IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Heat and Technology
Vol. 42, No. 1, February, 2024, pp. 101-110
Journal homepage: http://ieta.org/journals/ijht

Enhancing Water Purification in Solar Stills Through Incorporation of Renewable Energy Technology: An Experimental Study on the Efficiency and Cooling Mechanisms - A Review

Fatima Najaf [1*], Sami R. Aslan[2]

[1] Mechanical Power Technical Engineering Department, Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk 1069, Iraq
[2] Technical Engineering College of Kirkuk, Northern Technical University, Kirkuk 1069, Iraq

Corresponding Author Email: fatimanajaf88@ntu.edu.iq

https://doi.org/10.18280/ijht.420111

Received: 2 December 2023
Revised: 6 January 2024
Accepted: 16 January 2024
Available online: 29 February 2024

Keywords:
cooling glass cover, drinking water, evacuated tube collector, solar still

ABSTRACT

On a worldwide basis, freshwater is becoming increasingly limited, particularly in dry and distant regions. This presents a complex problem for regions such as islands, where the transportation of water that is suitable for drinking is expensive. In order to address this dilemma, the primary focus of the 21st century ought to be on boosting water purification through the use of renewable energy technology in the desalination industry. To be more specific, the incorporation of solar energy into the business has the potential to extend the lifespan of units, reduce expenses, and reduce the positive impact on the environment. The article contains a sufficient number of studies on a variety of passive and active stills, and it offers an understanding of the effectiveness of each form of still. Vacuum tube solar stills are more efficient than others. In addition to this, it investigates several approaches to cooling the glass cover and the elements that influence the productivity of solar stills, among which are environmental and design considerations. Resolving the problem of diminishing freshwater resources and integrating solar energy for water purification.

1. INTRODUCTION

Freshwater scarcity is increasing worldwide, especially in dry areas like deserts and industrial regions. The issue is more complicated in remote zones and islands where transporting drinkable water is expensive. Only 1% of the Earth's available water is fresh, while 99% is salty or brackish. Removing salt from seawater requires additional energy. The challenge of the 21st century is to improve water cleaning technologies to obtain fresh water and minimize environmental impact. Offering a long-term water supply Achieving water accessibility in underserved and arid regions. Supplying potable and agriculturally useful water [1]. The importance of assessing water quality to prevent disasters is discussed, focusing on the complexities of water hormonal disturbance and arsenic pollution in South Asia. Proper sampling, analysis, and purification are crucial for accurately evaluating and preventing water contamination. The significance of thorough evaluations and monitoring of various treatment methods for reusing produced water is emphasized [2].

Using renewable energy in the desalination industry can enhance its viability and reduce carbon emissions, especially when combined with solar power. This approach enables the application of desalination in remote water-scarce regions and extends the lifespan of units while decreasing costs through the use of corrosion-free materials [3]. The globe is grappling with a scarcity of water owing to industrialization, population growth, and water contamination; hence, it is imperative to investigate alternative decentralized systems like passive solar distillers that rely on renewable sources of energy to cater to the requirements of rural regions, even though their manufacture is somewhat constrained [4]. Clean drinking water may be distilled from dirty sources using solar energy, a sustainable and inexpensive power source that does not contribute to greenhouse gas emissions via the process of solar water distillation [5].

The mechanism of a solar still utilizes a black-painted basin filled with salt water that is heated by solar radiation, resulting in the evaporation and condensation of steam on a transparent glass cover, causing the flow of distilled water to a separate basin [6]. The scholars employed a mathematical model to analyze the thermal energy distribution in a solar still with an additional condenser, finding that the temperature of the core and the external section of the condenser follows a consistent pattern throughout the day, highlighting the importance of energy transfer techniques in solar stills for improved productivity and efficiency [7]. Researchers in Baghdad conducted an experiment using a solar distillation device and heater to purify water. The device produced clean water at different rates during the day and night. Distillation significantly reduced the levels of bacteria and pollutants. This method effectively decreased the bacterial content and eliminated E. coli. The study concluded that solar distillation is an effective way to purify water. The total amount of water produced per day was measured. The salt content in the water decreased after distillation. The solar distillation process also killed harmful bacteria [8].

The water productivity and cooling glass cover's efficiency in a double-slope passive solar distillation were tested, with actual water productivity measured at 4.36 L and theoretical water productivity at 7.57 L, resulting in system efficiencies of 52.32% and 90.88%, respectively [9].

Limited freshwater resources necessitate exploring alternative sources in arid regions. Solar-powered saltwater desalination provides a cost-effective answer, particularly in sunny areas. Solar desalination, commonly utilized, condenses evaporated water in basins on cold glass cover surfaces, but its efficiency is typically low, around 1.5-3 l/m. The effectiveness of solar desalination systems is influenced by climatic, design, and operational factors. Research indicates that higher ambient temperatures can significantly enhance productivity [10]. The researchers studied solar distiller designs and how well they turn saltwater into drinking water. They looked at factors like thermodynamics, heat transfer, and mass transfer to see how they affect water productivity. They also considered the angle and intensity of solar radiation. Water quality was tested based on pH, TDS, total hardness, and electrical conductivity, and the results showed high-quality drinking water being produced [11]. Analysis of unit orientation, water basin depth, meteorological conditions, and flow continuity on solar distillation performance in an experimental solar still unit. The device performed best at Water puddled 3cm deep. Oriented south during continuous flow operation for at least 3 days in sunny weather. Research indicates that unit orientation and pool depth have the biggest influence on water production performance [12]. Active solar stills supplement distillation with mechanical and external energy sources, whereas passive stills employ natural processes. Water flowing over the glass cover of the PVT hybrid active solar still increases thermal efficiency and daily exergy production, making it suitable for varied climates [13]. While the conventional solar still achieves an optimum hourly efficiency of 62%, the upgraded model achieves an impressive 88%, resulting in a 240% increase in cumulative production [1]. Combining the glass cover cooling method with evaporation techniques increases the water production rate in most solar stills. This provides a sustainable supply of water and helps meet the water demands of neglected and arid places. Supplying potable and agriculturally useful water [14].

This study provides a comprehensive review of various types of passive and active solar stills, evaluating their respective efficiencies. Additionally, it examines different techniques for cooling the glass cover and investigates the factors that influence the productivity of these solar stills, encompassing both environmental and design considerations. Optimizing Renewable Energy Use in Practical Application of Water Cleaning Technologies and Integration of Sustainable Practices The study offers viable solar water production methods for locations with acute water shortages.

2. CLASSIFICATION OF SOLAR STILL

2.1 Passive solar distiller

A passive solar distiller is a straightforward method for using solar energy to distill seawater, but it suffers from low thermal efficiency and a limited daily yield. Many studies have focused on improving the daily yield, thermal efficiency, and economic effectiveness, with a particular emphasis on enhancing evaporation and condensation processes. We review some types of passive distillers [15].

