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Productivity Augmentation of Solar Stills by Coupled Copper Tubes and Parabolic Fins

Ajay Kumar Kaviti [1,2], Magadapalli Teja [2], Oruganti Madhukar [2], Polaboina Bhanu Teja [2], Vakapalli Aashish [2], Gembali Srinivasa Gupta [2], Akkala Sivaram [1,2] and Vineet Singh Sikarwar [3,4,*]

1 Centre for Solar Energy Materials, VNRVJIET, Hyderabad 500090, India; ajaykumar_k@vnrvjiet.in (A.K.K.)
2 Department of Mechanical Engineering, VNRVJIET, Hyderabad 500090, India
3 Institute of Plasma Physics of the Czech Academy of Sciences, Za Slovankou 1782/3, 18200 Prague, Czech Republic
4 Department of Power Engineering, University of Chemistry and Technology, Technická 5, 16628 Prague, Czech Republic
* Correspondence: sikarwar@ipp.cas.cz; Tel.: +420-703-666-310

Abstract: A solar still is an eco-friendly device that makes use of ample solar energy for the purification of water. The main objective of this research is to increase the yield output of a double-slope solar still (DSSS) by coupling the basin liner with copper tubes and parabolic fins. In this work, the experiments were supervised for nine days with three different cases. For these experiments, copper tubes with thickness of 2 mm, outer diameter of 32 mm, inner diameter of 28 mm, and parabolic fins with 30 mm diameter and 50 mm height were considered. In the first case, non-coated copper tubes (NCCTs) were used, in the second case, coated copper tubes (CCTs) were employed, and in the last case, coated copper tubes with a combination of parabolic fins (CCTPFs) were used. The MSS (case-III) demonstrated a substantial yearly productivity enhancement of 57.79%, establishing its superiority in terms of output because of its higher daily distillate yield of 1215 mL/day in contrast to CSS. When compared, case III—CCTPF—performed better than case II—CCT—by 35.75%. The CSS and MSS both contributed to a decrease in the pH of the saline water, which went from 8.18 to 7.64 and 7.23, respectively. In comparison to the MSS and CSS, which had 0.428 mg/L and 0.569 mg/L of fluoride ions, respectively, brine water had a fluoride ion level of 0.734 mg/L. Total dissolved solids (TDS) concentration before desalination was 440 ppm and it was minimized to 20 ppm with MSS and 55 ppm with CSS, respectively, post-desalination. The corresponding cost per liter (CPL) of MSS and CSS is USD 0.053 and USD 0.040, respectively.

Keywords: copper tubes; desalination; distillate yield; parabolic fins; solar still

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1. Introduction

Around 97% of all the water in the world is in the oceans. The leftover 3% is freshwater. Out of all the water in the world, only 1% is usable by humans. Due to the scarcity of water, more than one-fifth of the population is affected by the issue. The rise in population and the expansion of the agricultural and industrial sectors are the main factors that cause water scarcity globally [1]. India's population is about 18% of world's population; even though India is surrounded on three sides by water, it still faces water scarcity. In India, more than 85% of water is used for agriculture, and the remaining is for other purposes, like household uses, industries, etc. [2,3].

Solar desalination is an eco-friendly method which uses renewable energy to produce pure water. Solar desalination is a method of providing safe and clean drinking water to rural communities. This method utilizes the energy from the sun to generate pure water. Solar stills are utilized to produce fresh potable water for remote communities. In isolated regions, solar energy can provide the fresh water needed to meet demand [4,5]. One of the primary challenges related to the performance of solar stills is the intermittent nature of sunlight, which remarkably affects their efficiency and performance. Various key issues arise because of the intermittent nature of sunlight, including energy storage and efficiency, inconsistent water production, operational reliability, sustainability, environmental viability, etc.

Irshad et al. [6] developed highly charged solar evaporation for the generation of power and freshwater. They obtained freshwater generation of 14.66 kg/m^2 and power generation of 45.4 W/m^2. Saravanan et al.'s [7] work is concerned with utilizing kanchey marbles to improve the yield output, where these marbles act as energy storage material. They coated the basin liner with black color to improve the temperature of the basin liner. Because of the use of kanchey marbles, the water temperature was enhanced, which resulted in an increase in efficiency. Wissam et al. [8] amplified the efficiency of DSSS via utilizing three distinct methods; one is modifying the solar still design, the second one is using a solar water heater, and the third one is utilizing heat storage material, such as gravel, when there is no proper sunlight. The increase in efficiency is greater when using the solar water heater and gravel. Panchal and co-researchers [9] determined the effect of parameters like sprinklers, water depth, and dye on a solar still. Experimentation was conducted on how black dye and sprinklers can increase the efficiency. By using a sprinkler, the condensation rate is increased, and thereby more distillate output is obtained. To observe the effect of dye, three different dyes were used: black, violet, and red. It was observed that black dye has a more significant effect than the remaining two dyes.

Muhammad et al. [10] developed a solar evaporator by augmenting the phase change material with Wormlike Perovskite Oxide, thereby obtaining 93% solar-to-vapor conversion efficiency, with an evaporator rate of 2.13 kg m^{-2} h^{-1}. Murugavel et al. [11] evaluated the effect of various energy storing materials includes quartzite rock, washed stones, cement concrete pieces, iron scraps, and red brick pieces. The experimentation values are compared with the still without energy storing materials, and it is observed that the quartzite rock has a greater effect when compared with other materials. Kumar et al. [12], under the meteorological circumstances of Hyderabad, India, experimentally investigated two solar stills, i.e., CSS and MSS, with varied permanent magnet sizes. The internal heat transfer and yield production are increased by the existence of magnets in the solar still. Dhivagar and Sundararaj [13] gave a detailed explanation about increasing the productivity of distilled water by using various methods like condensers, flat plate collector, reflectors, etc. Ihsan and Mohammad [14] give an overview of solar desalination by comparing with other filtration methods. The cost of desalination increases day by day due to the introduction of new filtration methods. Goswami and co-workers [15] gave a detailed overview of the solar desalination process. There it is explained that using this solar desalination system reduces the usage of fossil fuels. Desalination depends on location, weather, and season.

