the planet's surface. However, about 97% of the earth's water is salt water in the oceans, and a tiny 3% is fresh water. This small percentage of the earth's water which supplies most of human and animal needs exists in ground water, lakes and rivers. The only nearly inexhaustible sources of water are the oceans, which are of high salinity. Population growth is one factor, not only the need for drinking water and sanitation but also the need to produce more food. Agriculture accounts for 70% of water use. While reducing consumption is one way of helping to address the water crisis on an individual level, it is far from the complete solution. Something on a larger scale is also needed: Desalination. As climate change makes rainfall less predictable and droughts more common, a growing number of countries are turning to desalination. The term is used to refer to removing salt from both seawater and subterranean “brackish” water, as well as the treatment of waste water to make it drinkable. The separation of salts from seawater requires large amounts of energy which, when produced from fossil fuels, can cause harm to the environment. Therefore, there is a need to employ environmentally-friendly energy sources in order to desalinate seawater.

It’s true that freshwater scarcity is associated with large quantity of solar resource. It seems also logical and attractive to associate those two parameters for countries where grid electricity is not spread widely and with easy access to seawater or brackish water. Solar desalination is not a new idea: it has been known for ages, antique sailors used to desalt water with simple and small sized solar stills. It’s also a fact that production of fresh water requires a large amount of energy: 1000 m3 of freshwater per day requires 10000 tons of oil per year. Though solar energy is often labeled as ‘free energy’, it’s not so simple to evaluate feasibility and cost for solar desalination. Some technologies will not be taken in account in this report: solar ponds, which are a direct desalination method, as well as desalination with electrodialysis.

1.3 SALINITY OF WATER

Salinity is the saltiness or dissolved salt content of a body of water. Salinity is an important factor in determining many aspects of the chemistry of natural waters and of biological processes within it, and is a thermodynamic state variable that, along with temperature and pressure, governs physical characteristics like the density and heat capacity of the water.

Salinity of water can be expressed in units of parts per thousand (ppt or ‰). One Parts per thousand can be explained as one gram of dissolved solute per one kilogram of solution.

Type of water	Salinity in ppt upto
Drinking Water	0.05-0.1
Lakes, Rivers, Ponds	0.5
Used for irrigation	2
Average Sea water	34
Red sea	40
Brine pools	50+

Table no. 1.3 Salinity of different type of water

2. LITERATURE SURVEY

2.1 THE EARLY YEARS: PRIOR TO 1920

As early as in the fourth century BC, Aristotle described a method to evaporate impure water and then condense it to obtain potable water. However, historically probably one of the first applications of seawater desalination by distillation .The need to produce fresh water on board emerged by the time the long distance trips were possible. Alexander of Aphrodisias in AD 200, who said that sailors at sea boiled seawater and suspended large sponges from the mouth of a brass vessel to absorb what is evaporated. In drawing this off the sponges they found it was sweet water Solar distillation has been in practice for a long time. An Arab alchemist in the 15th century reported by Mouchot in 1869. Mouchot reported that the Arab alchemist had used polished Damascus mirrors for solar distillation. The great French chemist Lavoisier at about 1774 used large glass lenses, mounted on elaborate supporting structures, to concentrate solar energy on the contents of distillation flasks. The use of silver or aluminum coated glass reflectors to concentrate solar energy for distillation has also been described by Mouchot. In 1870 the first American patent on solar distillation was granted to the experimental work of Wheeler and Evans. Almost everything we know about the basic operation of the solar stills and the corresponding corrosion problems is described in that patent. High operating temperatures were claimed as well as means of rotating the still in order to follow the solar incident radiation. Two years later, in 1872, an engineer from Sweden, Carlos Wilson, designed and built the first large solar distillation plant, in Las Salinas, Chile, thus solar stills were the first to be used on large-scale distilled water production. The plant was constructed to provide fresh water to the workers and their families of a saltpeter mine and a nearby silver mine. They used the saltpeter mine effluents, of very high salinity (140,000 ppm), as feedwater to the stills. The plant was constructed of wood and timber framework covered with one sheet of glass. It consisted of 64 bays having a total surface area of 4450 m^2 and a total land surface area of 7896 m^2. It produced 22.70 m^3 of fresh water per day (about 4.9 l/m^2). The still was operated for 40 years.