2.1.1 Solar distiller single-slope

A single-slope solar still uses solar energy to purify dirty or salty water. The sloped shape collects condensed water efficiently. As the basin water warms up, it is a simple and affordable device. They studied the efficiency of a solar distillation single slope device and found that the theoretical and experimental values were similar. For 2 centimeters of water in the basin, the theoretical daily efficiency was 51.83%, and for 10 centimeters of water, it was 41.75%. The experimental values, on the other hand, were 41.49% and 32.422% [16]. Researchers in Iraq examined how water depth impacts heat transfer coefficients as well as solar distiller production with a single slope. Decreasing water depth increases heat transfer coefficients, with a depth of 1 cm being considered the most efficient. Radiation and convection had lower heat transfer coefficients compared to evaporation as shown in Figure 1 [17, 18].

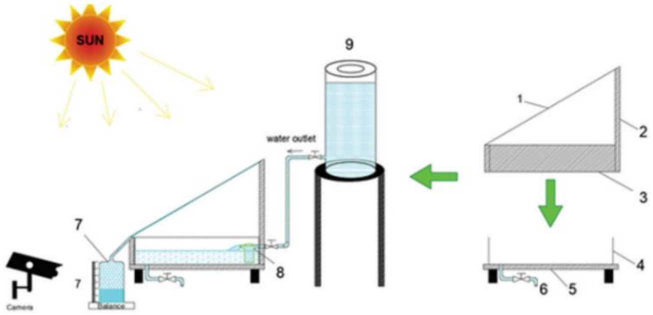

Figure 1. One-slope solar distiller [17]

2.1.2 Double slope solar distiller

The design includes a container for impure water and two sloping surfaces covered with transparent materials. Sunlight enters the still and heats the water in the basin. The daily passive solar distiller with double slope exergy ranges from 0.021 to 0.525 kWh. 0.928%-5.363% exergy efficiency. Efficiency is affected by solar radiation, evaporation coefficient, water's temperature, and ambient temperature [19]. Study of energy and also the exergy efficacy of the double slope's passive solar distiller for water desalination. Results showed energy efficiency ranged from 30.20% to 55.15%, and exergy efficiency ranged from 0.93% to 5.36%. Factors affecting efficiency include solar radiation, basin area, basin cover area, water production, and ambient temperature [20].

2.1.3 Pyramid solar still

The new multi-sided square base pyramid design of the solar still, covered with glass on four sides, concentrates sunlight and increases the solar surface area by 65% and 79.4%, respectively, while reducing heat loss and allowing natural heat recovery. generate 2.035 and 1.8 liters per square meter on bright and semi-cloudy fall days, and 11.93 and 12.39 liters on two warm summer days [21].

2.1.4 Tubular solar distiller

(TSS) is a clear polycarbonate cylinder; solar irradiance may penetrate from any direction, and it is regarded as a favored choice for obtaining pure water. It combines a TSS solar still with glass cover cooling. Changing the cooling flow rate and water depth allowed researchers to investigate ideal conditions for effectiveness and productivity. The best result was achieved with a lower water depth and a flow rate of 2 liters per hour for cooling water. Figure 2 shows that the proposed TSS with cap cooling raised yields as well as efficiency at 31.4% and 32.6%, respectively. comparison to the same still without cooling [22].

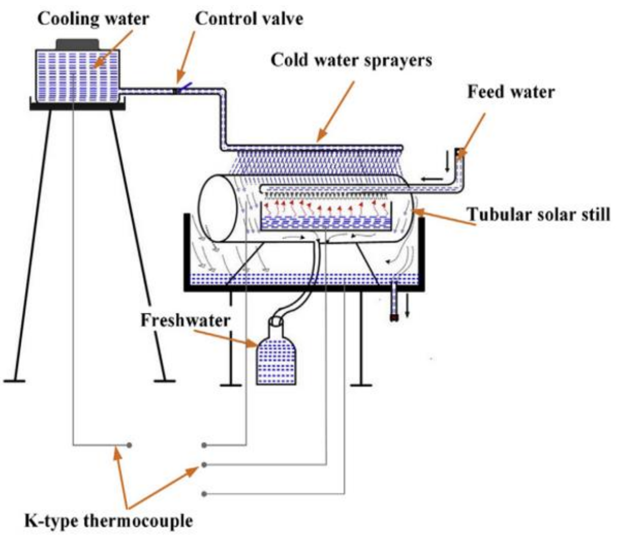

Figure 2. Solar still with a tubular design [23]

2.1.5 Hemispherical solar distiller

Hemispherical solar distiller, circular foundation for solar basin Covered with clear, hemispherical plastic. Using trays made of copper, zinc, and iron that had been coated black improved heat transmission and sped up the pace at which salt water evaporated. Copper trays have shown in Figure 3 the highest gain in production compared to the conventional hemispherical solar still, while all three metals have contributed to the still's increased efficiency [23].

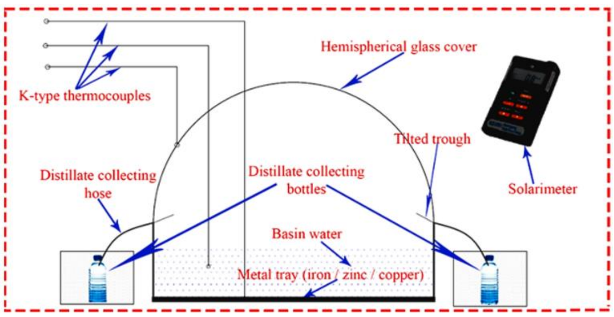

Figure 3. A traditional hemispherical solar basin's 2D design [23]

2.2 Active solar distiller

Active solar distillers use supplementary condensers or collectors in order to augment water output. These components collaborate with solar energy to enhance the efficiency of the distillation process. The incorporation of condensers or collectors has been seen to enhance both the condensation rate and overall water output. This phenomenon proves to be particularly advantageous in regions characterized by less solar radiation, since the incorporation of supplementary concentrators or collectors may effectively counterbalance the deficiency of solar energy [24, 25]. We review some solar stills in active form.

2.2.1 Solar still that incorporates FPC

Increased distillate output from an active solar distiller in seaboard climates by connecting multiple (FPCs) in series increases yield by 41% with two FPCs and by 89% with three FPCs, with the efficiency being slightly higher with two FPCs due to the increased radiation area [26]. According to the experiment results, using a modified pyramid solar still in conjunction with FPC produced the highest efficiency. The effectiveness of the solar still in terms of output is very sensitive to climate factors, especially solar radiation levels. Rising intake water temperatures boosted solar still output because of higher convection and evaporation heat transfer coefficients [27]. A double basin solar system with a solar flat plate collector and a solar pond handles water scarcity and desalination. Price-effective Desalination: Solar desalination is a cost-effective alternative to energy-intensive processes, especially in sunny places [28].

2.2.2 Solar still with parabolic collectors

A parabolic trough collector may raise water temperatures in a solar still, increasing its production. A parabolic trough collector complicates the solar still system and may need more maintenance and operation. Cost While the system is cost-effective, integrating a parabolic trough collector with a solar panel may require upfront expenditure [29]. Increases in daily freshwater output in both winter and summer may be attributed to the use of saline water mediums in a modified solar distiller with a TPTC (Figure 4) [30, 31].