Dinesh and co-researchers [16] evaluated the effect of various fins on distillate. It is revealed that fins increase the heat transfer rate, absorber temperature, and glass temperature of a solar still. Kaviti et al. [17] supervised the research to assess the effect of fins and contrasted them with the traditional solar still. And more distillate is obtained for the modified solar still than the traditional solar still. Hardik and Kalpesh [18] conducted research to investigate DSSS performance coupled with hollow fins both circular and square in shape. The still with the circular hollow fin obtained more distillate than with square hollow fin. Ajay et al. [19] assessed the energy and exergy efficiency evaluation of the truncated conical fins coupled to the DSSS. The truncated cones' energy efficiencies are enhanced by 8.54%, 29.61%, and 31.27%, and the exergy efficiencies by 6.20%, 10.52%, and 14.51% at 1 cm, 2 cm, and 3 cm, respectively. They also observed that higher exergy is obtained for basin when compared to other parts. Kabeel and co-researchers [20] enhanced productivity by 43% with hollow circular fins and 101.5% with the addition of phase change materials (PCMs). Jyotin and Vikas [21] evaluated the augmentation effect of PCMs and pin fins on the distillate output, which was improved by 30%. Modi and co-workers [22] studied the effect of wick segments of black cotton cloth and metal hollow fins having a circular cross-section. They concluded that daily efficiency was enhanced by 39.74% with hollow fins and 38.46% with wick segments, respectively.

The aforementioned works from the literature describe various ways of improving the distillate yield of a solar still via magnets, PCMs, energy absorbing and heat storage materials, dyes, marbles, stones, wick segments, and fins with different combinations. The present work uses copper tubes and parabolic fins to improve the distillate of DSSS by considering three different cases, i.e., case I—NCCT, case II—CCT, and case III—CCTPF. Further, the results of the current study were compared to the works of the previous literature for the benefit of upcoming young researchers. Moreover, an analysis of water quality has been carried out according to the standard procedures provided by WHO (World Health Organization) and BIS (Bureau of Indian Standards).

2. Materials and Experimental Framework

Copper tubes with dimensions of inner diameter 28 mm, outer diameter 32 mm, and thickness 2 mm, and parabolic fins with dimensions 50 mm height and 30 mm diameter were utilized. The basin of the solar still is made of aluminum. There are two DSSSs in the experimental configuration, as depicted in Figure 1, which consists of four 1000 mL beakers, temperature indicator (keysight data logger), thermocouples, copper tubes, parabolic fins, anemometer, and pyranometer. Both the solar stills are placed in a wooden box and stills are fabricated with dimensions of 1000 × 500 × 200 mm. A thermo-col sheet is placed in between the wooden box and aluminum still to provide insulation. Both these stills are covered with glass with a thickness of 4 mm, and these are placed at an angle of 17°. The angle at which the glass is placed is chosen based on the latitude and longitude of work location (17.5389° N, 78.3863° E). The CSS consists of the basin liner alone and the MSS consists of the basin liner coupled with copper tubes or fins or both, based on the experiment conducted. The still, basin liner, and copper tubes are powder-coated with black color to improve absorptivity.

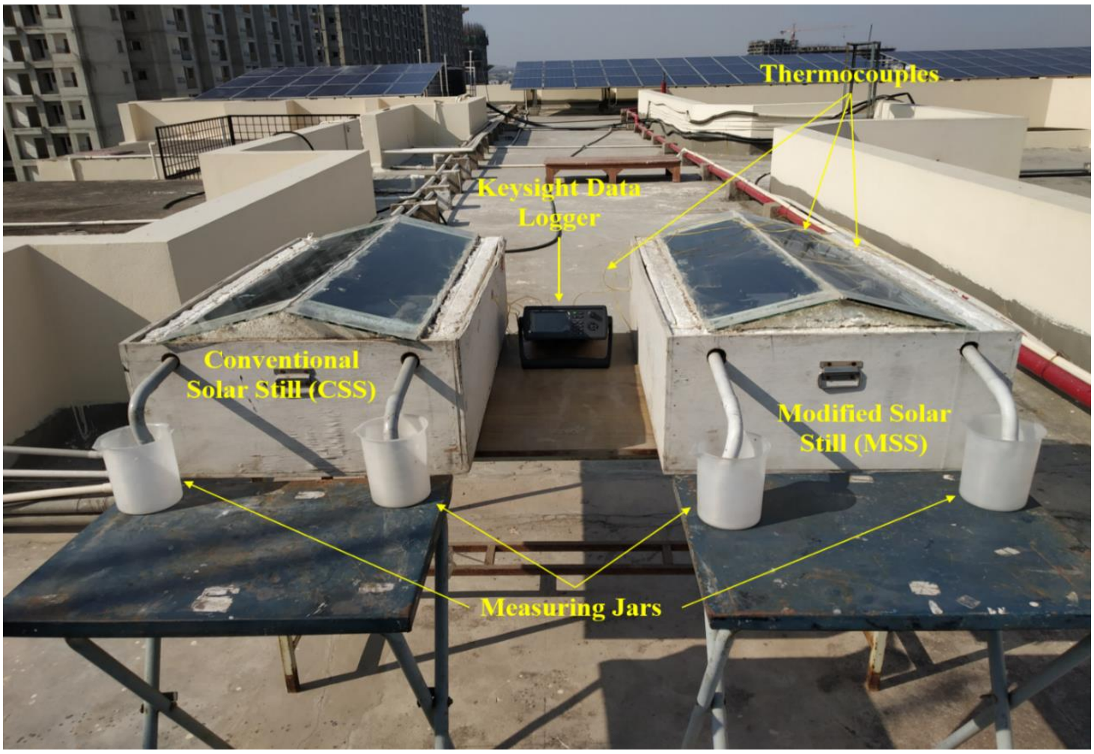
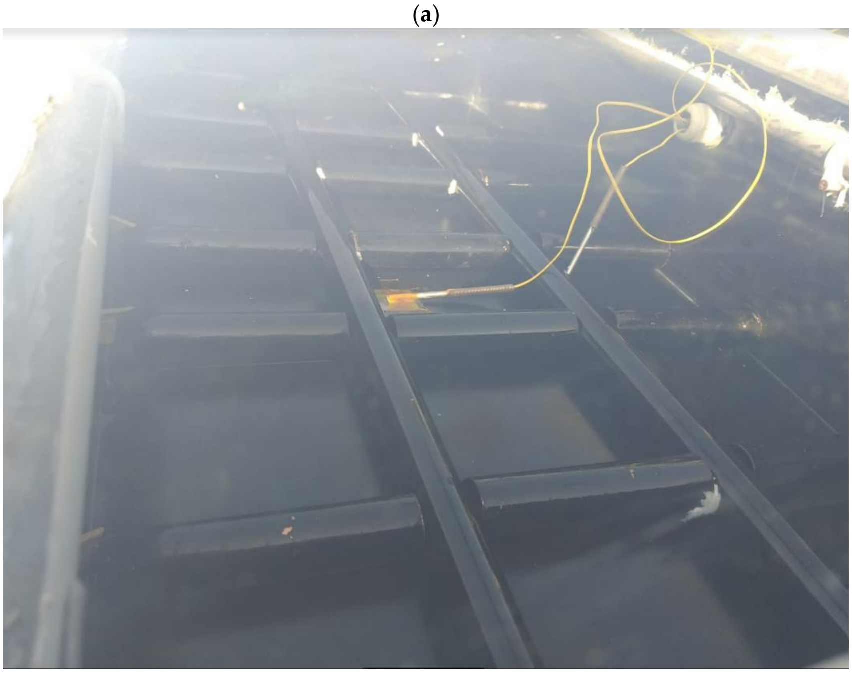


