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Review

Applications of Heat Exchanger in Solar Desalination: Current Issues and Future Challenges

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Abstract: Solar desalination is a process to convert saline water into potable water by the application of solar energy. The enhancement of the distillate output of the solar desalination is low, so it is not considered as a method to produce potable water. A heat exchanger is an important device used for heat transfer applications. The present review article illustrates the application of a heat exchanger with a solar desalination system to enhance the distillate output. In the current review, it is found that the heat exchanger is an important device to improve the distillate productivity of the solar desalination system. Finally, the future work and future challenges of using a heat exchanger with a solar desalination system are presented.

Keywords: solar desalination; solar still; distillate productivity; heat exchanger

Citation: Elsheikh, A.H.; Panchal, H.N.; Sengottain, S.; A. Alsaleh, N.; Ahmadein, M. Applications of Heat Exchanger in Solar Desalination: Current Issues and Future Challenges. *Water* **2022**, *14*, 852. https://doi.org/10.3390/w14060852

Academic Editor: Siamak Hoseinzadeh

Received: 16 January 2022
Accepted: 22 February 2022
Published: 9 March 2022

1. Introduction

The potable water scarcity problem worsens day by day due to various applications such as drinking, industrial applications and many more [1]. In many areas of the world, people suffer from many diseases due to the scarcity of potable water [2]. The distribution of water on the earth is very uneven [3]. The problem regarding the availability of freshwater to the population is significant in many areas of the world [4]. In African countries, this issue is very critical [5]. The people living in these countries do not have enough suitable drinking water [6]. The earth is predominantly covered with saline water, which is not directly usable for drinking [7]. In order to use seawater for drinking purposes, its salinity must be removed because a salinity level of around 500 ppm is recommended for drinking [8]. Desalination is a simple and easy-to-use technique to remove the impurity/salinity from seawater or brackish water [9]. There are many different techniques available for water cleaning, but solar desalination is the best among them due to its simplicity and non-polluting nature. It is also helpful in areas where there is a shortage of electrical energy resources [10]. This is the reason behind the wide usage of the solar desalination method [11]. Through evaporation and condensation processes, distilled water can be produced from the solar still [12]. Due to high heat losses, solar distillate productivity is still very low [13]. It provides an average of 3 L/day. This is not enough drinking water for a single person [14].

Many researchers have used different methods to lower the heat loss and increase the productivity of solar stills [15–17]. They used various techniques such as changing the configuration of the still, changing the solar still design, using a different absorbing material, or introducing components such as flat plate collectors, fins, evacuated tubes, etc. [18–21].

To increase the evaporative and absorber area, a solar still was modified with an attachment of trays and mirrors inside the still by Essa et al. [22]. A unique solar-geothermal-gas-driven polygeneration system was designed and developed to produce hot water, potable water, combined power, and hydrogen in [23]. Morad et al. [24] reduced the top cover losses by applying a cooling technique. An estimated 30% higher efficiency can be achieved by applying their technique to a solar still. Shyora et al. [25] conducted a similar experiment by modifying a stepped-type solar still and obtained a 23.5% higher efficiency. Panchal and Patel [26] observed that higher wind speeds and solar radiation increase distillate productivity. Badran and Tahaineh [27] used a flat plate collector (FPC). They achieved a 36% higher efficiency compared to a conventional solar still by preheating the water to enhance distillate productivity. Raju and Narayana [28] connected two FPCs in a series to a conventional solar still. They observed a 41% higher distillate productivity. Madiouli et al. [29] used a parabolic trough collector (PTC) and FPC to concentrate solar radiation in a conventional solar still. It has also been found that stills are at their maximum efficiency in summer compared with winter. Fathy et al. [30] experimented using a fixed and movable PTC with a double-slope still to enhance distillate productivity. Panchal [31] conducted an experiment using energy storage materials, such as metal stones and cow dung, and obtained better results. Panchal [32] reviewed different thermal energy storage materials such as black rubber, stones, ink, dyes, charcoal particles, jute wicks, etc. It was found that these materials have good energy-absorbing capacity. Murugavel and Shrithar [33] used a wick material inside the basin area as an absorber to lessen the volumetric heat capacity and enhance the heat transfer area inside the solar still. Omara et al. [34] used fins and corrugated absorber surfaces inside a solar still to improve the distillate productivity. Due to modifications, they achieved a 40% higher distillate productivity than a conventional solar still. Mevada et al. [35] reviewed different attachments of fins and found that increasing the height of the fins resulted an enhanced efficiency of the solar still. Sharshir et al. [36] used evacuated tubes and nanofluids with a pyramid-shaped solar still and compared the experiment with a conventional still. They also measured the performance of copper oxide and carbon black nanomaterial with a solar still. Kumar et al. [37] used a fan to circulate the water from the basin of the solar still to evacuated tubes. They found that the performance of the force mode system is higher than the natural mode. Panchal and Shah [38] experimented on a double-slope-type solar still with evacuated tubes and energy storage materials. They found that a minimum 2 cm basin water depth led to the optimum performance of the solar still.