Figure 4. Solar still with TPTC [30]

2.2.3 Solar distiller with solar pond

Increased productivity from a solar distiller is possible when hot water is supplied from a solar pond (SP), which also acts as heat storage. When used in tandem with (SS), shallow and tiny solar ponds (SPs) may significantly increase production. When used together, a solar still (SS) and a multi-stage solar greenhouse pond (MSGSP) provide much higher yields than each component used alone. Complex systems may need more monitoring and maintenance [32]. Modified solar distillers generated 53.5% more distillate than traditional stills due to a solar pond and floating wicks, with a 55% gain in distillate during the night and a 52% gain during the day, attributed to the least thermal inertia provided by floating wicks and heat from the solar pond at night [33].

2.2.4 Still using a solar photovoltaic PV system

Adding a PV/T collector to a solar still increases efficiency 18.81%, and utilizes sunlight, making it sustainable. delivering clean water other ways yield more water than solar distillation. Reduced system design and installation hassles System size, materials, and site circumstances affect solar distillation system installation costs. basic design and solar energy source reduce maintenance [34]. When solar stills and

PV/thermal solar collectors are combined, the result is a viable option for rural communities that lack access to clean water and consistent energy. Based on the available data, a PV/T collector coupled with an active solar still can generate 6-12 kg/m² fresh water per day; a passive solar still can generate just 2-5 kg/m² pure water per day [35, 36].

2.2.5 Solar still integrated with heat pipes

Researchers employed thermosyphon heat pipes and vacuum tubes for solar distillation. The investigation indicated that glass, aluminum, and steel coverings increased productivity. Glass coverings maximize productivity and efficiency. At its peak, the system generated 1.02 kg/m²h of desalinated water with 22.9% efficiency. The best basin water depth is 2 cm, matching the heat pipe condensation section length [37]. Solar distillation apparatus, furnished through reflectors and heat pipes, withstands very low temperatures, lasts a long time, doesn't cost much, and is easy to use. applicable in the climatic conditions of Baghdad produced 7.2 liters of water, in contrast to the passive solar distillation device, which produced 4.8 liters. The efficiency of a solar distillation device furnished through thermal tubes increased by 50% compared to a passive solar distillation device. Water production declined in the summer because of the elevated glass cover temperature. Growth in the basin water has decreased the yield as it requires more heat. The outcomes of the study theory were substantiated through an experimental test to measure the TDS and the PH value. It was established that the solar distillation device with heat pipes is harmless to drink [38].

2.2.6 Solar distiller with ETC

Desalination using solar thermal energy, and (ETC). Reduce heat loss. Optimizing solar radiation use Better thermal loading Enhance performance stability. The device kept the salt water at roughly 100 degrees Celsius for 4 hours, yielding 4.8 liters of potable water. System performance was measured in terms of exergy, with average values of 15.61 percent, and energy efficiency, with average values of 50.67 percent. The highest rate of flow for salt water was 0.0085 kg/s. Fresh water costs 0.01902 $/L, which is inexpensive compared to other solar-powered desalination systems as shown in Table 1 [39]. solar-assisted ETC distiller, focus on Thermosiphon ETC solar desalination units that are suitable for remote areas. There's a need for efficient and self-sustaining systems to address water supply and demand. The study concluded that these units have better efficacy than other complexes and can address freshwater scarcity in solar-rich, remote areas. They're also easy to maintain and clean [40]. Linking evacuated tubes with a solar distiller increases water temperature and production. Heat exchangers and internal reflectors in the still pool accelerate heat transfer, resulting in higher water temperatures and production. The modified solar distiller achieved a maximum water production of 2865 mL and an annual water production of 517.5 liters, which is 153.6% higher than the conventional still. The modified distillate also showed higher thermal efficiency throughout the year, with the highest thermal efficiency of 34.1 in June 2020. The modified distillate was concluded to be more efficient than the conventional one [41]. As shown in Figure 5, to improve the thermo-economic performance of a pyramid solar still, we increased the evaporation and condensation processes. Ultrasonic foggers and evacuated tubes were combined to achieve the best vapor generation. This led to a 7.6% cost reduction per liter of water production compared to standard pyramid solar. The findings demonstrated the application, sustainability, and practicality of the suggested additives in solar desalination [42].

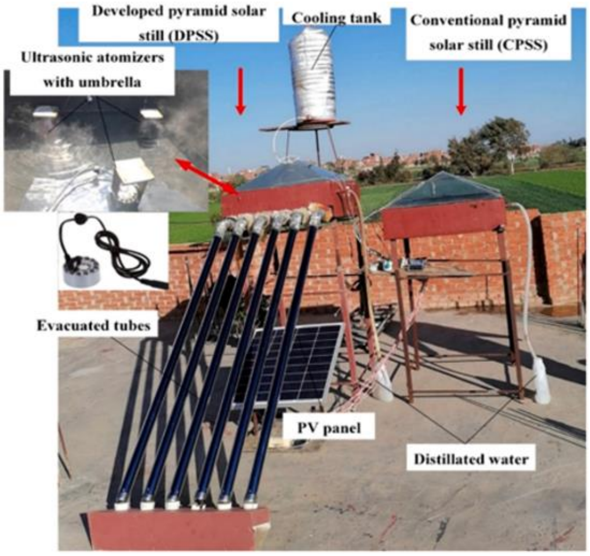

Figure 5. Pyramid solar still with ETC

Table 1. Review of some various developments in solar stills and their effects on productivity

No.	References	Type of Solar Still	Development	Remarks
1	[28]	Pyramid solar still	Integration with FPC	Integration of ETC
2	[34]	Solar still	Solar still with solar pond	An improved solar distiller produced 53.5% more than a conventional still
3	[35]	Active solar still	Solar still with [PV/T] system	Increase efficiency 18.81%
4	[38]	Solar still	Solar still with themosphone heat pipe	The system efficiency 22.9%
5	[40]	Active solar still	Integration of ETC	Energy efficiency 50.67%

3. CLIMATIC PARAMETER

The control of climate parameters is beyond the purview of human intervention, owing to the benevolence of nature. There are a myriad of climatic factors that exert influence over the operational efficacy of solar stills; the following items are mentioned below [43]:

solar radiation intensity
Speed of the wind
Temperature of the ambient
Dust and clouds
Latitude and longitude of the place

3.1 Solar radiation intensity

The solar radiation that is currently accessible is a major factor in the distillate yield produced with a solar distiller. discusses the correlation between the capacity of the distillate and the incident energy: $PD=0.0036I^2 + 0.0701I + 0.2475$ The quantity of water produced daily (PD) is directly proportional to the amount of incoming solar energy (I). The regression coefficient of 0.76 is the only one that can accommodate solar flux exposures between 8 and 30 $MJ/m^2/day$. The data presented indicated a distillate productivity ranging from 1.0 to 6.0 $L/m^2/day$ [44]. found the device absorbed 0.31 kWh of heat energy and had a solar density of 534.40 watts per square meter. Sunlight intensity affected water production, with a maximum of 2.6 kg per hour. Water temperatures rose with sunlight, and thermal energy continued water production [45].

