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Multi-Effect Desalination Powered by Concentrated Solar Power: A review

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Abstract

The desalination market is gradually growing as a result of the significant water scarcity in various regions throughout the world. Concentrated solar power (CSP) can be used to power distillation, which is an effective method for addressing water shortages in areas where there is both a severe lack of water and abundant direct normal irradiation. CSPs are ideal candidates for the advancement of desalination technologies due to their capacity to produce both thermal and electricity energy. This review article offers a comprehensive of the current status of cutting-edge CSP-desalination systems. The paper reviews previously published studies conducted by researchers in the field of multi-effect desalination using concentrated solar collectors, and they are classified into two main types. Exclusively freshwater generation and freshwater / electricity cogeneration. In addition, the paper reviews conventional desalination. This review illustrates that there are numerous prospective methods for integrating desalination systems into CSPs. Potential areas for future investigation in CSP-desalination systems. In particular, the most significant obstacles to be surmounted are lowering the costs and efficiency improvements of solar repayment and desalination equipment. A potential method to expedite the commercialization of these plants is to develop innovative strategies that optimize thermal efficiency and reduce costs. Environmental factors (solar radiation intensity, ambient temperature and wind speed) and design factors (solar field area, number of mirrors, number of stages, steam temperature, steam quantity and pressure) are the main effective parameters that affect the distilled water production process. In general, the CSP desalination systems are environmentally and technically appealing; however, there remains substantial progress to be made in order for these plants to be commercially viable.

1. Introduction

Desalinating seawater is a procedure that requires a significant amount of energy and is expensive. Nevertheless, with the ongoing increase in population, the frequency of electricity and fresh water shortages will also rise. Potential sources of feed water may encompass brackish water, seawater, well water, surface water such as (streams and rivers), industrial feed effluent, and process waters. Only a small fraction, specifically 2.53%, of the total water on Earth is categorized as fresh water, and even less, less than 0.36%, is easily available for human use [1]. The extreme scarcity of water is a consequence of the continuously growing global population, especially in emerging nations MENA region [2]. Approximately 40% of the global population experienced acute water scarcity prior to 2014. It is anticipated that this figure will increase to 55% by 2025. Furthermore, it is projected that by 2050, around 57% of the world's population will reside in areas experiencing severe water scarcity [3], [4]. As of June 30, 2015, the International Desalination Association (IDA) reported that there were around 18,436 desalination facilities worldwide. These plants were responsible for producing 92.5 million cubic meters of desalinated water per day, which was needed by over 300 million people globally [5]. Furthermore, the total contracted capacity is projected to be around 99.8 cubic meters per day on a global scale [6], [7].Seawater desalination and very brackish water is the most widely considered method for improving water supply. It is increasingly viewed as a feasible solution for meeting primarily home and municipal water needs. There is a salinity range of 35000 ppm to 45000 ppm in the seawater, which accounts for 58% of the world's water. Additionally, brackish water has a salinity that falls within the range of 500 ppm to 35000 ppm, which is intermediate between that of freshwater and seawater [10]. Seawater desalination is now being utilised at a global installed capacity of 68% [11], [12]. Approximately, a quantity of oil ranging from 8.75 to 10 million tonnes per year is necessary to create one million cubic meters per day of fresh water through the process of desalination [13], [14]. The excessive fuel use leads to environmental pollution, global warming, the greenhouse effect, and other harmful consequences that pose a threat to human life. Hence, it is imperative to reduce fuel usage by implementing sources of renewable energy in water desalination procedures. The findings of a study conducted on worldwide water shortage and the suitability of sun desalination [15] revealed that places experiencing high levels of fresh water scarcity are also the ones where solar desalination is highly applicable. In addition, a significant portion of the areas experiencing a shortage of fresh water are situated in close proximity to the ocean, where there is access to saline water that can be purified through distillation. Hence, the presence of abundant solar resources and salt water in areas experiencing severe water scarcity holds great potential for utilizing solar thermal energy to produce fresh water in a sustainable manner. CSP plants provide intense heat that can be utilized for generating power or fulfilling the thermal demands of many applications, such as the process of desalination [16]. CSP facilities can be effectively combined with other renewable and non-renewable energy sources by using thermal energy storage [17], [18]. The aforementioned attributes render CSP a compelling choice for extensive desalination, particularly in dry areas with ample solar irradiation and saline water resources. This article seeks to offer a thorough examination of the current state of desalination technologies. Concentrated solar power plants are categorized according to their dual purpose of generating both power and fresh water, or solely producing fresh water. They are further classified based on the specific technology employed in concentrated solar power and desalination processes.

2. The present state of desalination technologies

In phase change desalination thermal procedures, the temperature of the input water is raised until it reaches the saturation temperature at the working pressure. At this point, separation occurs through evaporation. Subsequently, the steam that is produced is condensed in the following heat exchanger in order to generate fresh water [19]. MED and multi-stage flash distillation (MSF) are the predominant thermal desalination technologies among phase change thermal desalination facilities, as stated in references [20], [21]. The Thermal Vapor Compression (TVC) unit is occasionally employed in MED desalination to enhance the efficiency of the facility. A comprehensive analysis was conducted and provided in reference [22] to compare the energy and fuel efficiency of MED, MSF, and SWRO desalination plants that are driven by oil-fired or combined cycle power plants. The study revealed that the MED with TVC unit exhibits similar energy efficiency as SWRO when integrated with a combined cycle power plant. The electricity consumption of MED desalination technology ranges from 1.5 to 2.5 kWh/m^3, which is lower than the electricity consumption of MSF and Seawater reverse osmosis (SWRO) desalination technologies. MSF has an electricity consumption of 2.5-4 kWh/m^3, while SWRO has an electricity consumption of 3-4 kWh/m^3. The MED (thermal/electricity) has a total energy consumption ranging from 5.5 kWh/m^3 to 9 kWh/m^3, which is significantly lower than the MSF's energy consumption range of 10 kWh/m^3 to 16 kWh/m^3 [23], [24]. The MED, which accounts for 8% of the global desalination capacity, requires a low-temperature heat source ranging from 64 °C to 70 °C. This heat can be obtained by utilising the waste heat generated by power plants [11]. In a thorough investigation was conducted to examine the worldwide situation of desalination facilities and their rates of brine output [25].

3. Concentrated solar power: potential and current technologies

Solar thermal collectors are utilised to capture solar energy by heating a liquid or operating medium, which is subsequently transmitted to the intended process. Solar collectors can be categorized into two primary types: concentrating collectors and non-concentrating collectors. The attributes of these collectors have been rigorously examined in several scholarly investigations, including the publications of [26]-[28]. Concentrating solar collectors are comprised of reflecting surfaces that focus solar radiation onto a very small absorption area [26]. The property mentioned results in elevated operating temperatures as a consequence of the significant concentration ratio and negligible heat losses caused by the limited absorption surface size [10]. Nevertheless, the effective functioning of these devices necessitates a sun monitoring mechanism to guarantee the most efficient use of solar radiation. Concentrating solar collectors can be classified into two primary types: Linear concentrating systems are solar energy systems that focus solar radiation in a linear manner. They often include a single axis tracking device to accurately track the sun's path. Point concentrating systems, are solar energy systems that concentrate solar radiation onto a central receiver. These systems require a two-axis system of tracking to assure efficient orientation and functioning. Concentrating solar power systems are categorized into four commercially accessible varieties based on the manner of gathering solar energy Fig. 1. Parabolic troughs employ parabolic reflectors to gather and guide solar light towards tubes containing a heat transfer fluid. Solar towers employ a sizable mirror to gather solar radiation and focus it onto a central tower, where the heat is transformed into steam for the purpose of generating energy. Compound concentrating mirrors utilise linear mirrors to concentrate radiation onto heat transfer tubes, employing a simplified design in comparison to alternative systems. Parabolic dishes employ parabolic mirrors to concentrate light towards a focal point, where heat is directly created to power Stirling engines. Presently, the overwhelming majority of Concentrated Solar Power (CSP) plants. Nevertheless, solar towers are garnering growing interest because of their capacity to attain larger concentration ratios, elevated working temperatures, and increased thermal efficiency. Academic review studies have examined many elements of CSPs, including the works of [26]-[30]. An advantageous aspect of CSP power plants is their potential for combining with thermal storage systems for energy, as well as with other power plants, such as those relying on fossil fuels or renewable sources. There is a comprehensive analysis of CSP in comparison to other sources in reference [30].

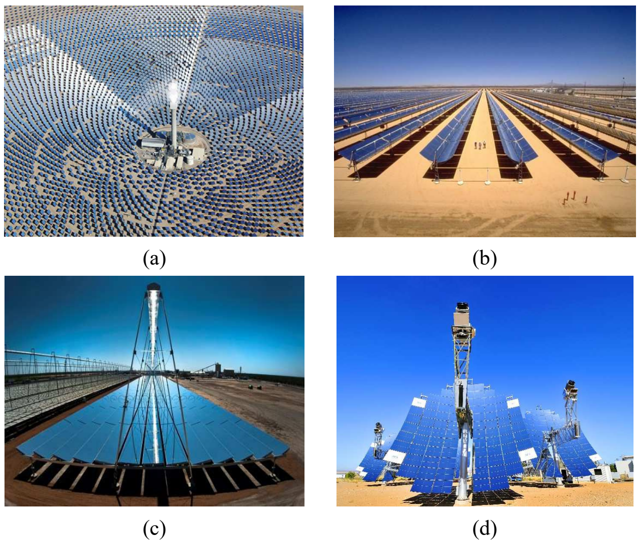


Fig. 1 Main CSP technologies: (a) PTC, (b) LF, (c) STP, and (d) PD [31].

4. CSP-desalination systems

Given the increasing water shortage in regions already under water stress due to environmental change and population increase, the development of CSP-desalination systems can be crucial in addressing this issue in the future. Various factors contribute to the use of CSP technologies in desalination systems, such as the alignment of areas with high Direct Normal Irradiance (DNI) potential and severe water scarcity. With the potential to integrate with power plants powered by fossil fuels, thermal storage of energy, and back-up sources of energy, Concentrated Solar Power (CSP) offers a reliable and adaptable means of generating power and heat. In order to provide freshwater in distant places that lack connection to the power grid, it is possible to create and design small-scale CSP plants specifically for the purpose of desalination [31].

Figure 2 illustrates the three currently viable choices for CSP systems with desalination capabilities.