Figure 1. Experimental setup.

A total of three sets of experiments were conducted. Each experiment was carried out at three distinct water depths (1 cm, 2 cm, and 3 cm; each depth on one day), i.e., three days for one experiment and a total of nine days for the three sets of experiments. All these experiments were carried out between 9:00 a.m. and 17:00 p.m. Every hour, the glass, water, and basin liner temperatures and amount of distillate obtained for both CSS and MSS along with the wind speed and solar irradiance were noted.

Copper tubes without coating were used in the initial series of experiments (Case I). The MSS coupled with non-coated copper tubes is as described in Figure 2a. The second experimental set (Case II) was performed by coating the copper tubes with black color, as depicted in Figure 2b, and the third experimental set (Case III) was conducted by coupling the basin liner with both coated copper tubes and parabolic fins, as shown in Figure 2c. By enhancing the water depth on each day from 1 cm to 3 cm, each set of experiments was conducted across three days.

(**a**)



(**b**)

Figure 2. *Cont.*

(**c**)

Figure 2. (**a**) MSS coupled with non-coated copper tubes (NCCT—Case I). (**b**) MSS coupled with coated copper tubes (CCT—Case II). (**c**) MSS coupled with coated copper tubes and parabolic fins (CCTPF—Case III).

Multiple measuring devices were used to assess various aspects of the solar still, as mentioned in Table 1. Using thermocouple sensors with a precision of 0.8 °C, at three distinct positions, temperatures were noted using a keysight data recorder. The three most crucial temperatures to monitor were water (T_w), ambient (T_a), and the glass cover (T_g). Solar intensity was measured by utilizing a pyranometer (Hukseflux—accuracy 10 W/m^2). An anemometer with a precision of 0.1 m/s was utilized to determine wind speed. The amount of water produced was assessed with the help of a calibrated measuring jar with a 1 L capacity having a 5 mL accuracy.

Table 1. Accuracy, percentage error, and uncertainty of the instruments.

Measuring Device	Accuracy	Percentage Error	Standard Uncertainty
Anemometer	±0.1 m/s	10	0.06 m/s
Keysight data logger	±0.1 °C	1.3	0.06 °C
Thermocouple sensors	0.5 °C	0.25	±0.8 °C
Measuring jars	±5 mL	5	3 mL
pyranometer	5.77 W/m^2	10	±10 W/m^2

Uncertainty Analysis

Uncertainty analysis involves estimating the variance between the actual and the calculated values, which is often called an error. This can be classified into two distinct categories: type A and type B errors. Type A errors are random and can be evaluated through repetitive and mathematical examination. On the other hand, type B errors are systematic, and it can be helpful to determine the information from the instrument's calibration report. The standard uncertainty is then derived with the help of using the mathematical theorem outlined below.

$$u = \frac{a}{\sqrt{3}} \quad (1)$$

where a = precision of measuring instrument; u = normal uncertainty.

3. Results and Discussions

The experiment was conducted to enhance the distillate obtained from the double-slope solar still. The experiments were conducted using non-coated copper tubes (case I—NCCT), coated copper tubes (case II—CCT), and coated copper tubes with the combination of parabolic fins (case III—CCTPF) coupled with DSSS. The values are reported between 9:00 a.m. and 17:00 p.m. on each day of experimentation. The experiments were conducted at three different water depths, i.e., 1 cm, 2 cm, and 3 cm of water. The results are discussed for the optimum depth of water, i.e., 1 cm depth, and are compared with CSS.

3.1. Solar Intensity

There is a one-to-one correlation between solar irradiation and the surrounding environment's ambient temperature. The obtained solar intensity values are plotted and depicted in Figure 3. Initially, the solar intensity reported was as low as 497 W/m^2 for case II. The highest solar intensity values obtained were 800 W/m^2 for case I, 768 W/m^2 for case II, and 954 W/m^2 for case III. Solar intensity values improved from 9:00 am to 12:00 pm and then decreased. The solar intensities were reported as 100 W/m^2 for case I, 20 W/m^2 for case II, and 156 W/m^2 for case III at the end of the day. The solar intensity curves for all three cases follow the trend of a bell curve.