Climatic parameters such as wind speed and solar intensity also affect the productivity of solar stills [39–41]. The performance decreases at lower wind speeds and low solar intensity [42]. To increase the heat transfer coefficient of water, Panchal and Sathyamurthi [43] used porous-type fins. Rajaseenivasan and Shrithar [44] measured the performance of a solar still using square and circular types of fins and found that both fins increase the efficiency of the solar still. Sebaii and Nagar [45] found that the fins' material did not affect the distillate productivity of the solar still. The productivity of a solar still could also be increased by various parameters reviewed by Panchal and Patel [1]. Diesel engine exhaust gases used with a solar desalination system were evaluated by Panchal Hitesh [38] to enhance distillate productivity. Various heat storage materials and their effects on distillate productivity have been reviewed by Panchal [46]. Nanofluids and their various challenges, applications, heat transport, and other qualities were explained very effectively by Said et al. [47]. A geothermal and solar energy-operated multigeneration system with a thermoelectric generator was proposed by Mahmoudan [48]. Saravanan et al. [49] used a kanchey marble to enhance the distillate productivity of a solar still. They observed that water temperature increases without affecting the phase of the water medium basin, and approximately a 163% higher distillate output could be achieved. In the current study, the current issues and future challenges of utilizing a heat exchanger with solar desalination are reviewed.

2. Heat Exchanger

A heat exchanger is used to transfer heat between two fluids [50]. It prevents the mixing of two fluids by acting as a separating wall. Heat exchangers are used in solar stills to recover wasted heat, which reduces the heat losses, and are essential from environmental and economic points of view [51].

To increase the inner water temperature and heat transfer capacity of water, a heat exchange medium is used, which preheats the water; hence, the efficiency of a solar still could be improved. In a heat exchanger, the liquid is separately passed into a tube where heat is exchanged between two fluids, and a thermal effect is achieved [52].

In this review, the ways in which different researchers have used heat exchangers with a solar still to enhance efficiency and their effects on the performance of solar stills are also discussed.

3. Solar Desalination System with Heat Exchanger

The efficiency of the solar still is determined by the ratio of the evaporative heat transfer coefficient and the product of the area of the solar still and solar intensity. The evaporative heat transfer coefficient depends on the temperature difference between the water and inner glass. Only solar energy is responsible for raising the temperature in a conventional solar still. However, with the help of a heat exchanger, external hot water is supplied, so the temperature difference will be higher compared with the conventional solar still, and so distillate productivity and efficiency are increased.

Many researchers have used a heat exchanger with a solar still in different ways to increase the distillate output as well as efficiency.

Yadav [53] conducted an experiment using a heat exchanger on a double-slope solar still. He found that the heat exchanger length had a significant effect on the performance of a solar still. He also concluded that the system improved distillate productivity but lessened efficiency.

Chorak et al. [54] developed a heat exchanger for a multi-effect desalination plant that was powered by solar energy. The heat exchangers utilized in the experiment were shell and tube heat exchangers, which allowed them to increase the distillate productivity. The heat transfer coefficients were determined using the Bell method for single-phase heat transfer, the Kandlikar method for boiling correlations, and the Kutateladze method for condensation correlations. They discovered that the technique they employed increased distillate productivity at minimal cost.