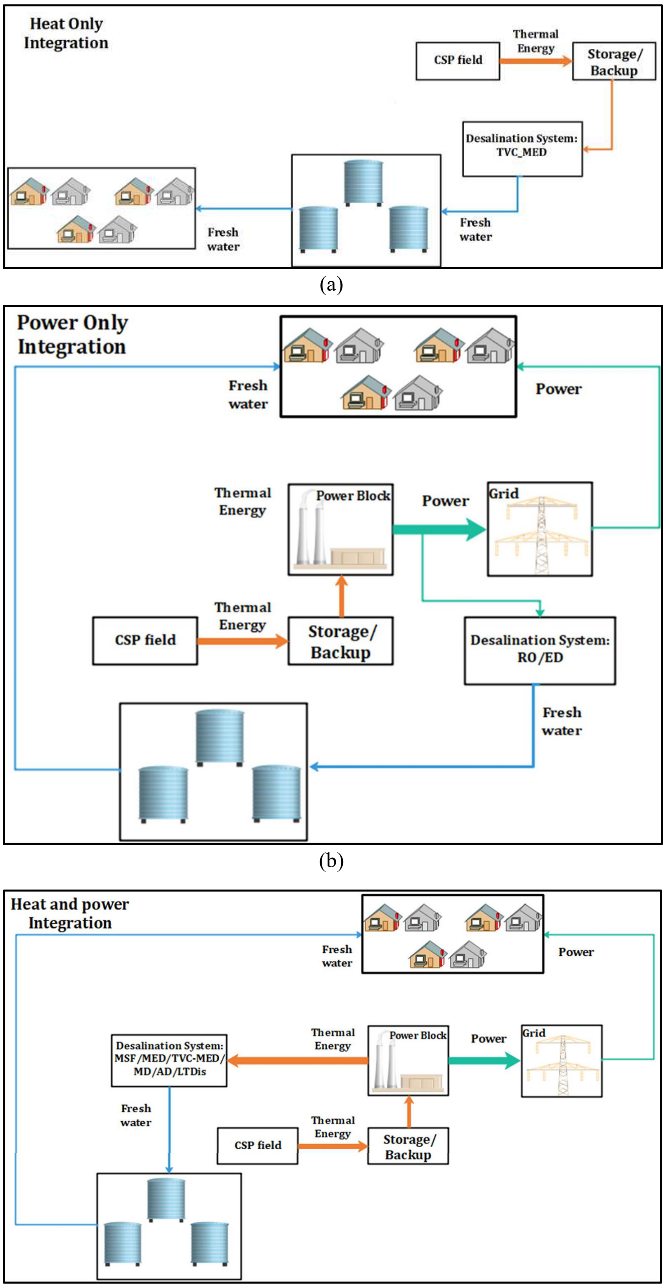


Fig. 2 Three primary technically viable choices available for CSPs that incorporate desalination units [22].

These solutions can be used for either producing freshwater alone or for simultaneously generating electricity and freshwater. All four primary categories of CSP can be utilised to produce freshwater, either as standalone freshwater generation or in combination with the production of electricity as well as freshwater. Thermal desalination facilities like MED, TVC-MED, MD, and MSF can be combined with CSP either directly as illustrated in Fig. 2 (a) or as a cogeneration plant as illustrated in Fig. 2 (b). The electricity produced by CSP plants can be immediately utilized to power electric-driven membrane desalination processes such as reverse osmosis (RO) or electrodialysis (ED) as in Fig. 2 (c).

Figure 3 illustrates the potential combinations of CSP plants and desalination methods. Three well-established CSP technologies, including solar tower (ST), Parabolic Trough Collector PTC, and LF, can be integrated with various power cycles such as steam RC, air Brayton, CO_2 supercritical Brayton/Rankine, transcritical-CO2 Rankine, and ORC. Utilizing a RO or ED system, the electricity generated by these power cycles can be utilized to generate freshwater in either a partial or full capacity. In addition, the surplus heat produced by these cycles can be used in thermally powered desalination system. These processes can operate the remaining heat from the exhaust emissions of a Brayton cycle, the steps of extracting and condensing in a RC, or the state of condensation and heat dissipation in CO_2 power cycles. In addition to generating electricity, the thermal energy generated by CSP systems can also be harnessed to power a desalination unit. Considering the available desalination methods, MED-TVC seems to be the most suitable option because it can produce steam at high temperatures within a pressure range of 500-4500 kPa [22].

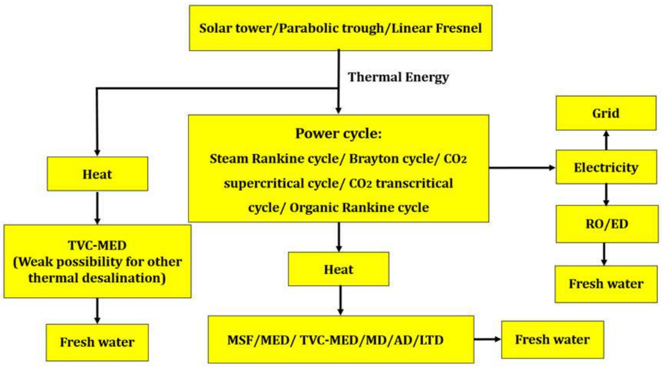


Fig. 3 Various viable arrangements for integrating CSP plants with desalination technology [31].

5. Freshwater production exclusively based on CSP

This section provides research carried outing desalination plants using concentrated solar power for the purpose of producing fresh water only.

Tellez et al. [32] assessed the economic, environmental, and technological factors involved in the production of drinking water in the southwestern region of New Mexico. Conducted an experiment using a plant with 9 effects and a sun field with linear Fresnel technology as shown in the Fig. 4. They evaluated three combinations. The idea was to operate the plant using solar electricity for a duration of 8 hours every day, while relying on a fossil fuel backup system for the other 6 hours. All three configurations employed sun distillation systems to minimize the outflow of brine from the final MED plant stage and to transfer the brine that has been concentrated through a deep well, however the specific features differed. Three distinct fresh capacities were considered 1412 m^3/day, 1109 m^3/day, and 743 m^3/day. The most efficient configuration for providing drinkable water was found to be one that utilizes distillation by solar to reclaim the residual brine produced during the final operation of the Multi-Effect Distillation (MED) plant. This configuration produced a return on expansionof 10.2% with a freshwater cost of \$5.00 /m^3.

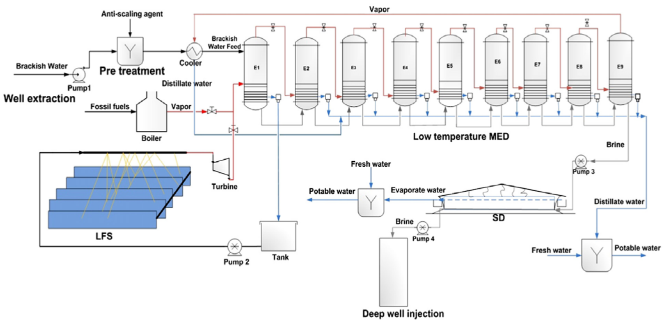
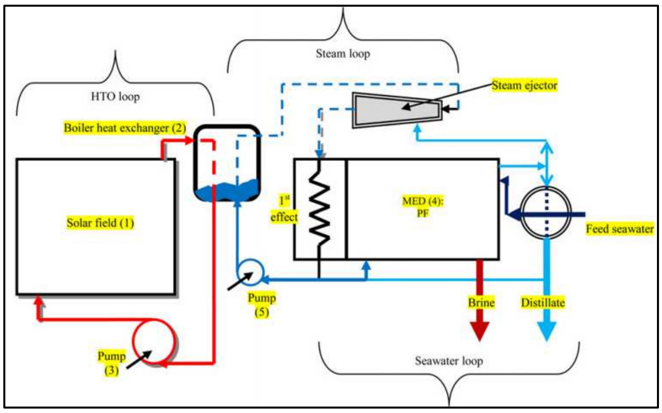
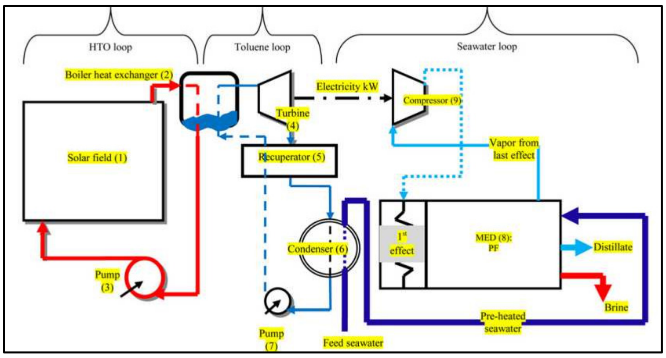


Fig. 4 Proposed concept of CSP-desalination [32].

Sharaf et al. [33] created and assessed, from a thermodynamic and economic perspective, two alternative layouts of PTC CSP-desalination units capable of processing 4545 m^3/day of fresh water. Both configuration 1 and configuration 2 may be seen in Fig. 5(a) and (b), respectively. In the first configuration , the heat collected from the solar field is sent to the boiler and then to the TVC-MED unit. In arrangement 2, the mechanical vapor compressor (MVC) was operated using the electricity produced by the ORC, while the excess heat was utilized to drive the MED system. While water and toluene were considered as potential working fluids in the ORC, the PTC field used Therminol-VP1 as its heat transfer oil. They demonstrated that the first setup is preferable because of its lower freshwater cost and greater gain output ratio (GOR), even if it calls for a bigger solar field.



(a)



(b)

Fig. 5 Schematic views of the provided CSP-desalination systems in [34]: (a) arrangement 1 and (b) arrangement 2.

The area of collector is 117,908.9 m^2 was necessary for the first arrangement, which showed a leveled price of water of \$1.57/m^3. These values were \$33.1/m^3 for the first setup and \$33,181.5 m^2 for the second.

Hammed et al. [34] investigated a pilot plant in Al-Jubail, Saudi Arabia, which integrated a TVC-MED unit with modified Fresnel collectors. Solar panels, a boiler, and a cooling system were all part of the concentrated solar power facility as shown in Fig. 6. The oil was a heat transfer fluid. and a solar multiple of 1, the LF field solar operated with area of 662.4 m^2. The authors compared the financial and technical viability of a CSP-driven plant versus one powered only by fossil fuels, using experimental test results as a basis. The results showed that the chosen TVC-MED needed a 55,737 m^2 Fresnel mirror area and a total thermal energy consumption of 13.6 MWth for keeping a freshwater yield of 4546 m^3/day.

