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Effects of Utilizing Black Glass Balls, Phase Change Material, and Fins on the Performance of the Single-Slope and Single-Basin Solar Water Distiller under Climate Conditions of Mosul City: An Experimental Study

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ABSTRACT

The present investigation involves an experimental examination of incorporating rectangular fins, black glass balls as porous media, and phase change material (PCM) above the absorber surface to improve the effectiveness of the single-slope and single-basin solar water distiller system, known as MSS-FPPCM. Data was gathered in November and December 2023 in Mosul City, Iraq. The performance was evaluated with and without the addition of porous media at varying water depths. The results indicated that the highest basin water temperature, PCM temperature, productivity, and efficiency were achieved when utilizing fins, black glass balls, and PCM. The maximum temperatures recorded for water basin and PCM, productivity, and efficiency were 55°C, 55.4°C, 1.01 kg/m^2, and 30.83%, respectively, at a water depth of 3cm. The results highlight the significant impact of porous media, phase change material, fins, and water depth on heat exchange, evaporation, and heat transfer rates.

1. Introduction

Water scarcity is a significant contemporary issue confronting both developed and developing nations, stemming from population growth, industrialization, and agricultural advancement, all of which vie for a finite fresh water supply [1]. Water covers approximately 97.5% of the earth's total water supply on the surface. As a result, the amount of fresh water is about 2.5%. Most of this freshwater trapped in glaciers and underground aquifers. Therefore, the accessible quantity of freshwater is exceedingly scarce and insufficient to meet the demands of rapid global development [2]. Hence, scientists use various technologies to face this challenge; solar desalination is one of the most efficient solutions [3]. In contrast to conventional desalination methods that rely on fossil fuels or electricity, solar distillation harnesses the sun's heat to generate freshwater, employing a solar still for the purification processes [4]. The environmental benefits of solar desalination systems and lower fuel costs drew a lot of attention. These systems are popular because of their simplicity, affordability, ease of manufacture using locally available materials, eco-friendliness, and low maintenance costs, but they suffer from a lack of production [5], [6], [7]. To increase the productivity and thermal efficiency of the SSs, various studies have been carried out. Various SS system configurations, including pyramid SS [8], [9], [10], stepped SS [11], [12], [13], Tubular SS [14], [15], [16], and trays SS [17]. Moreover, the performance of the SS system has been enhanced through the introduction of fins [18], reflectors [19], [20], phase change material [21], [22], [23], [24], nanoparticles [25], [26], wick materials [27], porous media [28]. These methods improve the performance of the SS systems. El-Samadony et al. [29] introduced a novel theoretical analysis of the radiation heat transfer rate in a stepped SS, emphasizing the radiation shape factor between the hot saline water and the glass cover. It examines how the glass cover's inclination angle and solar insolation affect the productivity of the stepped SS. The findings indicate that the radiation shape factor significantly affects thermal performance predictions, especially at lower solar insolation and higher glass cover inclination angles. Accounting for the radiation shape factor can increase the solar still's productivity by as much as 18.8%. Duskiardi et al. [20] presented the performance of solar water stills using reflectors in Padang City, Indonesia. The results show that when using the reflector, the freshwater output increased by 16.8%. Omara et al. [30] examined a new desalination system called the vertical rotating wick SS (VRWSS).

This system underwent testing in various scenarios, including the use of wick materials, belt rotational speeds, and direction of rotation. The VRWSS proved to be compact, facilitating rapid water evaporation and condensation due to its minimal thermal capacity. The jute wick outperformed the cotton wick in productivity at all belt rotational speeds, except 0.02rpm. Water production was enhanced with counterclockwise rotation and diminished as speed increased. Moreover, counterclockwise rotation yielded greater productivity than clockwise rotation at all speeds, barring 0.02rpm. Implementing solar tracking increased freshwater production by 37%, resulting in thermal efficiency. A comparative study by Hammad et al. [31] focused on enhancing the freshwater output of a single-slope solar distiller by incorporating a v-corrugated basin and PCM. Tests are conducted on distillers with both flat and v-corrugated basins, with and without PCM, under the climate conditions of Tanta, Egypt. Thermal analysis of four distillers is carried out to assess daily energetic efficiency and freshwater output.

The findings indicate that the VBSD-PCM significantly outperforms the other models in energetic efficiency and freshwater output. Specifically, water production and daily energetic efficiency are increased by 63.57% and 72.70%, respectively, over the TFBSD. The study suggests that the VBSD-PCM configuration holds considerable promise for boosting the efficiency and freshwater production of solar distillers. In addition, Badran et al. [32] conducted a study to improve the efficiency of the traditional multi-slope SS used in remote villages lacking electricity and clean water. These stills were modified with a photovoltaic array to heat water via an electric heater.