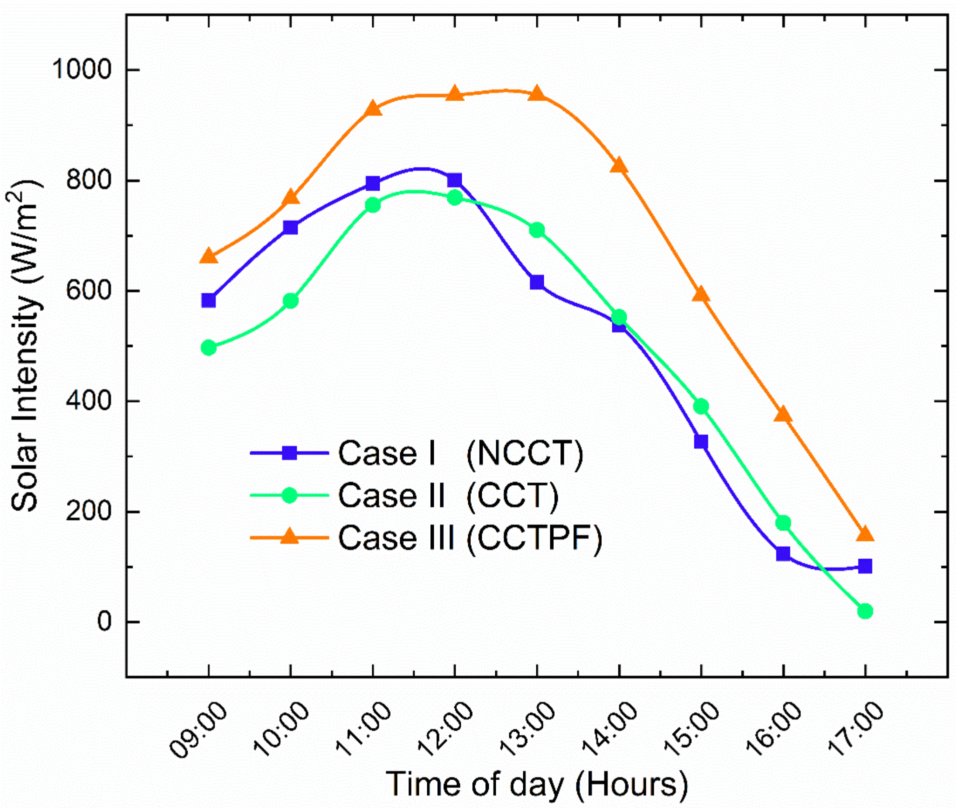
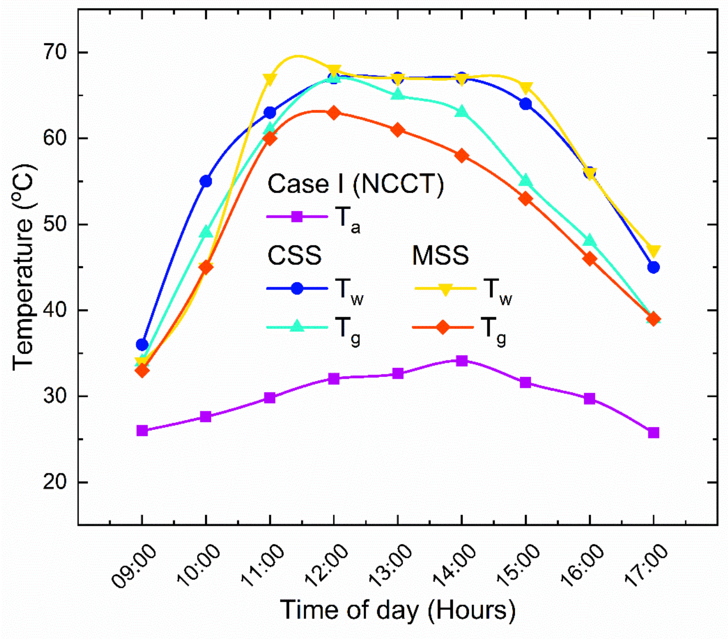


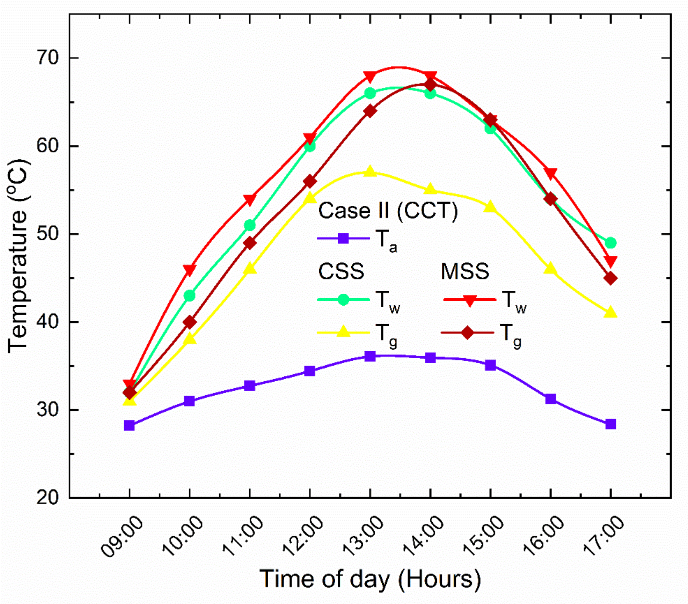
Figure 3. Solar intensity variation with respect to time for all three cases.

3.2. Temperature Profiles

The values of basin liner, glass cover, and water temperatures are recorded by utilizing thermocouples attached for both the Modified Solar Still (MSS) and Conventional Solar Still (CSS). The values of those temperatures are shown on the temperature indicator, to which thermocouples are connected. Along with these temperatures, the ambient temperature is also recorded, and all these temperature values are recorded hourly for both CSS and MSS. The temperature profile variations with respect to time for all three cases are depicted in Figure 4. In case I—NCCT, the extreme temperature values of the water (T_w), glass cover (T_g), and ambient temperature (T_a) for CSS were 67 °C, 64 °C, and 34 °C, respectively, and for MSS, the extreme water (T_w) and glass cover (T_g) temperatures were 67 °C and 62 °C, respectively. It was reported that the variation between the glass and water temperatures in MSS was 5 °C, and it was due to the presence of non-coated copper tubes (NCCTs), whereas in CSS, this difference is only 3 °C.

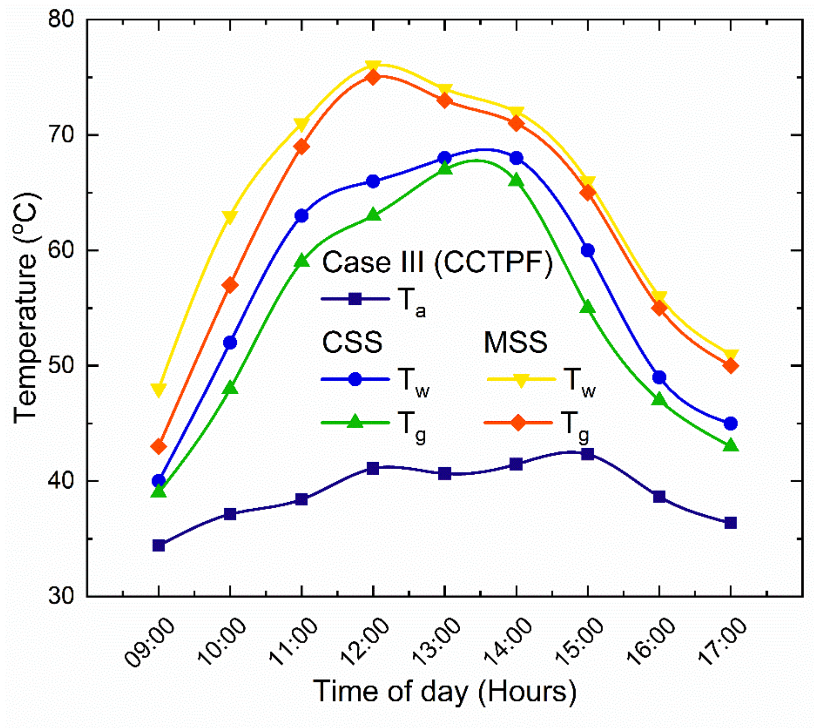


(**a**)



(**b**)

Figure 4. *Cont.*



(**c**)

Figure 4. Variation in temperature profiles concerning time: (**a**) case I—NCCT, (**b**) case II—CCT, and (**c**) case III—CCTPF.