2.2 THE MAJOR DEVELOPMENT YEARS: 1920'S – 1990'S

The use of solar concentrators in solar distillation has been reported by Pasteur in 1928 who used a concentrator to focus solar rays onto a copper boiler containing water. The steam generated from the boiler was piped to a conventional water cooled condenser in which distilled water was accumulated. The renewal of interest on solar distillation occurred after the First World War at which time several new devices had been developed such as: roof type, tilted wick, inclined tray and inflated stills. Until the Second World War only a few solar distillation systems existed. During the years 1930–1940, the dryness in California initiated the interest in desalination of saline water. Some projects were started, but the depressed economy at that time did not permit any research or applications. Interest grew stronger during World War II, when hundreds of Allied troops suffered from lack of drinking water while stationed in North Africa, the Pacific Ocean Islands and other isolated places. Then a team from MIT, led by Maria Telkes, began experiments with solar stills. At the same time, the US National Research Defense Committee (NRDC) sponsored research to develop solar desalters for military use at sea. The explosion of urban population and the tremendous expansion of industry after World War II, brought again the problem of good quality water into focus. In July 1952 the Office of Saline Water (OSW) was established in the United States, the main purpose of which was to finance basic research on desalination. OSW promoted desalination application through research. Five demonstration plants were built, and among them was a solar distillation in Daytona Beach, Florida, where many types and configurations of solar stills, were tested. Between the years 1965 and 1970, solar distillation plants were constructed on four Greek Islands to provide small communities with fresh water. The design of the stills was done at the Technical University of Athens and was of the asymmetric glass covered greenhouse-type with aluminum frames. The stills used seawater as feed and were covered with single glass. Their capacity ranged from 2044 to 8640 m3 /day. Then in later years desalination through membrane process was discovered such like reverse osmosis and electrodailysis, in this process sea water is passed through the membrane with the help of pump pressurization. Desalination through thermal technologies were observed, Thermal technologies have rarely been used for brackish water desalination, because of the high costs involved. They have however been used for seawater desalination and can be sub-divided into three groups: Multi-Stage Flash Distillation, Multi-Effect Distillation, and Vapor Compression Distillation.

2.3 THE PRESENT

Desalination based on the use of renewable energy sources can provide a sustainable way to produce fresh water. It is expected to become economically attractive as the costs of renewable technologies continue to decline and the prices of fossil fuels continue to increase. Using locally available renewable energy resources for desalination is likely to be a cost-effective solution particularly in remote regions, with low population density and poor infrastructure for fresh water and electricity transmission and distribution. The present deployment of renewable-based desalination – i.e. less than 1% of desalination capacity based on conventional fossil fuels does not reflect the advantages of this technology option. Renewable desalination is mostly based on the RO process (62%), followed by thermal processes such as MSF and MED. The dominant energy source is solar photovoltaic, which is used in some 43%, of the existing applications, followed by solar thermal and wind energy. The right combination of a renewable energy source with a desalination technology can be the key to match both power and water demand economically, efficiently and in an environmentally friendly way. Assessing the technical feasibility and cost effectiveness of renewable desalination plants requires a detailed analysis, including a variety of factors, such as location, quality of feed-water input and fresh-water output, the available renewable energy source, plant capacity and size, and the availability of grid electricity. Some of combination developed are Seawater desalination via MSF and MED using solar heat as the energy input are promising desalination processes based on renewable energy, Photovoltaic technology can be connected directly to RO desalination processes, which are based on electricity as the input energy, The electrical and mechanical power generated by a wind turbine can be used to power desalination plants, notably RO and ED desalination units, and vapor compression distillation process. As geothermal energy can produce electricity and heat, it can be combined with both thermal and membrane desalination technologies. Low-temperature geothermal energy, typically in the range of 70–90°C, is ideal for MED desalination. Desalination requires a considerable amount of energy. Membrane desalination requires only electricity while thermal desalination requires both electricity and thermal energy, and in total more energy than the membrane process. Other variable renewable energy sources, such as solar PV and wind power can also offer significant contributions if associated with energy storage systems. Desalination itself can be seen as a viable option to store renewable electricity, which exceeds the demand.

3. DESALINATION TECHNOLOGIES

3.1 VARIOUS DESALINATION TECHNOLOGIES

The two major types of technologies that are used around the world for desalination can be broadly classified as either thermal or membrane. Both technologies need energy to operate and produce fresh water. Within those two broad types, there are sub-categories using different techniques. There are different ways to produce freshwater with desalination technologies. More common technologies are:

- Reverse Osmosis
- Multi-stage Flash Process
- Multi Effect distillation

3.2 PROCEDURE INVOLVED IN DESALINATION

It's normally considered that salinity below 500 ppm is suitable as drinking water. Basically, a complete desalination process includes 3-4 steps with

1. Pumping water (from sea, estuaries or saline aquifers)
2. Pre-treatment of pumped water (filtration, chemical addition)
3. Desalination Process
4. A post treatment if necessary (in some case, adding few minerals).

4. REVERSE OSMOSIS

The RO technology is based on the properties of semi-permeable membranes which can separate water from a saline solution, when excess of osmotic pressure is applied on the membrane systems. Pressure is applied with a high pressure pump, High pressure pumps supply the pressure needed to enable the water to pass through the membrane and have the salt rejected. The pressures range from about 150 psi for slightly brackish water to 800 - 1,000 psi for seawater. Part of the flow (35 to 50%) goes through the membrane, with a salt concentration less than 500 ppm, rest of the flow called retentate (50 to 65%), containing high concentration of salts, doesn't pass through the membrane and is directly rejected at a high pressure.