The study assessed the performance of the photovoltaic-coupled SS (PVSS) with a basin area of $0.64 m^2$ against a conventional SS (CSS). Findings revealed that the PVSS's productivity in active mode was more than three times higher than the CSS, which produced 2.2-2.34 L/m^2 in passive mode. Additionally, the study indicated that the SS's daily efficiency reached approximately 44.8% when operated in active mode with additional energy, yielding 6 liters of distilled water. Furthermore, Chichan et al. [33] have created a unique solar design specifically for the tough environment of Baghdad. To minimize evaporation energy, the design temporarily stops the distillation process between 12 and 3 PM using an ordinary sun-cover glass with high temperatures. Solar air temperature has significant impact in severe areas. Without any cooling aid, the suggested method increased production by 120.8%; when the fixed cover was cooled with a fan after 4 PM, productivity increased by 337.36%; and when the lid was cooled with water, output increased by 403%. In addition, Al-Doori et al. [34] utilized three local rocks (crushed rocks, concrete bricks, and basalt rocks) to enhance water production in a double-slope SS. Productivity increased by 42% with concrete bricks, while it surged by 111% with basalt rocks. The highest recorded water temperatures were 73.2°C in concrete bricks and 75.2°C in clear basins. The peak water temperatures observed in basalt rocks and clear basins were 71.6°C at 3 PM and 77.3°C at 2 PM, respectively. Jamal and Siddiqui [35] researched the effects of water depth in the basin at east-west and north-south orientations. Using a double-sloped SS, they looked at the heat transfer coefficient between the surface of the glass cover and the water. The study was carried out in Aligarh, India, under open-environment conditions. The yield is highest in shallow water and when the still is oriented north - south, according to the results. Productivity declines with increasing water depth, peaking at 5cm.

The examination of the literature reveals that the majority of research focuses on enhancing the performance and water productivity of solar water distillers, mostly on conventional models with expanded surfaces, PCM, nanoparticles, water depth, integrated photovoltaic, and cooling an inclined cover. However, single-basin and single-slope solar distillers with phase change material (PCM) and a porous media have not been included in prior studies. According to this study, a single-slope solar water distiller's performance may be improved by adding fins, a porous media, and phase change material (PCM) above the absorber surface.

Iraq is acknowledged for dedicating considerable electrical power to water purifiers, leading to spending a lot of money. However, Iraq has significant solar energy that could be harnessed for water distillation. Implementing a solar distillation system emerges as a promising solution for generating pure water and saving energy consistently throughout the year. This system can be utilized in regions lacking access to clean drinking water, with the potential to connect well water to provide safe water for human use. The main objective of the present work is to investigate the effects of fins, porous media (black glass balls), and phase change material (paraffin wax packed in circular tubes) on the performance of solar water distillers with a single slope and single basin.

2. Experimental Set-up

To achieve the highest thermal capacity of traditional SS, the performance of the single-slope and single-basin solar water distillers can be enhanced by utilizing fins, black glass balls as porous media, and PCM (paraffin wax packed in circular tubes).

The system was designed and constructed. The schematic view is shown in Figure 1. The experimental set-up is installed at the laboratories of the Northern Technical University, Iraq/Mosul (36°22'32.0"N 43°09'03.2" E). The system is called a modified solar still with fins, porous media, and PCM above the absorber (MSS-FPPCM). The MSS-FPPCM is made from a galvanized iron sheet with a thickness of 2mm. The distiller body insulated with cork is 2cm thick from five sides, and then the still's body with insulation is put in a wooden box to reduce heat losses to the ambient. The wooden box walls are 18mm in thickness. The corners of the basin welded to prevent leakage.

The fins constructed from galvanized iron and arranged in a staggered form above the absorber plate. Each fin measures 8 cm in length, 4cm in width, and 2mm in thickness, with a 5cm gap maintained between them. The basin area is 0.504m^2. Figure 2 shows the distiller body during the manufacturing process. Both the fins and the basin coated with matte black paint to enhance the absorption of solar radiation. The distiller's body has two holes: one for water intake connected to a feeder tank via a rubber tube, and the other for drainage at the basin used for cleaning the basin after post-use.

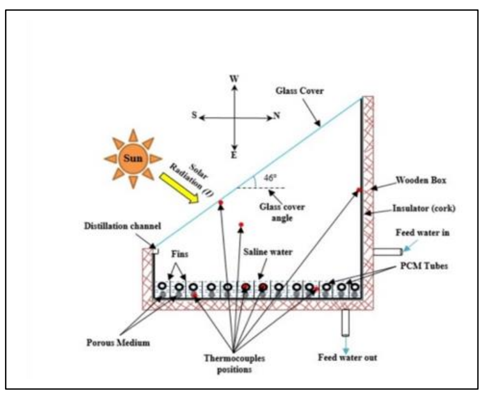


Figure 1: Schematic view of the MSS-FPPCM Model

The distiller's glass cover is 6mm thick, with rubber seals along the basin edges to prevent vapor escape and around the glass cover to protect it from damage. The inclination angle of the glass cover is selected to be 46° from the horizontal [36]. The tests done in November and December 2023 in Mosul, Iraq. The condensate water is gathered in a channel made from PVC that moves on the inner side of the glass cover. The amount of condensate water is collected and measured in a scaled cylinder. The tests are conducted according to the standard conditions specified by ASHRAE [37].