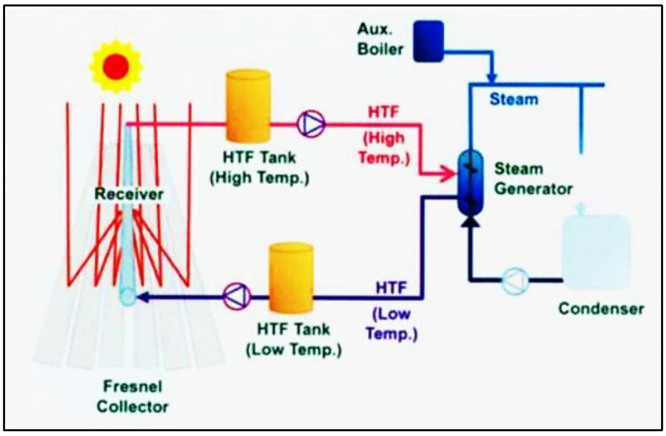


Fig. 6 The diagram illustrates an improved Fresnel collectors- Multiple Effect Distillation (MED) plant designed for production of freshwater at Al-Jubail/Saudi Arabia [34].

Alikulov et al. [35] assessed and designed a PTC that integrates with an existing MED plant in Uzbekistan; this facility can produce up to 200 tones/h of freshwater as show on in Fig. 7 .The system's parabolic trough field was engineered to meet the thermal requires of the MED plant to a certain extent. Saturated steam, with design parameters of, 8 bars, 200 °C, and 32 t/hr, was used for this purpose. In June 2014, they discovered that the planned solar field could produce over 7,057.08 tonnes of saturated steam, in January 2014, the figure was 966.90 tonnes. The ability to cut fossil fuel use was demonstrated in Jan, Mar, Jun, and Sep, respectively, by 59.64, 95.24, 389.96, and 298.26 tonnes, thanks to the integration of the PTC field.

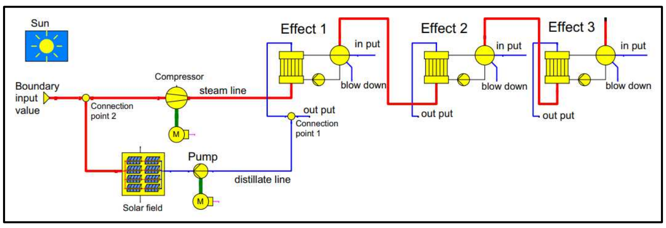


Fig. 7 PTC with a MED unit [35].

El-Agouz et al. [36] utilized an experiment on a solar desalination system that utilized spray evaporation in an arid area. The experiment involved a solar water collector with an area of 1 m^2. They conducted a study on the impact of water inlet temperature on several factors, including efficiency, GOR, productivity rate, and the cost of potable water per liter in the system desalination. It has been observed that an increase in the inlet temperature of water has a direct impact on productivity, GOR, efficiency and productivity rate. The highest daily rate production has been increased to 9 L/m^2. The peak efficiency during daylight hours is roughly 87%. The price of one litre of drinkable water is 0.029$.

In a study conducted by Gude et al. [37] a groundbreaking low-temperature desalination method was introduced. This innovative technique utilizes a flat plate solar collector to produce an impressive 100 L/d of freshwater. Based on their research, an 18 m^2 solar collector area and a 3 m^3 thermal energy storage capacity can generate 100 L/d of freshwater, considering meteorological conditions.

Saettone et al. [38] conducted experimental investigations on a 5.5 m^2 intense black aluminum PTC that lacked a solar tracking system mechanism and had a line focal distance of 0.7 m. It was aligned East-West and measured 2.5 meters in length with a 1 meter rectangular absorber cavity made of black aluminum. Cocayalta, a city 48 kilometres away from Lima, was the site. A 95% increase in freshwater flow was achieved by making simple changes to the cavities, taking the model with thermal insulated and wind protection from 3.25 litres to 6.36 litres.

Stuber et al. [39] analyzed the outcomes of models and experiments conducted on a prototype system that utilized a one-effect heat pump absorber (HPA)-MED, which was operated by a PTC solar field as depicted in the Fig. 8. Both the HPA and the MED cycles were designed as open-loop systems. The AHP cycle utilized an generator and absorber, while the MED cycle had a design similar to a closed-loop system, consisting of an evaporator, expansion valve, and condenser. The steams that was produced in the generator part was absorbed by the saltwater after being condensed in the first effect of the MED. This procedure persisted after the first effect's condensation of steam. At finally, the steam from the MED system's last effect was directed to the HPA's absorber portion. Two distinct operating modes, namely solely-MED and coupled HPA-MED, were examined for the three-effect and final condenser pilot system. As a feed water source, we utilized agricultural drainage water. The MED unit would be first supplied with steam at a pressure of 30 kPa, which is produced by transferring the thermal energy absorbed by the PTC to the HPA at a temperature of 180°C.

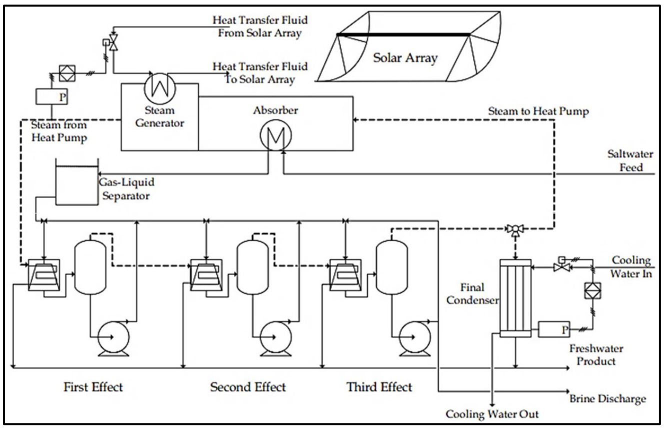


Fig. 8 Illustrates a PTC solar field that is equipped with a one-effect HPA-MED [39].

As contrasted to the solely-MED, the HPA considerably reduced the unit's thermal energy need from 0.261 MWh/m^3 to 0.133 MWh/m^3, and it also greatly enhanced performance. The solar field size has to be reduced by 49% due to the lesser thermal energy. The optimised combination HPA-MED system with 10 effects lowered the energy thermal need to 34.0 kWth/m^3, according to their simulation results.

Yuan et al. [40] analyzed a CR solar power plant that generates both power and water by employing a supercritical carbon dioxide S-CO_2 Brayton cycle with MED. The MED process, as it was powered by the exhausted gases of the Brayton cycle. They utilized a MED system with five effects to attain a water production of 459 m^3/d and a solar thermal power efficiency of 24%.

Cioccolanti et al. [41] assessed the efficiency of a small-scale, focussing heliostat collector powering one effect in a thermal desalination unit at three sites: Crendi, Palma de Mallorca, and Pantelleria. The plant was designed with 25 non-imaging heliostats in a hexagonal shape, featuring a reflective surface spanning 9.5 m^2 as shown in Fig. 9. It had a maximum output power of 6 kWh and could generate up to 150 L/day of fresh water using a single stage desalination thermal plant. They found that in batch mode, the plant produced approximately 1.3 L/kWh of freshwater relative to the thermal energy input, while in continuous mode, it produced roughly 1.16 L/kWh. In their analysis, the researchers found that the suggested system would offer significant benefits for small-scale operations in rural regions with a need for freshwater ranging from 30 L/d to 60 L/d.

Blanco et al. [42] analyzed how well the new CSP-desalination facility was doing. The nominal freshwater production capacity of this plant was 3 m^3/h when it was designed. A TVC-MED system, thermal energy storage, and a PTC solar field were all part of the system. Solar steam at 10 pressure and 180 °C was supplied by the PTC array. Phase 2 of the project involved developing a concept to decrease electrical and thermal demands. This was achieved by incorporating a steam ejector system and replacing the vacuum system that is based on the hydroejector with a two effect AHP. The applied changes decreased the energy of thermal demand by 44%, from 63 to 36 kWh/m^3, and the electrical usage by 12%, from 3.3 to 2.9 kWh/m^3.

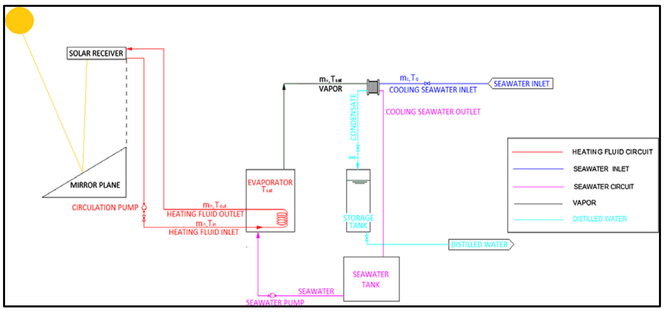


Fig. 9 Scheme of the integrated plant [41].

Al-Hajri et al. [43] created forth a plan for determining the process parameters and equipment size for a multiple-effect distillation station that runs on concentrated solar power. Directly inputted the obtainable hourly solar radiation information in Kuwait during the design process as shown in Fig. 10. Desalination plant output capacity of 400,000 m^3/day in winter and 865,000 m^3/day in summer are determined by comparing the minimum and maximum amounts of available solar energy, which corresponding to the shortest and longest days of the year, respectively. A total of 2,670,000 m^2 of reflector surface area and 85,500 tones of molten salt heat storage.

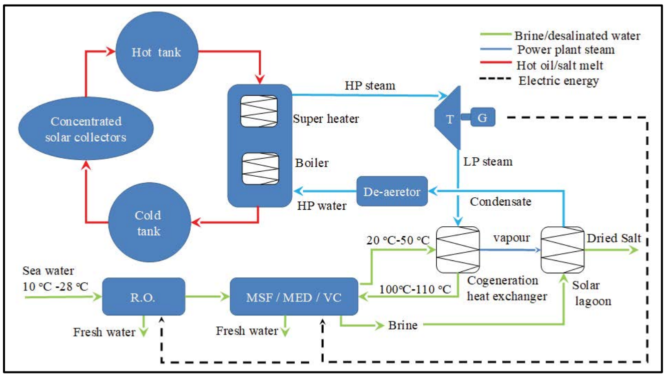


Fig. 10 STP with desalination plant [43].

Mishal et al. [44] introduced a MED system that is powered by concentrated solar collectors type PTC, by heating brine indirectly; this system then uses a charging tank to store this energy as shown in Fig. 11. Using 4 effects MED, a dynamic mathematical model is created and then simulated. Based on the results, it is possible to produce 2200 metric tons of distillate utilizing a 92,000 m^2 plot of land for PTC, with a maximum daily feed water mass of 67,000 metric tons of brine. There is an average specific thermal energy expenditure of 1,140 kJ/kg and a daily performance ratio (PR) of 2.

