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Concentrating solar power (CSP)-desalination systems: A review.

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ABSTACT: Several countries around the world are suffering from water stress. Desalination of seawater can be a solution for water supply. However, this alternative is energy intensive for poor countries. In this article, we have reviewed the literature on the possibility of connecting new solar stations called Concentrating Solar Power stations to thermal or membrane desalination stations and the future prospects of this combination. Concentrating Solar Power technologies are technically very diverse and are already seen as an energy source for desalination plants instead of fossil fuels. The development of new hybrid schemes, maximizing thermal efficiency and minimizing costs through the thermal energy storage system, offers a potential means to accelerate the commercialization of these hybrid plants.

KEYWORDS: Water supply, Desalination, Solar Desalination, water cost.

I. INTRODUCTION

SeveralregionsintheworldsuchastheMiddle East and North Africa(MENA)regionsuffer from water scarcity (Sinan and Belhouji, 2016) because water demand exceeds the available resources and the demand on water is increasing (Daghari et al., 2020). Thus, in the future, the installation of new desalination stations must be planned to fill this shortage (Verdier and Viollet, 2015) but a major environmental problem has arisen. Themainproblemwiththeuseoffossilfuelsisthattheyareverypolluting; thecarbonintensity of electricity generation from fossils fuels is considerable. This is partly the cause of global warming. The excessive use of fossil fuels, such as coal, gas and oil, produces far too much greenhouses gas. These gases cause global warming. Moreover, these energies serve us on a daily basis so as they are used a lot, in a few years they will be exhausted and we will not be able to count on them anymore and they are not renewable sources. However, in desert regions as the Middle East and North Africa (MENA) Region where direct solar irradiance is high, a new generation of thermal plants called Concentrating Solar Power plants is seen as a promising technology for water desalination (Al Ansari, 2013).CSP technologies use mirrors to focus light energy from the sun and convert it into heat to create high temperature steam to drive a turbine that generates electrical energy for osmosis reverse (RO) or this heat can be used as thermal energy to desalinate the feed water in the Multi-Stage Flash (MSF) and Multi-Effect Distillation (MED) plants (Laborde and Perret, 2010). These power plants are made up of two parts: one that collects solar energy and converts it into heat and the second part that converts thermal energy into electricity for power generation. CSP plants built in recent years are often fitted with thermal storage energy (TES) systems to extend operation when solar radiation is not available (Mohammadia et al., 2019). CSP plants are also large enough to provide the base energy for medium to large scale seawater desalination. CSP technologies work with four alternative technological approaches: trough systems, power tower systems, antenna / motor systems, and Fresnel linear reflector.

II. CONCENTRATING SOLAR POWER TECHNOLOGIES

Trough parabolic systems : Trough parabolic systems use parabolic trough-shaped mirrors, each mirror concentrates light on a tube containing oil or similar fluid that takes the heat to where it can be used to generate electricity (Pic.1) or desalinate feedwater by thermal energy in thermal desalination plants (MED, MSF).

Picture1: Trough system (picture: Issam Daghari, 2015)

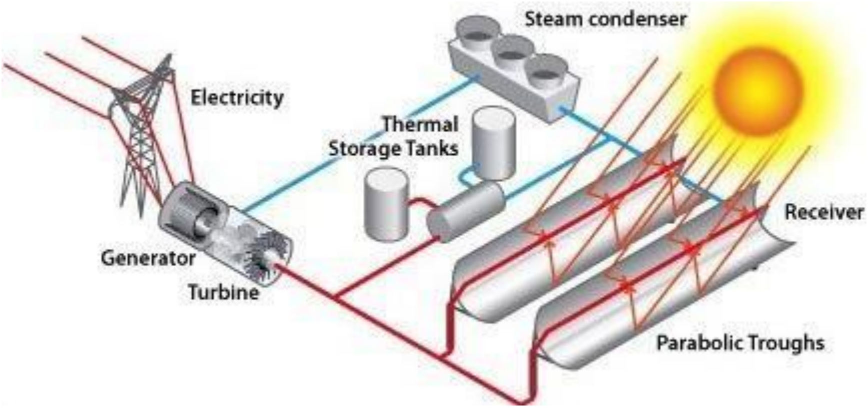


Figure 1: Concentrating Solar Power Plant Using Parabolic Trough Collectors. (Abengoa Solar, 2013)