In case II—CCT, the highest temperature values of the water (T_w), glass cover (T_g), and ambient (T_a) for CSS were 66 °C, 62 °C, and 36 °C, respectively, and for MSS, they were 68 °C and 63 °C. It was noticed that the temperature variation in glass and water in MSS was 5 °C, which was the same as case I. But in case II, this variation in temperature was maintained for a prolonged period of time, in contrast to case I, because the coated copper tubes' (CCTs) powder coating allows them to absorb the maximum solar radiation. In case III—CCTPF, the highest temperature values of water (T_w), glass cover, (T_g) and ambient (T_a) for CSS were 68 °C, 65 °C, and 42 °C, respectively, and for MSS, they were 74 °C and 66 °C. For case III, the temperature variation in the glass and water reached 8 °C in MSS, which was more when compared to case I and case II. The reason is that the augmentation of parabolic fins (PFs) with CCT helped to exchange the energy absorbed with the surrounding water.

3.3. Hourly and Cumulative Yields

The productivity output gained from the MSS and CSS was collected in two beakers for each still of 1000 mL capacity. One beaker was used to collect the distillate output from the west side, and other to collect the distillate output from the east side. The distillate output collected was recorded hourly. In all the three cases, the highest yield was obtained at 1 cm depth of water, because the heat absorption surface area was higher. So, the heat transfer between the copper tubes, parabolic fins, and surrounding water surface was higher, and the heat transfer between the basin liner and the water was also higher. The hourly and cumulative yield output obtained for all three cases of both CSS and MSS between 9:00 a.m. and 17:00 p.m. is shown in Figures 5 and 6. It can be seen in the hourly yield graph that the maximum hourly distillate obtained at 13:00 p.m. for CSS and MSS reached values of 110 mL and 140 mL for case I, 152 mL and 185 mL for case II, and 210 mL and 270 mL for case III. The difference in hourly distillate yields between CSS and MSS was more in case III, in contrast to case I and case II. The energy exchanges between the basin of the solar still and the NCCT, CCT, and CCTPF are responsible for this phenomenon.

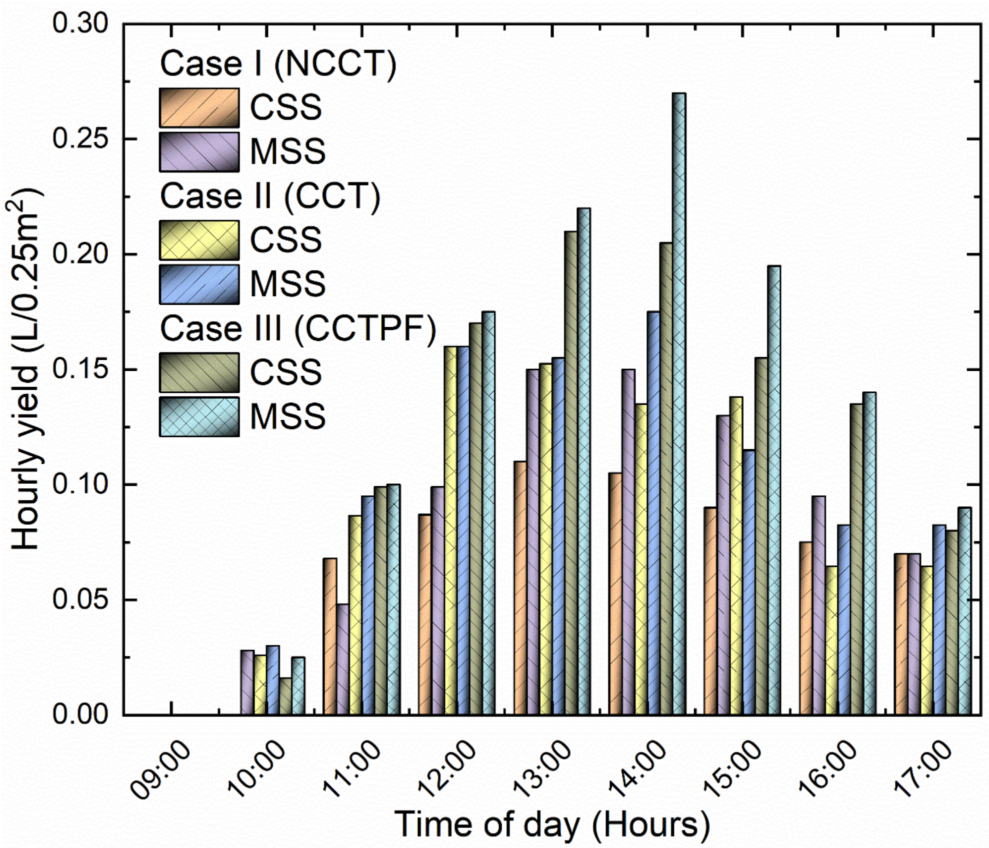


Figure 5. Variation in hourly distillate output concerning time for all three cases.