To investigate the performance of solar stills, Hosseini et al. [55] conducted an experiment on a solar distillation system with a parabolic trough collector (PTC) with a vacuum-type HE. A schematic diagram of the experimental setup is shown in Figure 1. The oil inside the PTC passed through a pump to the vacuum-type HE. The temperature of the oil and water increased with higher solar intensity (Figure 2), and 1.5 $kg/m^2/day$ of distilled water was produced through the system.

Kabeel et al. [56] conducted a review of different heat exchange mechanisms to enhance the performance of solar stills. They found that heat loss could be minimized by minimizing the glass cover temperature or applying the glass-cooling technique. Different thermal energy storage materials ensure a better performance to enhance the day/night distillate productivity of solar stills. Through heat exchange mechanisms, up to 70 °C basin water temperature can be achieved. These modifications of solar stills have a considerable effect on distillate productivity.

Sahota et al. [57] conducted an experiment on a double-slope solar still using a helical coil-type heat exchanger and nanofluids. An evaporative heat transfer coefficient improvement can be achieved with a flat plate collector (FPC) and different nanomaterials such as CuO, Al_2O_3, and TiO_2– metallic nanoparticles (Figure 3). A modification of the system gives a higher value of energy and exergy efficiency. The heat exchanger improved the performance in terms of the distillate productivity of the solar still.

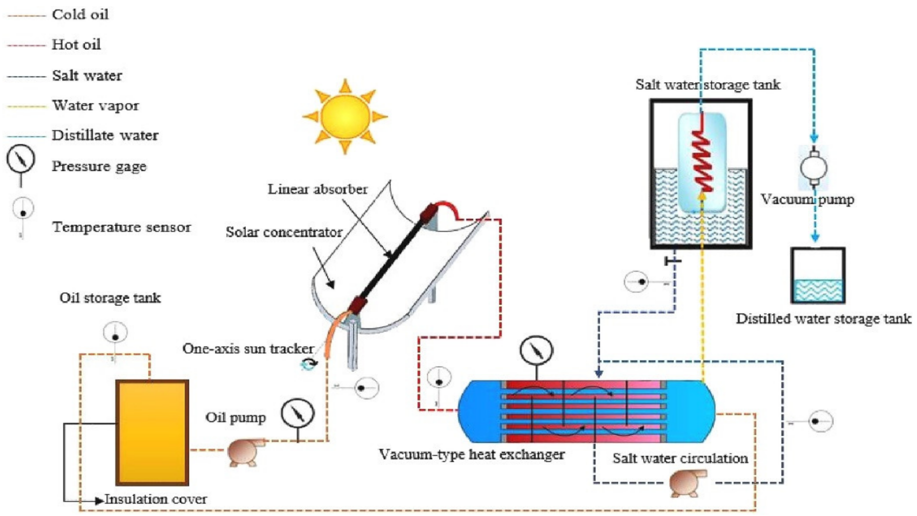

Figure 1. Schematic diagram of solar distillation system integrated with PTC and vacuum-type HE [55].