3.2 Speed of the wind

The optimal wind velocity is important for effective heat transfer in solar stills, as shown in the Figure 6, as wind with high velocity can cause heat loss and a reduction in condensation. A transient computational fluid dynamics model was utilized to explore the efficiency of a solar distiller by analyzing design parameters and weather data. The action of various factors, such as water level, wind velocity, glass cover width, cover inclination angle, and surface coverage space, on productivity was studied. Findings revealed that increasing wind velocity by 1 to 6 meters per second improved efficiency by 14.4%. The ideal depth and distance for water surface to glass covering were determined to be 2 centimeters and 8 centimeters, respectively. The productivity of the distiller was significantly improved by modifying design standards, including reducing glass thickness and aligning the cover angle with latitude [46, 47].

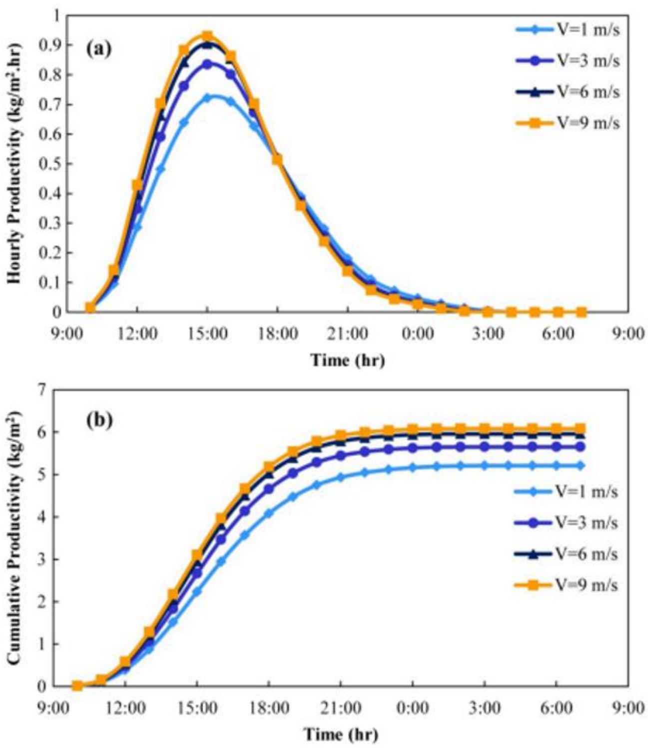

Figure 6. Basin solar still output (a) hourly (b) accumulated at various wind speeds [46]

3.3 Temperature of the ambient

When the ambient temperature rises, distillation walls lose less heat, so the temperature of the distilled water rises, increasing production. Increased ambient temperature from 36°C to 40°C led to a 7.4% increase in pyramid solar still production from 5400 to 5800 $mL/m^2.day$ [48].

3.4 Dust and clouds

Dust on the glass cover reduces transmittance, reducing incoming solar energy. Dust reduces the incidence of light and damage, depending on several variables. Dust from sandstorms covers collectors and reflectors until the wind blows them away, affecting their effectiveness. Clouds reduce freshwater output compared to clear days without clouds [49].

3.5 Latitude and longitude of the place

The angle of the cover plates depends on where they are located. The inclination of the solar condenser's surface affects the effectiveness of distilled water. The appropriate angle should be selected to ensure smooth water collection and minimize loss. The latitude and location angles are what determine the best angle [50, 51]. A study examined ways to enhance solar distiller production by adjusting glass cover orientations. Six identical solar stills with varying cover inclinations were put side by side in the same weather circumstances at Ouargla city, Algeria (31.95° North, 5.32° East). The experiment examined angles of 10, 15, 20, 30, 35, and 45°. The optimal tilt was 30° in fall and winter, yielding 3.517 and 3.633 kg/m^2 [52].

4. DESIGN PARAMETER

The level of production of solar stills can be altered by several design parameters. Here are some examples [53]:

Material selection
Depth of water
The thickness of the glass cover
Cap distance
Insulation thickness and material

4.1 Material selection

The materials utilized in the solar still should be readily accessible and inexpensive in order to effectively increase the production of distilled output. In the initial investigation, the researcher observed that incorporating aluminum plates in solar distillation led to a rise in the production of distilled distillate compared to the conventional solar distiller, with an average increase of 45%; similarly, the utilization of galvanized iron sheets also enhanced the production of distillate with an average increase of 15%, implying that the effectiveness of solar distillers can be heightened by enlarging the active surface area using diverse plates [54].

4.2 Depth of water

The efficiency of a solar water desalination device with one slope at various depths of 1, 4, 6, 8, and 10 cm was examined. It was observed that productivity increases with decreasing depth and that the depth of the brine is a significant factor affecting productivity. Three types of solar desalination devices were tested, and the complex system connected to evacuated tubes yielded the best results due to superheating. Planar solar collectors generate less heat than evacuated tubes due to heat dissipation [55].

4.3 The thickness of the glass cover

Glass is a better condensation surface material than plexiglass or polycarbonate [56]. The influence of various glass cover thicknesses on solar distiller performance in cold weather was investigated by researchers in Mehsana, India, using three identical solar stills with 4 mm, 8 mm, and 12 mm glass covers (Figure 7). The study determined that the glass cover thickness has a significant influence on solar distiller function in winter conditions, with a 4mm glass cover enhancing distilled water yield, evaporative heat transfer coefficient, water temperature, overall solar distillation productivity, and convective heat transfer coefficient [57, 58].

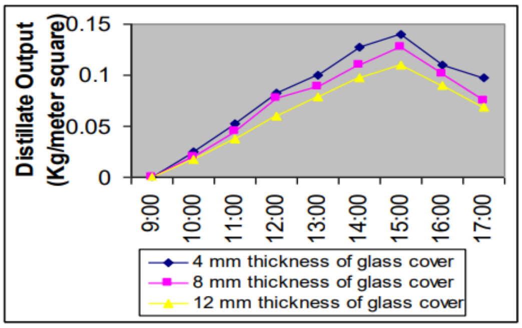

Figure 7. Solar still distillate yield is affected by glass cover thickness [57]

4.4 Cap distance

Distillate production was studied with changes in water depth and the gap from surface cover to the water's surface (WCD), which ranged from 9 to 23 cm. The findings indicated a decrease of up to 26% in distillate production when there were changes in the surface cover distance. The research findings indicate that employing multiple distillers simultaneously is recommended in order to maintain a consistent surface cover distance while investigating the impact of water depth. The researchers found a link between the depth of the water used for distillation and the product that was produced. The proposed model's theoretical predictions and real-world observations agreed very well [59].