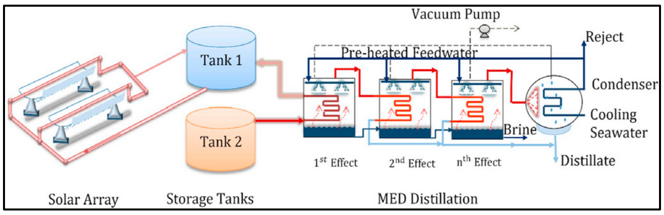


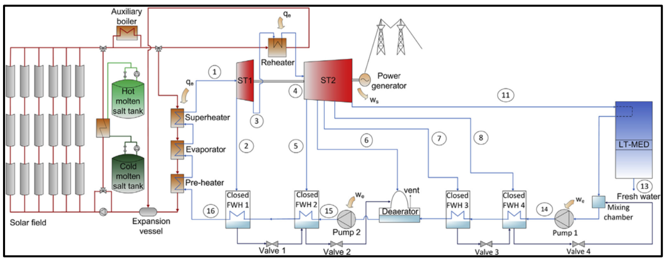
Fig. 11 Comprehensive diagram illustrating the planned design [44].

Table 1 summary a concise overview of the key attributes of the evaluated CSP-desalination units specifically designed for the production of freshwater.

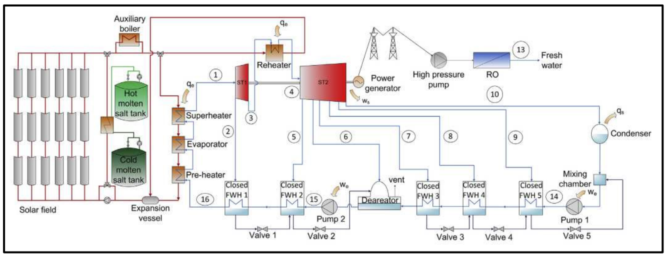
6. Cogeneration of freshwater/electricity through CSP

This section examines the research that has been conducted to propose and develop CSP-desalination systems for the cogeneration of freshwater and electricity.

Palenzuela [45] contrasted and evaluated the competitiveness and suitability of CSP-MED plants with varying configurations in comparison to the integration of a CSP plant with a RO unit. The diagrams of combinations 1-2 are depicted in Figs. 12 (a) and (b). Using the turbine's steam as a thermal energy source, they compared their desalination process to that of a straightforward combination of a solar power plant with a reverse osmosis system. In terms of GOR, the data demonstrated that the 11-affect MED plant achieved 8.4 and the 14-affect MED plant achieved 10. More exhaust steam and, by extension, more fresh water extracted from the MED plant, is a direct result of a larger MED's higher total turbine power. The 11-affect MED station yielded results ranging from 34,000 to 35,000 m^3/day, while 14-affect MED station produced results ranging from 41,000 to 42,000 m^3/day.



(a)



(b)

Fig. 12 the established CSP-desalination combinations: (a) combination 1, (b) combination 2 [45].

Frantz and Seifert [46] conducted a thorough thermal analysis of a MED system powered by a solar tower as shown in Fig. 13. By increasing the steam temperature from 65 to 90 °C, distillate production doubled, albeit with an 11% decrease in power production. On the other side, increasing the heat transfer surface of the desalination plant by 30% could result in a significant boost in water production, exceeding 50%. Due to the increased power usage of the desalination plant, the yearly electricity production is only reduced by 1% in this case.

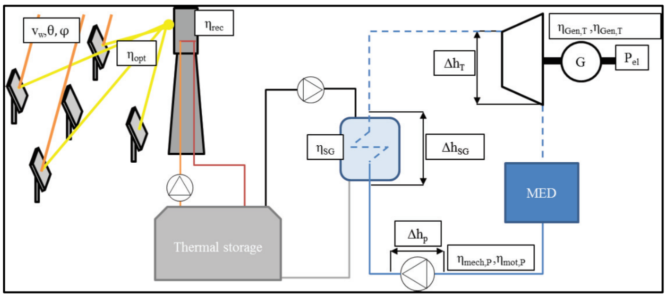


Fig. 13 Schematic of the STP-MED plant [46].

Laissaoui et al. [47] examined the thermodynamic analysis of the integration of the STP plant and MED. Examine the performance of the STP-MED plant in the MOSTAGANEM region, which is a coastal site in northern Algeria Fig. 14.

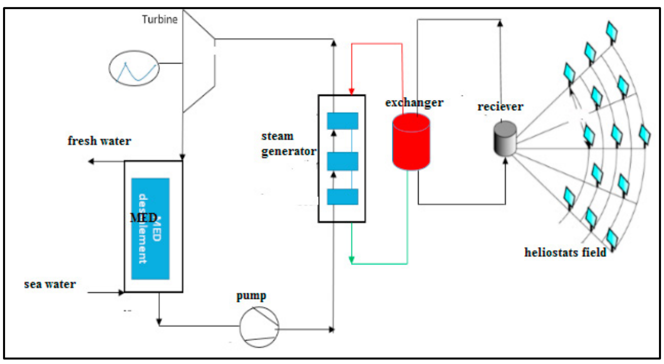


Fig. 14 the STP-MED plant [47].

The case studies have considered a net electric output of 50 MWe and a fresh water production of 22568 m^3/d. Consequently, the integration of a multi-effect desalination MED plant may be a viable option for the integration of STP and desalination.

Demir et al. [48] devised an integrated STP combination cycle system to simultaneously generate energy and freshwater through cogeneration. The depicted system, as seen in Fig. 15, comprised of a compressed air storage tank, a combination of a thermoelectric generator ,a gas turbine power plant, a flash distillation system and a steam RC,. The system achieved a total energy efficiency of 44.5% and a total exergy efficiency of 54.9% when solar power provided half of the thermal energy and natural gas provided the other half. The combined system exhibited a total energy output of 21,800 kW, with the gas turbine cycle contributing 19,150 kW, the Rankine cycle contributing 2,632 kW, and the TEG contributing 32.94 kW. The system of TEG demonstrated an efficiency of 2.02%. Findings indicated that the unit of distillation flash they designed produced a daily output of 290 m^3/day of freshwater.

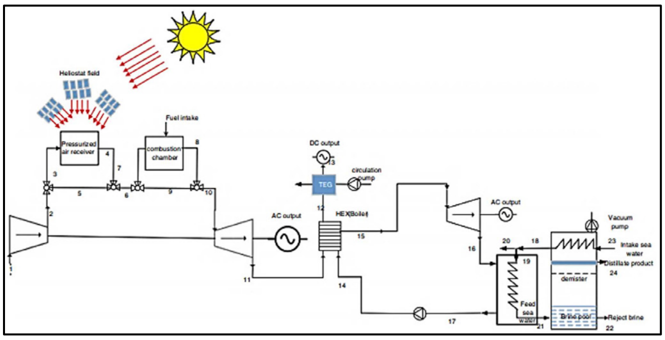


Fig. 15 The CSP-MED plant is a schematic that integrates a steam RC, TE ,solar gas turbine, and MED unit [48].

Palenzuela et al. [49] conducted a thermodynamic analysis of different configurations, including MED desalination, RO desalination, and MED-TVC. In conjunction with solar power facilities that use parabolic troughs (PTC). The settings for the steam exhaust outlet turbine in all instances were 58 °C (0.18 bar absolute), with 50 MW being deemed net power and 48,498 m^3/day being regarded water production Figs. 16 (a) to (d) illustrate configurations 1-4, correspondingly. In terms of thermodynamic efficiency , the results demonstrate that, under simulated conditions, a PTC-CSP plant with a MED unit integrated to replace the turbine exhaust steam condenser is preferable to one coupled with a reverse osmosis desalination plant. With reduced plant cooling requirements compared to the CSP+RO scenario, loss of energy to the ambient environment is also reduced with the MED-TVC design. In dry climates, a CSP+D configuration that combines the MED plant with thermal compression could be a good alternative to CSP+RO due to the reduced cooling needs.

By incorporating new functionality into the SAM software, Casimiro et al. [50] created a novel method for modeling plant of a CSP-MED that combines the production of freshwater and electricity. A parabolic trough field was incorporated into their system to power a steam RC with a forward feed-MED unit. Four distinct cooling systems were assessed regarding this particular system, boasted a 111 MWel power capacity and a production capacity of freshwater is 16,400 m^3/day: a standalone SWCC, dry cooling, moist cooling, and the MED/Seawater Cooling Circuit (SWCC). The feasibility and economic appeal of the system that integrates MED/SWCC were demonstrated by their findings. They noted that this system produces 5% smaller amounts of electricity compared to a CSP facility that utilised a moist system of cooling, but at the expense production of freshwater.

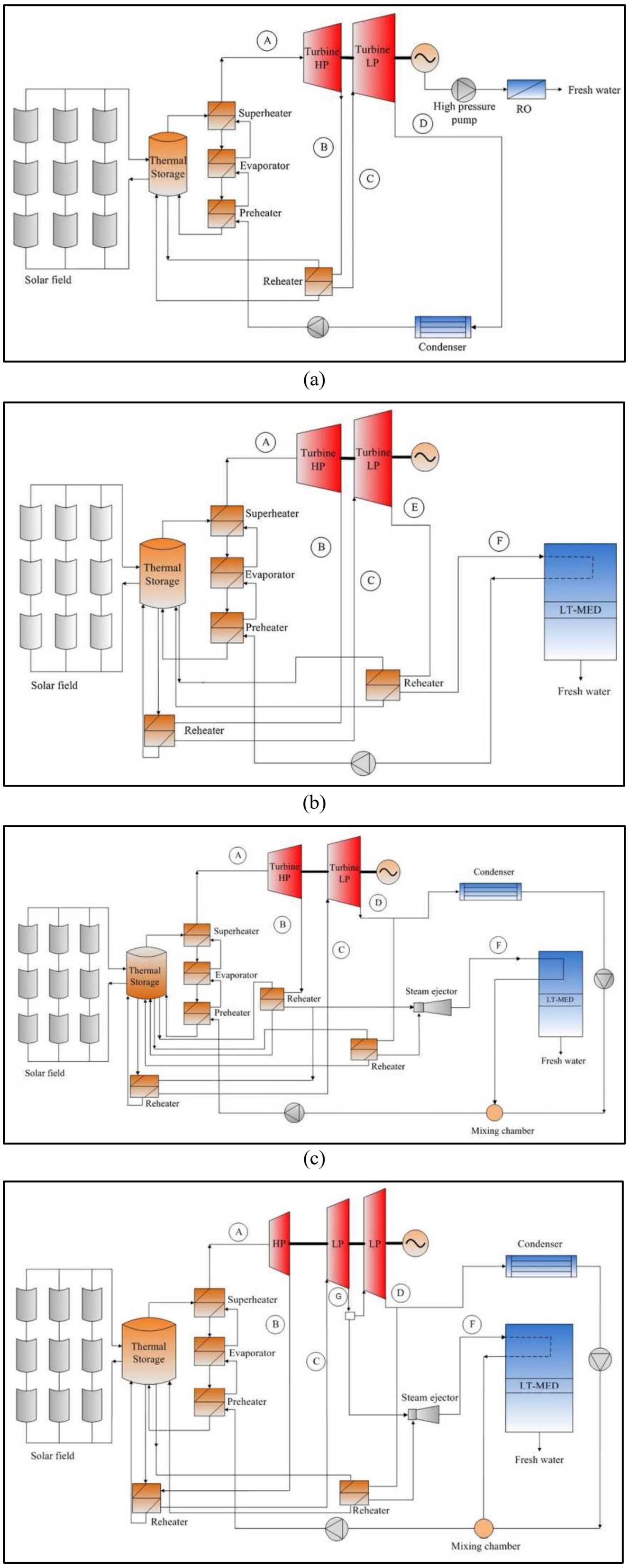


Fig. 16 the configurations of CSP-desalination: (a) layout 1, (b) layout 2, (c) layout 3, and (d) layout 4 [104].