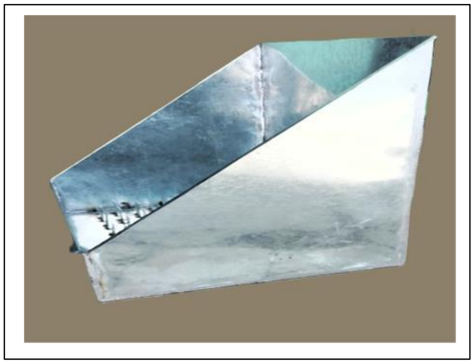


Figure 2: A photograph of the distiller body

Table1 presents the thermophysical properties of paraffin wax that packed in circular tubes used in the tests.

Table 1. Thermophysical properties of paraffin wax [38].

Property	**Values**
Melting temperature (°C)	54 - 57
Specific heat $\mathbf{Cp_S}$ (KJ/Kg.K)	2
Specific heat $\mathbf{Cp_L}$ (KJ/Kg.K)	2.15
Thermal conductivity $\mathbf{K_S}$ (W/m.K)	0.22
Thermal conductivity $\mathbf{K_L}$ (W/m.K)	0.24
Density $\boldsymbol{\rho_S}$ (Kg/m^3)	910
Density $\boldsymbol{\rho_L}$ (Kg/m^3)	790
Latent heat of fusion (KJ/Kg)	170
Volume expansion (solid/liquid phase change)	16%
Total weight of PCM paraffin wax for 10 circular pipes (Kg)	0.8

3. Experiment procedure

The experiment is carried out at two different water depths (3 and 5cm). Before initiating the test, the glass cover is cleaned, and all equipment is checked to confirm there are no leaks at any connection. The actual photographs of the test-rig experimental model are displayed in Figure 3. The solar radiation and temperatures of the ambient air, vapor, glass, and water are measured, and the tests are carried out from 8 AM to 7 PM. The solar radiation is measured by a digital pyranometer (Seaward Solar Survey 100 Irradiance Meter) with an accuracy of ±0.85W/m^2.

Figure 3: Test-rig experimental model

A multi-channel thermocouple with an accuracy of ±0.65°C is used to record the temperatures of various solar still components. All reading takes every 15 minutes. The porous media (black glass balls) inside the basin of the MSS-FPPCM system is shown in Figure (4).

Figure 4: The porous media (black glass balls) in the basin of the MSS-FPPCM system

In the current investigation, the effectiveness (η_{dms}) and the water productivity (M'_{dms}) of systems are determined as follows [39]:

$$M'_{dms} = \sum M_{ms} \quad \text{.....................} (1)$$

$$\eta_{dms} = \frac{M'_{dms} * L_{ev}}{\sum I * 3600 * A_b} \quad \text{....................} (2)$$

Where $I,\ L_{ev}, A_b,\ and\ M_{ms}$ represent the total intensity of solar radiation, water latent heat of evaporation, basin area, and total solar water distiller's hourly distillate production for 10 hours respectively. The water latent heat of evaporation is calculated as follows [40]:

For *Tv <70 °C :*

L_{ev} = 2.4935 x 10^{6} [1 – 9.4779 x 10^{-4} x Tv + 1.3132 x 10^{-7} xTv^{2} – 4.7974 x 10^{-9} x Tv^{3}] ………………….... (3)

For *Tv >70 °C:*

L_{ev} = 3.1615 x 10^{6} [1 – (7.616 x 10^{-4} x *Tv*)] ..…. (4)

5. Results and Remarking Discussion

To illustrate how the addition of fins, PCM, and porous media above the MSS-FPPCM absorber surface affects the system's performance experimental study is conducted. The purpose of using fins, PCM, and porous media is to increase the basin's surface area, raise the water's temperature and productivity by optimizing heat exchange between the absorber and the water, store solar thermal energy, and release it into the water during periods of low solar radiation. The solar radiation (*I*) fluctuations for the MSS-FPPCM system is shown in Figure 5 as hourly fluctuations at different water depths, both with and without the use of black glass balls.