Picture2: A sea of mirrors directs a powerful beam of light toward a solar power tower. (NASA, 2016)

Power Towers: The solar power tower is a type of solar furnace using a tower to receive the focused sunlight. It uses movable mirrors called heliostats (Pic. 2) to focus the sun's rays upon acollector tower (the target). Then it's the same way for the production of electricity or to desalinate feed water by comparing it with the previous technology (Fig. 2).

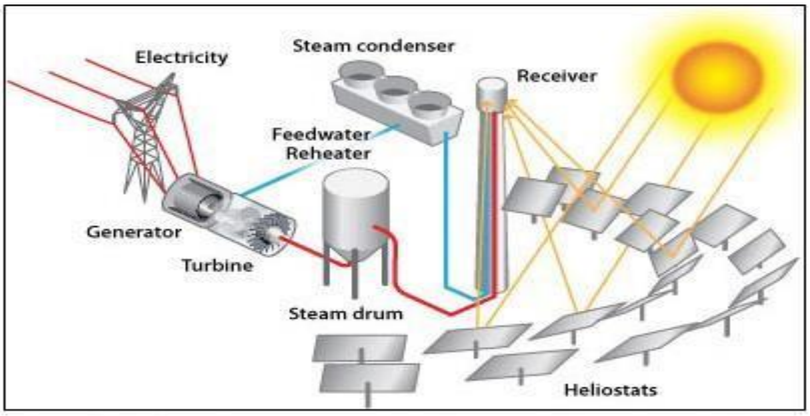
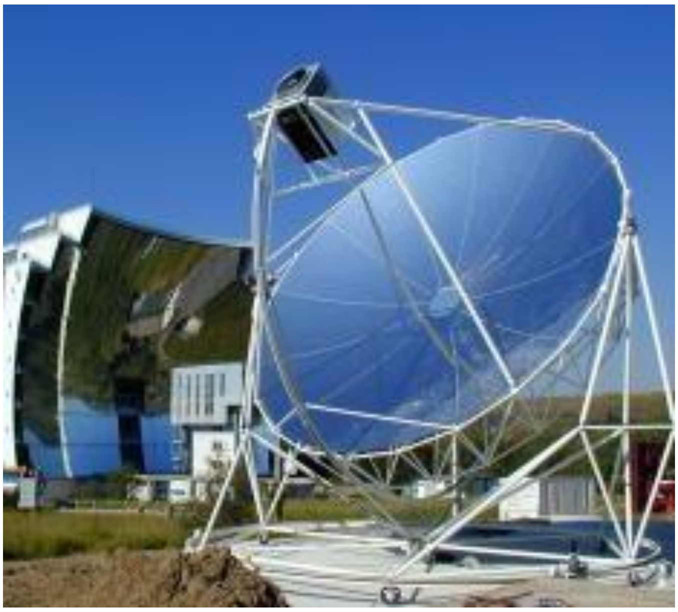


Figure 2: Power Tower Power Plant (Abengoa Solar, 2013)

Dishsystems: AdishStirlingsystemusesalargereflectiveparabolicdishsimilarinshapetoasatellite television dish (Pic. 3). It focuses all the sunlight that strikes the dish up onto a single point above the dish, where a receiver captures the heat and transforms it into electricity (Fig.3).



Picture3: Stirling Solar Dish Engine (Reinalter and al., 2007)