Sharan et al. [51] Examined the combination of a STPP and a MED desalination unit to generate both water and electricity as shown in Fig. 17. A novel method has been suggested to increase the water capacity factor by as much as 75% by utilising water tanks to store waste heat generated from the Brayton cycle. This not only improves efficiency but also leads to a significant reduction in water costs, cutting them down by 19%. After conducting a thorough analysis of various locations, it was determined that in Saudi Arabia, utilising MED as the desalination system would result in the production of 115 MWel and 4720 m^3/d of distillate at a cost 16% lower than using RO. Additionally, this system boasts a thermal efficiency of 48%.

Sergio et al. [52] investigated a parallel MED system that used CSP as its power source. Incorporating steam ejectors into the model allowed for its validation with data from a real-life medium-sized industrial plant that used a thermal steam compressor (TVC). For the first examination of these kinds of investments, the findings demonstrate that the MED model gives good predictions of plant behavior. These findings suggest that CSP+MED can be financially appealing when contrasted with the current TVC-MED facility. the CSP+MED/SWCC simulation, has an installed capacity of 110 MW, produces around 297 GW of electricity per year, and uses around 5.4 million m^3 of distillate. Due to its lower size, the CSP plant performs better than its nominal output, resulting in an annual capacity factor of 34.2% for the CSP plant and 41.4% for the larger plant.

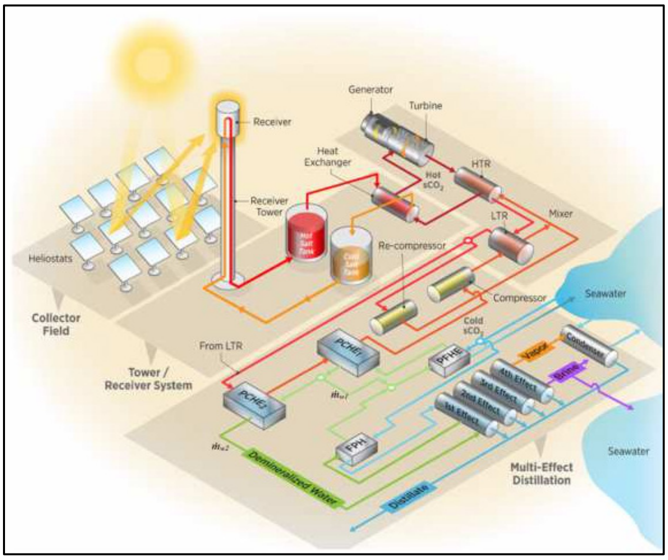


Fig. 17 A solar tower powered CO_2 power plant equipped with a MED unit [51].

Ortega et al. [53] performed a systematic investigation to assess the incorporation of a 12-effect MED-TVC system with a steam RC powered by a PTC solar field. The arrangement of the CSPP in combination with the MED-TVC system as illustrated in Fig. 18. The researchers examined how the suction steam pressures and motive influenced several characteristics, such freshwater output, GOR, and specific heat transfer area. It was discovered that there is an optimal location for the ejectors of the steam that optimizes the GOR for each steam motive pressure. To achieve higher steam pressures, it is necessary to position the steam ejector in close proximity to the final stage of the multi-effect distillation (MED) unit. The freshwater output experiences a substantial decrease when the ejector of the steam is positioned in closer proximity to the 5-effect. Their findings indicated that the MED-TVC unit should be supplied with a lower-pressure steam and the ejector of the steam ought to be situated nearer to the 5-effect (number of stage) in order to accommodate high electricity demands. For the MED-TVC unit, this resulted in an increase in electricity production and a decrease in freshwater production. To boost the operation of the MED- TVC plant during periods of low electricity needs, it is recommended to supply steam at a greater pressure and position the ejector steam nearer to the last effect.

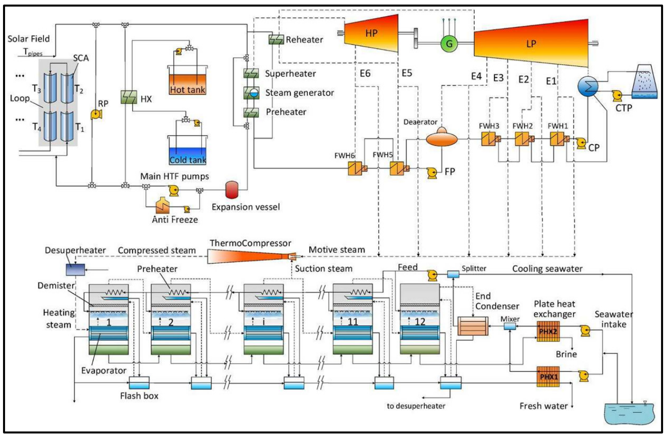


Fig. 18 CSP- MED-TVC system examined by [53].

Zhaorui et al. [54] developed a MED system that was fitted into a solar collector made of porous wood. A MED system was combined with a bilayer wood solar steam generator. The wood solar collector reaches its maximum steam production at a temperature of around 145 °C, while the minimum power consumption for the MED specific is 24.88 kWh/t. The increase in solar capacity from 50 kW to 230 kW results in a corresponding rise in the average temperature difference, from 1.88 °C to 6.27 °C. This parametric research enhances the performance of both the MED system and the bilayer wood solar steam generator.

Ghorbani et al. [55] utilized solar dish collectors in conjunction with a PCM storage to supply the necessary thermal power for a steam generating station with a net production capacity of 1,063 MW. Materials that change phase are stored overnight and when there are no solar thermal energy sources available. In order to reduce heat loss in the condenser, a substantial quantity of lost heat is transferred to a three- MED system as shown in Fig. 19. Software such as Hysys, Transys, and Matlab were utilized to simulate the system using climate input data for the case study in Bushehr city. Based on the findings, it was observed that the desalination system generates a significant amount of fresh water by effectively utilising heat loss from the steam power plant. This system achieves an impressive total electrical efficiency of 28.84%, along with an exceptional total thermal efficiency of 97.18%.

Talebbeydokhti [56] an MED system was incorporated with a PTC Solar Power (PTC-CSP) plant results shows, the most efficient layout was the integration of a MED with 11-effects (number of stage). The conventional CSP plant was sized to accommodate the maximum steam (thermal requirements) extractable from the turbine, resulting in an overall electrical energy request of 0.195 kW/m^3·day.

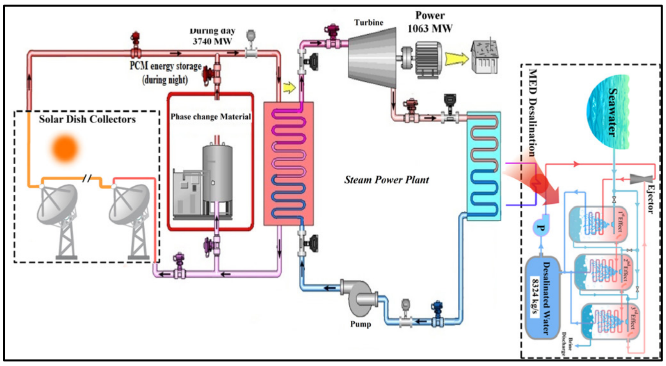


Fig. 19 Integrated structure block diagram [55].

Figure 20 shows how GOR decreases with the increase in the steam inlet temperature. This is due to the fresh water production employed in the various cases, which leads to a decrease in the quantity of vapor produced in each effect. Consequently, the quantity of steam necessary for evaporation in the initial effect decreases in proportion to the quantity of vapor generated in each effect. Finally, Fig. 21, demonstrates that the GOR rises as the number of effects increases, owing to the presence of extra heat exchangers, which results in an increased heat transfer area.

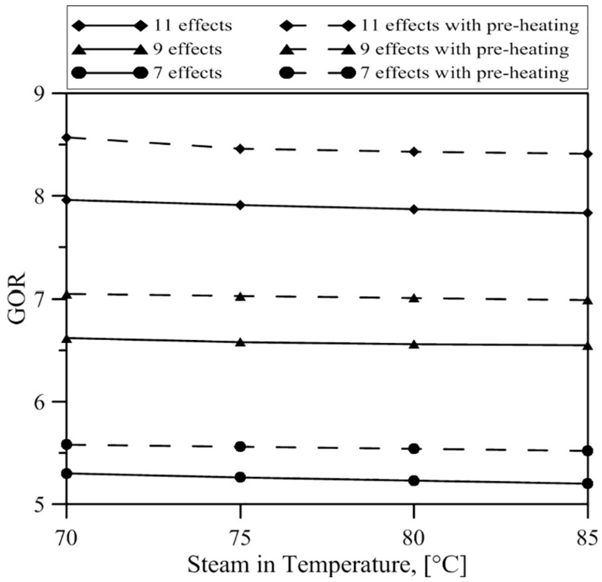


Fig. 20 Effect of the steam-in temperature on the GOR [56].

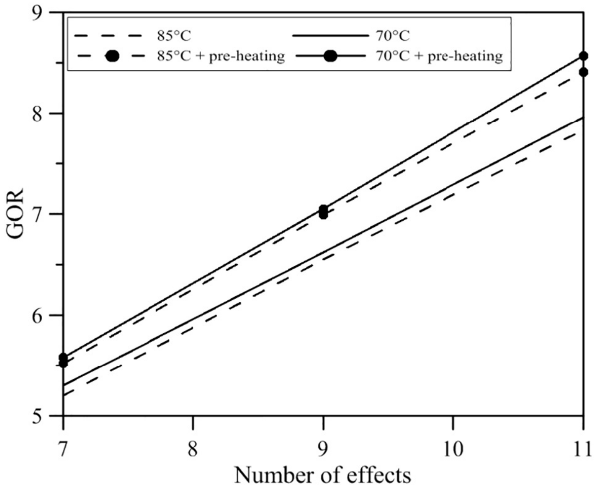


Fig. 21 Effect of the number of effects on GOR value [56].