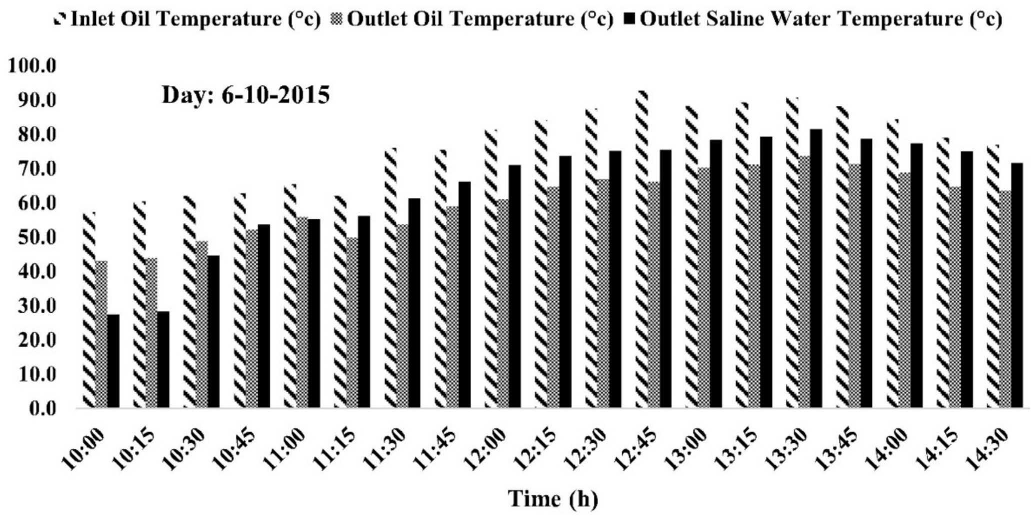

Figure 2. Differentiation in oil and water temperatures inside heat exchanger [55].

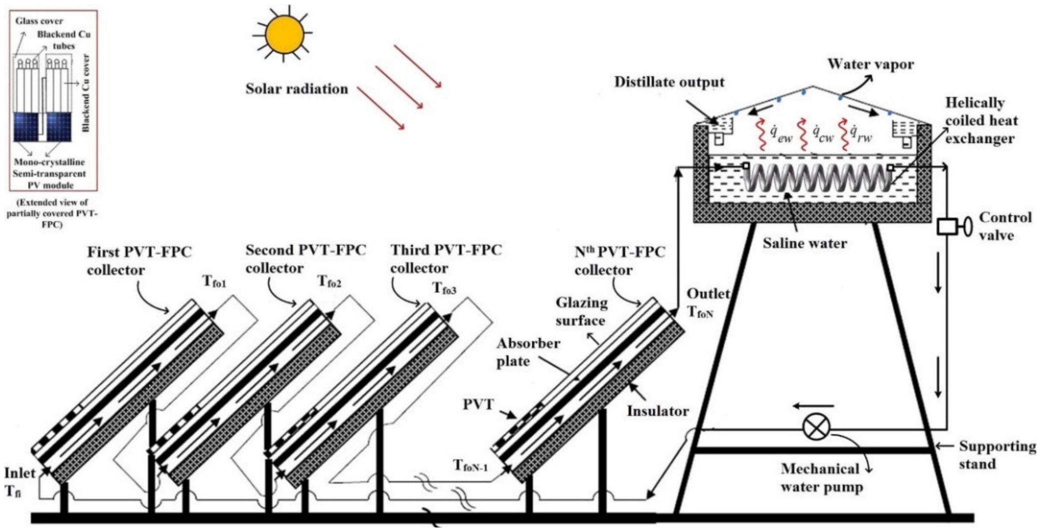

Figure 3. Schematic diagram of double-slope solar still with helical coil heat exchanger and nanofluids [57].

Dhivagar and Sundararaj [58] modified a solar still coupled with a copper material heat exchanger, using a coarse aggregate as an energy-absorbing material, as shown in Figure 4. They concluded that the modification of the solar still produced 28% and 17% higher efficiencies compared with the conventional solar still. For the distillate output, modified and conventional solar stills produced 6.23 and 2.41 kg/m^2 (Figure 5). In addition, they achieved higher evaporative and convective heat transfer coefficients due to the modification of the solar still.

Hammadi [59] found that a ground heat exchanger coupled with a solar still benefited soil temperature, as shown in Figure 6. They dipped an HE pipe with a 0.2 m diameter and 70 m length 1 m into the soil. They found that with a greater length and diameter of the pipe, both condensation and evaporation rates decreased due to constant condensation and moisture content. They also received 7.48 and 5 kg/m^2 distillate output during experimentation.

Bhargava and Yadav [60] conducted experimental work on a solar still using an HE and evacuated tubes. The problem of scaling on the inner surface of evacuated tubes was avoided with an attachment to the heat exchanger. Experiments were conducted with three different water depths at 4, 5 and 6 cm. The experiment (Figure 7) found that the attachment of the heat exchanger and evacuated tubes ensured the maximum distillate productivity at 4 cm water depth.

