Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors (TCC-RM) : Optimum inclination of Reflector Mirrors

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Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors (TCC-RM): Optimum inclination of Reflector Mirrors

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Abstract

The present study aims to achieve the highest cumulative yield of the hemispherical distillers, by designing and constructing new reflector mirrors, which are truncated circular cone-shaped reflector mirrors (TCC-RM). To obtain the optimum inclination of TCC-RM that achieves a highest hemispherical distiller's performance, eight inclination angles (10^o, 15^o, 20^o, 25^o, 30^o, 35^o, 40^o and 45^o with vertical) was experimentally studied. To achieve this, a series of experimental tests were carried out on the three hemispherical solar distillers, the first represents the reference distiller (traditional hemispherical solar distiller- THSD) and the other two devices are the hemispherical solar distiller with truncated circular cone-shaped reflector mirrors (HSD-TCCRM) with different inclination angles. The experimental results indicate that utilizing TCC-RM with a 25^o inclination angle achieves the maximum cumulative yield of 8.35 L/m^2 with an improvement of 42.74% compared to THSD. While the utilization of TCC-RM with the inclination angles by 30^o, 35^o, 20^o, 40^o, and 15^o achieves the cumulative yield of 7.9, 7.3, 7.05, 6.67, 6.6 L/m^2 compared with 5.85 L/m^2 for THSD. On the contrary, adjusting the inclination angle of TCC-RM at 10^o, and 45^o affects negatively the cumulative yield of the HSD with TCC-RM in comparison with THSD. Based on the data of cumulative yield, daily efficiency, and the economic analysis it's recommended to utilize TCC-RM with a 25^o inclination

angle to achieve the highest performance and minimum distillate cost of hemispherical solar distillers.

Keywords: Hemispherical Solar Distiller, Truncated Circular Cone-Shaped Reflector Mirrors, Optimal Inclination Angle, Economic Analysis, Performance Improvement.

Introduction

Life on Earth is linked to the element of water. Water is essential to the life of all living and minute organisms. But many people do not have access to safe water to drinking, with more than 5 million people dying each year from diseases transmitted through unclean water (Prasad et al., 2021; Dubey and Mishra, 2021, Arani et al., 2021). Population growth and pollution of natural resources are among the reasons for scarcity of drinking water worldwide. The desert regions in Algeria, especially the city of El Oued, contain large quantities of saline groundwater, and a large solar field, and long insolation period throughout the year (Sharshir et al., 2020; Kabeel and Abdelgaied, 2017; Natarajan et al., 2022; Azari et al., 2021). Saltwater affects the human body and machinery and factories as well because it contains salt. The solution is to remove the salts from the saltwater before using them. There are several ways to convert saltwater into safe water such as membrane distillation (Manokar and Winston, 2017; Thakur et al., 2021, Abdelgaied et al., 2021a,b). Solar distillation is an easy process was utilized for this. In fact, solar distillation has played an important role to produce clean water in arid desert and dry regions. In the literature, many studies (Abd Elbar and Hassan, 2020a,b; Abd Elbar et al., 2019; Suraparaju and Natarajan, 2021, Gnanaraj and Ramachandran, 2022) have focused on produce clean water from seawater by using the solar energy.

Chandrika et al. (2021) empirically examined the influences of internal reflectors (aluminum foil sheet and glass mirror) on single slope solar distiller's performance. They found that the optimal daily efficiency of the solar distillers with internal reflectors (aluminum foil sheet and glass mirror) was 48.57 and 68.57%, respectively, compared for classical still. Attia et al. (2021) analytically investigated the effect of internal reflectors (aluminum foil sheet and mirror) on the performance enhancements of hemispherical distillers. They conducted that the optimal daily efficiency of the hemispherical distillers with an internal reflector aluminum foil sheet was 30.53% and using an internal reflector mirror was 52.63%, compared to a classical hemispherical distiller. Khechekhouche et al. (2020) conducted the impact of a single external refractor on a single slope distiller productivity has been investigated, under the climatic conditions of El Oued, Algeria. From the information obtained, it was found that the technology achieves a performance improvement for the single slope solar distiller, which amounted to about 45%, and the efficiency also draws 35%, and they also indicated that in a period of 23 days they can recover the amount of the cost and concluded that this technology is suitable for many regions in the world. Experimental work was conducted by Tanaka (2009) to obtain the enhancement of solar distillers by using basin liners with internal/external reflectors. They conducted that an increase of 100% in the distillate yields on winter days. A numerical study was conducted by Tanaka and Nakatake (2006) to obtain the influences of applying the reflectors; they found the yield improved by 48% on average over the year-round. A theoretical analysis was done by Tanaka and Nakatake (2007), to evaluate the performance of tilted wick solar distillers by modifying a vertical flat plate external reflector. They observed that increase in the daily productivity was 9% on year-round average. Tanaka and Nakatake (2009) studied the effect of the length of inclined flat plate external reflector on tilted-wick distiller production. The results found that the distillate yield when using the length of reflector is half of the distiller's length was used is 15% greater compare to the classical distiller and 27% greater when utilizing the length of the deflector is equal to the length of the distillers compared to the classical distiller. Boubekri and Chaker (2011) performed a study on a single slope solar distiller integrated with solar reflectors. They conducted that the efficiency of solar reflectors still used single slope solar distiller improves by 72.8%, for better output, the inclination angle must be less than 25°. Badran (2007) investigated the yield of distiller active with flat collector using the mirror. The percentage of improvement by using flat plate collectors and mirrors together is 36%. Hiroshi (2010) investigated the yield of distiller passive with external/internal reflectors. They found the percentage of improvement is 48% when using external/internal reflectors. They concluded that using external/internal reflectors is very effective than the internal reflector only.