RO can be applied to different types of water: seawater as well as brackish water, with the equivalent objectives depending on the pressure applied to the membrane. Reverse osmosis has known a great development over the last twenty years due to its easy and rather low cost technology and great improvement on membrane quality. Two developments have helped to reduce the operating cost of RO plants during the past decade: the development of more efficient membranes and the use of energy recovery devices. The newer membranes have higher flux (rate of water flow per unit area), improved rejection of salts, lower prices and longer service life.

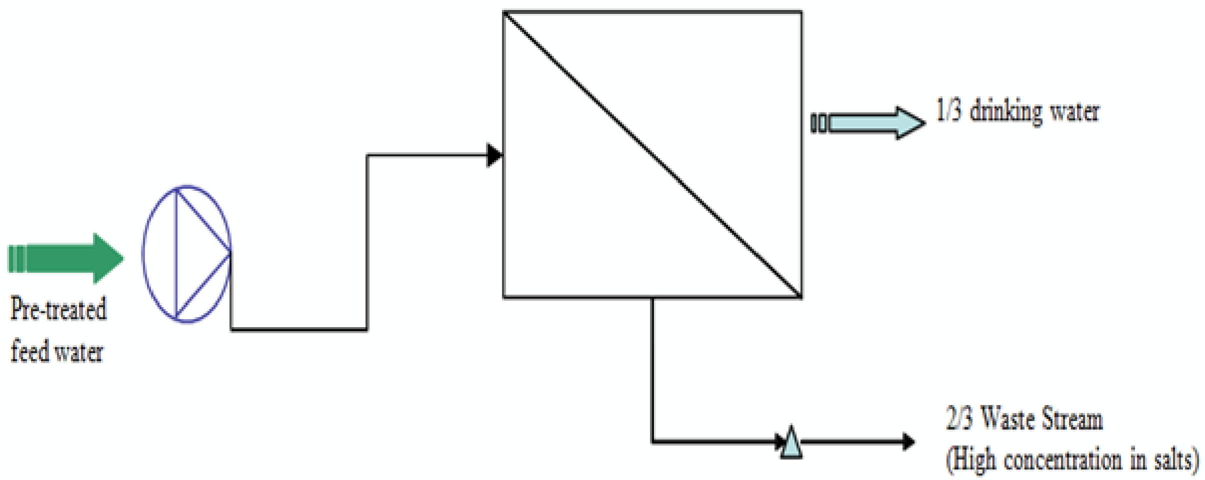


Fig 4.1 Schematic of Reverse Osmosis System

4.1 KEY FEATURES OF REVERSE OSMOSIS

Key features of the RO process are the following:

- Low energy consumption.
- Easy and ready to use: immediate stop and start.
- Needs important pre-treatment: pre-filtration and chemical to avoid fouling on the membrane.
- Outlet salt concentration around 500 ppm.

Fig 4.2 Reverse Osmosis plant

5. MULTI STAGE FLASH DESALINATION

In the MSF process, seawater is heated in a vessel called the brine heater, up to a temperature of 120°C, and then flows into another vessel, called a stage, where the ambient pressure is lower, causing water to boil. Steam is then condensed on a range of tubes passing through the vessel. Low pressure ensures seawater cooling down to 40°C.

This well known technology has been used on large installations (more than 50,000 m3/day), with coupling of heat generation from a power plant, but MSF process can also be used with solar power. MSF plants are subject to corrosion unless stainless steel is used extensively. In addition to corrosion, MSF plants are also subject to erosion and impingement attack. Erosion is caused by the turbulence of the feed water in the flash chamber, when the feed water passes from one stage to another. This process produces about 3.4 billion Gallons per day globally, which is about 50 percent of the worldwide desalination capacity. MSF plants provide about 84 percent of that capacity. Most of those plants have been built overseas, primarily in the Middle East, where energy resources have been plentiful and inexpensive.