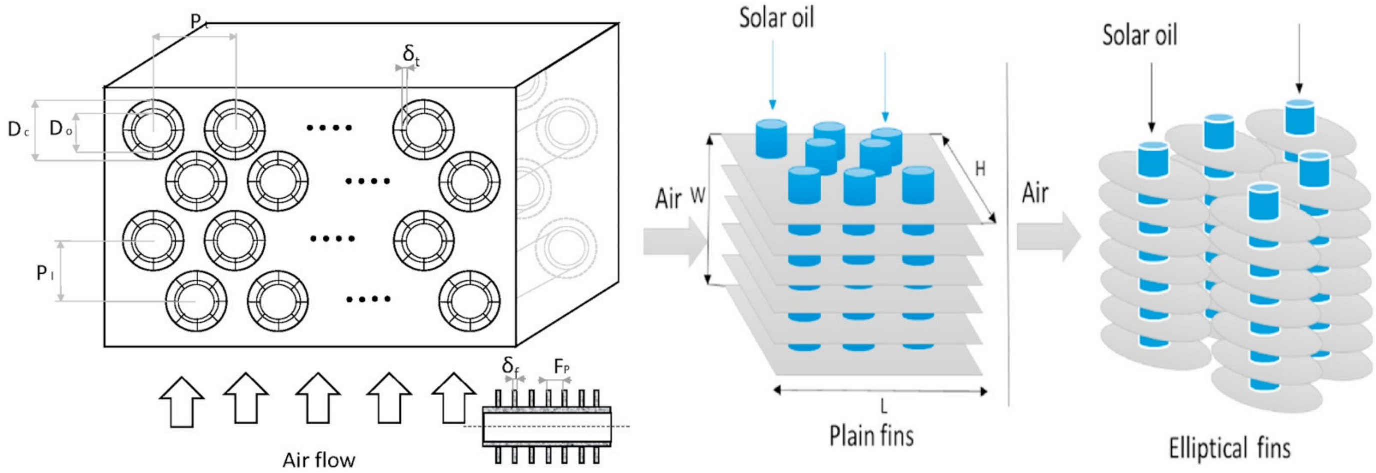

Figure 4. Geometry arrangement of finned tube heat exchanger [61].

Chaanaoui et al. [61] conducted a comparative analysis for fin configuration on the performance of solar drying applications. A fin tube-type heat exchanger was used for experimental study, as shown in Figure 4. A comparison was made based on fins' material, geometry, and cost analysis. It was found that a lower number of fins produces a higher evaporation rate. In addition, aluminum materials have good thermal properties, and their cost is lower compared to copper materials, which reduces the total cost of productivity.

Mohammadi et al. [62] conducted a comparative analysis on different designs of heat exchangers with solar stills, as shown in Figure 5. The authors designed a novel shape and compared the performance with parallel-shaped and serpentine heat exchangers. The experiment (Figure 6) found that due to the lower pressure drop, higher volumetric flow rate, and minimum thermal resistance, heat exchangers with novel designs ensure higher freshwater productivity than other shape designs of heat exchangers.