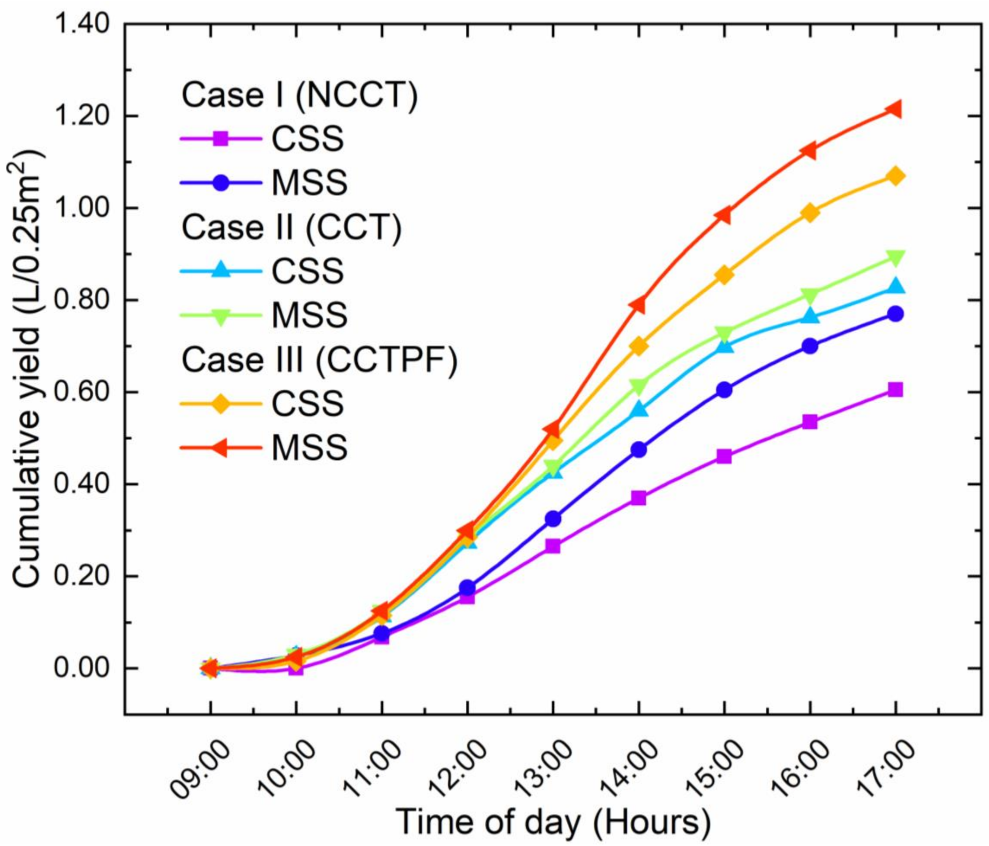


Figure 6. Variation in cumulative distillate output concerning time for all three cases.

The accumulated distillate productivity output obtained for CSS was 605 mL for case I, 827 mL for case II, and 1070 mL for case III, and for MSS it was 770 mL, 895 mL, and 1215 mL for case I, case II, and case III, respectively. Case III—CCTPF outperformed case II—CCT and case I—NCCT by 35.75% and 57.79% when compared. The CCTPFs in the solar basin are able to absorb a greater quantity of solar energy, which results in the localization of heat and transmits a major portion of the energy received from the sunlight to the surrounding water that is present on the CCTPF surface. In addition, Table 2 outlines the comparison between the current study and previous research.

Table 2. Comparison between the presented investigation and previous work.

S. No.	Author	Material Type	Desalination Percentage	Distillate Yield (L/m^2)
1.	Mevada et al. [23]	Marbles stones & Black granite	72.6%	2.50
2.	Balachandran et al. [24]	Nano-Fe_2O_3	68%	4.39
3.	Hossain and Sahin [25]	Hybrid nanofluid (Al_2O_3-water-SiO_2)	37.76%	4.99
4.	Kumar et al. [26]	Magnets and charcoal	104.54%	6.3
5.	Kabeel et al. [27]	Cement coated red bricks coated	45%	6.3
6.	Singh al. [28]	Wicks and nanofluid	89.9%	NA
7.	Kaviti et al. [29]	Camphor soothed stems	36.35%	3.7
8.	Panchal et al. [30]	TiO_2 and MgO nanofluids	20.4% & 45.8%	3.5 & 2.7
9.	Hitesh et al. [31]	Magnesia Waste brick	NA	2.07
10.	Present study	Case I—NCCT Case II—CCT Case III—CCTPF		3.08 3.58 4.86

3.4. Water Quality Analysis

The quality of distilled water of MSS and CSS has been evaluated both before and after desalination, as per the standard procedures provide by the Bureau of Indian Standards and WHO (World Health Organization) requirements. The water quality analysis results were investigated at the VNRVJIET Environmental Engineering Laboratory in Hyderabad, India, and are organized in Table 3.

Table 3. Analysis of water quality.

Parameters of Water Quality	Prior to Desalination	After Desalination (MSS)	After Desalination (CSS)	Maximum Permitted Quantities in Drinkable Water (WHO and BIS Standards) [32]
Hardness (mg/L)	380	140	160	200
pH	8.18	7.23	7.64	8.5
Fluoride (mg/L)	0.734	0.428	0.569	1.5
Chloride (mg/L)	75.6	10.58	15.73	250
TDS (ppm)	440	20	55	500

The MSS and CSS both contributed to a decrease in the pH of the saline water, which went from 8.18 to 7.64 and 7.23, respectively. The total dissolved solids (TDS) concentration before desalination was 440 ppm; the TDS concentration was minimized to 20 ppm for MSS and 55 ppm for CSS, respectively, after desalination. In MSS, the TDS levels were 95.45% lower than in salt water. The hardness readings were 380 mg/L for CSS, 140 mg/L for MSS, and 160 mg/L for brine water. In comparison to the MSS and CSS, which had 0.428 mg/L and 0.569 mg/L of fluoride ions, respectively, brine water had a fluoride ion level of

0.734 mg/L. The quality requirements of all for the CSS and MSS were in compliance with the BIS and WHO, India, authorized standards [32].

4. Monetary Analysis

The mathematical expressions from (2) to (10) are employed to investigate the financial analytical modeling, and these mathematical equations are sourced from [33,34].

$$\text{CRF (Capital recovery cost)} = \frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{y}}}{[(1+\mathrm{i})^{\mathrm{y}}-1]} \tag{2}$$

Assumptions:
Number of sunny days (n) = 250;
Interest rate (i) = 12%;
Life of solar still (y) = 10 Years.

$$\text{FAC (Fixed annual cost)} = \text{P (Capital cost)} \times \text{CRF} \tag{3}$$

$$\text{S (Salvage value)} = 0.2 \times \text{P} \tag{4}$$

$$\text{SFF (Sinking fund factor)} = \frac{\mathrm{i}}{[(1+\mathrm{i})^{\mathrm{y}}-1]} \tag{5}$$

$$\text{ASV (Annual salvage value)} = \text{SFF} \times \text{S} \tag{6}$$

$$\text{AMC (Annual maintenance operational cost)} = 0.15 \times \text{FAC} \tag{7}$$

$$\text{AC (Annual cost)} = \text{FAC} + \text{AMC} - \text{ASV} \tag{8}$$

$$\text{M (Average annual productivity in liters)} = \mathrm{c} \times \mathrm{n} \tag{9}$$

where

c = Yield/day;
n = sunny days/year.

$$\text{CPL (cost per liter)} = \frac{\text{AC}}{\text{M}} \tag{10}$$

The cost of manufacturing for CSS and MSS, including all the required components detailed in Table 4, is USD 56 and USD 83, respectively. Table 5 describes a compilation of monetary analysis inputs utilized in the mathematical modeling. MSS (case III) demonstrated a substantial yearly productivity enhancement of 57.79%, establishing its superiority in terms of output because of its higher daily distillate yield of 1215 mL/day in contrast to CSS. The corresponding cost per liter (CPL) of CSS and MSS is USD 0.040 and USD 0.053, respectively.

