Water Desalination Driven by Solar Energy

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Abstract: - The abundance of drinking water is necessary for daily needs, but recently it has become a worrying obsession worldwide, as it requires the use of fossil fuels for its production, and since the whole world is moving to reduce greenhouse gases emissions, it was necessary to think about using alternative renewable energy in the production of drinking water and that was through desalination of salty water. Solar energy has been widely used. The methods that use solar power are divided into direct and indirect, which include several steps, and the solar energy systems used are varied. In the present study, desalination methods and some types of solar energy systems used are mentioned with a comparison of the amount of production and costs, in addition to the improvement resulting from the use of PCM. It was found that the solar Fresnel lens system is the most effective in producing fresh water compared with its cost. The solar desalination stations in Jordan are 29 and only 1 solar-powered desalination plant out of them, but the universities and independent factories have their solar deamination systems.

Key-Words: - Water desalination; Solar energy; PCM in solar desalination; direct solar desalination; Jordan water desalination.

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1 Introduction

The fact is that water covers about 71 percent of the earth's surface, but it's a challenge to meet all life's needs in freshwater, since freshwater is 2.5 percent as quantity where most of it is groundwater, ice caps, and glaciers, and only 0.008 percent is the accessible freshwater on the surface [1]. Water desalination became one of the most promising solutions for providing fresh water, which is defined as removing salts and minerals from saline water [2]. Water desalination required 10000 tons of fossil fuel per year to produce 1000 m3 of water each day [3].

Using renewable energy, mainly solar, instead of fossil fuel for the same purpose of producing fresh water will decrease the effect of global warming and climate change by reducing the carbon footprint and greenhouse gases emission. This review study will be focused on solar desalination systems, their methods, comprising cost and outcomes, and using the PCM in such solar desalination systems.

1.1 Water desalination

Due to the shortage of freshwater, nowadays, the world adopted desalination of saline water and it became a worldwide use technique using different technologies [4].

The whole process of desalination involves three-four steps as follows.

1. Pumping water from sea or saline aquifers,
2. Pre-treatment of pumped water like filtration or chemical addition,
3. Desalination process,
4. Post-treatment if needed such as adding a few minerals.

Different ways are used in water desalination with the aim of producing freshwater, and the most common ways are Reverse Osmosis, Multi-stage Flash Process, and Multi Effect distillation [5,6]. Using thermal energy in running the desalination plans by using fossil fuels, was seen to require a huge amount of energy which makes it unviable from both sides; economically and ecologically which mainly affects global warming and it's not a permanent energy source [7,8].

1.2 Renewable energy in water desalination

The use of green energy resources, (Renewable energy) in water desalination within its technologies is a good alternative source to lessen the impact on climate due to the desalination [9].

Solar-water desalination is defined as the process where the salt is dismantled from the salt water by using solar energy [8,10]. It was recognized that solar desalination is a very good technique from the

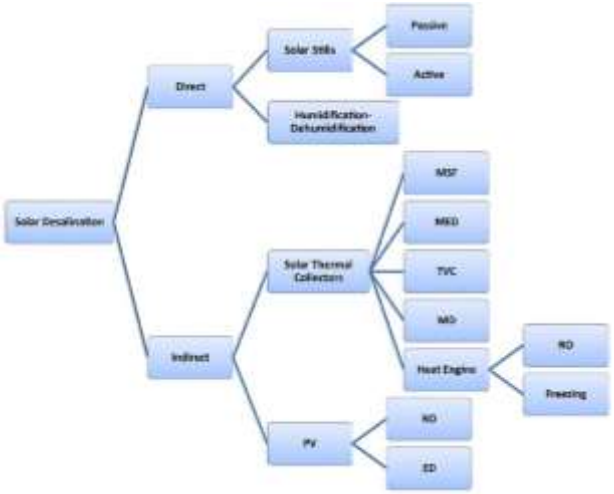
economic and environmental point of view that producing fresh water from saline water [11], and that's due to the natural validity of solar which is free from the cost used directly in water desalination [12].