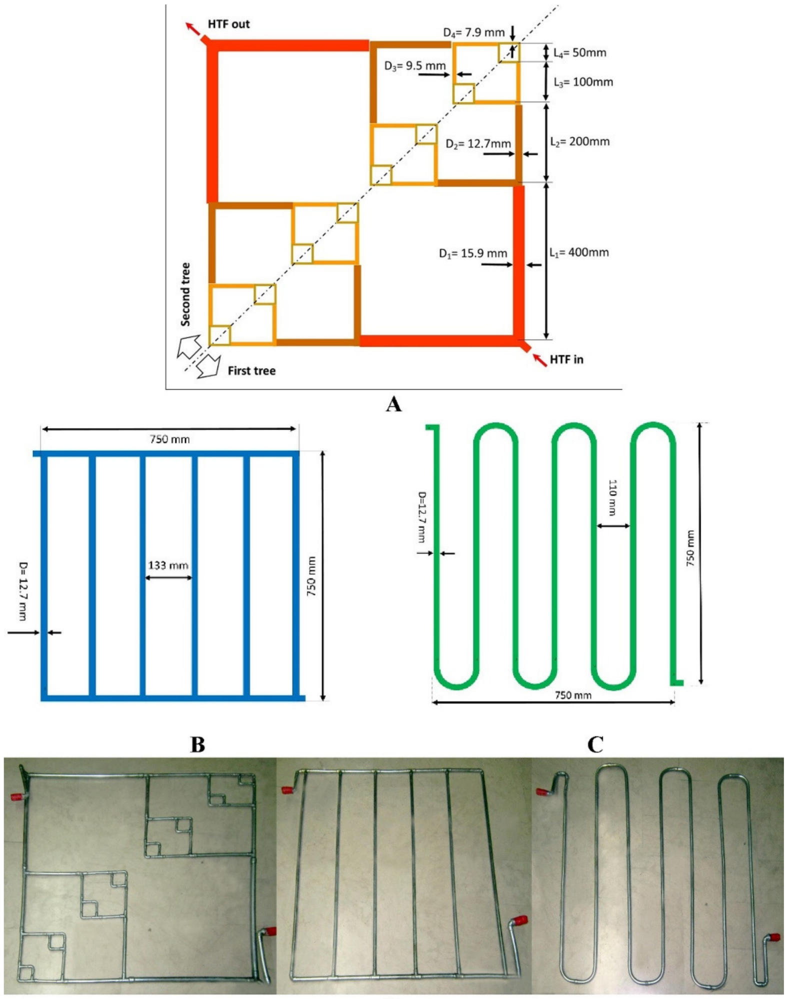

Figure 5. Different designs of heat exchangers: (**A**) novel design; (**B**) parallel channel; (**C**) serpentine design; (**D**) different designs of heat exchanger [62].

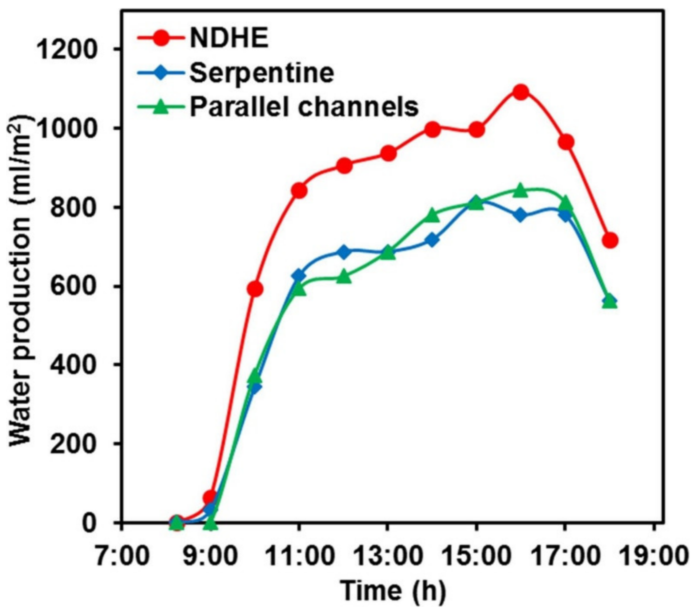

Figure 6. Hourly variation of water production for different heat exchangers [62].

Heat exchangers' transient performance with double-slope solar stills was investigated by Kumar et al. [63]. An investigation was performed using different parameters such as water depth, mass, heat transfer coefficient, inlet water temperature, etc. The authors found that a higher inlet temperature of water in the HE pipe and lower mass and depth of water lead to a higher efficiency. The distillate output varies with the length of the heat exchanger.

Kumar and Tiwari [64] used wasted heat through the heat exchanger, which is released from the top glass cover to enhance the distillate productivity of solar stills. In their research work, the night performance of the still was improved with the heat exchanger by recovering wasted heat in water inside the solar still.

Mahian et al. [65] investigated the performance of solar stills with heat exchangers and nanomaterials with different concentrations and flow rates. A schematic diagram of the experimental setup is shown in Figure 7. They used SiO_2/water and Cu/water as a nanofluid. They found that with a higher concentration of nanofluid and higher inlet temperature of the water with a heat exchanger, a higher heat transfer coefficient could be achieved.