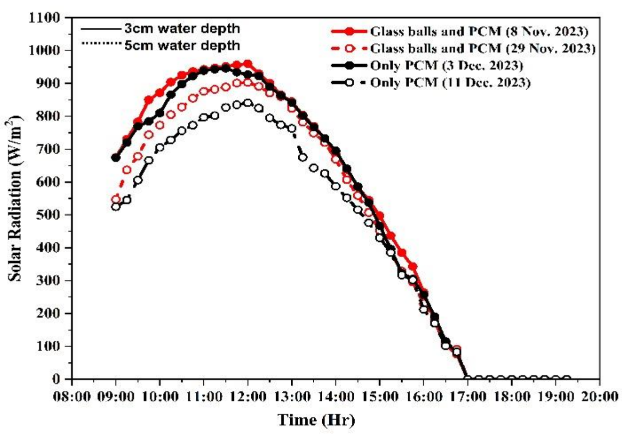


Figure 5: Variations of intensity solar radiation for various days and water depth.

Based on available data, November 8th was the day when the irradiance peaked at 960 W/m^2. In contrast, that day's sunset had a minimum irradiation of 76W/m^2. The maximum irradiance levels occurred between 11 AM and 12 PM. Figure 5 demonstrates that irradiance levels begin to drop after 12 PM on all days studied. Water evaporation energy is mostly dependent on the quantity of irradiance that the system can capture.

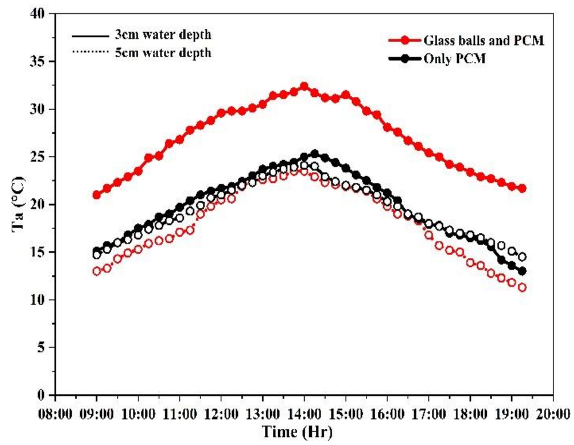


Figure 6: variation of the ambient air temperature at 3cm and 5cm water depth

Figure 6 illustrates the variation of the ambient air temperature during various days. The distillation process is also influenced by ambient temperature. A higher ambient temperature contributes to a warmer environment inside the distiller, which can speed up the evaporation rate. On the other hand, an excessively high ambient air temperature might result in a smaller temperature differential between the water and the air, which could reduce the condensation rate on the distiller's glass cover.

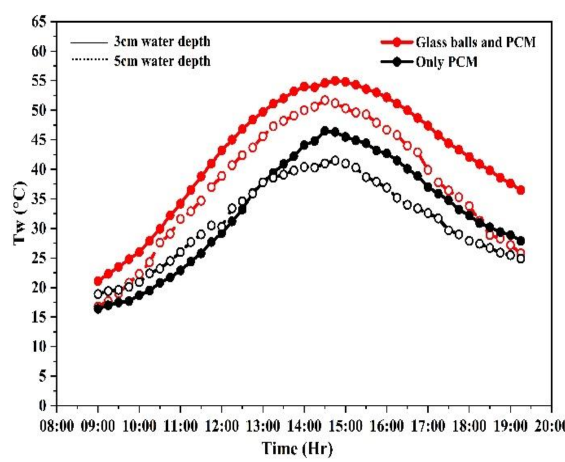


Figure 7: Variations of basin water temperature at 3cm and 5cm water depth

Figure (7) depicts the variations in water temperature (T_w) at depths of 3cm and 5cm. The data confirm that T_w is significantly influenced by water depth. The basin's T_w peaks between 1 and 3 p.m., and then gradually decreases until 7 p.m. This suggests that water depth, the surrounding environment, and solar energy received are all factors affecting the basin's T_w.

Furthermore, the results indicate that the porous media influences T_w more than the phase change material (PCM). Water evaporation is accelerated by adding fins and porous media, which expand the heat exchange surface area and enhance the exposure to solar radiation. The integration of PCM aids in storing heat and releasing it after sunset. The results show that the peak T_w was achieved when using black glass balls and PCM, reaching 55 °C at a water depth of 3cm and 51.7 °C at 5cm. On the other hand, the peak T_w when using only PCM reaches 46.5 °C at 3cm water depth and 41.5 °C at 5cm. Consequently, these findings verify that heat exchange is more efficient at the lowest possible water depth.

The temperature behavior of PCM (paraffin wax) with and without black glass balls at various water depths is depicted in Figure 8. According to the data, when black glass balls are used together with PCM (paraffin wax) reaches the highest temperature of 55.4°C at a water depth of 3cm and 54.4°C, at a depth of 5cm. In contrast, when PCM is used alone, its peak temperature reaches 49°C and 46.8°C at water depths of 3cm and 5cm respectively. Moreover, Fig. 8 shows that the temperature of PCM rises when a porous media is added, as opposed to when PCM is employed alone. The purpose of using PCM is to ensure the system's increased water production by capturing and storing excess energy during periods of peak solar radiation and releasing it after sunset.