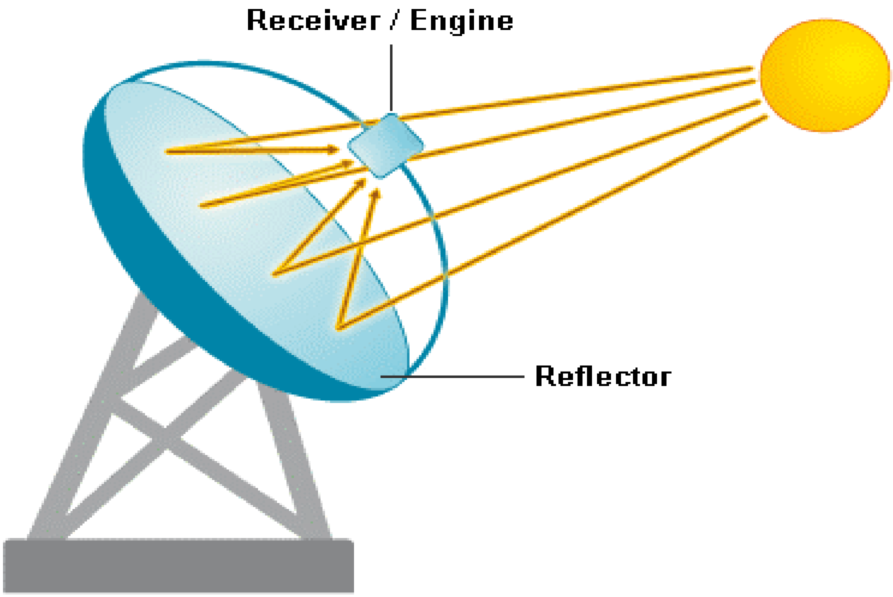


Figure 3: Parabolic dish system (Word Press, 2012)

Linear Fresnel Reflector : In linear Fresnel systems, as with parabolic-trough collector systems (Pic.4) solar radiation is concentrated onto a line and can be coupled to steam cycles for electricity generation. These systems have been developed with the aim of attaining a simpler design and at less cost than the parabolic-trough systems, (Palenzuela and al., 2016). The first prototypes have shown promise and the first CSP plants that include this technology are currently in the construction phase. The collectors in a linear Fresnel system are made up of a large number of mirror segments that can individually follow the path of the sun (Fig. 4).

Picture4: A linear Fresnel Reflector (Solar Energy Industries Association, 2014)

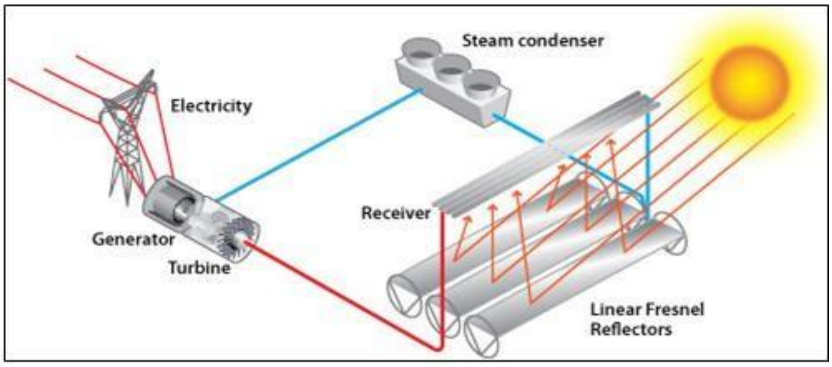


Figure 4: Linear Fresnel Reflector Power Plant (AbengoaSolar, 2013)

In the table 1, there is a comparison of concentrating solar power technologies. As conclusions, Fresnel systems offer some advantages over parabolic troughs. The footprint is lower as the distances between mirrors are much smaller. The collector aperture area covers between 65% and 95% of the required land, while for a parabolic trough, only 33% of theland iscoveredbymirrors,becausethedistancesbetweenthesingleparabolic-trough-rowsrequired to avoid mutual shading are considerable. Land use efficiency of a linear Fresnel can thus be about 3 times higher than that of a parabolic trough. Considering the lower optical efficiency of the Fresnel (2/3 of that of a parabolic trough), this leads to a roughly two times better solar energy yield per square meter of land of the Fresnel system when compared to a parabolic trough.