The comprehensive experimental study in this paper aims to overcome the disadvantages of the declining productivity of solar distillers. Since the design of the hemispherical distillers was characterized by having a large area of receiving and condensing, so the utilization of truncated circular cone-shaped external reflector mirrors (TCC-RM) is very interesting to increase the intensity of solar rays falling on the receiving surface. To obtain the optimum inclination of TCC-RM that achieves the maximum hemispherical solar distiller's performance, eight inclination angles of reflector mirrors (10°, 15°, 20°, 25°, 30°, 35°, 40° and 45° with vertical) was studied. To achieve this, a series of experimental tests were carried out on the three hemispherical solar distillers, the first represents the reference distiller (traditional hemispherical solar distiller- THSD) and the other two devices are the hemispherical solar distiller with truncated circular cone-shaped reflector mirrors (HSD-TCCRM) with different inclination angles. In the first experiment, we studied the effect of TCC-RM with tilt angles of 10 and 15 degrees on a yield of second and third hemispherical distillers and were compared to the first THSD. On the second experiment day, we change the tilt angles of TCC-RM to 20 and 25 degrees in the second and third hemispherical distillers and were compared to the first reference distiller THSD. On the third experiment day, we change the tilt angles of TCC-RM to 30 and 35 degrees in the second and third hemispherical distillers and were compared to the first reference distiller THSD. On the fourth experiment day, we change the tilt angles of TCC-RM to 40 and 45 degrees in the second and third hemispherical distillers and were compared to the first reference distiller THSD. All experiments were conducted in the same weather condition in El Oued City, Algeria on August 5, 6, 7, and 8, 2021.

Experimental set-up procedure

This study aims to achieve the highest cumulative yield of hemispherical distillers, by designing and constructing new reflector mirrors, which are truncated circular cone-shaped reflector mirrors (TCC-RM). Since the design of the hemispherical distiller was characterized by having a great area of receiving and condensing, so the utilization of truncated circular cone-shaped external reflector mirrors (TCC-RM) is very interesting to increase the solar rays falling on the receiving surface. To obtain the optimum inclination of TCC-RM that achieves a maximum hemispherical distiller's performance, eight inclination angles of reflector mirrors (10°, 15°, 20°, 25°, 30°, 35°, 40° and 45° with vertical) was studied. To achieve this, three distillers were constructed with the same dimensions, and tested in Faculty of Exact Science, El Oued University-El Oued, Algeria during the month of August 2021. These three hemispherical distillers are made of a wooden basin with a circular inner diameter of 0.38 m, and the wooden basin is coated with the black silicone to absorb solar radiation and prevent water leakage. The water level inside the basin was kept at 1 cm. The hemispherical distiller basin was covered with a transparent hemispherical plastic cap, 0.40 m diameter, and 3 mm thick. A circular duct was formed on the entire circumference under the transparent plastic cover to collect the condensate and then collected in the distillate water tank. Fig. 1 shows the schematic view of hemispherical solar distillers.

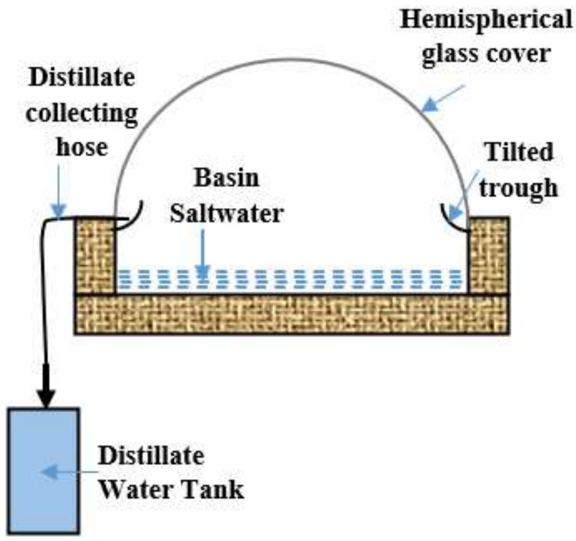


Fig. 1. The schematic view of the hemispherical solar distiller design.

To study the effect of the angle of inclination of the truncated circular cone-shaped reflector mirrors (TCC-RM) with a vertical position on the hemispherical distillers and to obtain an optimum angle of inclination that achieves a maximum performance. We made hemispherical solar distillers with the truncated circular cone-shaped reflector mirrors (TCC-RM) and changed the tilt angle from vertical each time (θ = 10, 15, 20, 25, 30, 35, 40 and 45 degrees with vertical). The truncated circular cone-shaped reflector mirrors (TCC-RM) are designed with 0.30 m high, surrounding the hemispherical cover with a lower base with a fixed diameter of 0.41 m and an upper base whose diameter is changed according to the angle of inclination with the vertical position, as shown in Fig. 2.

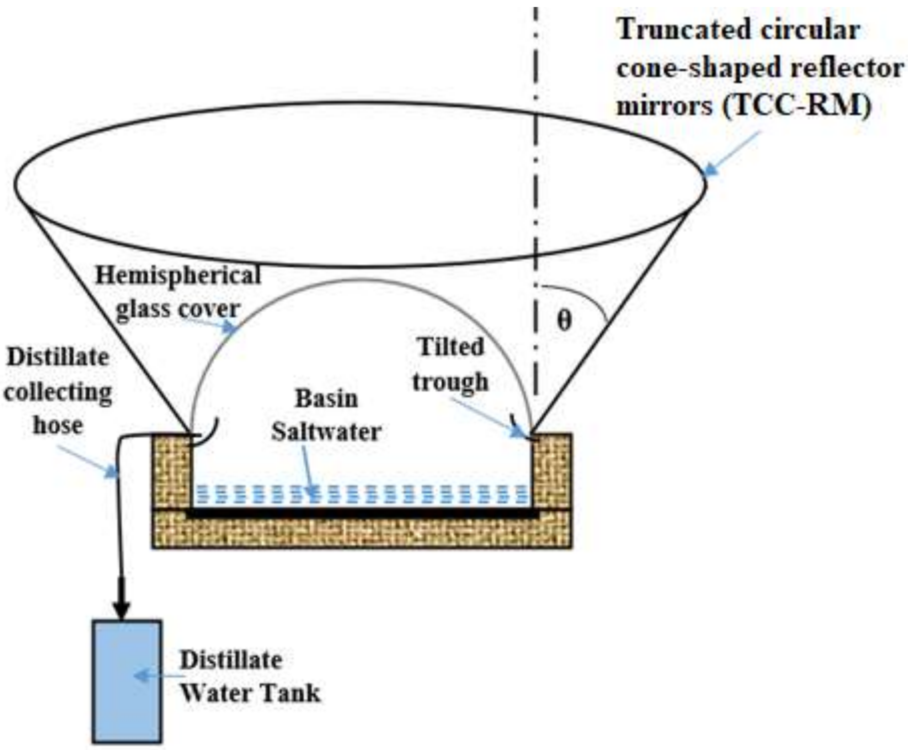
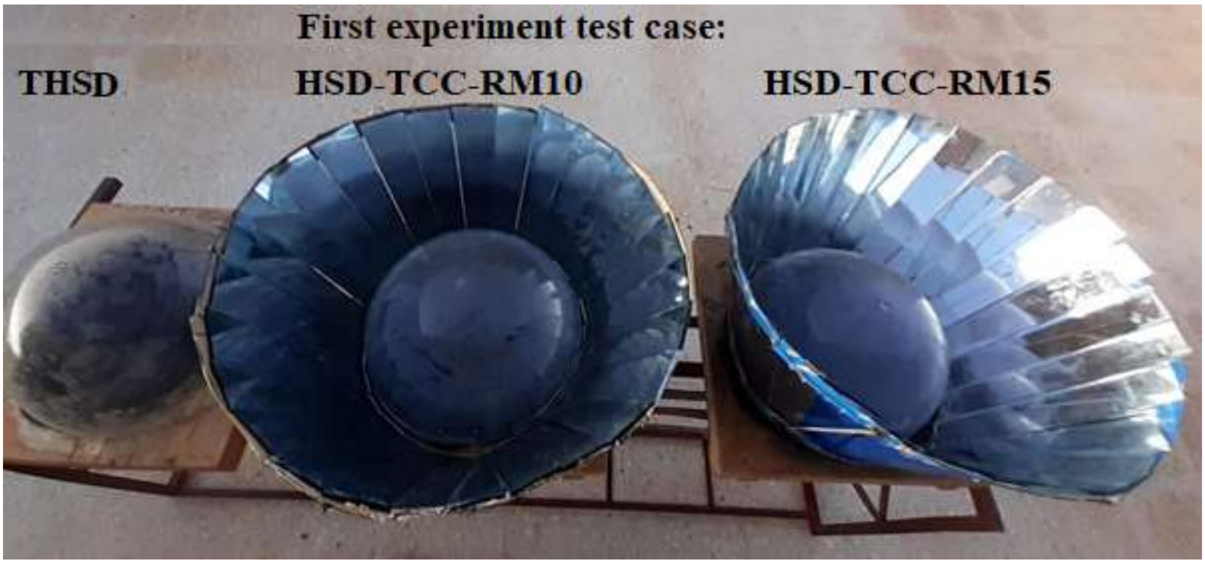