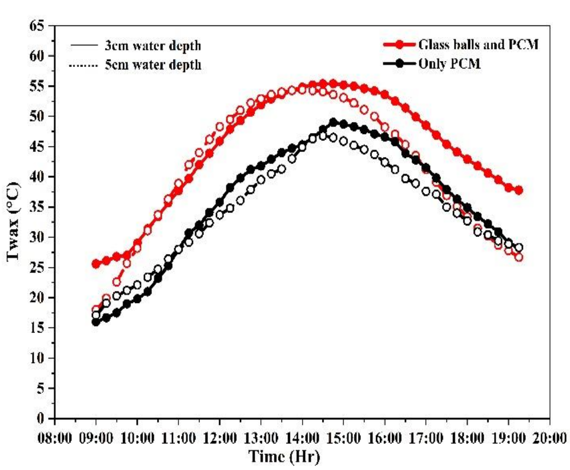


Figure 8: Temperature behavior of paraffin wax at 3cm and 5cm water depths

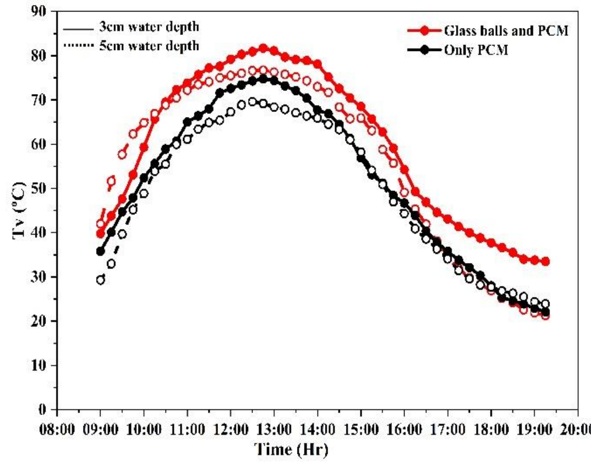
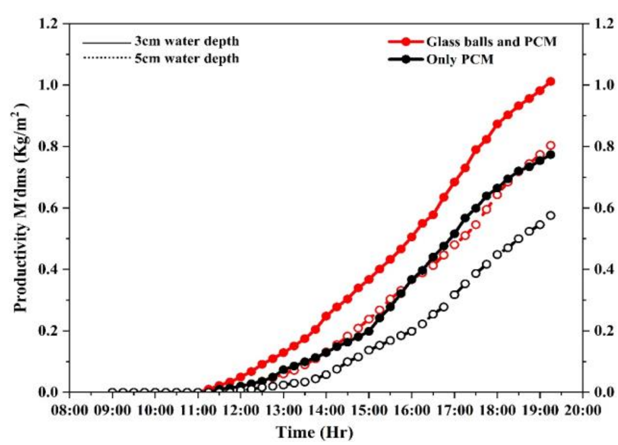


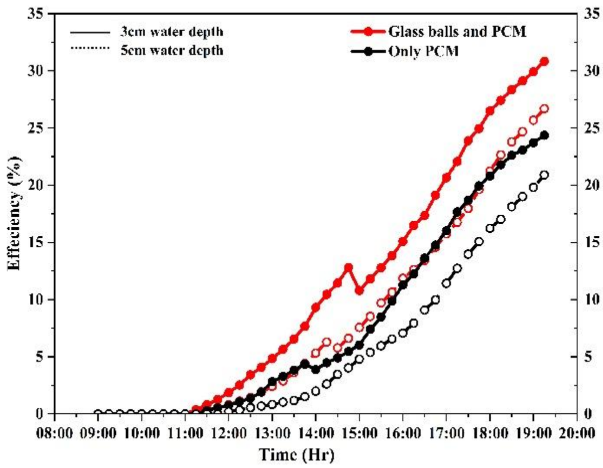
Figure 9: Vapor temperature behavior at 3cm and 5cm water depth

Figure 9 illustrates the characteristics of vapor water temperature for water depths of 3cm and 5cm. These temperatures play a crucial role in determining the rate of saltwater evaporation and condensation. It is noteworthy that in this study, vapor temperatures are influenced by several factors: intensity of the solar radiation, water depth, porous media, PCM, basin water temperature, and the absorptivity of the basin plate. The findings reveal that the maximum vapor water temperature is achieved when black glass balls and PCM are incorporated with fins. This can be attributed to the PCM, which, in conjunction with black glass balls and fins, increased the heat exchange surface area between the water and the absorber plate, thus expediting the evaporation process.