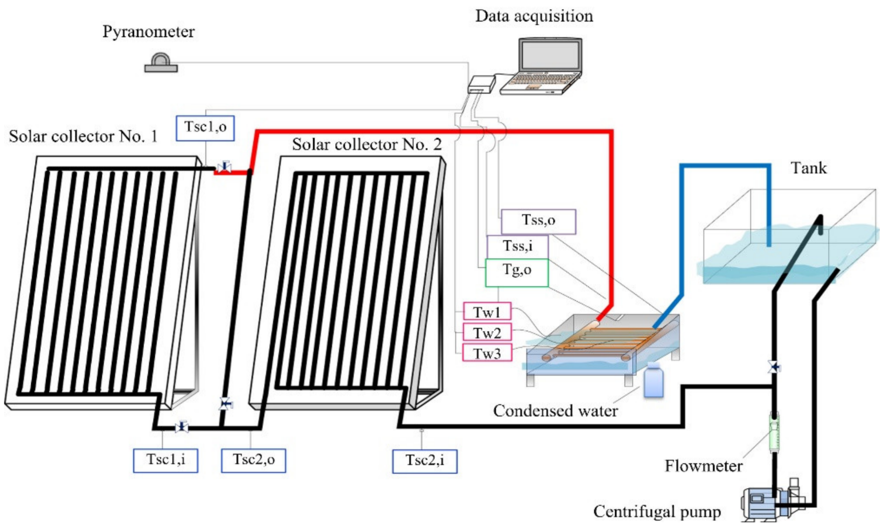

Figure 7. Schematic diagram of the effect of varying heat transfer coefficient of heat exchanger-equipped solar still by nanofluids [65].

An experimental study to determine the thermal performance of heat exchangers using different soils was performed by Al-Ameen et al. [66]. A ground heat exchanger was developed in this work, and sand was used as the absorber. From the results, it was found that the soil inside the tube increased the temperature of the heat exchanger and heat transfer coefficient too.

Joshi and Tiwari [51] conducted a comparative study to analyze the economic and energy parameters of solar stills with a heat exchanger and a flat plate collector. A comparison was made between fully covered FPCs, partially covered FPCs, and conventional stills. It was observed that systems with fully covered flat plate collectors and heat exchangers produce more distillate water at lower cost and generate more electricity. Table 1 shows the comparison of different Researchers work on solar still with Heat exchanger.

Table 1. Comparison of Different Research Work on solar still with Heat exchanger.

Author(s)	Configuration	Observations
Yadav [53]	Double-slope solar still with HE	• HE recovers the wasted heat of still and improves its performance.
Chorak et al. [54]	Shell- and tube-type HE	• Higher distillate productivity can be achieved at lower cost.
Hosseini et al. [55]	PTC and shell- and tube-type HE	• Both PTC and HE increased the system's temperature and produced 1.5 kg/m^2/day daily water.
Sahota et al. [57]	Helical coil-type HE	• The system produces higher energy and exergy efficiency by adding different nanomaterials and flat plate collectors.
Dhivagar and Sundararaj [58]	Copper material HE	• Marble stone as heat storage material improved the heat transfer coefficient of system. • Around 17% higher distillate productivity can be achieved.
Hammadi [58]	Ground Heat exchanger	• A heat exchanger coupled to ground with 70 m length and 0.2 m diameter pipe is dipped 1 m into the soil.
Bhargava and Yadav [60]	HE with evacuated tubes	• Experiment was conducted with three different depths of water, at 4, 5 and 6 cm. • Results show that at 4 cm water, optimum performance can be achieved.
Chaanaoui et al. [61]	Fin tube-type heat exchanger	• A comparison was made based on a different configurations such as geometry, material, etc., of heat exchangers. • It was found that lower no. of fins and HE having aluminum material gives better productivity.
Mohammadi et al. [62]	Novel shape, parallel, serpentine heat exchangers	• A comparative analysis shows that due to lower pressure drop, higher volumetric flow rate, and minimum thermal resistance, a novel-shaped HE gives higher performance compared to other designs.
Kumar et al. [63]	Double-slope solar still with HE	• It was found that the system produces higher efficiency with higher inlet temperature and lower mass and depth of water.
Kumar and Tiwari [64]	HE with solar still	• Waste heat was used to increase the nocturnal productivity of the system.