Fig. 2. Hemispherical solar still with truncated circular cone-shaped reflector mirrors (TCC-RM).

The experiments were conducted on four tests, on days from August 5, 6, 7, and 8, 2021, throughout the day (12 hrs). Experimental work has been extended to investigate the effect of truncated circular cone-shaped reflector mirrors (TCC-RM) inclination angle on hemispherical distillers yield and obtain an optimal inclination angle that achieves a maximum cumulative yield of hemispherical distillers. To achieve this, eight inclination angles of reflector mirrors (10^o, 15^o, 20^o, 25^o, 30^o, 35^o, 40^o, and 45^o with vertical) were studied as shown in Fig. 3.

Three hemispherical solar distiller's modules are provided in each test. In the first test: the second and third hemispherical solar distiller's units are provided by the truncated circular cone-shaped reflector mirrors (TCC-RM) with inclination angle θ equal 10 and 15 degrees (HSD-TCC-RM10 and HSD-TCC-MR15), were tested and compared to THSS. In the second test: the second and third hemispherical solar distiller's units are provided by the truncated circular cone-shaped reflector mirrors (TCC-RM) with inclination angle θ equal 20 and 25 degrees (HSD-TCC-RM20 and HSD-TCC-MR25), were tested and compared to THSS. In the third test: the second and third hemispherical solar distiller's units are provided by the truncated circular cone-shaped reflector mirrors (TCC-RM) with inclination angle θ equal 30 and 35 degrees (HSD-TCC-RM30 and HSD-TCC-MR35), were tested and compared to THSS. In the fourth test: the second and third hemispherical solar distiller's units are provided by the truncated circular cone-shaped reflector mirrors (TCC-RM) with inclination angle θ equal 40 and 45 degrees (HSD-TCC-RM40 and HSD-TCC-MR45), were tested and compared to THSS. To maintain the same heat capacity of brine water, the same depth (1 cm) of brine is maintained for each of the three units as shown in Fig. 3.



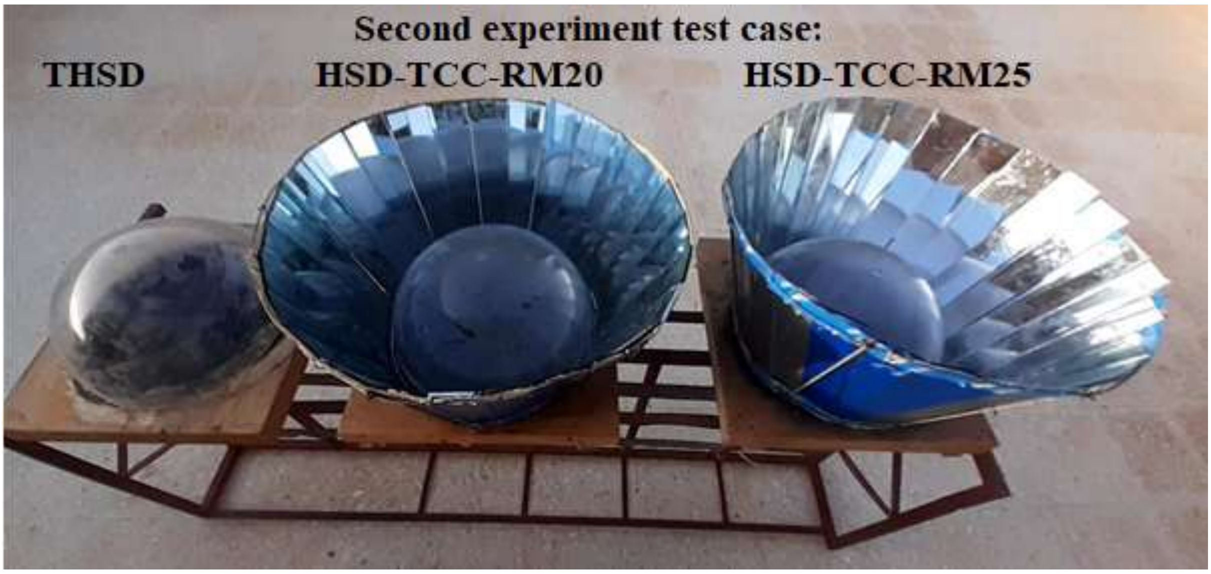


Fig. 3. The pictorial view of the hemispherical solar distillers actual experimental.