Many advantages of using solar energy in water desalination and mentioning here [13]:

1. Zero impact on the environment
2. The least maintenance
3. Low cost in operation
4. Moderately skilled works.

2 Solar Desalination Methods

There are two categories where solar desalination is applied, those are; direct and indirect techniques, the direct method means that both the desalination process and solar radiation are collected at the same location, whereas the indirect is the opposite, as the collection of solar radiation in an indirect way to be used in different locations [6,14]. Fig. 1 shows the most commonly utilized processes of desalination which are compatible with solar energy.



MSF: Multi–Stage Flash, MED: Multi–Effect Distillation, TCV: Thermal Vapor Compression, MD: Membrane Distillation, RO: Reverse Osmosis, ED: Electrodialysis.

Fig. 1. Direct and indirect solar desalination processes [14].

2.1 Solar desalination in Direct Method

Simply, the direct method is the direct collection of solar energy and desalination of the saline water in the same place. And it's one of the sustainable methods to get fresh water from saline water [14]. In the direct method as shown in Fig. 2, the devices could be operated in passive and active modes, one of the oldest and simplest direct water desalination techniques is solar still, and it featured low fabrication cost as well as maintenance, and technology is environmentally friendly [15]. The good use of solar still, which is designed properly and energy-efficient will reduce the effect of a carbon footprint on the environment [16]. Another type of direct solar desalination is the solar bonds, their design based on increasing salinity relative to depth, where the solar radiation would increase the water temperature [17].

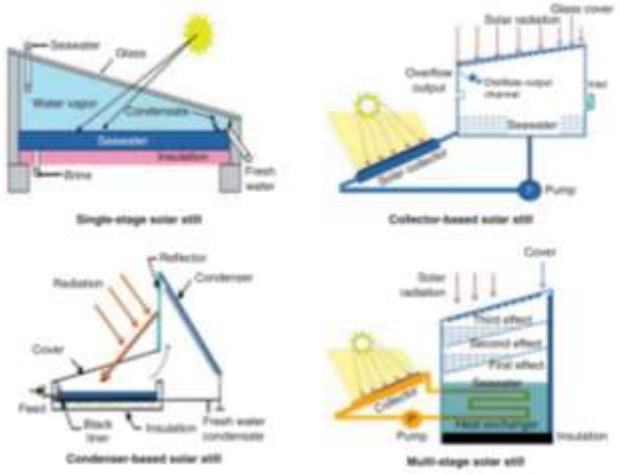


Fig. 2. Different configurations of solar stills [18].

2.2 Solar desalination in Indirect Method

A combined sub-system is the structure of indirect solar desalination, one for collecting solar radiation and another for the desalination process. The first one is used for collecting solar radiation via collectors and supplying it through the heat exchanger for thermal desalination or transferring the heat to electricity via PV cells to run the physical desalination process as shown in Fig. 3 [18]. The indirect solar desalination method applies in two ways, the first is the single-phase process that uses photovoltaic and the other is a multi-phase process that does not depend on the membrane [19-21].

Therefore, it's clear the direct method could be used on a small scale and the indirect for a large scale, which means the direct method can work effectively in low temperatures, and for collecting more solar radiation which means producing more fresh water, then the indirect method is more effective.

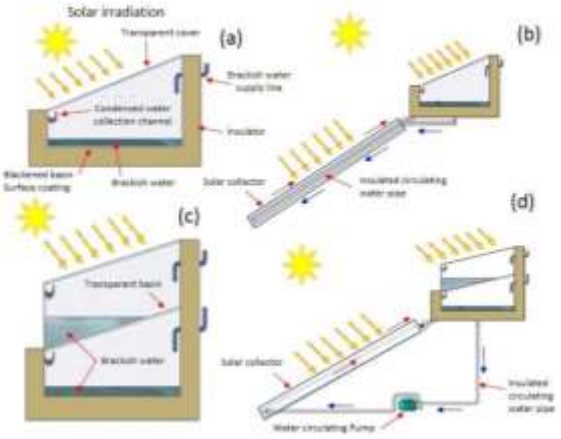


Fig. 3. Indirect solar desalination [22].