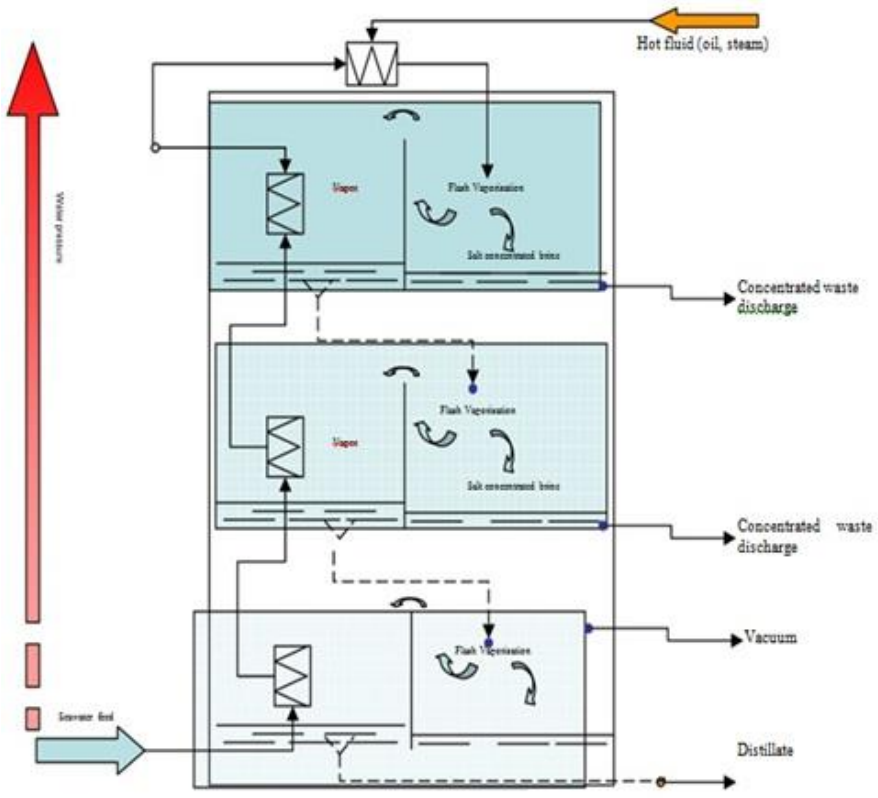


Fig 5.1 Schematic drawing of MSF system

5.1 KEY FEATURES OF MULTI STAGE FLASH DESALINATION

Key features for MSF are the following:

•High reliability.

•No need for complicated pre-treatment due to very limited scaling: simple filtration, and anti-scalant.

•High investment cost.

•High quality of produced freshwater (depending on the number of cells): salts concentration below 50 ppm.

• Low running flexibility (low variation in flow rate).

MSF plants are now installed worldwide, even though performance is not high and represent 40 - 45% of the total capacity in desalination.

Over the last 40 years, cost of desalinated water with MSF technology decreased by a factor 10 (from 10 $\$/m^3$ in 1960 down to less than 1 $\$/m^3$ in 2002).

6. MULTI EFFECT DISTILLATION

Multi Effect Distillation (MED) process is based on using latent heat of condensation of the vapor from the first cell to provide heat to a second cell. The evaporation takes place in cells where equilibrium temperature (Te) liquid / vapor is between 40 ° C and 68 ° C.

In the first cell, the steam produced is injected into the second effect, in order to ensure the evaporation and condensation at a lower temperature. This is then repeated in all following cells. The more vessels or effects there are, the higher the performance ratio. Depending upon the arrangement of the heat exchanger tubing, MED units could be classified as horizontal tube, vertical tube or vertically stacked tube bundles.

In case of using solar source as heat source, hot water from the solar collector is introduced at the bottom tray, either directly or through a heat exchanger. MED units with horizontal sprayed tubes are generally made with materials like, aluminum brass (AlBr) for tubes and stainless steel 316L for the casing. Sometimes, vertical heat exchanger can be used.