Thermocouples by ±0.1°C accuracy were placed at appropriate places in the hemispherical distillers to record a temperature at different segments. The basin temperature, ambient temperature, and inner and outer cover temperature were measured. A solar power meter with an ±10 W/m^2 accuracy was used to record and log solar radiation. A graduated cylinder with ±1 mL measuring is used to collect the freshwater from the strip. Table 1 summarizes the instruments used and their accuracy values.

Table 1: Standard uncertainties and errors of measuring devices

Instrument	Range	Accuracy	Standard uncertainty
Thermocouple	−100 – 500 °C	± 0.1°C	0.08°C
Solar power meter	0-1999 W/m^2	± 10 W/m^2	5.78 W/m^2
Graduated cylinder	0–500 mL	± 1 mL	0.5 mL

System performance

Thermal daily efficiency $\eta_{daily,th}$ can be calculated by:

$$\eta_{daily.th} = \frac{\sum \dot{m}_{ev} \; h_{fg}}{\sum I(t) \; A_s \; \times 3600} \times 100, (\%) \quad (1)$$

Latent heat h_{fg} can be calculated by (Kabeel and Abdelgaied, 2017);

$$h_{fg} = 10^3 \left[2501.9 - 2.40706 \times T_w + 1.192217 \times 10^{-3} \times T_w{}^2 - 1.5863 \times 10^{-5} \times T_w{}^2 \right] \quad (2)$$

Where; A_s is absorber area (m^2); I(t) is solar radiation (W/m^2); T_w is basin saltwater temperature (°C) ; $\dot{m}_{ev}$ is hourly distillate production (kg/m^2 h); h_{fg} is a latent heat (J/kg).

Results and discussions

The freshwater yield is the main goal of hemispherical distillers. This output is determined by the amount at which saline water evaporates and the rate at which evaporated water vapor condenses. The evaporation rate increases with argument saltwater temperature and temperature difference between saltwater and internal glass. Furthermore, increasing temperature differential between internal glass and external glass, the temperature difference between ambient air and external glass, and increasing outside wind speed all enhance the condensation rate. As a result, evaluating the still temperatures provides a clear picture of the still performance.

Hemispherical Solar Still temperatures

Figs. 4, 5, 6, and 7 illustrate the temperature variations with time of the proposed hemispherical solar Distillers components and the corresponding ambient temperature and solar rays within tested days. Fig. 4 introduces the changes in temperature throughout time of saline water, internal glass, external glass, and ambient of Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors (HSD-TCC-RM) at inclination angles of 10 and 15 degrees (with vertical) compared with Traditional Hemispherical Solar Distiller (THSD). However, all these temperature variations of HSD-TCC-RM20 and HSD-TCC-RM25 in comparison to THSD are presented in Fig. 5. Furthermore, Fig. 6 illustrates the temperature gradients of HSD-TCC-RM30 and HSD-TCC-RM35 components contrasted with THSD. Additionally, the changes of temperature with time of HSD-TCC-RM40 and HSD-TCC-RM45 main parts and its difference with traditional solar still temperatures are displayed in Fig. 7.

As indicated from these Figs. 4, 5, 6, and 7 the solar intensity profile has the same trend during all tested days and its values have nearly the same values during the four days. This is because the cases studied were performed within four successive days in the period between 5/8/2021 and 8/8/2021 to avoid any variations in ambient conditions. It is clear from Figures 4, 5, 6, and 7 that solar intensity values have a small value at the sunrise and rises gradually until it reaches its maximum value at noon time and then its values decline with time to hit the lowest value at the end of daytime. However, the solar intensity gets its maximum value at 12:00 am, it is noticed that the maximum values of all components for the proposed systems were obtained three hours later at 3:00 pm. The reason of this time delay is that heat transferred through the solar radiation needs time to be absorbed by the hemispherical solar still components and to get warmer. Furthermore, it is obvious that the saline water temperatures for all studied cases have the maximum values, followed by the internal glass temperatures, and then the external glass temperatures which are always higher than the ambient temperatures. The reason of this is that the solar rays is transmitted through a still glass and absorbed by still absorber which in contact with saltwater. Then, the water is heated and evaporated. The water vapor is condensed on the internal surface of the glass.

Fig. 4 demonstrates the water, internal glass, external glass, and ambient temperature variation over time for HSD-TCC-RM10, and HSD-TCC-RM15 compared with traditional hemispherical solar distiller (THSD). It is illustrated from Fig. 4 that the internal glass temperatures for any system is higher than the corresponding values of external glass temperatures due to the thermal resistance of glass and the latent heat of condensing absorbed by internal glass surface. It is revealed that using truncated circular cone-shaped reflector mirrors (TCC-RM) with an inclination angle of 10º has a negative effect on the water temperature values. However, using the TCC-RM with 15º enhanced the maximum water temperature by 2.78% compared with THSD due to increasing the incident solar radiation on HSS area.