Table1: Comparison of concentrating solar power technologies, (Fichtner, 2011)

Technology	Parabolic Trough	Linear Fresnel System	Solar Power Tower	Dish Stirling Engine
Application	Superheated steam for grid connected power plants	Saturated and superheated steam for process heat and for grid connected power plants	Saturated and superheated steam for grid connected power plants	Stand-alone, decentralized, small off-grid power systems. Clustering possible
Capacity Range (MW)	10 – 250	5 – 250	10 – 100	0.1 – 1
Peak solar efficiency	21 %	15 %	< 20 %	31,25 %
nnual solar efficiency	10 – 16 % (18 % projected)	8 – 12 % (15 % projected)	10 – 16 % (25 % projected)	16 – 29 %
Heat transfer fluid	Synthetic oil, water/steam demonstrated	water/steam	ir, molten salt, water/steam	Air, H2, He
Temperature (°C)	350 – 415 (550 projected)	270 – 450 (550 projected)	250 – 565	750 – 900
Operation mode	Solar or hybrid	Solar or hybrid	Solar or hybrid	Solar or hybrid
Land Use (m²/MWh/year)	6 – 8	4– 6	8 – 12	8 – 12
Development Status	Commercially proven	Recently commercial	Semi-commercial	Prototype testing
Storage options	Molten salt, concrete, Phase Change Material	Concrete for pre-heating and superheating, Phase Change Material for evaporation	Molten salt, concrete, ceramics, Phase Change Material	No storage available
Reliability	Long-term proven	Recently proven	Recently proven	Demonstrated
Advantages	- Long-term proven reliability anddurability · Storage options for oil- cooled troughavailable	- Simple structure and easy field construction - Tolerance for slight slopes - Direct steam generation proven	- High temperature allows high efficiency of power cycle - Tolerates non-flat sites- Possibility of powering gas turbines and combinedcycles	- High temperature allows high efficiency of power cycle - Independent from land slope - High modularity
Disadvantages	- Limited temperatureof heat transfer fluid hampering efficiency and effectiveness - Complex structure, high precision required during field construction Requires flat landarea	- Storage for direct steam generation (Phase Change Material) in very early stage	igh maintenance and equipment costs	- Not commercially proven - High complexity compared to stand-alone PV - No storage available

Desalination and CSPfeasibility: Desalination is introduced as a major option for water production in the medium and long term to close eventually opening gaps of water supply (Haouchine and al., 2016; Barraque and al.,2017). The table 2 shows desalination by CSP towards the year 2040 will be the second water supply source with 79,5 10^9 m^3 ahead of the wastewater reuse with 44,1 10^9m^3.

Table2: Water supply ($10^9m^3/yr$) within the average climate change scenario for MENA (Fichtner, 2011)

Year	2000	2010	2020	2030	2040
Unsustainable Extractions	32,4	47,01	44,6	9,1	7,1
CSP Desalination	0	0	23,4	55,8	79,5
Conventional Desalination	4,6	9,21	12,7	9,7	1
Wastewater Reuse	4,4	4,93	17	29,6	44,1
Surface Water Extractions	185,2	173	146,7	162,1	165,7
Groundwater Extractions	39,1	43,1	48,1	41,5	36

Different configurations for desalination powered by heat only, power only or combined heat and power are given in figure 5.The storage of thermal energy is possible for the MED and RO desalination technologies. This thermal energy can be converted by a power generation plant if the desalination plant is powered by electric power. The storage unit provides backup power when there is no solar radiation. This is verified in the CSP station of Ouarzazat in Morocco, where the solar station provides electricity 24 hours a day, 7 days a week (World Bank Group, 2014).