Table 4. Manufacturing cost of solar stills.

S. No	Service/Material	Quantity/Area/per Still	CSS (USD)	MSS (USD)
1.	Aluminum basin	2.5 m^2	15	15
2.	PVC channel	2	3	3
3.	Black powder coating	0.5 m^2	2	2
4.	Glass cover, 0.4 cm	0.5 m^2	1	1
5.	Double-side tape	1.5 m	1	1
6.	Silicon glue	1	2	2
7.	Copper tubes	17	-	12
8.	Fins	18	-	15
9.	Thermocol	-	2	2
10.	Fabrication charges	-	30	30
	Total cost	-	56$	83$

Table 5. Monetary analysis inputs utilized in the mathematical modeling.

Parameters in USD	Conventional Still (CSS)	Modified Still (MSS)
P	56	83
CRF	0.177	0.177
FAC	9.91	14.69
S	11.2	16.6
SFF	0.05698	0.05698
ASV	0.6381	0.9458
AMC	1.48	2.20
AC	10.75	15.94
M	267.5	300
CPL	0.040	0.053

5. Conclusions

To increase the yield output of DSSS, three sets of experiments were performed. In the first case, non-coated copper tubes (NCCTs) were used, in the second case, coated copper tubes (CCTs) were used, and in the third case, coated copper tubes with a combination of parabolic fins (CCTPFs) were utilized. From the results obtained, it is concluded that case 3, i.e., MSS with both parabolic fins and coated copper tubes, gave higher distillate due to improved surface area and heat transfer rate. The maximum hourly distillate obtained at 13:00 pm for MSS and CSS reached values of 140 mL and 110 mL for case I, 185 mL and 152 mL for case II, and 270 mL and 210 mL for case III.

The total distillate productivity output obtained for CSS was 605 mL for case I, 827 mL for case II, and 1070 mL for case III, and for MSS it was 770 mL, 895 mL, and 1215 mL for case I, case II, and case III, respectively. Case III—CCTPF outperformed case II—CCT and case I—NCCT by 35.75% and 57.79% when compared.

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References

1. Akkala, S.R.; Kaviti, A.K. Impact of different fins designs on performance of solar still desalination system: A review. *Environ. Dev. Sustain.* **2023**, *29*, 1–42. [CrossRef]
2. Akkala, S.R.; Kumar Kaviti, A. Advanced design techniques in passive and active tubular solar stills: A review. *Environ. Sci. Pollut. Res.* **2022**, *29*, 48020–48056. [CrossRef] [PubMed]
3. Kaviti, A.K.; Akkala, S.R.; Ali, M.A.; Anusha, P.; Kaviti, A.K. Amplification of productivity of distillate using cerium oxide nanofluid in solar powered desalination. *Energy Sources Part A Recovery Util. Environ. Eff.* **2023**, *45*, 1226–1240. [CrossRef]
4. Ram, S.; Kumar, A.; Arunkumar, T.; Singh, V. Progress on suspended nanostructured engineering materials powered solar distillation—A review. *Renew. Sustain. Energy Rev.* **2021**, *143*, 110848. [CrossRef]