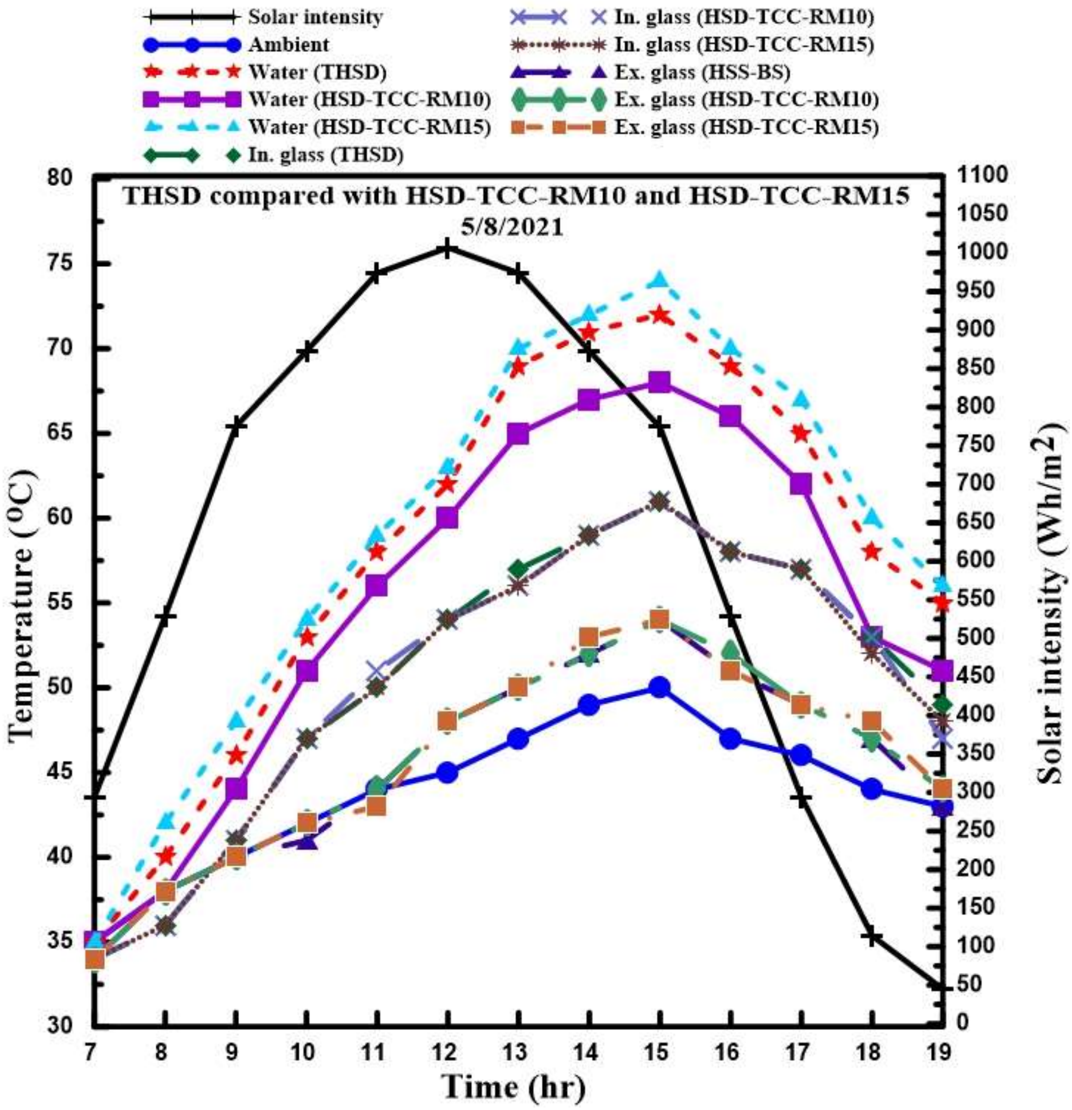


Fig. 4. Temperature Variations of THSD compared with HSD-TCC-RM at inclination angles of 10 and 15 degrees

The effect of using TCC-RM with inclination angles of 20 and 25 angles on the temperatures of HSD is introduced in figure 5. Results in figure 5 reveals that using TCC-RM20, and TCC-RM25 improves the maximum water temperature of THSD by 2.78%, and 5.56%, respectively. The maximum difference in temperature between saltwater and internal glass of THSD, HSD-TCC-RM20, and HSD-TCC-RM25 systems were 12, 14, and 15 degrees, respectively. That means that the evaporation rate of HSD-TCC-RM25 is higher than HSD-TCC-RM20, followed by traditional solar distiller (THSD). Furthermore, it is noticed from Fig. 5 that the maximum temperature difference between internal and external glass of THSD, HSD-TCC-RM20, and HSD-TCC-RM25 systems were 6, 6, and 7 degrees, respectively. This interprets that HSD-TCC-RM with 25^{o} inclination angle has the maximum condensation rate compared with other corresponding systems.