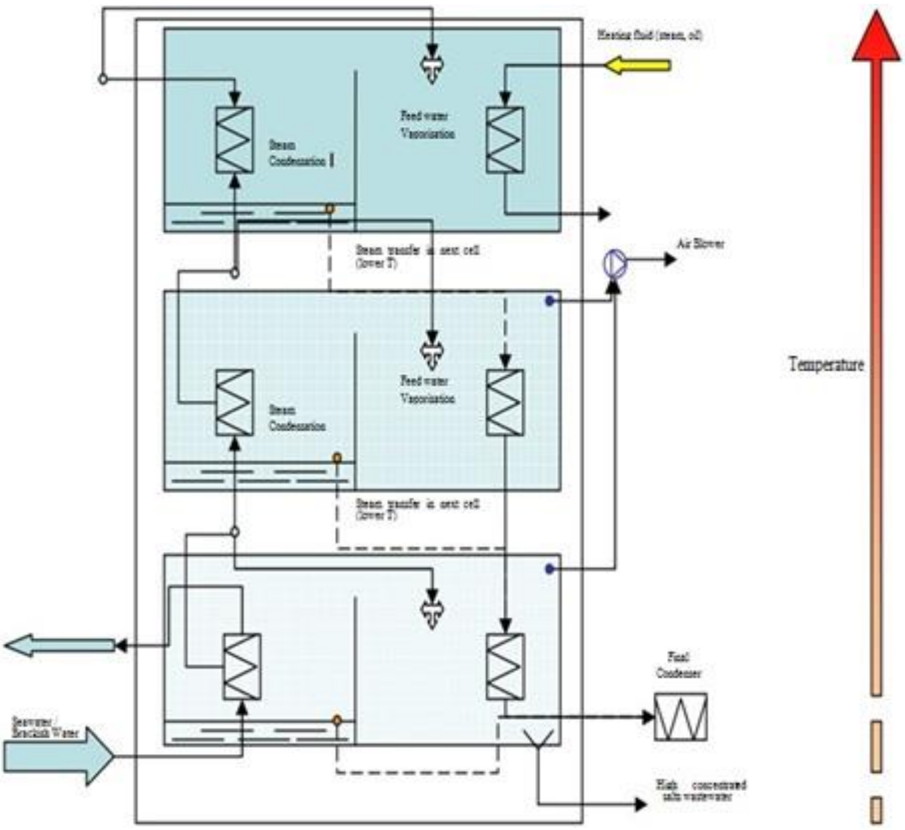


Fig 6.1 Schematic diagram of MED system

6.1 KEY FEATURES OF MULTI EFFECT DISTILLATION

Key features for MED are the following:

• High reliability, easy start of the system (less than 1 hour).

• High quality of produced freshwater (depending on the number of cells): salts concentration below 50 ppm.

• No need for complicated pre-treatment due to very limited scaling: simple filtration, and anti-scalant.

• Can be used on low temperature heat (from 60°C), which can be easily recovered as by-product in industrial plants.

MED is also suitable for small capacity installations and now represents more than 10% of the total capacity in desalination, with still promising developments. Use of coupling MED with Thermal vapor compression helped in decreasing running costs, as well as increase in unit capacity and heat transfer coefficients. Water cost with recent MED is 0,7 US$/$m^3$ which is close to RO .

7. COMPARISON OF DESALINATION TECHNOLOGIES

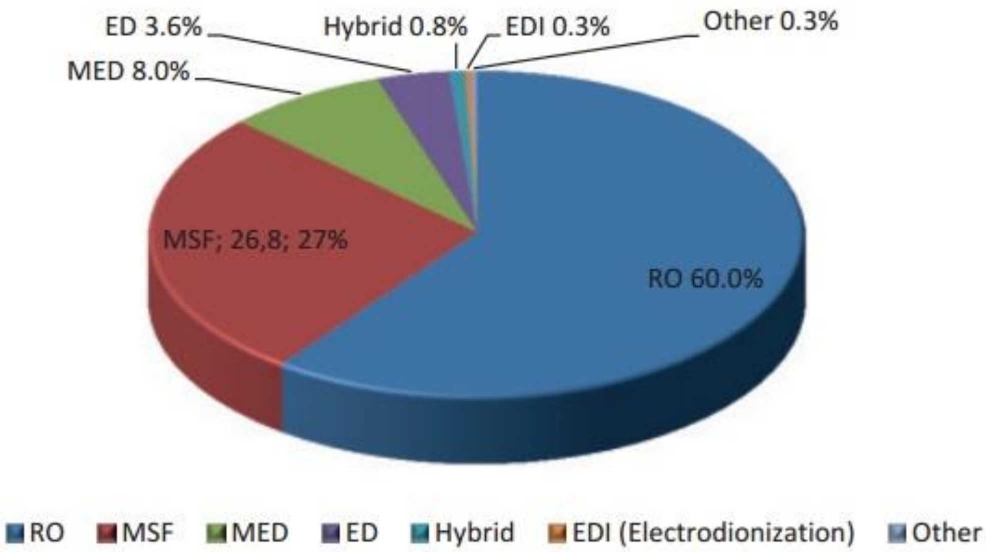
7.1 COMPARISON OF ENERGY CONSUMPTION OF DESALINATION TECHNOLOGIES

The energy required for various desalination processes, as obtained from a survey of manufacturers data is shown in Table. It can be seen from Table that the process with the smallest energy requirement is RO with energy recovery. But this is only viable for very large systems due to the high cost of the energy-recovery turbine. The next lowest is the RO without energy recovery and the MEB.

	Multi stage Flash	Multi effect distillation	Reverse Osmosis
Electrical Demand, kWh/m^3	2.5 – 3.5	1.5 – 2.5	3 – 6
Thermal Demand, kWh/m^3	80 – 120	50 – 90	0

Table no. 7.1 Energy consumption of desalination Technologies

7.2 COMPARISON OF DESALINATION TECHNOLOGY MARKET



Pie Chart no. 7.2 Global desalination technology Market

8. SOLAR TECHNOLOGIES

All desalination technologies described here mainly use thermal energy. Knowing that desalination needs are mainly in dry countries receiving huge intensity solar radiation, it comes as an evidence to use solar power for the running of the plants. Solar technologies can produce heat and thus electricity through a turbine (CSP), or directly electricity (PV and CPV). Growing interests and developments on CSP as well as PV tend to make those technologies more and more attractive.

Concentrated solar power systems generate solar power by using mirrors or lenses to concentrate a large area of sunlight, or solar thermal energy, onto a small area. Electricity is generated when the concentrated light is converted to heat, which drives a heat engine connected to an electrical power generator.