5. Kaviti, A.K.; Akkala, S.R.; Ali, M.A.; Anusha, P.; Sikarwar, V.S. Performance Improvement of Solar Desalination System Based on CeO_2-MWCNT Hybrid Nanofluid. *Sustainability* **2023**, *15*, 4268. [CrossRef]
6. Irshad, M.S.; Hao, Y.; Arshad, N.; Alomar, M.; Lin, L.; Li, X.; Wageh, S.; Al-Hartomy, O.A.; Al-Sehemi, A.G.; Dao, V.-D.; et al. Highly charged solar evaporator toward sustainable energy transition for in-situ freshwater & power generation. *Chem. Eng. J.* **2023**, *458*, 141431. [CrossRef]
7. Muthu Saravanan, N.; Rajakumar, S.; Moshi, A.A.M. Experimental investigation on the performance enhancement of single basin double slope solar still using kanchey marbles as sensible heat storage materials. *Mater. Today Proc.* **2020**, *39*, 1600–1604. [CrossRef]
8. Alawee, W.H.; Dhahad, H.A.; Mohamed, T.A. An experimental study on improving the performance of a double slope solar still. In Proceedings of the 7 th International Conference on Sustainable Agriculture for Food, Energy and Industry in Regional and Global Context, Kuala Lumpur, Malaysia, 25–27 August 2015; Volume 5, pp. 1–11.
9. Panchal, P.H.N. Effect of Different parameters on double slope solar still productivity. *Int. J. Adv. Sci. Eng.* **2011**, *1*, 17–21.
10. Irshad, M.S.; Arshad, N.; Zhang, J.; Song, C.; Mushtaq, N.; Alomar, M.; Shamim, T.; Dao, V.-D.; Wang, H.; Wang, X.; et al. Wormlike Perovskite Oxide Coupled with Phase-Change Material for All-Weather Solar Evaporation and Thermal Storage Applications. *Adv. Energy Sustain. Res.* **2023**, *4*, 2200158. [CrossRef]
11. Murugavel, K.K.; Sivakumar, S.; Ahamed, J.R.; Chockalingam, K.K.S.K.; Srithar, K. Single basin double slope solar still with minimum basin depth and energy storing materials. *Appl. Energy* **2010**, *87*, 514–523. [CrossRef]
12. Kaviti, A.K.; Ram, A.S.; Thakur, A.K. Influence of fully submerged permanent magnets in the evaluation of heat transfer and performance analysis of single slope glass solar still. *J. Power Energy* **2021**, *236*, 109–123. [CrossRef]
13. Dhivagar, R.; Sundararaj, S. A Review on Methods of Productivity Improvement in Solar Desalination. *Appl. Mech. Mater.* **2018**, *877*, 414–429. [CrossRef]
14. Ullah, I.; Rasul, M.G. Recent developments in solar thermal desalination technologies: A review. *Energies* **2019**, *12*, 119. [CrossRef]
15. Li, C.; Goswami, Y.; Stefanakos, E. Solar assisted sea water desalination: A review. *Renew. Sustain. Energy Rev.* **2013**, *19*, 136–163. [CrossRef]
16. Mevada, D.; Panchal, H.; Kumar Sadasivuni, K.; Israr, M.; Suresh, M.; Dharaskar, S.; Thakkar, H. Effect of fin configuration parameters on performance of solar still: A review. *Groundw. Sustain. Dev.* **2020**, *10*, 100289. [CrossRef]
17. Kaviti, A.K.; Mary, B.; Ram, A.S. Effect of Truncated Conic Fins in Distillate of Double Slope Solar Still. In *Innovations in Mechanical Engineering: Select Proceedings of ICIME 2021*; Springer: Singapore, 2022. [CrossRef]
18. Jani, H.K.; Modi, K.V. Experimental performance evaluation of single basin dual slope solar still with circular and square cross-sectional hollow fins. *Sol. Energy* **2019**, *179*, 186–194. [CrossRef]
19. Kaviti, A.K.; Naike, V.R.; Ram, A.S.; Thakur, A.K. Energy and exergy analysis of a truncated and parabolic finned double slope solar stills. *Int. J. Ambient. Energy* **2021**, *43*, 6210–6223. [CrossRef]
20. Kabeel, A.E.; El-maghlany, W.M.; Abdelgaied, M.; Abdel-aziz, M.M. Performance enhancement of pyramid-shaped solar stills using hollow circular fins and phase change materials. *J. Energy Storage* **2020**, *31*, 101610. [CrossRef]
21. Kateshia, J.; Lakhera, V.J. Analysis of solar still integrated with phase change material and pin fins as absorbing material. *J. Energy Storage* **2021**, *35*, 102292. [CrossRef]
22. Modi, K.V.; Patel, U.N.; Patel, S.J.; Patel, J.N.; Patel, S.R. Efficacy of partially and fully submerged circular cross-section metal hollow-fins and black cotton cloth wick-segments on a single-basin dual-slope solar still. *J. Clean. Prod.* **2022**, *344*, 131059. [CrossRef]
23. Mevada, D.; Panchal, H.; Ahmadein, M.; Zayed, M.E.; Alsaleh, N.A.; Djuansjah, J.; Moustafa, E.B.; Elsheikh, A.H.; Sadasivuni, K.K. Investigation and performance analysis of solar still with energy storage materials: An energy-exergy efficiency analysis. *Case Stud. Therm. Eng.* **2022**, *29*, 101687. [CrossRef]
24. Balachandran, G.B.; David, P.W.; Mariappan, R.K.; Kabeel, A.E.; Athikesavan, M.M.; Sathyamurthy, R. Improvising the efficiency of single-sloped solar still using thermally conductive nano-ferric oxide. *Environ. Sci. Pollut. Res.* **2020**, *27*, 32191–32204. [CrossRef] [PubMed]
25. Rabbi, H.M.F.; Sahin, A.Z. Performance improvement of solar still by using hybrid nanofluids. *J. Therm. Anal. Calorim.* **2021**, *143*, 1345–1360. [CrossRef]
26. Kaviti, A.K.; Akkala, S.R.; Sikarwar, V.S. Productivity enhancement of stepped solar still by loading with magnets and suspended micro charcoal powder. *Energy Sources Part A Recovery Util. Environ. Eff.* **2021**, *43*, 1–19. [CrossRef]
27. Kabeel, A.E.; El-Agouz, E.S.; Athikesavan, M.M.; Duraisamy Ramalingam, R.; Sathyamurthy, R.; Prakash, N.; Prasad, C. Comparative analysis on freshwater yield from conventional basin-type single slope solar still with cement-coated red bricks: An experimental approach. *Environ. Sci. Pollut. Res.* **2020**, *27*, 32218–32228. [CrossRef]
28. Singh, J.; Mittal, M.K.; Khullar, V. Nanofluid-based wick-type integrated solar still for improved diurnal and nocturnal distillate production. *Energy Sources Part A Recovery Util. Environ. Eff.* **2022**, *44*, 10094–10115. [CrossRef]
29. Kaviti, A.K.; Akkala, S.R.; Sikarwar, V.S.; Snehith, P.S.; Mahesh, M. Camphor-Soothed Banana Stem Biowaste in the Productivity and Sustainability of Solar-Powered Desalination. *Appl. Sci.* **2023**, *13*, 1652. [CrossRef]
30. Panchal, H.; Sathyamurthy, R.; Kabeel, A.E.; El-Agouz, S.A.; Rufus, D.; Arunkumar, T.; Manokar, A.M.; Winston, D.P.; Sharma, A.; Thakar, N.; et al. Annual performance analysis of adding different nanofluids in stepped solar still. *J. Therm. Anal. Calorim.* **2019**, *138*, 3175–3182. [CrossRef]

31. Panchal, H.; Sadasivuni, K.K.; Shanmugan, S.; Pandya, N. Performance analysis of waste brick magnesia as a storage material in a solar still. *Heat Transf.* **2021**, *50*, 1799–1811. [CrossRef]
32. Afzal, S.; Kumar, A.; Rao, S.; Sakthivel, S.; Harish, T.; Kumar, K.V.; Rao, T.S.; Thaker, A.; Reddy, K.V.; Naga Sai, A.M.; et al. Performance analysis of non-contact nanostructure solar desalination system by varying water depth at a constant air gap. *Sol. Energy* **2022**, *247*, 485–498. [CrossRef]
33. Rufuss DD, W.; Suganthi, L.; Iniyan, S.; Davies, P.A. Effects of nanoparticle-enhanced phase change material (NPCM) on solar still productivity. *J. Clean. Prod.* **2018**, *192*, 9–29. [CrossRef]
34. Fath, H.E.S.; El-Samanoudy, M.; Fahmy, K.; Hassabou, A. Thermal-economic analysis and comparison between pyramid-shaped and single-slope solar still configurations. *Desalination* **2003**, *159*, 69–79. [CrossRef]