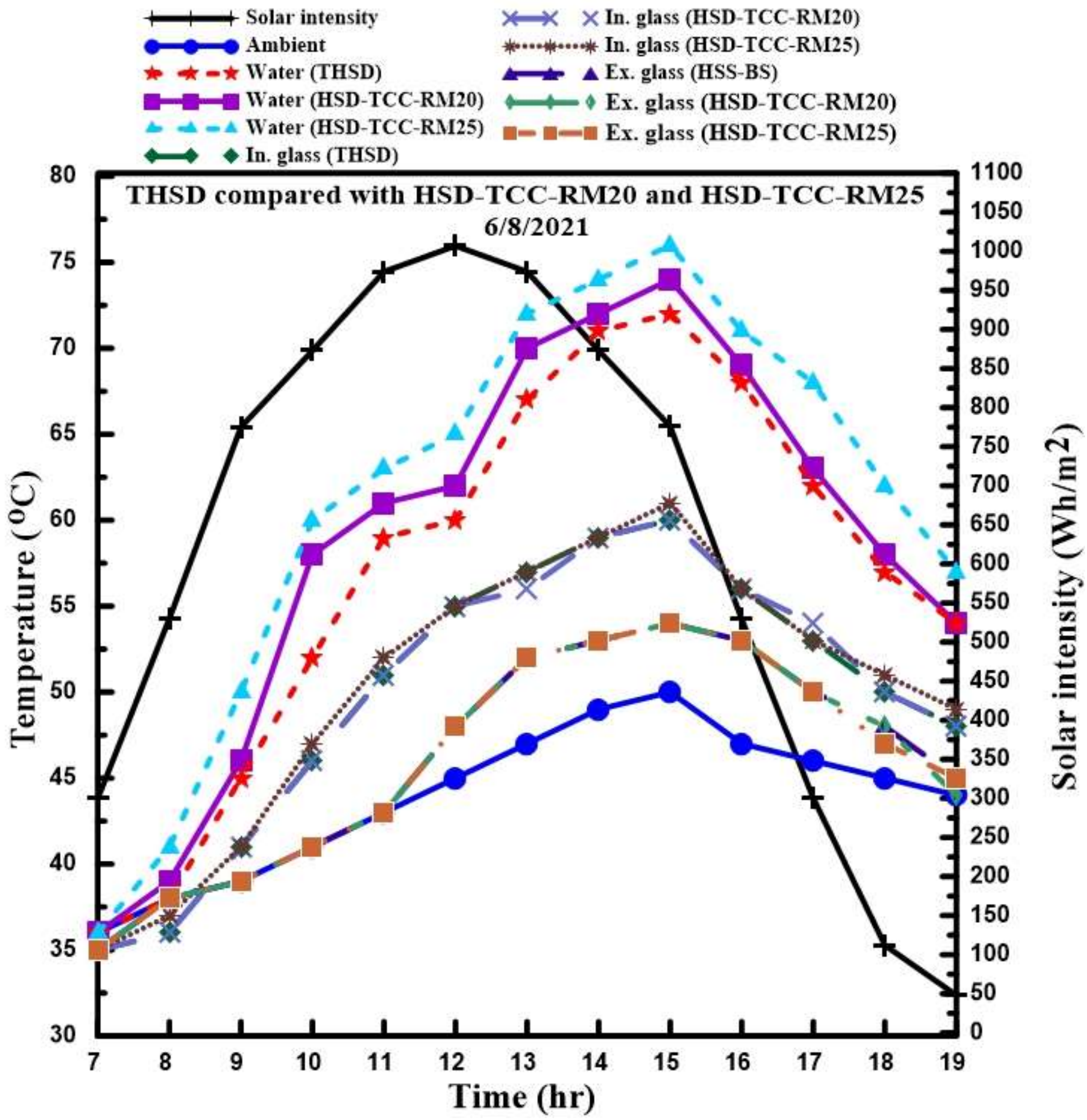


Fig. 5. Temperature Variations of THSD compared with HSD-TCC-RM at inclination angles of 20 and 25 degrees

Fig. 6 demonstrates the effect of utilizing ERM with inclination angles of 30, and 35 degrees on THSD temperatures. It is concluded that using TCC-RM30 and TCC-RM35 argument the maximum water temperature of traditional THSD by 4.23%, and 2.82%, respectively. THSD, HSD-TCC-RM30, and HSD-TCC-

RM35 systems have maximum temperature differences of 12, 13, and 12 degrees, respectively, between water and internal glass. That result in HSD-TCC-RM30 achieved more evaporation rate of water vapor compared with HSD-TCC-RM35 and THSD systems. However, when comparing findings in previous Figs.(4, 5, and 6), it is clear that HSD-TCC-RM25 has a maximum saltwater temperature (76°C), and a maximum difference in temperature between saltwater and internal glass (15°C) compared with other mentioned systems.

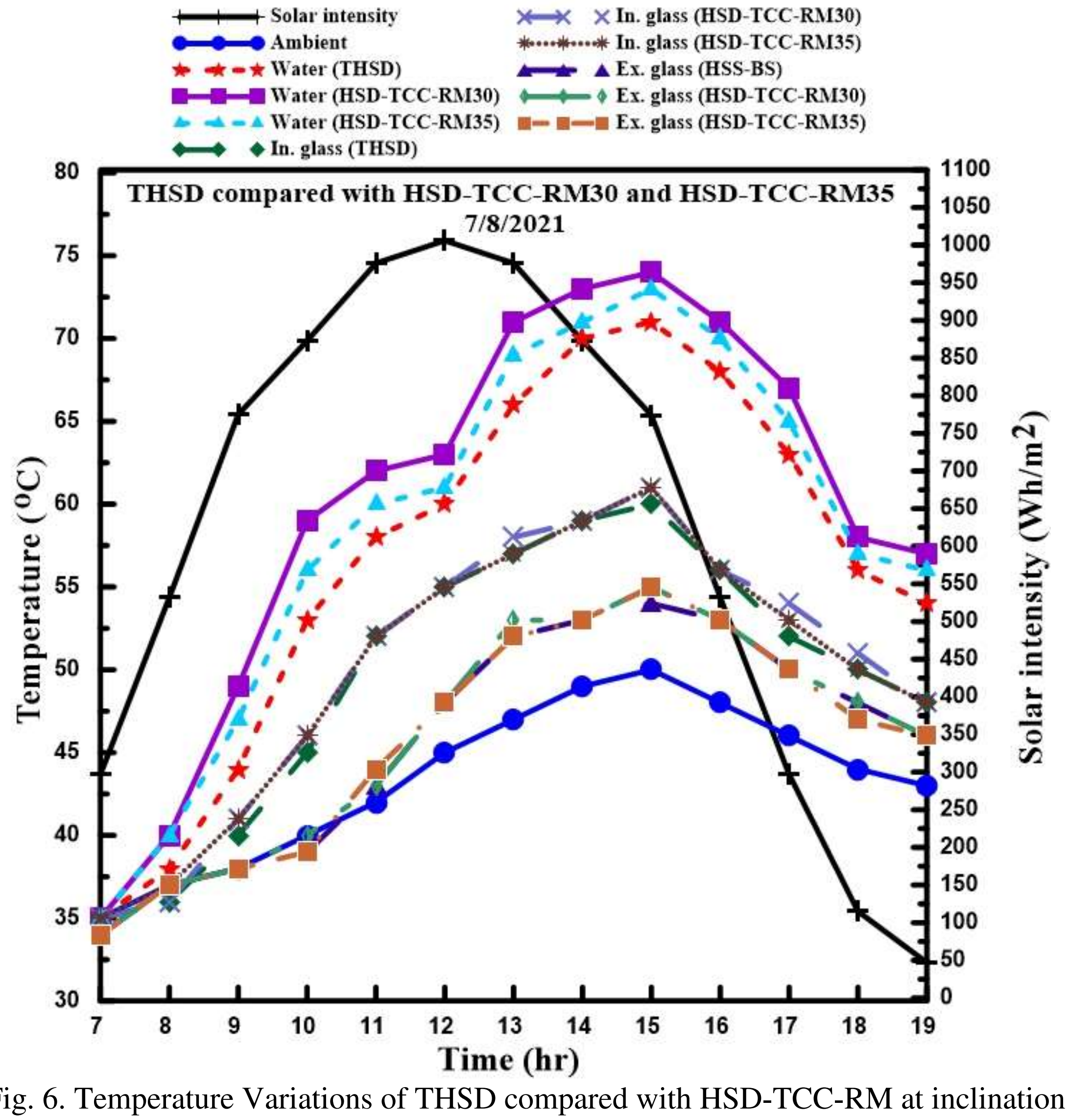


Fig. 6. Temperature Variations of THSD compared with HSD-TCC-RM at inclination angles of 30 and 35 degrees

The impact of using TCC-RM with inclination angles of 40, and 45 degrees on traditional THSD temperatures is shown in Fig. 7. It can be concluded from Fig. 7 that utilizing TCC-RM with 45° inclination angle has a negative impact on the water temperature compared with conventional distiller. The maximum water temperatures obtained from THSD, HSD-TCC-RM40, and HSD-TCC-RM45 were 71, 71, and 69°C, respectively.