Concentrator photovoltaic (CPV) is a photovoltaic technology that generates electricity from sunlight. Contrary to conventional photovoltaic systems, it uses lenses and curved mirrors to focus sunlight onto small, but highly efficient, multi-junction (MJ) solar cells. In addition, CPV systems often use solar trackers and sometimes a cooling system to further increase their efficiency.

Solar technologies can be divided in two categories:
Concentrating solar power (CSP) technology and photovoltaic

Concentrating Solar Power Technologies mainly include:

- Parabolic trough,
- Linear Fresnel reflector systems.

8.1 PARABOLIC TROUGH

CSP parabolic troughs produce steam and electricity through the use of a parabolic reflecting surface that concentrates direct normal solar radiation (DNI) onto a receiving tube surrounded by a glass element.

The solar collectors track the sun from east to west during daytime, allowing the continuous focus of sun on the solar collectors. Thermal fluid is transferred through the receiving tube where it is heated to approximately 350-400°C. It is then used as heating fluid to the power plant for generation of high-pressure steam. Thermal storage (on sensible or latent heat) can be added to the system to ensure continuity during low solar radiation period (nighttime or cloudy days). Parabolic trough is the most developed of the CSP technologies and is now commercially available for industrial heat production purpose.

Fig 8.1 Parabolic trough

8.2 LINEAR FRESNEL REFLECTORS SYSTEMS

A linear Fresnel reflector technology uses thin segments of mirrors arranged in long parallel lines to reflect sunlight onto a fixed receiver, allowing thus to transfer energy through the absorber into some thermal fluid (water or oil). Concentration capacity of the mirrors is approximately 30 times sun’s energy normal intensity. As for parabolic troughs, thermal storage can be added to the system.

The fluid then goes through a heat exchanger to power a steam generator, thus producing electricity and heat as a by-product. LFR technology has great advantages on parabolic troughs and is the most promising technology in CSP. First, manufacturing process doesn’t need high precision in bending mirrors, keeping Fresnel mirrors at a low cost, with manufacturing sites close to the installation location; then, structure and equipment are much lighter than parabolic troughs, which is another cost saving argument.

Fig 8.2 Fresnel lens

8.3 FLAT PLATE PHOTOVOLTAIC

Photovoltaic panels generate electrical power through the use of semiconductors, converting both DNI and diffuse irradiation into electricity. The most efficient photovoltaic technology is a flat-plate module with a core composed of mono-or polycrystalline silicon cells, which. A less efficient panel uses a thin film of cadmium telluride deposited onto a substrate. The cells or film absorb both direct and indirect solar radiation, which excite the electrons and induce an electric current. The panels are interconnected into a circuit to convert the direct current into an alternating current for the grid. With diffuse collection, flat plate PV systems can operate effectively under conditions of light cloud cover.

8.4 CONCENTRATING PHOTOVOLTAIC

Almost similar to the Flat Plate PV, CPV technology is the most promising one with the following differences:

CPV technologies use DNI as a solar source instead of Global Irradiation.

CPV systems incorporate optical components such as mirrors combined with optical devices, to concentrate the DNI onto the photovoltaic cell, thus improving significantly the solar energy reaching the surface.

CPV technology uses multi-junction cells designed to convert a whole spectral region of solar radiation to reach great efficiencies, almost double the efficiency of the conventional PV solar cell.

CPV technology requires a highly accurate two-axis tracking system with tracker control units to continuously track the sun for a maximum DNI during daytime.

CPV technology may need cooling systems to disperse heat due to high concentration of solar radiation on cells.

9. COUPLING SOLAR ENERGY AND DESALINATION

When coupling desalination methods and solar power, it can result in many combinations. In that part, we will describe and evaluate here projects already realized mainly PV/RO, parabolic troughs/MSF, parabolic troughs/MED.

9.1 PHOTOVOLTAIC / REVERSE OSMOSIS

Many demonstration plants were carried out coupling RO systems with solar PV electricity. Most common way is to convert DC from PV panels through an inverter, to produce AC immediately used in pumps. Some developments anyway were done on connecting panels to a brushless DC motor, powering a low pressure pump, thus allowing direct use from PV panel to pump. Furthermore, battery banks are added to the system to store energy during night time to allow continuous running of RO operation.

PV-RO systems of capacities ranging from 0.5 to 50m^3/d have been installed as demonstrators. Regarding costs, investment cost is higher than conventional RO, but also vary on location, quality of saline water and plant capacity. Cost is extremely dependent from one location to the other, ranging from 30 US$/m^3 down to 3 US$/m^3 Cost reductions have been investigated, smartest approach is to eliminate storage battery (giving 15-20% of cost reduction) with varying flow of seawater through membrane with regards to available energy.