4.5 Insulation thickness and material

To enhance solar still productivity, it is crucial to minimize or eliminate heat transmission from the base and sides. This can be achieved by incorporating an appropriate thickness of insulating material, which ensures the retention of solar thermal energy absorbed during daylight hours. Researchers looked at how water depth and insulation affect how well solar distillers work. They found that a water depth of 3 cm increases thermal efficiency, while insulation increases distillate output by raising basin temperature and reducing heat transfer, which leads to higher water temperatures and more distillate production every day [60].

5. VARIOUS METHOD USED TO COOL GLASS COVER

Cooling the glass cover improves condensation, reduces heat loss, prevents overheating, maintains performance over time, and is beneficial in high-temperature situations. The fact that solar desalination machines are 15.5% more efficient and 20% more productive when the glass cover is cooled shows how important good design is for keeping efficiency. The difference in temperature between the salt water and the glass cover is linked to both of these numbers. Glass coverings may be cooled in a number of different ways [61].

5.1 Glass covers are cooled by the flow of air

It has been found that increasing the water temperature by installing a water heater in the main reservoir of a solar distiller can increase efficiency by as much as 250 percent, while increasing the wind speed and utilizing an additional cooling fan can reduce the glass's surface temperature, which improves efficiency between 5.2% and 10.3%, respectively, for wind speeds of 7 and 9 meters per second [62]. Using a thermoelectric cooling channel with nanofluid copper oxide, the performance of a solar distiller was improved, resulting in higher yield, energy efficiency, and energy efficiency compared to conventional solar stills. The modified solar distiller's productivity was raised by 41.8% in comparison to conventional solar distillation facilities thanks to the utilization of a cooling air flow rate of 180 litter per minute [63].

5.2 Water and air flow to cool glass covers

Researchers enhanced the condensation rate and highlighted the significance of uniform water distribution for effective condensation by evenly distributing water on a glass cover and studying the impact of airflow on cotton gauze cooling, thus promoting increased productivity and the combination of cotton gauze cooling and airflow [64].

5.3 Condensers are used to cool glass covers

To make solar distillers better, suggestions are to flow water on the glass to cool it and use a condenser to cool the glass. Adding condensers to solar distillers has improved productivity. The glass slope matches the latitude for better results and allows for more condensation [65].

For experimental work, MSS was linked with fins, evacuated tube, and condenser to increase distillate production by 73.45% above CSS. MSS's zig-zag condenser keeps inner glass cover cooler than CSS. This reduces vapor pressure inside the still basin and enhances its volumetric heat capacity. At night, it condenses the vapor within. following equation was used for daily solar efficiency [66]. $nD = \frac{\sum mD \times hlg}{\sum Ag \times It}$ and exergy efficiency (**η** exergy) following equation used $\eta = \frac{\mathrm{Exout}}{\mathrm{Exinp}}$ here $Ex_{out} = Ex_{e,bw-ig}$ and $\mathrm{Ex_{inp}} = \mathrm{Ex_{sun}} = Abw \times It \times 1 - \frac{4}{3} \times \left(\frac{Ta + 273.15}{Ts}\right) + \frac{1}{3}\left(\frac{Ta + 273.15}{Ts}\right) 4.$

5.4 Water flowing over glass covers to cool them down

The utilization of square, hollow fins and a single-slope solar distillation device yielded a remarkable 40% boost in productivity, achieved by attaching the fins to the absorption plate. Moreover, the introduction of glass cooling, performed either through continuous water spraying or pulse cooling, further enhanced productivity, with the optimal timing determined to be (30 seconds/10 minutes), resulting in a significant improvement ranging from 13.3% to 36.7% [67]. An evaporative cooler is used to cool the solar distiller's glass cover. An experimental study resulted in a 7.3% increase in efficiency, a 17.69 degrees lower cooling water temperature compared to ambient conditions, and a 3.32 times increase in distillate production, demonstrating the effectiveness of this method in enhancing overall performance (Figure 8) [68]. The experimental investigation explored the effects of shadows and sunglass evaporative cooling methods on coating as shown in Figure 9, revealing a 16.4% increase in fresh water productivity and a 3.8% boost in total efficiency when applying the half-shading technique with glass cover cooling. However, exceeding 50% shading and cooling on the glass cover resulted in reduced performance of the solar distiller, with the maximum freshwater yield achieved at 2114 ml/day when only half of the cover glass was exposed to these techniques [69].

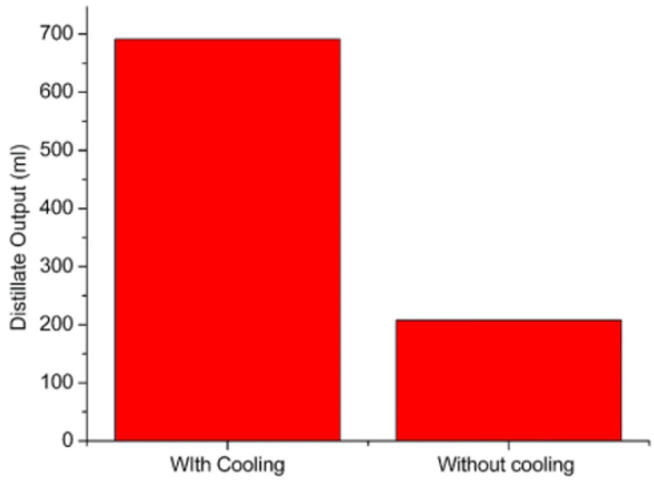

Figure 8. Comparison between the production of distillate in a solar still, with and without the utilization of a glass cover to facilitate cooling [69]

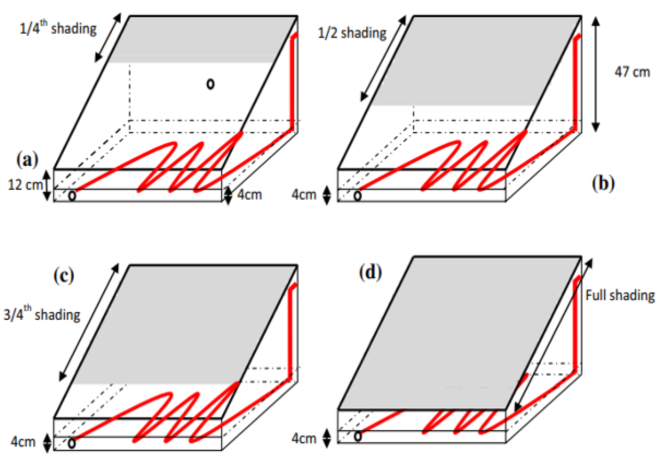

Figure 9. The glass cover provides shading and cooling to different proportions of the surface area, including 1/4th, 1/2nd, 3/4th, and the full area [69]

6. CONCLUSION

The review encompassed the categorization of solar stills, the assessment of production characteristics, and the examination of glass cover cooling techniques. Examine the efficacy of various solar still designs or explore the influence of alterations on production. This article draws the following conclusions:

- Modified solar stills are more productive than conventional ones.
- Active solar stills that are coupled to vacuum tubes are often regarded as one of the most effective forms.
- The glass cover may be cooled in a number of different ways, including using air, water, a condenser, or a combination of air and water. Condensation on the glass cover may be increased with the use of water cooling, which in turn boosts efficiency.
- The intensity of solar radiation, wind speed, ambient air temperature, and dust adhered to the glass cover are the most significant environmental parameters affecting the productivity of the solar still. The glass cover must have an inclination angle equivalent to the local latitude.
- Numerous significant design factors, such as the metal choice, the depth of the water in the basin, the thickness of the glass cover, the distance between the water surface and the glass cover, and the type and thickness of insulating material, all have an impact on a solar still's productivity.