Al-Addous et al. [57] studied the analysis of a CSP plant that with a MED technology to produce electricity and desalinate water all at once. What the simulation results revealed was that the cogeneration system's water and electricity production varied greatly. In June, the concentrated solar power plant's output, excluding water production, reached 58.7 MWel. Dehydration of water at 170 m^3/h resulted in about 49.5 MWel of energy. Also, because of temperature variations within the desalination stages, the flexible operation of the power plant was limited, although the number of stages had the biggest impact on distillate production generally. For 10 steps, the mass flow of distilled water was 498 m^3/h. Findings from the sale of generated electricity indicated that the design was profitable to the tune of €78.84 million. In addition, the ideal pressure for producing both power and distilled water was determined to be 0.45 bar in the condenser.

Wellmann et al. [58] offered a representation of the combined water and electricity production process that incorporates a desalination plant with several effects. CSP plant was type Fresnel with a capacity of 10 MWel, and the energy process simulation program “Ebsilon Professional” are both used to implement the model. With a desalination capacity of 520 m^3/day and a concentrated solar power plant co-generation capacity of 2.2 MW, the results were impressive. In addition, input salinity, temperature, and cogeneration fraction are some of the process characteristics that affect the final product.

Table 2 summarizes a concise overview of the significant attributes of the CSP-desalination systems that were examined for the purpose of generating both energy and freshwater.

7. Conventional MED desalination

This section offers a concise overview of the literature pertaining to multi-effect distillation and the approaches employed to improve the thermal and economic efficiency of multi-effect distillation systems. The study focusses on analysing various aspects of MED systems and examining the elements that influence their performance.

Guo et al. [59] conducted research on the impact of preheaters, including their placement and quantity, on the GOR and the overall heat transfer area in the plant. The researchers examined the MED desalination plant, which comprised 10-effects as shown in Fig. 22. They separated these effects into three groups, with the forward feed arrangement used between teams and the parallel feed configuration used among evaporators within each group.

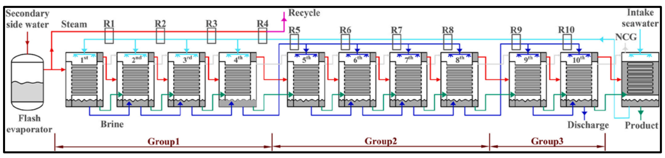


Fig. 22 MED 10-stage system with preheaters [59].

Elsayed et al. [60] conducted a thermo-economic analysis on configuration of MED, all of which are integrated with TVC. Their aim was to identify the configuration with the best performance and estimate the cost of water using the specific exergy cost flow method. The authors concluded that the PCF-MED configuration has the highest GOR (gain output ratio), the lowest specific heat consumption, and the lowest total power consumption. However, it is worth noting that this configuration requires a significant specific cooling water flow rate.

Cipollina et al. [61] conducted a thorough analysis of the PF-MED-TVC plant, incorporating preheaters and non-condensable gases, but excluding flash boxes as shown in Fig. 23. They subsequently validated the dynamic model using real data and achieved a near match.

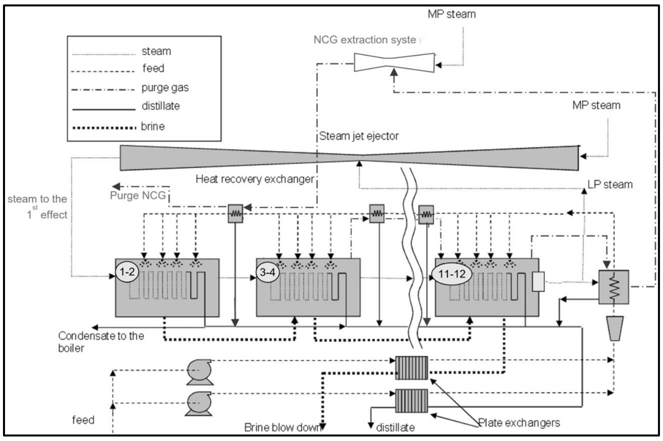


Fig. 23 Simplified sketch of the MED-TVC [61].

Garuso and Naviglio [62] reported the performance results from a one-year experimental study done at the solar pond site of the University of Ancona, Italy. The study took place in a MED plant with a capacity of 30 m^3/day. The MED evaporator in this facility was fabricated using solely titanium material. The investigation was carried out using three distinct operational modes. The initial mode involved utilizing steam generated from the boiler, the subsequent mode involved utilizing a thermo vapor compressor, and the last mode involved utilizing heat obtained from a solar pond. The freshwater production rate for the first, second, and third modes was reported as 540, 480, and 600 kg/h, respectively. The heat performance values for the first, second, and third modes were 667, 750, and 700 kJ/kg, respectively.

Abubaker [63] Investigated the impact of operating parameters on the performance of the MED-TVC system, with a particular emphasis on the enhancement of key performance indicators, such as water production. The results of MED-TVC are illustrated in Fig. 23, which illustrates the fluctuation of GOR in relation to the number of effects. Consequently, there was a robust positive correlation between the quantity of effects and an increased GOR. The number of effects increases, resulting in a significant increase in the water product, which in turn advances the GOR. It is important to mention that the simulation is conducted at a consistent steam flow rate of 8 kg/s.

Jyoti and Khanam [64] created a seven effect of MED system model that accommodates various operating configurations, including steam division, condensate flashing, and vapour bleeding. Likewise, they optimized the quantity of flash canisters in the system by conducting an economic analysis. As a consequence, a modified system was identified that improved the steam economy by 23.77% and decreased steam consumption by 36.76%.

Kamali et al. [65] created mathematical models to predict the design data for a 1200 m^3/day capacity MED-TVC unit that includes a plate type evaporator and a shell and tube type evaporator. They have also compared the results of the evaporator. Additionally, they have demonstrated the impact of design and operating parameters, including the first effect steam temperature, number of effects, and salt concentration ratio, on the system's performance ratio.

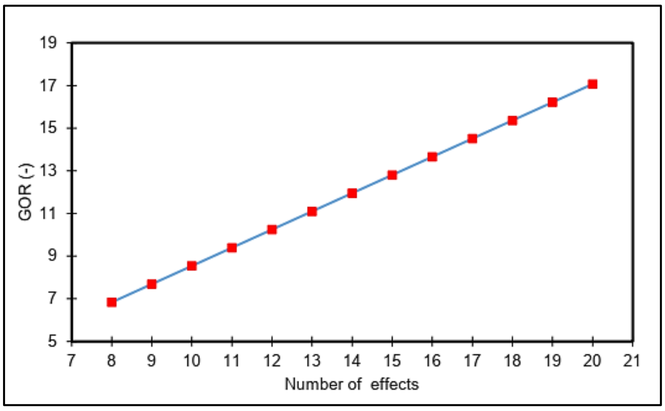


Fig. 24 Effect on number of effect on the GOR [63].

Yilmaz and Soylemez [66] developed a mathematical model of MED steady state and conducted an analysis of the plant's performance in relation to design parameters and operating variables as shown in Fig. 25. The conclusion was that the gain output ratio varied between 7.34 and 15.04 for 4 effects and 12 effects.

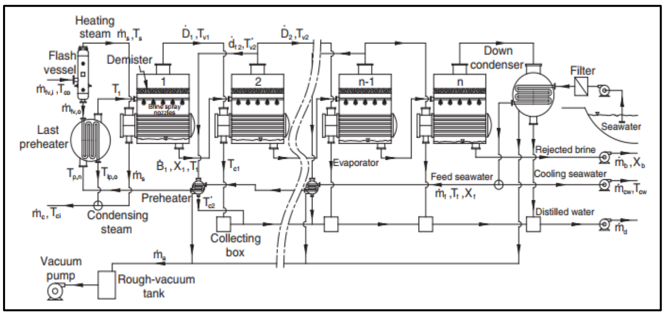


Fig. 25 schematic process of the FF-MED seawater desalination system [66].

Gong et al. [67] established a series of mathematical models for MED plant, that were employed to analyses the coefficient of heat transfer along the tube row, tube length, and tube column directions. The brine inlet spray density was varied from 0.05 kg/m-s to 0.09 kg/m-s, and the brine inlet salinity was varied from 30 g/kg to 50 g/kg. The results indicated that the heat transmission coefficient is higher in the evaporating zone than in the preheating zone.

A new design scheme and mathematical model for geothermal-driven MED plants were proposed by Wang et al. [68]. The geothermal hot water was initially incorporated into the first effect, and the water that exited the module was redirected to a seawater distillation module as shown in Fig. 26. A portion of the vapor was produced, and it was then pumped into the corresponding effect within the MED plant. Consequently, the yield was increased by 25 to 60% in comparison to conventional MED plants.

Esfahani et al. [69] conducted optimization experiments in the MED-TVC system. To achieve this objective, they proposed two mathematical models. There was a section dedicated to economic analysis, while another was dedicated to the procedure. Optimization results indicated that the MED-TVC system with six effects is the most effective system among the systems with three, four, five, and six effects.

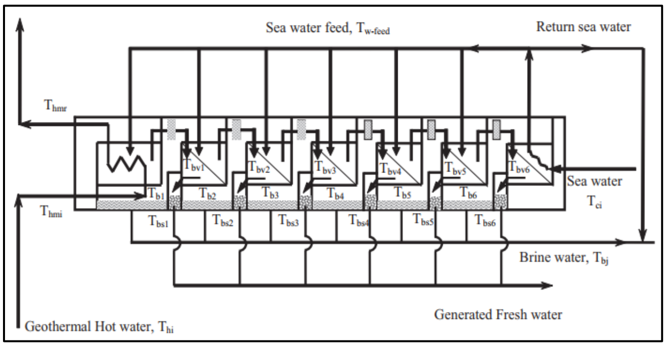


Fig. 26 Diagram of a geothermal/low grade heat multi-effect distillation (MED) plant [68].

Under ideal operating conditions, the system with 6 effects can achieve cost savings of 14%, 12.5%, and 2%, as well as reduce the steam consumption for producing 1 cubic meter of fresh water by 50%, 34%, and 18% compared to systems with 3, 4, and 5 effects, respectively as shown in Fig. 27. Furthermore, the system consisting of 6 effects exhibits the largest GOR value, as depicted in the Fig. 28.

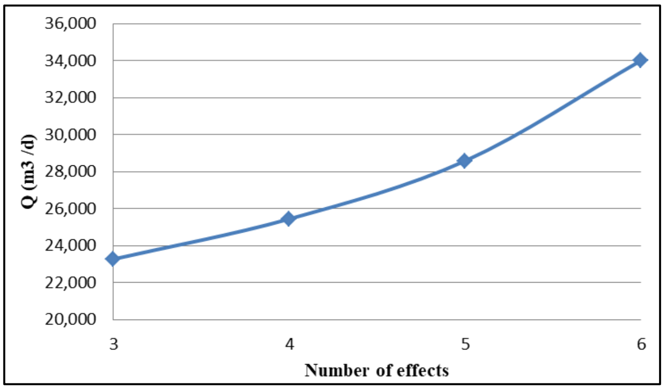


Fig. 27 Effect of the number of effects on the amount of freshwater production [69].