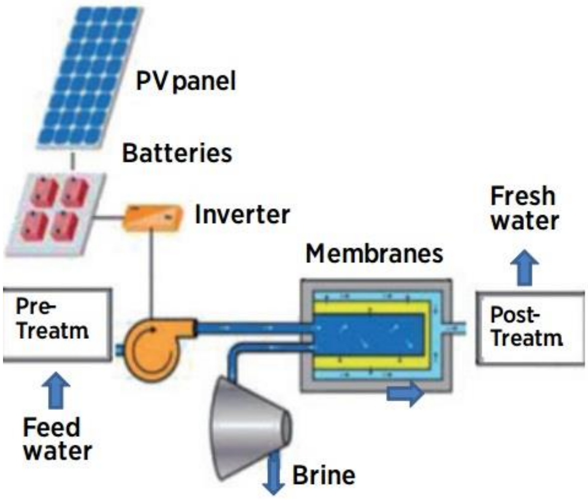


Fig 9.1 Coupled PV and RO desalination plant

9.2 PARABOLIC TROUGHS / MULTI STAGE FLASH

The MSF process as a thermal process can also use solar power with parabolic troughs. Steam produced by parabolic troughs is used as heat source through a heat exchanger for MSF inlet. A thermal storage system can be added to the system to smooth variation of thermal energy supply and allow the continuous production of fresh water (during nighttime or low radiation period). Demonstrator realised in Kuwait showed a capacity of 10 m^3/d, for a surface parabolic trough collector of 220 m^2. This corresponds to the average 10 - 60 l/m^2.day for solar powered MSF. There are commercially available small-scale units combining MSF process with steam generating parabolic troughs, whose approximate costs is 7-9 US \$/m^3 of produced freshwater.