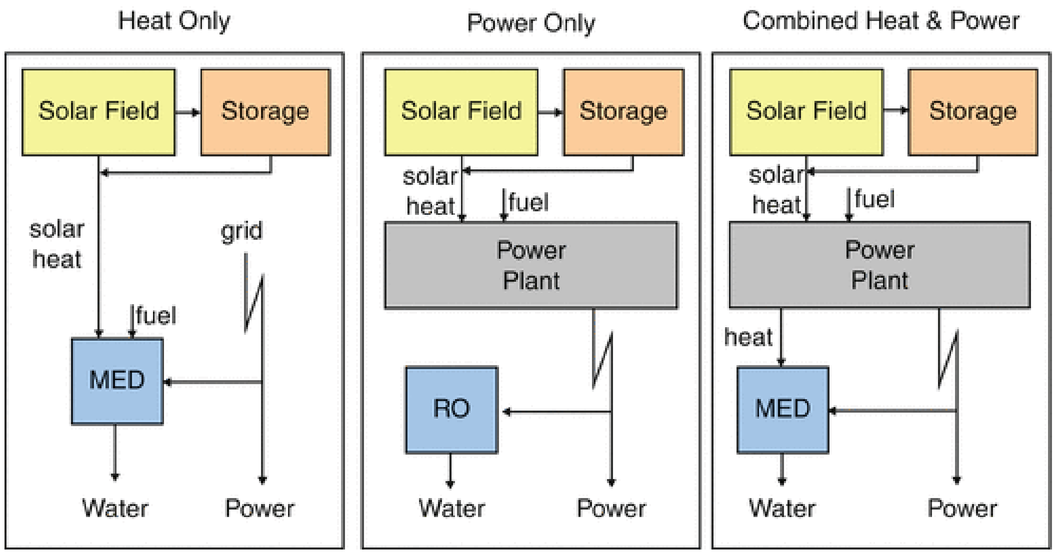


Figure 5: Different configurations for desalination powered by CSP. ("Left: Solar field directly producing heat for thermal multi-effect desalination". "Center: Power generation for reverse osmosis (RO)". "Right: Combined generation of electricity and heat for thermal multi-effect desalination" (German Aerospace Center, 2007)

Inseveralcountries,inspiteofbeingthelastoptionaccordingtotheassumptionsmade, seawater desalination combined with CSP achieves a major share of water production in the medium and long term. CSP plants can be designed from 5 Megawatt (MW) to several 100 MW of capacity. The growing MENA water gap can be eliminated by around 2030 (Fichtner,2011) if immediate political steps are taken now to introduce and expand CSP desalination technology in a decided way because water cost prices have been steadily decreasing as new CSP plants generation became available in recentyears.

A study carried out in 2013 (AlKaraghouli and Kazmerski, 2013) showed that the cost of water production from MED desalination coupled to a CSP station varies from 2.4 and 2.8 $/m^3 for a capacity greater than 5000 m^3 without thermal energy storage system. However, in the same study, when a thermal energy storage system is presented, the cost of the product water of the CSP/MED units declined from 0.71 to 0.89 US $/m^3.We have noticed that the cost of the cubic meter of desalinated water decreases in the presence of thermal energy storage. Indeed, the thermal energy storage for CSP plantsis a new determining factor in the cost of water. All existing CSP desalination concepts have exactly the same prospect of further increasing the time of electricity generation by using a thermal energy storage source with molten salt technology that stores thermal energy for hours. An attractive water price was measured in Jordan (AlAddous et al., 2020) for the CSP/MED configuration for a sale price of 0.58$/m^3 with the energy storage option. The same author conducted a study on the annual energy efficiency of a CSP plant design with a MED desalination plant. Using a fully loaded 6-hour thermal energy storage system, the electricity production of the desalination plant was 317.7 GWh with storage and only 195.84 GWh without storage. A CSP/MED and CSP/RO techno-economic analysis in the Mediterranean region as well as in the MENA region was studied with 6.5 hours of thermal energy storage (Palenzuela et al., 2015). The cost of desalinated water obtained from thermo-economic analysis in Abu Dhabi varies from 0.92to 1.02$/m^3 while the cost of desalinated water obtained from thermo-economic analysis in Almeria in Spain varies from 1.07 to 1.22$/m^3. Generating electricity in large CSP Plants with thermal storage can have significant energy and economic benefits for supplying regions with high direct solar radiation and good access to seawater (AIP Conference Proceedings, 2016).

III. CONCLUSION:

Thermal Desalination Plants (MED) and CSP Solar units can be interconnected for water supply to urban cities. This connection does not require a physical phase change for the thermal energy produced by the CSP units and furthermore this thermal energy can be stored as a steady backup energy which is the determining factor in the desalinated water unit cost. This will create fresh water when there is hardly any left on earth. Certainly, this configuration should be the subject of several studies at the state level so that the political decision-makers begin to think about this alternative for the water supply of arid countries even for the irrigation of agricultural perimeters.

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