Figure 10 illustrates the cumulative water productivity and efficiency of the MSS-FPPCM system using black glass balls with PCM and PCM



(a)



(b)

Figure 10: Variation of (a) Water Productivity and (b) Efficiency at 3cm and 5cm water depth

The addition of porous media, PCM, and fins, above the basin, is responsible for the highest values of water productivity and efficiency. These elements combine to increase surface area for heat exchange and provide additional energy storage through latent heat from solar radiation, which is subsequently released after sunset.

Conclusions and final remarks

Experimental investigation on the effect of adding rectangular fins, porous media, and PCM above the absorber plate of single-slope and single-basin solar water distiller under different water depth experimentally evaluated. Two cases applied. Case1 used black glass balls, PCM, and fins above the system's basin, and Case2 uses PCM only with fins. Experiments were conducted under the climate conditions of Mosul, Iraq, in November and December 2023. The next observations are ascertained as follows:

1. The results show that Case1, which uses black glass balls, PCM, and fins at 3 and 5cm water depths, achieved the highest daily production and efficiency compared to Case2 that utilized only PCM with fins at the same water depths.
2. Case1 reached the highest water temperature of 55°C at 3cm water depth, while Case 2 reached a maximum of 46.5°C at the same water depth.
3. Case1 also recorded the highest water production, with 1.01 kg/m^2 at 3cm water depth.
4. The results indicated that the thickness and angle of the glass cover, the basin area, weather conditions, and the intensity of solar radiation significantly affect the efficiency and productivity of a solar water distiller.

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References

[1] Y. Li *et al.*, “Graphene oxide-based evaporator with one-dimensional water transport enabling high-efficiency solar desalination,” *Nano Energy*, vol. 41, pp. 201–209, 2017, doi: 10.1016/j.nanoen.2017.09.034.
[2] G. Xiao *et al.*, “A review on solar stills for brine desalination,” *Appl. Energy*, vol. 103, pp. 642–652, 2013, doi: 10.1016/j.apenergy.2012.10.029.
[3] N. Ghaffour, J. Bundschuh, H. Mahmoudi, and M. F. A. Goosen, “Renewable energy-driven desalination technologies: A comprehensive review on challenges and potential applications of integrated systems,” *Desalination*, vol. 356, pp. 94–114, 2015, doi: 10.1016/j.desal.2014.10.024.
[4] A. K. Tiwari and G. N. Tiwari, “Thermal modeling based on solar fraction and experimental study of the annual and seasonal performance of a single slope passive solar still: The effect of water depths,” *Desalination*, vol. 207, no. 1–3, pp. 184–204, 2007, doi: 10.1016/j.desal.2006.07.011.
[5] A. E. Kabeel, Z. M. Omara, and M. M. Younes, “Techniques used to improve the performance of the stepped solar still-A review,” *Renew. Sustain. Energy Rev.*, vol. 46, pp. 178–188, 2015, doi: 10.1016/j.rser.2015.02.053.
[6] K. Voropoulos, E. Mathioulakis, and V. Belessiotis, “A hybrid solar desalination and water heating system,” 2004.
[7] A. E. Kabeel, Z. M. Omara, F. A. Essa, A. S. Abdullah, T. Arunkumar, and R. Sathyamurthy, “Augmentation of a solar still distillate yield via absorber plate coated with black nanoparticles,” *Alexandria Eng. J.*, vol. 56, no. 4, pp. 433–438, Dec. 2017, doi: 10.1016/j.aej.2017.08.014.
[8] W. H. Alawee *et al.*, “Improving the performance of pyramid solar distiller using dangled cords of various wick materials: Novel working mechanism of wick,” *Case Stud. Therm. Eng.*, vol. 28, no. November 2020, p. 101550, 2021, doi: 10.1016/j.csite.2021.101550.
[9] A. S. Abdullah, W. H. Alawee, S. A.

Mohammed, A. Majdi, Z. M. Omara, and F. A. Essa, “Increasing the productivity of modified cords pyramid solar still using electric heater and various wick materials,” *Process Saf. Environ. Prot.*, vol. 169, no. August 2022, pp. 169–176, 2023, doi: 10.1016/j.psep.2022.11.016.

[10] A. Saravanan and M. Murugan, “Performance evaluation of square pyramid solar still with various vertical wick materials – An experimental approach,” *Therm. Sci. Eng. Prog.*, vol. 19, no. March, p. 100581, 2020, doi: 10.1016/j.tsep.2020.100581.

[11] H. Amiri, “Enhancing the stepped solar still performance using a built-in passive condenser,” *Sol. Energy*, vol. 248, no. November, pp. 88–102, 2022, doi: 10.1016/j.solener.2022.11.006.

[12] R. Grewal and M. Kumar, “Investigations on effect of mass of phase change material on sugarcane juice concentration and distillate production in a stepped solar system,” *J. Energy Storage*, vol. 52, no. PB, p. 104878, 2022, doi: 10.1016/j.est.2022.104878.