3 Solar desalination with PCM

Recently, heat storage became present in the theatre due to its various engineering applications, which depend on using the Phase Change Material (PCM). Solar desalination is one of the popular methods using storage systems [23, 24].

3.1 Solar desalination with PCM components

As shown in the above Fig. 4, the solar desalination system contains the following: condensing glass cover; the mixture of heated air and steam; brackish water, basin liner (Absorber), the storage medium (PCM), thermal insulation, non-return valve; outlet of distilled water, floating water level switch, feed tank, and brackish water reservoir [25].

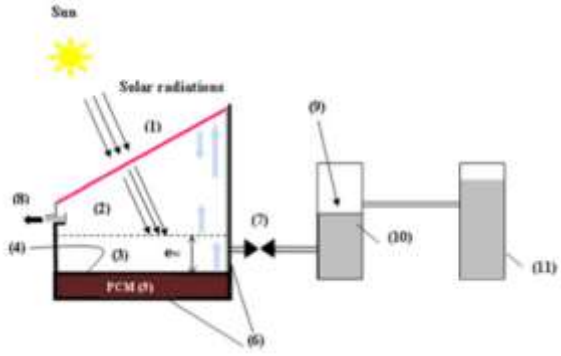


Fig. 4. System schematic diagram [25].

3.2 Analysis of using PCM in solar desalination

In Jeddah, Saudi Arabia, the stearic acid has been used as PCM during summer and winter, 3.3 cm of it under the basin line showed that the coefficient of convective heat transfer from the basin liner to basin water increased to double, and the evaporative heat transfer coefficient became 27% [26].

Another PCM, which is paraffin wax, has been used to keep the high temperature of the still to produce distilled water during the absence of solar radiation. Especially at night, taking into consideration that there are some factors affecting the performance of the still-like distance between water and glass surface, and the level of water on the absorber [27]. In Morocco, have been used three types of PCM with different melting temperatures, and it was recognized from the results that the excess energy produced during the daylight, is stored within the PCMs to be used later, and highlighted the most important factor to choose the PCM depends on the temperature of the brackish water which could reach it [28]. Analysis in Fig. 5, has been performed and comparing the thermal performance of PCM in solar still, and as shown in the below figure, the water temperature without PCM between 9 a.m, and 12 p.m. is the highest, where we can store energy in this time, with using PCM caused higher temperature for more time 2 p.m. to 7 p.m. The use of PCM will reduce the temperature drop, as the energy in the PCM will be released by sunset [29]. As shown in below Fig. 6, the performance of solar desalination depends on the distillation amount, which concluded that adding more paraffin produces more fresh water which indicates the performance of the still, and that's due to the basin being kept warmer because of PCM [29].

Fig. 5. Comparison between temperatures in the absence and presence of PCM and nano-PCMs [29].

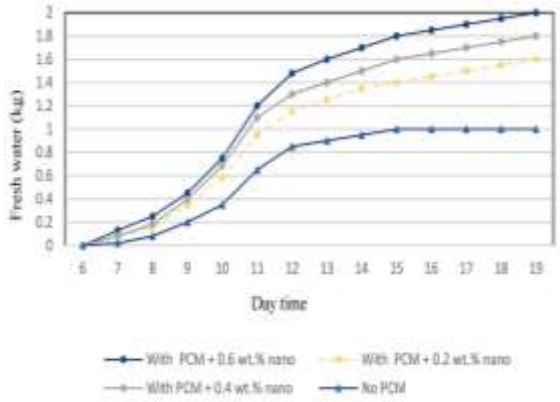


Fig. 6. Freshwater production in the absence and presence of PCM and nano-PCMs [29].

The use of PCM has been a benefit to solar desalination and that is due to having more time out of the day using the heat stored, working in a wide range of temperatures, and producing more freshwater.

4 Solar systems applications in solar desalination

Many concentrated collectors were used combined with still, like the Fresnel lens, parabolic trough, and parabolic solar dish [30].