REFERENCES

[1] Tarik Ahmed, S., Hayder Mohammed Ali, H. (2020). D theoretical study of the conventional and modified solar still. The Iraqi Journal for Mechanical and Materials Engineering, 20(2): 122-142. https://doi.org/10.32852/iqjfmme.v20i2.493

[2] Ahuja, S. (2019). Overview: Evaluating water quality to prevent future disasters. Separation Science and Technology, 11: 1-12. https://doi.org/10.1016/B978-0-12-815730-5.00001-6

[3] Sharon, H., Reddy, K.S. (2015). A review of solar energy driven desalination technologies. Renewable and Sustainable Energy Reviews, 41: 1080-1118. https://doi.org/10.1016/j.rser.2014.09.002

[4] Vigneswaran, V.S., Kumar, P.G., Sakthivadivel, D., Balaji, K., Meikandan, M., Dinakar, B.V., Kumaresan, G. (2021). Energy, Exergy, and Economic analysis of low thermal conductivity basin solar still integrated with Phase Change Material for energy storage. Journal of Energy Storage, 34: 102194. https://doi.org/10.1016/j.est.2020.102194

[5] Ahmed, S.T., Ali, H.H.M. (2020). Experimental investigation of new design of solar water distillation coupled with flat plate solar water collector. The Iraqi Journal for Mechanical and Materials Engineering, 20(3): 193-207. https://doi.org/10.32852/iqjfmme.v20i3.512

[6] Mohiuddin, S.A., Kaviti, A.K., Rao, T.S., Sikarwar, V.S. (2022). Historic review and recent progress in internal design modification in solar stills. Environmental Science and Pollution Research, 29(26): 38825-38878. https://doi.org/10.1007/s11356-022-19527-x

[7] Ibraheem, N.T., Hussain, H.H., Khaleed, O.L. (2021). Modelling heat transfer in solar distiller with additional

condenser studying. Al-Mustansiriyah Journal of Science, 32(2): 25-32. https://doi.org/10.23851/mjs.v32i2.979
[8] Dayer, Z.E., Al-Saleem, H.H. (2018). Diagnostic of Water Purity by Using Solar Distiller. Al-Mustansiriyah Journal of Science, 29(2): 10-16. https://doi.org/10.23851/mjs.v29i2.348
[9] Ambarita, H., Nababan, J.P. (2020). Effect of cooling water on the glass cover of the double slope solar still. In Journal of Physics: Conference Series, Medan, Indonesia, p. 012058. https://doi.org/10.1088/1742-6596/1542/1/012058
[10] Altarawneh, I., Rawadieh, S., Batiha, M., Al-Makhadmeh, L., Alrowwad, S., Tarawneh, M. (2017). Experimental and numerical performance analysis and optimization of single slope, double slope and pyramidal shaped solar stills. Desalination, 423: 124-134. https://doi.org/10.1016/j.desal.2017.09.023
[11] Shelake, A., Kumbhar, D., Sutar, K. (2023). Desalination using solar stills: A review. Environmental Progress & Sustainable Energy, 42(3): e14025. https://doi.org/10.1002/ep.14025
[12] Shakerian, M., Karrabi, M., Gheibi, M., Fathollahi-Fard, A.M., Hajiaghaei-Keshteli, M. (2022). Evaluating the performance of a solar distillation technology in the desalination of brackish waters. Processes, 10(8): 1626. https://doi.org/10.3390/pr10081626
[13] Gaur, M.K., Tiwari, G.N., Singh, P., Kushwah, A. (2021). Heat transfer analysis of hybrid active solar still with water flowing over glass cover. Journal of Thermal Engineering, 7(6): 1329-1343. https://doi.org/10.18186/thermal.989993
[14] Shoeibi, S., Rahbar, N., Esfahlani, A.A., Kargarsharifabad, H. (2021). A review of techniques for simultaneous enhancement of evaporation and condensation rates in solar stills. Solar Energy, 225: 666-693. https://doi.org/10.1016/j.solener.2021.07.028
[15] Le, T.H., Pham, M.T., Hadiyanto, H., Hoang, A.T. (2021). Influence of various basin types on performance of passive solar still: A review. International Journal of Renewable Energy Development, 10(4): 789-802. https://doi.org/10.14710/ijred.2021.38394
[16] Agrawal, A., Rana, R.S., Srivastava, P.K. (2017). Heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition: Experimental and theoretical comparison. Resource-Efficient Technologies, 3(4): 466-482. https://doi.org/10.1016/j.reffit.2017.05.003
[17] Alwan, N.T., Shcheklein, S., Ali, O. (2021). Investigation of the coefficient of heat transfer and daily cumulative production in a single-slope solar distiller at different water depths. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 43(21): 2820-2837. https://doi.org/10.1080/15567036.2020.1842561
[18] Sanserwal, M., Singh, A.K., Singh, P. (2020). Impact of materials and economic analysis of single slope single basin passive solar still: A review. Materials Today: Proceedings, 21: 1643-1652. https://doi.org/10.1016/j.matpr.2019.11.289
[19] Saragi, J.H., Napitupulu, F.H., Nasution, A.H., Ambarita, H. (2020). Exergy analysis of double slope passive solar still. In IOP Conference Series: Materials Science and Engineering, Nommensen HKBP University, Indonesia, pp. 1-7. https://doi.org/10.1088/1757-899X/725/1/012005
[20] Saragi, J.F.H., Damanik, W.S. (2020). Energy and exergy efficiency of double slope passive solar still. Journal of Mechanical Engineering Science and Technology (JMEST), 4(2): 82-90. https://doi.org/10.17977/um016v4i22020p082
[21] Beik, A.J.G., Assari, M.R., Tabrizi, H.B. (2020). Passive and active performance of a multi-side-stepped square pyramid solar still; experimental and modeling. Journal of Energy Storage, 32: 101832. https://doi.org/10.1016/j.est.2020.101832
[22] Kabeel, A.E., Sharshir, S.W., Abdelaziz, G.B., Halim, M.A., Swidan, A. (2019). Improving performance of tubular solar still by controlling the water depth and cover cooling. Journal of Cleaner Production, 233: 848-856. https://doi.org/10.1016/j.jclepro.2019.06.104
[23] Attia, M.E.H., Kabeel, A.E., Abdelgaied, M., Essa, F.A., Omara, Z.M. (2021). Enhancement of hemispherical solar still productivity using iron, zinc and copper trays. Solar Energy, 216: 295-302. https://doi.org/10.1016/j.solener.2021.01.038
[24] Das, D., Bordoloi, U., Kalita, P., Boehm, R.F., Kamble, A.D. (2020). Solar still distillate enhancement techniques and recent developments. Groundwater for Sustainable Development, 10: 100360. https://doi.org/10.1016/j.gsd.2020.100360
[25] Manchanda, H., Kumar, M. (2018). Study of water desalination techniques and a review on active solar distillation methods. Environmental Progress & Sustainable Energy, 37(1): 444-464. https://doi.org/10.1002/ep.12657
[26] Raju, V.R., Narayana, R.L. (2018). Effect of flat plate collectors in series on performance of active solar still for Indian coastal climatic condition. Journal of King Saud University-Engineering Sciences, 30(1): 78-85. https://doi.org/10.1016/j.jksues.2015.12.008
[27] Subramanian, R.S., Kumaresan, G., Ajith, R., Sabarivasan, U., Gowthamaan, K.K., Anudeep, S. (2021). Performance analysis of modified solar still integrated with flat plate collector. Materials Today: Proceedings, 45: 1382-1387. https://doi.org/10.1016/j.matpr.2020.06.409
[28] Kumara, M.M., Rajesha, S., Gnanarajb, S.J.P. (2023). Experimental investigation of double basin solar still integrated with solar flat plate collector and solar pond with modified design. Desalination and Water Treatment, 290: 26-35. https://doi.org/10.5004/dwt.2023.29454
[29] Panchal, H., Sadasivuni, K.K., Suresh, M., Israr, M., Sengottain, S. (2022). A concise review on Solar still with parabolic trough collector. International Journal of Ambient Energy, 43(1): 4812-4819. https://doi.org/10.1080/01430750.2021.1922938
[30] Hassan, H., Ahmed, M.S., Fathy, M. (2019). Experimental work on the effect of saline water medium on the performance of solar still with tracked parabolic trough collector (TPTC). Renewable Energy, 135: 136-147. https://doi.org/10.1016/j.renene.2018.11.112
[31] Mortazavi, S.M., Maleki, A. (2020). A review of solar compound parabolic collectors in water desalination systems. International Journal of Modelling and Simulation, 40(5): 339-354. https://doi.org/10.1080/02286203.2019.1626539
[32] Panchal, H., Sadasivuni, K.K., Essa, F.A., Shanmugan, S., Sathyamurthy, R. (2021). Enhancement of the yield