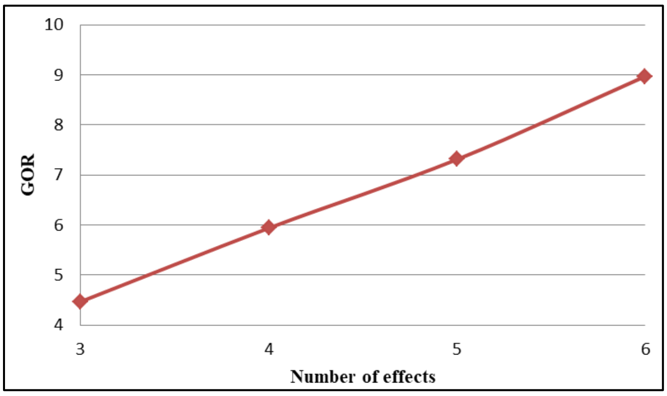


Fig. 28 The GOR is affected by the number of effects [69].

Wade [70] conducted a comprehensive economic evaluation of the reverse osmosis (RO) process and various thermal desalination methods, such as multi-stage flash (MSF), multi effect distillation with thermal vapor compression (MED+TVC), and multi-effect distillation with mechanical vapor compression (MED+MVC).He determined that in places with low energy costs, particularly in the Gulf countries, big thermal desalination units are economically viable and comparable to the reverse osmosis (RO) technique. The author's conclusion is that the MED process possesses numerous appealing characteristics that will enable it to dominate the desalination industry in the near future, particularly for facilities with moderate output rates.

Kamali [71] presented the parametric optimization approach of the multi-effect desalination process employing steam-thermal compression (MED-TVC) to enhance the gain ratio (GOR) value. A comprehensive mathematical model has been established to accurately forecast the impact of various factors on the overall capacity, PR, temperature differential between effects, and pressure across each effect, considering both design and operational conditions. The results showed that total distillated product is 1536 ton/day, and the GOR increases with increasing number of effects as shown in Fig. 29, and decreases when the steam temperature increases as shown in Fig. 30.

Temstet and Laborie [72] described the key features of three MED-TVC units at Curaceau. Each unit consists of 12 effects and runs in parallel feed mode. They have a high performance ratio of 17 and a capacity production of 12000 m^3/day.

Temstet et al. [73] provided a description of four MED-TVC units that were placed in Sicily. Each unit consists of 12 effects and works in the parallel feed mode, resulting in a low top brine temperature. The system's production rate is 9000 m^3/day of desalination water, and its performance ratio is 16.7.

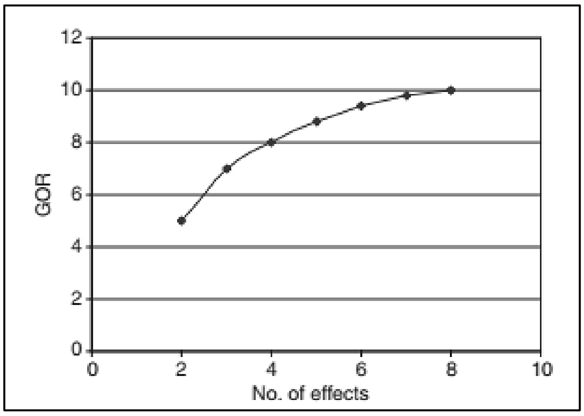


Fig. 29 GOR value change with number of effects [71].

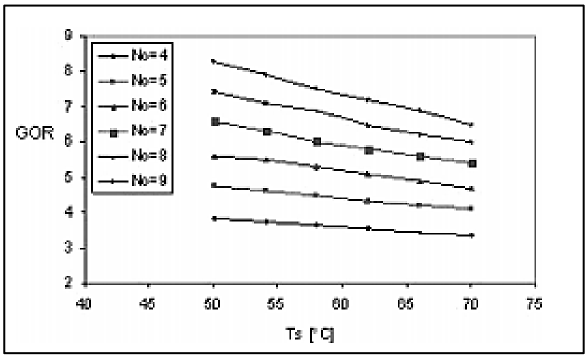


Fig. 30 GOR value change with steam temperature [71].

Table 3 provides a brief summary of previous studies by researchers in the field of conventional MED desalination.

Table 1. Summary of the primary CSP desalination systems and their characteristics that were reviewed for the sole purpose of producing freshwater.

Authors	Systems	Freshwater capacity	Remarks
[32]	LF-MED	freshwater capacities are 1,412 m^3/day 743 m^3/day and 1,109 m^3/day	The assessment was conducted by incorporating an LF solar field into a 9-effect MED unit, either with or without the inclusion of solar distillation. A normalized water cost of $5.00/$m^3$ was determined to be the most suitable configuration, which was achieved through solar distillation.
[33]	CSP-MED-TVC and CSP-MED-MVC	4,545 m^3/day	Two alternative layouts for the PTC-MED units were developed. In the first configuration, a boiler was utilized to receive the thermal energy from the solar field and then immediately sent to the TVC-MED unit. In the second arrangement, the heat waste from the ORC was sent to the MED unit, while the electricity generated from the ORC powered a mechanical vapor compressor (MVC).
[34]	LF-MED-TVC	4,546 m^3/day	Integrated a TVC-MED unit with Fresnel collectors. Solar panels, a boiler, and a cooling system were all part of the concentrated solar power system. The results showed that the chosen TVC-MED needed a 55,737 m^2 Fresnel mirror area and a total thermal energy consumption of 13.6 MWth
[35]	PTC-MED	200 m^3/h	PTC field was created and integrated into an existing MED facility. The system resulted in a substantial decrease in the utilization of fossil fuels.
[36]	CSP-MED	9 L/m^2	The experiment involved a solar collector with MED. Revealed that increasing water inlet temperature directly impacts productivity, GOR, efficiency, and productivity rate. The highest daily production rate is 9 L/m^2, with 87% efficiency during the day.
[37]	FP-MED	100 L/d	A groundbreaking low-temperature desalination method was introduced. This innovative technique utilizes a flat plate solar collector to produce an impressive 100 L/d of freshwater.
[38]	PTC-MED	6.36 L/day	Experimental investigations on a 5.5 m^2 intense black aluminum PTC that lacked a solar tracking system mechanism. A 95% increase in freshwater flow was achieved by making simple changes to the cavities, taking the model with thermal insulated and wind protection from 3.25 L to 6.36 L.
[39]	PTC-MED with HPA	The ranges variable from 0.24 m^3/h to 0.47 m^3/h on different days.	The addition of an absorption heat pump resulted in a substantial decrease in the size of the PTC and the amount of thermal energy needed.
[40]	CR-MED	459 m^3/d	Analysis of a CR solar power plant that generates both power and water using the s CO_2 Brayton cycle with MED. They used a five-effect MED system. The results show that the solar thermal efficiency was 24%.
[41]	CSP with single effect thermal desalination	0.15 m^3/day	A small-scale CSP plant was equipped with a thermal desalination plant that only had one effect. For rural locations with freshwater needs between 0.03 m^3/day and 0.06 m^3/day, the system is an excellent choice.
[42]	PTC-two effects TVC-MED/MED with HAP	72 m^3/day	System comprised of a PTC in conjunction with a two effect HAP TVC-MED/MED. The thermal energy need was lowered by 44% and the electricity usage was reduced by 12% compared with the system that did not have an HPA.
[43]	CSP-MED	in winter 400,000 m^3/day and in summer 865,000 m^3/ day	Created forth a plan for determining the process parameters and equipment size for a multiple-effect distillation station that runs on concentrated solar power. A total of 2,670,000 m^2 of reflector surface area and 85,500 tons of molten salt heat storage.
[44]	PTC-MED	2200 metric tons	Multi-Effect Distillation system that collects energy from PTC type. Using four MED effects. Based on the results, it is possible to produce 2200 metric tons of distillate utilizing a 92,000 m^2 plot of land for PTC. There is an average specific thermal energy expenditure of 1,140 kJ/kg and a daily performance ratio of 2.

Table 2. Summary a concise overview of the key features of the CSP-D systems that were assessed for the purpose of co-generating freshwater and electricity.

Authors	Systems	Freshwater capacity	Power capacity	Remarks
[45]	CSP-MED and CSP-RO	11-effect MED 34000-35000 m^3/day and 14-effect MED 41000- 42000 m^3/day	50 MWel	Four combinations of CSP-desalination were examined, three of which included MED/MED-TVC and one of which utilized RO. Furthermore, three distinct cooling systems were considered: dry cooling, evaporative water cooling, and once-through cooling. Certain circumstances, the results suggested that a CSP-MED is more enticing than a CSP-RO configuration. The RO unit requires a significant amount of electricity, namely over 4.5 kWh/m^3, and high temperatures are necessary during the condensation phase.
[46]	STP-MED	3,000 m^3/day	3 MWel	Thermal analysis of a MED system powered by a solar tower. By increasing the steam temperature from 65∘C to 90 °C, distillate production doubled, albeit with an 11% decrease in power production.
[47]	STP-MED	22568 m^3/d	50 MWel	Examined the thermodynamic analysis of the integration of the STP plant with MED unit. The integration of a MED plant may be a viable option for the integration of STP and desalination.
[48]	CSP-flash distillation	290 m^3/day	21.82 MWel	An integrated system that was suggested included a ST, a steam RC, a thermal energy generator, a distillation of the flash system, and a pressure air receiver-GT power plant. GT cycle output was 19,150 kW, RC output was 2,632 kW, and total electrical generator output was 32.94 kW in the integrated system.
[49]	PTC-MED/TVCMED and PTC-RO	48,493 m^3/day	50 Mwel	Four designs were proposed, each of which consists of a steam RC propelled by a PTC and a variety of desalination methods. The CSP power facility was found to be more efficient when combined with a MED unit.
[50]	CSP-MED	16400 m^3/day and 36112 m^3/day	111 MWel and 110 MWel	The feasibility of a system that comprised a PTC, a steam RC, and a MED unit was assessed. Assessed four distinct cooling technologies and determined that the CSP-MED SWCC configuration yielded the lowest electricity production. Nevertheless, this cogeneration has the potential to produce a substantial quantity of freshwater annually, despite some electricity loss.
[51]	CSP-MED	2,558 m^3/day	115 MWel	An innovative idea was presented for a MED system that uses a solar superstructure to power a Brayton cycle that recompresses supercritical CO_2. Costs were cut by half due to the proposed strategy, which in turn reduced the size of the MED facility. Furthermore, the idea enhanced the MED system's capacity factor and reduced the LCOW by 19%, from \$1.81/m^3 to \$1.48/m^3.
[52]	PTC-MED-TVC	390 m^3/h	110 Mwel	Parallel MED-TVC system for these findings suggest that CSP+MED can be financially appealing when contrasted with the current TVC-MED facility. Due to its lower size, the CSP plant performs better than its nominal output, resulting in an annual capacity factor of 34.2% for the CSP plant and 41.4% for the larger plant.
[53]	CSP-MED and CSP-RO	158.6 m^3/h and 186.4 m^3/h	5 MWel	The assessment involved 2 CSP-MED systems and one CSP-RO configuration, which consisted of a PTC and a steam RC. Compared these arrangements where the RO system is connectivity to the grid. The LCOWs for these designs were 1.239, 1.265, and 1.055 €/m^3, respectively. The arrangement that linked the RO system to the grid achieved an LCOW of 0.76 €/m^3.
[54]	CSP-MED	0.3 kg/s and 3 kg/s	50 kWel and 230 kWel	A MED system was combined with a bilayer wood solar steam generator. The increase in solar capacity from 50 kW to 230 kW results in a corresponding rise in the average temperature difference, from 1.88 °C to 6.27 °C. This parametric research enhances the performance of both the MED system and the bilayer wood solar steam generator.
[55]	PD-MED	8321 kg/s	1,063 MWel	Utilized solar dish collectors in conjunction with a PCM storage to supply the necessary thermal power for a steam generating station. Materials that change phase are stored overnight and when there are no solar thermal energy sources available. This system achieves an impressive total electrical efficiency of 28.84%, along with an exceptional total thermal efficiency of 97.18%.