[13] A. N. Shmroukh and S. Ookawara, “Evaluation of transparent acrylic stepped solar still equipped with internal and external reflectors and copper fins,” *Therm. Sci. Eng. Prog.*, vol. 18, no. September 2019, p. 100518, 2020, doi: 10.1016/j.tsep.2020.100518.

[14] F. A. Essa, A. S. Abdullah, and Z. M. Omara, “Improving the performance of tubular solar still using rotating drum – Experimental and theoretical investigation,” *Process Saf. Environ. Prot.*, vol. 148, pp. 579–589, 2021, doi: 10.1016/j.psep.2020.11.039.

[15] M. Elashmawy, M. Alhadri, and M. M. Z. Ahmed, “Enhancing tubular solar still performance using novel PCM-tubes,” *Desalination*, vol. 500, no. December 2020, p. 114880, 2021, doi: 10.1016/j.desal.2020.114880.

[16] F. A. Essa *et al.*, “Experimental enhancement of tubular solar still performance using rotating cylinder, nanoparticles’ coating, parabolic solar concentrator, and phase change material,” *Case Stud. Therm. Eng.*, vol. 29, no. May 2021, p. 101705, 2022, doi: 10.1016/j.csite.2021.101705.

[17] A. S. Abdullah, M. M. Younes, Z. M. Omara, and F. A. Essa, “New design of trays solar still with enhanced evaporation methods – Comprehensive study,” *Sol. Energy*, vol. 203, no. April, pp. 164–174, 2020, doi: 10.1016/j.solener.2020.04.039.

[18] K. M. Bataineh and M. A. Abbas, “Performance analysis of solar still integrated with internal reflectors and fins,” *Sol. Energy*, vol. 205, no. April, pp. 22–36, 2020, doi: 10.1016/j.solener.2020.04.059.

[19] F. Ketabchi, S. Gorjian, S. Sabzehparvar, Z. Shadram, M. S. Ghoreishi, and H. Rahimzadeh, “Experimental performance evaluation of a modified solar still integrated with a cooling system and external flat-plate reflectors,” *Sol. Energy*, vol. 187, no. June 2018, pp. 137–146, 2019, doi: 10.1016/j.solener.2019.05.032.

[20] Mulyanef, Duskiardi, K. Sopian, Kaidir, and Z. Rahman, “Performance Experimental Study of Solar Still With Reflector To Produce Fresh Water and Salt,” *MATEC Web Conf.*, vol. 248, pp. 0–5, 2018, doi: 10.1051/matecconf/201824801004.

[21] H. Mousa and A. M. Gujarathi, “Modeling and analysis the productivity of solar desalination units with phase change materials,” *Renew. Energy*, vol. 95, pp. 225–232, Sep. 2016, doi: 10.1016/j.renene.2016.04.013.

[22] B. Li and X. Zhai, “Experimental investigation and theoretical analysis on a mid-temperature solar collector/storage system with composite PCM,” *Appl. Therm. Eng.*, vol. 124, pp. 34–43, 2017, doi: 10.1016/j.applthermaleng.2017.06.002.

[23] M. Abu-Arabi, M. Al-harahsheh, H. Mousa, and Z. Alzghoul, “Theoretical investigation of solar desalination with solar still having phase change material and connected to a solar collector,” *Desalination*, vol. 448, pp. 60–68, Dec. 2018, doi: 10.1016/j.desal.2018.09.020.

[24] T. Arunkumar, D. Denkenberger, A. Ahsan, and R. Jayaprakash, “The augmentation of distillate yield by using concentrator coupled solar still with phase change material,” *Desalination*, vol. 314, pp. 189–192, 2013, doi: 10.1016/j.desal.2013.01.018.

[25] W. M. Farouk, A. S. Abdullah, S. A. Mohammed, W. H. Alawee, Z. M. Omara, and F. A. Essa, “Modeling and optimization of working conditions of pyramid solar still with different nanoparticles using response surface methodology,” *Case Stud. Therm. Eng.*, vol. 33, no. March, p. 101984, 2022, doi: 10.1016/j.csite.2022.101984.

[26] O. Bait and M. Si-Ameur, “Enhanced heat and mass transfer in solar stills using nanofluids: A review,” *Sol. Energy*, vol. 170, no. June, pp. 694–722, 2018, doi: 10.1016/j.solener.2018.06.020.

[27] K. V. Modi and J. G. Modi, “Influence of wick pile of jute cloth on distillate yield of double-basin singleslope solar still: Theoretical and experimental study,” *Sol. Energy*, vol. 205, no. February, pp. 512–530, 2020, doi: 10.1016/j.solener.2020.05.086.

[28] J. Zhang *et al.*, “Three-dimensional porous photo-thermal fiber felt with salt-resistant property for high efficient solar distillation,” *Chinese Chem. Lett.*, vol. 32, no. 4, pp. 1442–1446, Apr. 2021, doi: 10.1016/j.cclet.2020.10.004.