of solar still with the use of solar pond: A review. Heat Transfer, 50(2): 1392-1409. https://doi.org/10.1002/htj.21935
[33] Bisht, S., Dhindsa, G.S., Sehgal, S.S. (2020). Augmentation of diurnal and nocturnal distillate of solar still having wicks in the basin and integrated with solar pond. Materials Today: Proceedings, 33: 1615-1619. https://doi.org/10.1016/j.matpr.2020.05.732
[34] Jasim, M.A., Ahmed, O.K. (2023). Comparative evaluation of a conventional and photovoltaic/thermal-integrated solar distiller under Iraqi climatic conditions. Journal Européen des Systèmes Automatisés, 56(5): 765-774. https://doi.org/10.18280/jesa.560507
[35] Jasim, M.A., Ahmed, O.K., Alaiwi, Y. (2023). Performance of solar stills integrated with PV/Thermal solar collectors: A review. NTU Journal of Renewable Energy, 4(1): 97-111. https://doi.org/10.56286/ntujre.v4i1
[36] Pansal, K., Ramani, B., kumar Sadasivuni, K., Panchal, H., Manokar, M., Sathyamurthy, R., Israr, M. (2020). Use of solar photovoltaic with active solar still to improve distillate output: A review. Groundwater for Sustainable Development, 10: 100341. https://doi.org/10.1016/j.gsd.2020.100341
[37] Mamouri, S.J., Derami, H.G., Ghiasi, M., Shafii, M.B., Shiee, Z. (2014). Experimental investigation of the effect of using thermosyphon heat pipes and vacuum glass on the performance of solar still. Energy, 75: 501-507. https://doi.org/10.1016/j.energy.2014.08.005
[38] Kadhum, N.A., Jassim, N.A., Lateef, K.H. (2020). Thermal modeling of solar still coupled with heat pipes and experimental validation. Journal of Engineering, 26(6): 172-192. https://doi.org/10.31026/j.eng.2020.06.14
[39] Tiwari, A., Agrawal, A., Kumar, A. (2022). An experimental investigation of a desalination system based on an evacuated tube collector coupled with a heat exchanger. Heat Transfer, 51(8): 8005-8019. https://doi.org/10.1002/htj.22678
[40] Singh, A.K. (2021). A review study of solar desalting units with evacuated tube collectors. Journal of Cleaner Production, 279: 123542. https://doi.org/10.1016/j.jclepro.2020.123542
[41] Bhargva, M., Yadav, A. (2023). Annual thermal performance analysis and economic assessment of an evacuated tube coupled solar still for Indian climatic conditions. Environmental Science and Pollution Research, 30(11): 31268-31280. https://doi.org/10.1007/s11356-022-24342-5
[42] Liu, H., Ji, D., An, M., Kandeal, A.W., Thakur, A.K., Elkadeem, M.R., Sharshir, S.W. (2023). Performance enhancement of solar desalination using evacuated tubes, ultrasonic atomizers, and cobalt oxide nanofluid integrated with cover cooling. Process Safety and Environmental Protection, 171: 98-108. https://doi.org/10.1016/j.psep.2023.01.009
[43] D'Cotha, J.S., Sajeesh, P., Suresh, P.R., Jithu, J. (2021). Inherent configuration characteristics altering the distillate enhancement of passive stepped solar still: A review. Journal of King Saud University-Engineering Sciences, 10: 1. https://doi.org/10.1016/j.jksues.2021.10.001
[44] Hammoodi, K.A., Dhahad, H.A., Alawee, W.H., Omara, Z.M. (2023). A detailed review of the factors impacting pyramid type solar still performance. Alexandria Engineering Journal, 66: 123-154. https://doi.org/10.1016/j.aej.2022.12.006
[45] Damanik, W., Siregar, M.A., Lubis, S., Ambarita, H., Singh, A.K. (2022). Single slope modification design for experimental study of solar desalination system performance. Journal of Engineering Research, 11(3): 100-111. https://doi.org/10.36909/jer.15987
[46] Keshtkar, M., Eslami, M., Jafarpur, K. (2020). Effect of design parameters on performance of passive basin solar stills considering instantaneous ambient conditions: a transient CFD modeling. Solar Energy, 201: 884-907. https://doi.org/10.1016/j.solener.2020.03.068
[47] Panchal, H.N., Patel, S. (2017). An extensive review on different design and climatic parameters to increase distillate output of solar still. Renewable and Sustainable Energy Reviews, 69: 750-758. https://doi.org/10.1016/j.rser.2016.09.001
[48] Farouk, W.M., Abdullah, A.S., Mohammed, S.A., Alawee, W.H., Omara, Z.M., Essa, F.A. (2022). Modeling and optimization of working conditions of pyramid solar still with different nanoparticles using response surface methodology. Case Studies in Thermal Engineering, 33: 101984. https://doi.org/10.1016/j.csite.2022.101984
[49] Feria-Díaz, J.J., López-Méndez, M.C., Ortiz-Monterde, L. (2023). Correlation between solar intensity and relative humidity and its influence on the performance of solar stills. Journal of Positive Psychology and Wellbeing, 7(1): 293-310.
[50] Chauhan, V.K., Shukla, S.K. (2022). Experimental study of effect of glass cover tilt angle of solar still in winter season of India's composite climate. Thermal Science and Engineering Progress, 33: 101348. https://doi.org/10.1016/j.tsep.2022.101348
[51] Selvaraj, K., Natarajan, A. (2018). Factors influencing the performance and productivity of solar stills-A review. Desalination, 435: 181-187. https://doi.org/10.1016/j.desal.2017.09.031
[52] Cherraye, R., Bouchekima, B., Bechki, D., Bouguettaia, H., Khechekhouche, A. (2022). The effect of tilt angle on solar still productivity at different seasons in arid conditions (south Algeria). International Journal of Ambient Energy, 43(1): 1847-1853. https://doi.org/10.1080/01430750.2020.1723689
[53] Jathar, L.D., Ganesan, S., Shahapurkar, K., Soudagar, M.E.M., Mujtaba, M.A., Anqi, A.E., Safaei, M.R. (2022). Effect of various factors and diverse approaches to enhance the performance of solar stills: A comprehensive review. Journal of Thermal Analysis and Calorimetry, 147(7): 4491-4522. https://doi.org/10.1007/s10973-021-10826-y
[54] Panchal, H.N., Shah, P.K. (2012). Performance improvement of solar stills via experimental investigation. International Journal of Advanced Design and Manufacturing Technology, 5(5): 19-23.
[55] Balamurugan, S., Sundaram, N.S., Marimuthu, K.P., Devaraj, J. (2017). A comparative analysis and effect of water depth on the performance of single slope basin type passive solar still coupled with flat plate collector and evacuated tube collector. Applied Mechanics and Materials, 867: 195-202. https://doi.org/10.4028/www.scientific.net/AMM.867.195