[56]	PTC-MED	14,000 m^3/day	51.84 MWel	An MED system was incorporated with a PTC Solar Power plant. Results shows the most efficient layout was the integration of a MED with 11-effects and GOR decreases with the increase in the steam inlet temperature. Finally, demonstrates that the GOR rises as the number of effects increases, owing to the presence of extra heat exchangers, which results in an increased heat transfer area.
[57]	CSP-MED	170 m^3/h	58.7 MWel	Analysis of a CSP plant that with a MED technology to produce electricity and desalinate water all at once. CSP output, excluding water production, reached 58.7 MWel. 125 dipteran of water at 170 m^3/h resulted in about 49.5 MWel of energy. For 10 effects, the mass flow of distilled water was 498 m^3/h. Findings from the sale of generated electricity indicated that the design was profitable to the tune of €78.84 million. In addition, the ideal pressure for producing both power and distilled water was determined to be 0.45 bar in the condenser.
[58]	LF-MED	520 m3/day	10 MW	Cogeneration of the water and electricity production using a LF type concentrated solar power. With a desalination capacity of 520 m^3/day and a cogeneration capacity of the CSP plant of 2.2 MW, the results were impressive. In addition, the input salinity, temperature and cogeneration ratio are some of the process characteristics that affect the final product.

Table 3. Summary of the primary characteristics of the conventional desalination systems that were reviewed.

Authors	Systems	Type of feeding	Number of effects	Distillate production	Remarks
[59]	MED-TVC	FF PF PCF	10	15,000 m^3 /d	A thermo-economic analysis on four configurations of MED, all of which are integrated with TVC. Their aim was to identify the configuration with the best performance and estimate the cost of water using the specific exergy cost flow method.
[60]	MED-TVC	FF PF BF and PCF	10	56.12 kg/s	Impact of preheaters, including their placement and quantity, on the GOR and the overall heat transfer area in the plant. The researchers examined the MED desalination plant.
[61]	MED-TVC	FF	12	101.5 kg/s	Analysis of the PF-MED-TVC plant, incorporating preheaters and non-condensable gases, but excluding flash boxes. They subsequently validated the dynamic model using real data and achieved a near match
[62]	MED heat from a boiler MED-TVC MED heat from solar pond	PF	3	540 kg/h 480 kg/h 600 kg/h	Investigation was carried out using three distinct operational modes. The initial mode involved utilizing steam generated from the boiler, the subsequent mode involved utilizing a thermo vapor compressor, and the last mode involved utilizing heat obtained from a solar pond. The heat performance values for the first, second, and third modes were 667, 750, and 700 kJ/kg respectively.
[63]	MED-TVC	PF	17 20	10027.14 m^3/d 11794.40 m^3/d	Investigated the impact of operating parameters on the performance of the MED-TVC system, with a particular emphasis on the enhancement of key performance indicators, such as water production. The results of MED-TVC are which illustrates the fluctuation of GOR in relation to the number of effects. Consequently, there was a robust positive correlation between the quantity of effects and an increased GOR. Additionally, a maximal GOR value of 17.06 that can be achieved by utilizing the 20 effects of the MED system.
[64]	MED	PF	7	0.1004 kg/s	Optimized the quantity of flash box in the system by conducting an economic analysis. As a consequence, a modified system was identified that improved the steam economy by 23.77% and decreased steam consumption by 36.76%.
[65]	MED-TVC	PF	5	1200 m^3/day	Mathematical models to predict the design data for a MED-TVC unit that includes a plate type evaporator and a shell and tube type evaporator. They have also compared the results of the evaporator. Additionally, they have demonstrated the impact of design and operating parameters, including the first effect steam temperature, number of effects, and salt concentration ratio, on the system's performance ratio.

[66]	MED	PF	4 12	1000 l/day	Developed a mathematical model of MED steady state and conducted an analysis of the plant's performance in relation to design parameters and operating variables. The conclusion was that the gain output ratio varied between 7.34 and 15.04 for 4 effects and 12 effects.
[67]	MED-TVC	PF	6	15,000 m^3/day	A series of mathematical models for MED plant, that were employed to analyses the coefficient of heat transfer along the tube row, tube length, and tube column directions. The results indicated that the heat transmission coefficient is higher in the evaporating zone than in the preheating zone.
[68]	MED	PF	6	126.5 m^3/day	A new design scheme and mathematical model for geothermal-driven MED plants. The geothermal hot water was initially incorporated into the first effect, and the water that exited the module was redirected to a seawater distillation module. Consequently, the yield was increased by 25 to 60% in comparison to conventional MED plants.
[69]	MED-TVC	PF	3 4 5 6	15,116 m^3/day 19,713 m^3/day 24,2505 m^3/day 28,8985 m^3/day	Proposed two mathematical models. There was a section dedicated to economic analysis, while another was dedicated to the procedure. Under ideal operating conditions, the system with 6 effects can achieve cost savings of 14%, 12.5%, and 2%, as well as reduce the steam consumption for producing 1 cubic meter of fresh water by 50%, 34%, and 18% compared to systems with 3, 4, and 5 effects, respectively
[70]	RO MSF MED+TVC MED+MVC	FF	6 1 4 4	32000 m^3 /day	Conducted a comprehensive economic evaluation of the RO process and various thermal desalination methods, such as MSF, MED+TVC, and MED+MVC. They determined that in places with low energy costs, particularly in the Gulf countries, big thermal desalination units are economically viable and comparable to the RO technique.
[71]	MED-TVC	PF	7	1536 ton/day	Presented the parametric optimization approach of the multi-effect desalination process employing steam-thermal compression (MED-TVC) to enhance the gain ratio (GOR) value. The results showed that the GOR increases with increasing number of effects and decreases when the steam temperature increases
[72]	MED-TVC	PF	12	12000 m^3 /day	Described the key features of three MED-TVC units. Each unit consists of 12 effects and runs in parallel feed mode. They have a high-performance ratio of 17 and a capacity production of 12000 m^3 /day.
[73]	MED-TVC	PF	12	9000 m^3 /day	provided a description of four MED-TVC units. Each unit consists of 12 effects and works in the parallel feed mode, resulting in a low top brine temperature. The system's production rate is 9000 m^3 /day of desalination water, and its performance ratio is 16.7.

8. Conclusions

This article examined the present condition of cutting-edge CSP-desalination systems. The review provides a comprehensive overview of the present state of CSP and desalination technology, with a particular emphasis on two types of systems, plants that exclusively produce freshwater and plants that cogenerate freshwater with power. CSP is suitable for powering a diverse array of desalination systems due to its ability to generate electricity and fluctuate in operating temperature. Thermal desalination systems utilize the process of evaporation to separating water from salt. Systems include processes involving MED, MSF and TVC, as well as other less common systems. Integrating a TVC or heat. The future direction can be classified into research on improving the efficiency of solar collector and thermal efficiency of multi-effect desalination technology and integration method as well as preliminary feasibility analysis of selecting a suitable site for CSP plant with high solar radiation level. Currently, the application of solar thermal desalination/multi-effect desalination technology leads to high cost of fresh water production. Pump absorbed can enhance performance and reduce costs in numerous thermally-driven systems. The studies mentioned here have different scopes, but most of them incorporate certain performance indicators, such as Levelized Cost of Electricity (LCOE), Levelized Cost of Water (LCOW), total thermal efficiency, power generation capacity, and freshwater capacity for production. Multiple studies have assessed the effectiveness of different setups and operational approaches to determine the most efficient plan, with some incorporating the incorporation of thermal energy storage. Ultimately, a few studies directly compare the efficiency of plants powered by renewable energy sources with those powered by conventional fuels. The completed review revealed various viable methods for coupling concentrated solar power (CSP) with desalination plants. Overall, CSP-desalination plants have the ability to produce freshwater in a sustainable and ecologically benign way. However, further research and advancements are needed to make these plants economically viable.

Nomenclatures

Name	Description
BF	Backward feed
CSP	Concentrated solar power
DNI	Direct normal irradiance
ED	Electrodialysis
FF	Forward feed
GT	Gas turbine
GOR	Gain output ratio
HAP	Heat absorption pump
LCOE	Levelized cost of electricity
LCOW	Levelized cost of water
LF	Linear Fresnel solar field
LTD	Low temperature distillation
MED	Multi-effect distillation
MD	Membrane distillation
MENA	Middle East and North Africa
MSF	Multi-stage flash distillation
MVC	Mechanical vapor compression
ORC	Organic Rankine cycle
PCM	Phase change material
PCF	Parallel cross Feed
PD	Parabolic dish
PF	Parallel cross feed
PTC	Parabolic Trough Collector
RC	Rankine Cycle
RO	Reverse osmosis
SAM	Systems Advisor Model
ST	Solar Tower
STP	Solar Tower Power
SWCC	Seawater cooling circuit
SWRO	Seawater reverse osmosis
TEG	Thermoelectric generator
TVC	Thermal vapor compression

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