Table 1. *Cont.*

Author(s)	Configuration	Observations
Mahian et al. [65]	Heat exchanger with nanomaterial	• Heat exchangers with SiO_2/water and Cu/water as nanomaterial increase the heat transfer coefficient of the system.
Al-Ameen et al. [66]	Heat exchanger with Soil	• Soil as a heat storage medium gave a better performance to increase the temperature of heat exchanger, which gave the higher heat transfer coefficient.
Joshi and Tiwari [51]	Heat exchanger with FPC	• A comparative analysis was performed using a heat exchanger with a fully covered and partially covered flat plate collector compared to conventional system. • The result shows that HE with fully covered FPC system gives generates higher electricity and higher distillate at a lower cost.

4. Conclusions

The present review article shows the application of heat exchangers to enhance the distillate output of solar desalination systems. A review of various researchers' works on solar desalination systems with heat exchangers is presented in this review article. From the various researchers' works, the following points are concluded:

(1) Heat exchangers can recover the wasted heat of solar stills and improve their performance.
(2) Heat exchangers are considered important devices attached to the solar desalination system to improve performance at low cost.
(3) The combination of the solar desalination system with a PTC and heat exchanger improved the solar desalination system's performance compared with the passive solar desalination system.
(4) Sensible heat storage materials in the solar desalination system with a heat exchanger also enhance the distillate output.
(5) Heat exchangers coupled with heat pipes also enhance the distillate productivity of the solar desalination system.
(6) Solar desalination coupled with a heat exchanger improves the nocturnal distillate output of the solar desalination system.
(7) Heat exchangers could also be coupled with the flat plate-type solar collector to enhance the distillate productivity of the solar desalination system.

5. Future Scope

The research on solar desalination systems with heat exchangers has much scope. Some opportunities for further research are detailed below:

- Computational fluid dynamics (CFD) is also a very important tool to test the performance of a solar desalination system with a heat exchanger.
- Very limited research has been conducted on the solar desalination system with a heat exchanger and sensible heat storage materials.
- An investigation of the performance of latent and combined heat storage materials (sensible, latent heat storage materials) is still unaddressed by researchers.

6. Future Challenges

- A heat exchanger can be used in conjunction with a solar still to increase the amount of distillate produced. However, there will be certain obstacles in the future, and academics will need to handle them appropriately in their studies.
- When saline water is passed through heat exchanger tubes, it has the potential to cause corrosion issues. In order to function with solar desalination systems in the future, it will be necessary to develop heat exchangers that can prevent or significantly minimize corrosion.
- The material of heat exchangers is always important in terms of enhancing the heat transfer efficiency. Therefore, novel and inexpensive but highly efficient materials are required to operate with the solar desalination system. As a result, working on a novel/cheap heat exchanger with a solar desalination system presents a significant challenge to researchers.
- In the course of working with heat exchangers, leakage is considered to be a significant difficulty for researchers. Therefore, an effective method must be employed to detect and prevent leakage when the heat exchanger works with the solar desalination system.
- Another issue for researchers is employing heat exchangers with solar desalination systems with the least fouling.

Author Contributions: Writing—review and editing, A.H.E., H.N.P., S.S., N.A.A. and M.A. All authors contributed equally to this paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by [Imam Mohammad Ibn Saud Islamic University] grant number [RG-21-12-03].

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No data is used in this review manuscript.

Acknowledgments: The authors extend their appreciation to the Deanship of Scientific Research at Imam Mohammad Ibn Saud Islamic University for funding this work through Research Group no. RG-21-12-03.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

H.E.	Heat Exchanger
CFD	Computational fluid dynamics
FPC	Flat plate collector
PTC	Parabolic trough collector

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