By comparing the temperatures of all proposed systems in Figs. (4, 5, 6, and 7), it is revealed that an optimal inclination of TCC-RM is 25° which result in a maximum water temperature of 76°C, and maximum difference in temperature between saltwater and internal glass (15°C) compared with all other proposed systems. This means that HSD-TCC-RM25 has the maximum evaporation rate, and then maximum freshwater productivity.

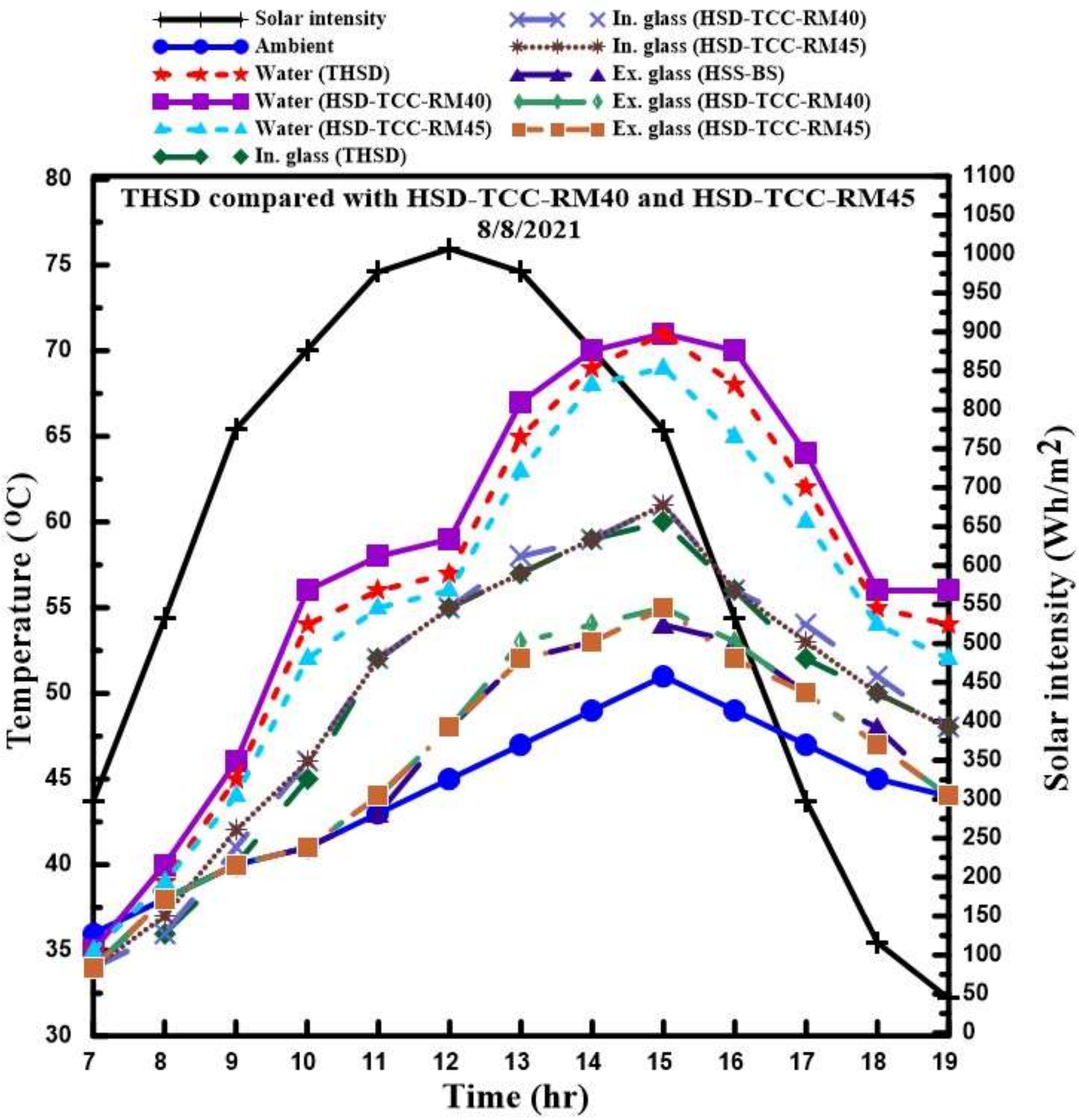


Fig. 7. Temperature Variations of THSD compared with HSD-TCC-RM at inclination angles of 40 and 45 degrees

Hemispherical Solar Distillers Freshwater Yield

Fig. 8 depicts the effect of adjusting the inclination angle of the truncated circular cone-shaped reflector mirrors (TCC-RM) with the hemispherical sola distiller on the hourly yield. The hourly productivity of the traditional (THSD) and the hemispherical solar distiller with truncated circular cone-shaped reflector mirrors (HSD-TCC-RM) at various inclination angles are shown in this graph. Fig. 8 depicts that the hourly production rises progressively from a morning until reaches to maximum value on 14:00 PM, which corresponds to nearly the time of maximum temperature as previously stated due to increased solar irradiation. After that, as the solar intensity diminishes, the amount of freshwater produced decreases till the end of day. Fig. 8 indicates that using TCC-RM with 25°, and 30° inclination angle achieve the maximum hourly yield of 1.1 litter/h for each system, followed by HSD-TCC-RM20, and HSD-TCC-RM35 with 1 litter/h compared with 0.85 litter/h for THSD. Findings reveal that using TCC-RM with 15°, 40° inclination angle improves the maximum hourly productivity by 5.88%, and 11.76% relative to THSD, respectively. On the contrary, adjusting the inclination angle of TCC-RM at 10°, and 45° effects negatively on the hourly yield of the still in comparison with THSD.