Different solar collectors can be companies and used in water desalination, they can be classified into concentrating or non-concentrating, which affect the flux of radiation, also it could be tracking or non-tracking, the choice of the solar collector is based on the operative temperature as in the below Table 1 [31].

Table 1: Solar collectors.

Tracking	Collector Type	Absorber	CR*	Operational range
Stationary	Flat plate	Flat	1	30-80 ºC
	Evacuated tube	Flat	1	50-200 ºC
	Compound parabolic	Tubular	1-5	60-240 ºC
Single-axis	Compound parabolic	Tubular	5-15	60-300 ºC
	Linear Fresnel	Tubular	10-40	60-250 ºC
	Parabolic trough	Tubular	15-45	60-300 ºC
	cylindrical trough	Tubular	5-50	60-300 ºC
Double-axis	Parabolic dish	Point	100-1000	200-500 ºC
	Heliostat field	Point	100-1500	150-2000 ºC

*CR: Concentration ratio

3.1 Fresnel lens application in solar desalination

The use of the Fresnel lens as shown in Fig. 7 has the attractive characteristic to redirect the concentrated radiations, which could be combined with a unit to receive the lights; it was shown that such use of Fresnel in solar radiation would produce about 355 kg/day, and the cost of it around $23.4/m^3 [32].

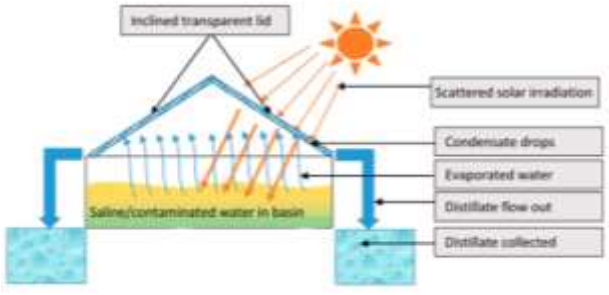


Fig.7 Fresnel lens combined with solar desalination [33].

3.2 Parabolic trough application in solar desalination

Solar desalination powered by the parabolic trough as shown in Fig. 8, is one of the promising systems for desalination, although it has less area for less heat loss, its more commercially distributed, this solar system by PTC could produce 459.9 MW of electrical power and 3628 kg/h of pure water [34]. In producing freshwater with a capacity of 4545 m^3/day it required 1.57$/m^3 [35].

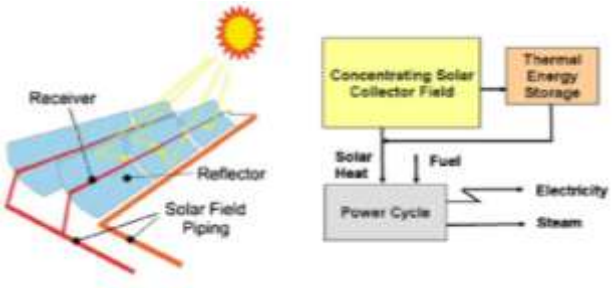


Fig. 8 Parabolic trough combined with solar desalination [36-38].

3.3 Solar dishes Stirling application in solar desalination

Solar dishes Stirling system is highly considered in solar desalination as a big amount of solar can be concentrated which led to an increase in the temperature to produce more electrical power and pure water as shown in Fig. 9, it was observed that can produce 14 kW and 20.05 kg/s of pure water [39]. The cost of producing fresh water from such a system is about 0.35$/m^3 to produce 1.8 m^3/ day [40]. In below Table 2 and Fig. 10, I conclude the comparison of the three used systems in three parameters; electrical power needs, pure fresh water produced, and the cost for this freshwater production; as shown the solar dish is the best among the three systems in producing fresh water comparing its cost.