[29] Y. A. F. El-Samadony, W. M. El-Maghlany, and A. E. Kabeel, “Influence of glass cover inclination angle on radiation heat transfer rate within stepped solar still,” *Desalination*, vol. 384, pp. 68–77, 2016, doi: 10.1016/j.desal.2016.01.031.

[30] Z. M. Omara, A. S. Abdullah, F. A. Essa, and M. M. Younes, “Performance evaluation of a vertical rotating wick solar still,” *Process Saf. Environ. Prot.*, vol. 148, pp. 796–804, 2021, doi: 10.1016/j.psep.2021.02.004.

[31] F. A. Hammad, S. M. Shalaby, A. E. Kabeel, and M. E. Zayed, "Experimental investigation and thermo-economic performance analysis of a modified solar distiller design with thermal storage material and v-corrugated absorber basin," *J. Energy Storage*, vol. 52, no. August, 2022, doi: 10.1016/j.est.2022.105020.

[32] O. Badran, A. Alahmer, F. A. Hamad, Y. El-Tous, G. Al-Marahle, and H. M. A. Al-Ahmadi, "Enhancement of solar distiller performance by photovoltaic heating system," *Int. J. Thermofluids*, vol. 18, no. February, p. 100315, 2023, doi: 10.1016/j.ijft.2023.100315.

[33] M. Tariq Chaichan, H. A. Kazem, A. H. A. Al-Waeli, S. A. Mohammed, Z. M. Omara, and K. Sopian, "Performance enhancement of solar distillation system works in harsh weather conditions: An experimental study," *Therm. Sci. Eng. Prog.*, vol. 43, no. June, p. 101981, 2023, doi: 10.1016/j.tsep.2023.101981.

[34] G. F. L. Al-Doori, I. S. Moosa, and A. A. M. Saleh, "Enhanced productivity of double-slope solar still using local rocks," *Int. J. Smart Grid Clean Energy*, vol. 8, no. 3, pp. 307–312, 2019, doi: 10.12720/sgce.8.3.307-312.

[35] W. Jamal and M. A. Siddiqui, "Effect of water depth and still orientation on productivity for passive solar distillation," *Int. J. Eng. Res. Appl.*, vol. 2, no. 2, pp. 1659–1665, 2012, [Online]. Available: https://www.ijera.com/papers/Vol2_issue2/JW2216591665.pdf%0A

[36] M. A. Mohmood, M. M. M. Salih, O. R. Alomar, and K. H. Mohammed, "An Experimental Study on Performance Analysis of Solar Water Distiller System Using Extended Fins under Iraq Climatic Conditions," *AIP Conf. Proc.*, vol. 2862, no. 1, 2023, doi: 10.1063/5.0171639.

[37] ANSI/ASHRAE 93-1986 (RA 91) - Methods of Testing to Determine the Thermal Performance of Solar Collectors, (accessed January 30, 2024).

[38] M. N. Yousif, O. R. Alomar, and A. M. Saleem, "Performance of compound parabolic concentrator solar air flat plate collector using phase change material," *Appl. Therm. Eng.*, vol. 240, no. August 2023, p. 122224, 2024, doi: 10.1016/j.applthermaleng.2023.122224.

[39] A. Agrawal, R. S. Rana, and P. K. Srivastava, "Heat transfer coefficients and productivity of a single slope single basin solar still in Indian climatic condition: Experimental and theoretical comparison," *Resour. Technol.*, vol. 3, no. 4, pp. 466–482, 2017, doi: 10.1016/j.reffit.2017.05.003.

[40] A. K. Tiwari and G. N. Tiwari, "Effect of water depths on heat and mass transfer in a passive solar still: in summer climatic condition," *Desalination*, vol. 195, no. 1–3, pp. 78–94, 2006, doi: 10.1016/j.desal.2005.11.014.

Nomenclature

SS	Solar Still
CSS	Conventional Solar Still
TSS	Tubular Solar Still
PCM	Phase Change Material
NPCM	Nanoparticles Phase Change Materials
VRWSS	Vertical Rotating Wick Solar Still
VBSD-PCM	V-corrugated Basin Solar Distiller integrated with Phase Change Material
TFBSD	Traditional Flat Basin Solar Distiller
PVSS	Photovoltaic coupled with Solar Still
MSS-FPPCM	Modified Solar Still integrated with Fins, Porous media, and PCM
I	Solar radiation, W/m^2
A_b	Basin area, m^2
M'_{dms}	Daily distillate productivity, kg/m^2
L_{ev}	Latent heat of evaporation of water, J/kg
η_{dms}	*Efficiency of the Solar Still (%)*
T_a	Ambient Temperature, °C
T_w	Water basin temperature, °C
T_{wax}	Phase change material temperature, °C
T_v	Vapor temperature, °C