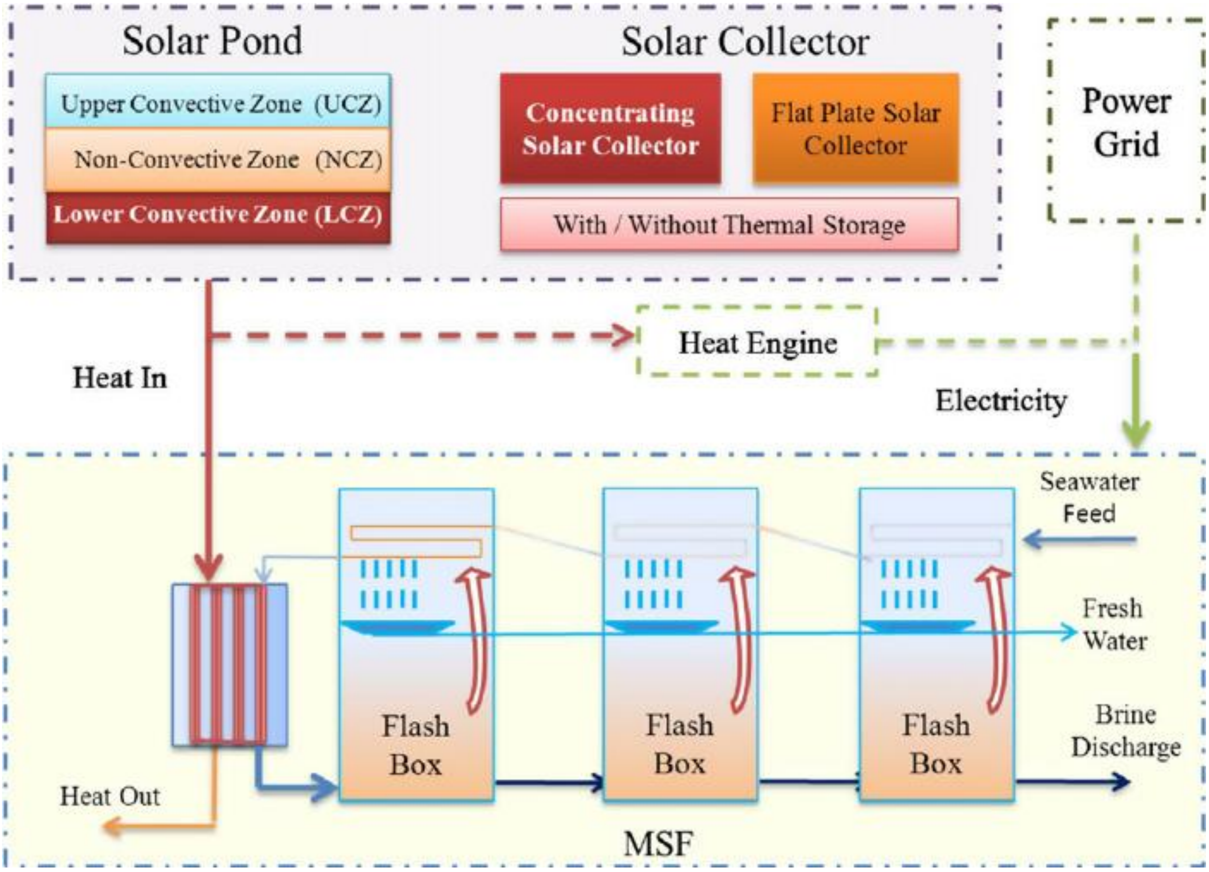


Fig 9.2 Coupled CSP with Multi stage flash desalination plant

9.3 PARABOLIC TROUGH / MULTI EFFECT DISTILLATION

We can find more installations of MED worldwide, coupled with solar energy from different technologies. Water production cost for seawater desalination with MED coupled with a solar field has been proven to be quite dependent from plant capacity: for large plants (5000 m^3/d), cost is around 2 US $/$m^3$ and is increasing up to 3, 2 US$/$m^3$ for smaller plants (500 m^3/d).

Also as an example, Abu Dhabi installation can run 85 m^3/day of freshwater; in that case, heat source is water passing through evacuated-tube solar collectors (1862 m^2). After several years of operation, critical point of the installation was maintenance of the pumps due to silt removal. Some demonstrators were also realized to prove a total autonomy on energy with both thermal and electric energy (Parabolic troughs and PV panels). Aquasol is a hybrid project running with both gas and solar energy. Now in operation for several years, freshwater production is 3 m^3/h of freshwater, combined to parabolic troughs with a surface of 500 m^2.

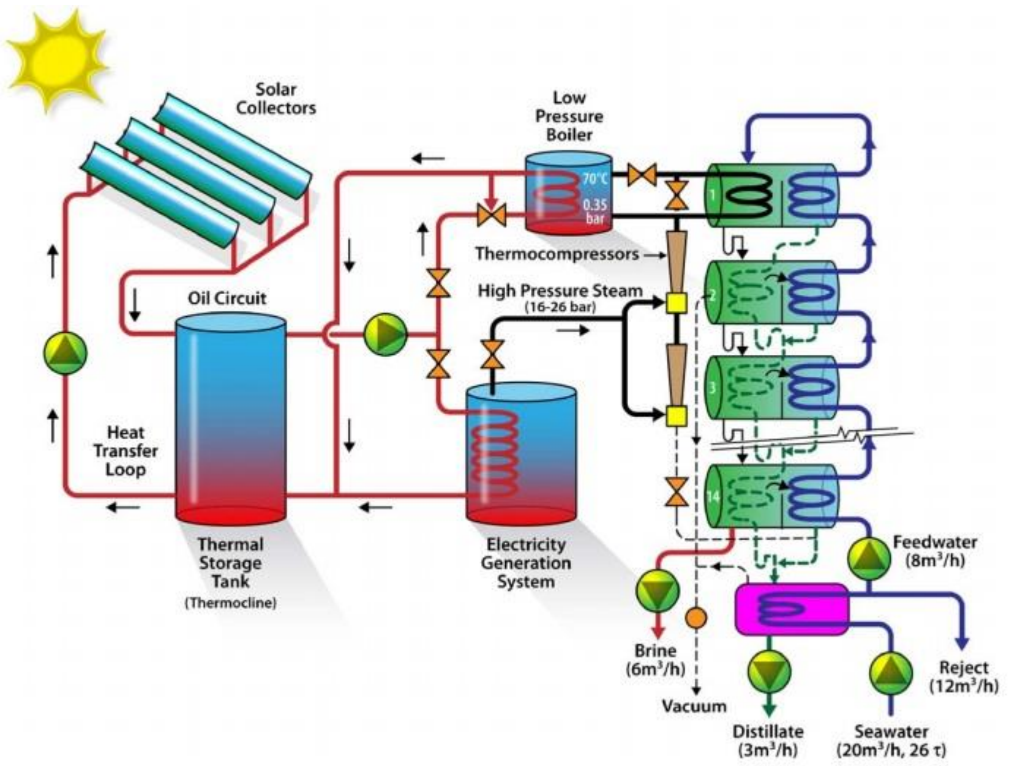


Fig 9.3 Coupled CSP with Multi effect distillation plant

10. CONCLUSION

Solar MED and MSF, though appearing to be natural and tempting solutions, cannot be taken as proven technologies. More and more developments in both solar power and desalination technologies are expected to keep these solutions competitive compared to RO systems coupled with conventional power plant. Somewhere, solution lies in combination: combination of heat sources and combination of processes. Recent developments present desalination systems including MSF combined with reverse osmosis, heat source being a thermal power plant, but coupling with solar resource can be imagined.

Main advantage of that installation is that RO can run during night times when electricity costs are low and MSF work during daytime with low running costs due to low pressure steam. Water storage offers flexible solution with energy consumption optimized. Addition of solar energy from start of the project (with parabolic troughs) would have low cost impact but no Greenhouse gas emissions.

We can note that the range of possibilities is widely open in desalination. Need for fresh water will always be present, therefore desalination technologies must be enhanced to become cleaner, more efficient and more virtuous.

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