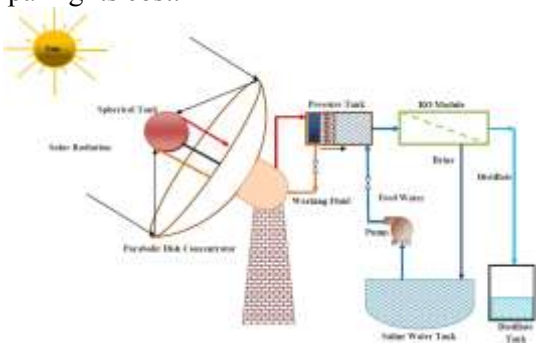


Fig. 9 Solar dishes combined with solar desalination [41].

Table 2: Comparison of the solar collectors.

Parameters/system	Fresnel lens	Parabolic trough	Solar Dish Stirling
Electrical power	37	459.9	14
Pure water	355	1.01	20.05
Cost ($/m^3)	23.4	1.57	0.35

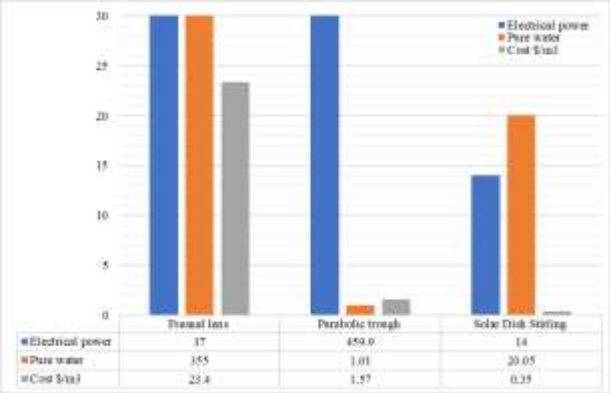


Fig. 7. Comparison between the use of Fresnel lens, Parabolic, and dish.

5 Solar water desalination in Jordan

In 2020 Al-Hashimiya desalination plant run and the implementation of this project came following the vision to enhance the principle of the university's independence and self-reliance in a very important field, which is the provision of water and the diversification of its sources. The desalinated water is desalinated according to the most advanced technology, which relies on membrane units for desalination and filtration of water by reverse osmosis (Reverse Osmosis Desalination Plant) and in eight stages, with a production rate of (83) cubic meters per hour. This product has achieved self-sufficiency for the university, so that the amount of production is equal to three times the university's daily consumption of its needs for drinking, irrigation, and others, which led to saving approximately (600) thousand dinars annually, depending on their sources of water supply from the three artesian wells located on the university campus entirely [42].

The Jordanian Phosphate Mines Company and the British "Solar Water" signed in 2022; the construction and operation of a seawater desalination plant using concentrated solar energy to provide the needs of the industrial complex of the Phosphate Company in Aqaba from industrial water. It will contribute to meeting the needs of the industrial complex of water, which is estimated at 4 million cubic meters annually, and achieve financial savings for the company of up to 3 million dinars annually. The work system in the new station provides high and efficient storage capacity at a lower cost and enables it to operate 24 hours a day [43].

Limited freshwater resources in Jordan as well as suffering from limited sources of fossil fuel have led Jordan to consider renewable energy choices like solar energy, which is an attractive option for remote areas in small-scale applications. Another obstacle in Jordan is the low water quality and shortage in supplies where solar energy is used to produce fresh water not only for the remote area but also for additional supply.

Solar desalination is the most promising source for having fresh water at a low cost and good quality. The two methods of solar radiation (direct and indirect) can be employed in an effective way by coming solar systems (Fresnel lens, solar dishes, or parabolic), adding a PCM has highlighted a new great benefit which is reserving more time during the day to produce fresh water.

6 Conclusion

The advantages of using solar energy in water desalination are that it reduces cost, effort, and time consumed and in parallel produces fresh water while saving the environment. Comparing the three, solar desalination systems are driven by different applications. It has been obtained that solar Fresnel lens collectors are the most effective systems in water desalination. In addition to the high advantage of using the PCM inside the solar still, which keeps the high temperature of the still that is mean, keeps the system running for more time. Jordan is working hard to have on their map many solar desalination systems. The universities and some factories in Jordan make use of such technology to build some water desalination systems in their area to supply it with fresh water.

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