[56] Akrout, H., Hidouri, K., Chaouachi, B., Slama, R.B. (2021). Modeling and simulation of water production for different solar still heights and condensation surfaces. Desalination and Water Treatment, 213: 26-34. https://doi.org/10.5004/dwt.2021.26679
[57] Panchal, H.N., Shah, P.K. (2012). Effect of varying glass cover thickness on performance of solar still: In a winter climate conditions. International Journal of Renewable Energy Research, 1(4): 212-223. https://doi.org/10.20508/ijrer.v1i4.65.g58
[58] Panchal, H., Mevada, D., Sathyamurthy, R. (2021). The requirement of various methods to improve distillate output of solar still: A review. International Journal of Ambient Energy, 42(5): 597-603. https://doi.org/10.1080/01430750.2018.1542630
[59] Feilizadeh, M., Estahbanati, M.K., Ahsan, A., Jafarpur, K., Mersaghian, A. (2016). Effects of water and basin depths in single basin solar stills: An experimental and theoretical study. Energy Conversion and Management, 122: 174-181. https://doi.org/10.1016/j.enconman.2016.05.048
[60] Manokar, A.M., Taamneh, Y., Winston, D.P., Vijayabalan, P., Balaji, D., Sathyamurthy, R., Mageshbabu, D. (2020). Effect of water depth and insulation on the productivity of an acrylic pyramid solar still–An experimental study. Groundwater for Sustainable Development, 10: 100319. https://doi.org/10.1016/j.gsd.2019.100319
[61] Omara, Z.M., Abdullah, A.S., Kabeel, A.E., Essa, F.A. (2017). The cooling techniques of the solar stills' glass covers–A review. Renewable and Sustainable Energy Reviews, 78: 176-193. https://doi.org/10.1016/j.rser.2017.04.085
[62] Al-Garni, A.Z. (2014). Productivity enhancement of single slope solar still using immersion-type water heater and external cooling fan during summer. Desalination and Water Treatment, 52(34-36): 6295-6303. https://doi.org/10.1080/19443994.2013.822151
[63] Nazari, S., Safarzadeh, H., Bahiraei, M. (2019). Performance improvement of a single slope solar still by employing thermoelectric cooling channel and copper oxide nanofluid: an experimental study. Journal of Cleaner Production, 208: 1041-1052. https://doi.org/10.1016/j.jclepro.2018.10.194
[64] Suneesh, P.U., Jayaprakash, R., Arunkumar, T., Denkenberger, D. (2014). Effect of air flow on "V" type solar still with cotton gauze cooling. Desalination, 337: 1-5. https://doi.org/10.1016/j.desal.2013.12.035
[65] Kabeel, A.E., Omara, Z.M., Essa, F.A., Abdullah, A.S. (2016). Solar still with condenser–A detailed review. Renewable and Sustainable Energy Reviews, 59(C): 839-857. https://doi.org/10.1016/j.rser.2016.01.020
[66] Mevada, D., Panchal, H., Sadasivuni, K.K. (2021). Investigation on evacuated tubes coupled solar still with condenser and fins: Experimental, exergo-economic and exergo-environment analysis. Case Studies in Thermal Engineering, 27: 101217. https://doi.org/10.1016/j.csite.2021.101217
[67] Hameed, H.G. (2022). Experimentally evaluating the performance of single slope solar still with glass cover cooling and square cross-section hollow fins. Case Studies in Thermal Engineering, 40: 102547. https://doi.org/10.1016/j.csite.2022.102547
[68] Shivamallaiah, M.M., Reddy, S.K., Shrikanth, V., Shetty, G., Rakesh, S.A., John, J.M., Aftab, A. (2020). Experimental study of the influence of glass cover cooling using evaporative cooling process on the thermal performance of single basin solar still. Journal of Mechanical Engineering and Sciences, 14(1): 6334-6343. https://doi.org/10.15282/jmes.14.1.2020.11.0496
[69] Bhargva, M., Yadav, A. (2020). Effect of shading and evaporative cooling of glass cover on the performance of evacuated tube-augmented solar still. Environment, Development and Sustainability, 22: 4125-4143. https://doi.org/10.1007/s10668-019-00375-8

NOMENCLATURE

SS	solar-still
TSS	tubular-solar-still
FPC	flat-plate-collector
PTC	parabolic-trough-collector
SP	solar-pond
PV	photovoltaic
ETC	evacuated-tube-collector
TDS	total-dissolved-solids
MSS	modified. solar. still