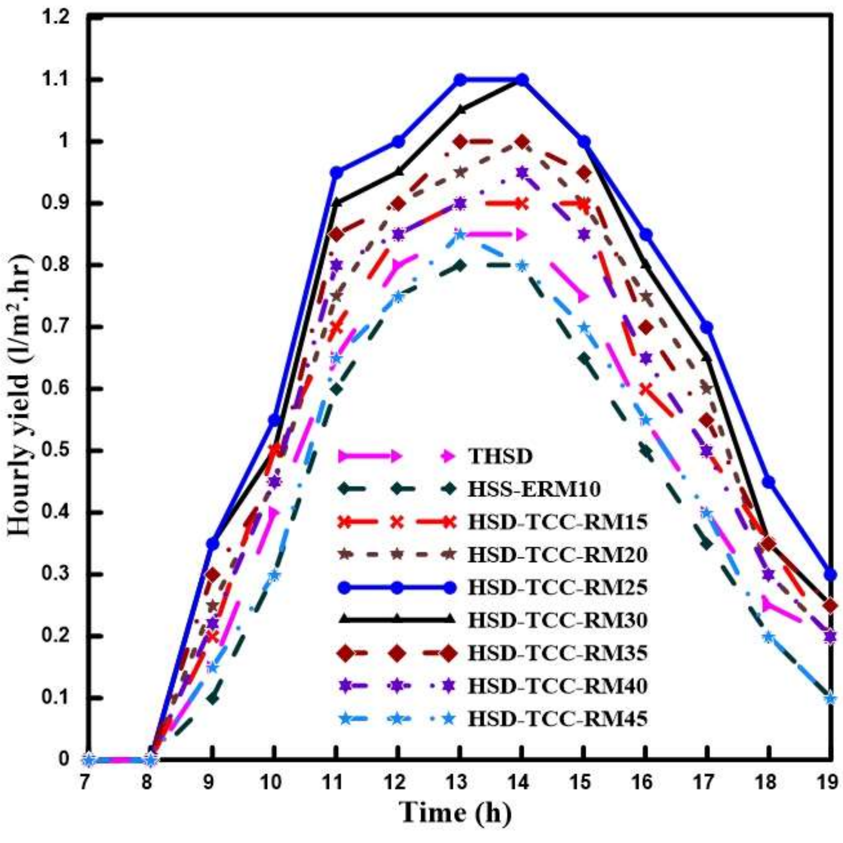


Fig. 8. Variation of hourly yield for all studied cases of THSD and HSD-TCC-RM

Fig. 9 shows how, till the sunset, the accumulated freshwater yield for all proposed solar stills grows. Furthermore, it is resulted that using truncated circular cone-shaped reflector mirrors with an inclination angle of 15, 20, 25, 30, 35, and 40 degrees enhanced the accumulated freshwater productivity of the traditional THSD by 12.82%, 20.51%, 42.74%, 35.04%, 24.79%, and 14.02%, respectively. However, the total accumulated yield of HSD-TCC-RM10, and HSD-TCC-RM45 declined by 11.97%, and 6.84%, respectively relative to THSD system. Also, Table 2 shows the influences of utilization the truncated circular cone-shaped reflector mirrors with an inclination angle on the percentage improvement in cumulative yield of hemispherical solar distillers.

From the findings presented in Fig. 9, all studied hemispherical solar still systems can be put in descending order as follow: HSD-TCC-RM25, HSD-TCC-RM30, HSD-TCC-RM35, HSD-TCC-RM20, HSD-TCC-RM40, HSD-TCC-RM15, THSD, HSD-TCC-RM45, and HSD-TCC-RM10. As a result, it is concluded that the optimum inclination angle for the truncated circular cone-shaped reflector mirrors used with hemispherical solar distiller is 25^{o}, which achieves the maximum accumulated freshwater yield between all other HSS proposed systems.

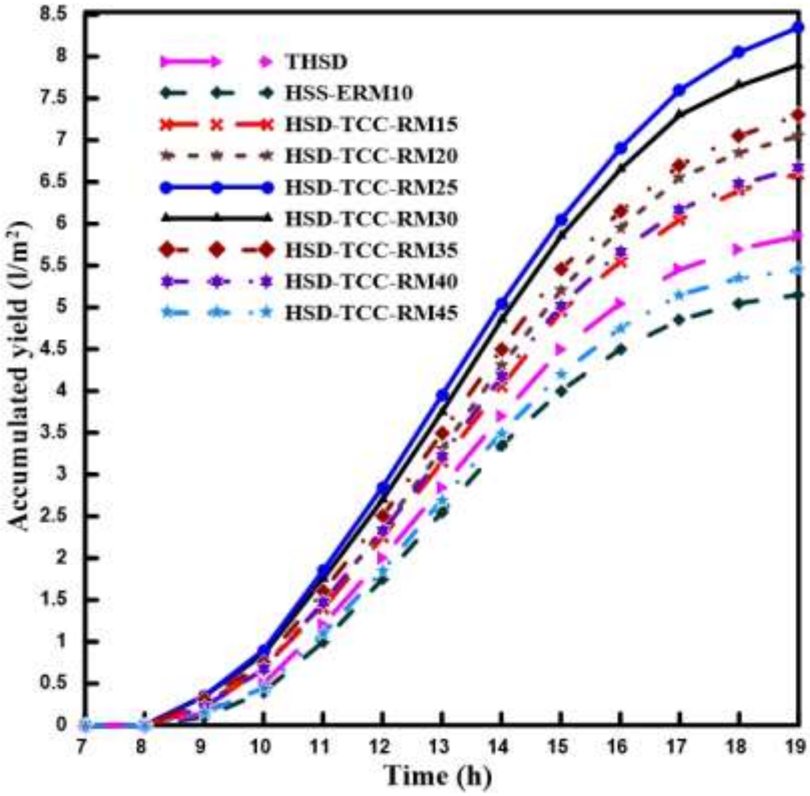


Fig. 9. Variation of accumulated yield for all studied cases of THSD and HSD-TCC-RM.

Table 2. The improvement in cumulative yield at different inclination angles of TCC-RM.

Date of experiment	**THSD**	**HSD-TCC-RM**							
		Truncated circular cone-shaped reflector mirrors inclination angle θ (°)							
		10	**15**	**20**	**25**	**30**	**35**	**40**	**45**
05-08-2021	5.85	5.15	6.60	-	-	-	-	-	-
06-08-2021	5.85	-	-	7.05	8.35	-	-	-	-
07-08-2021	5.85	-	-	-	-	7.90	7.30	-	-
08-08-2021	5.85	-	-	-	-	-	-	6.67	5.45
Improvement (%)	-	11.97	12.82	20.51	42.74	35.04	24.79	14.02	-6.84

Daily Efficiency

Fig. 10 depicts the effect of adjusting the inclination angle of the truncated circular cone-shaped reflector mirrors (TCC-RM) on cumulative yield and thermal daily efficiency of HSD. The results presented in Fig. 10, indicated that the optimum inclination angle for the truncated circular cone-shaped reflector mirrors used with hemispherical solar distiller is 25°, which achieves the maximum accumulated freshwater yield and maximum thermal daily efficiency between all other HSS proposed systems.

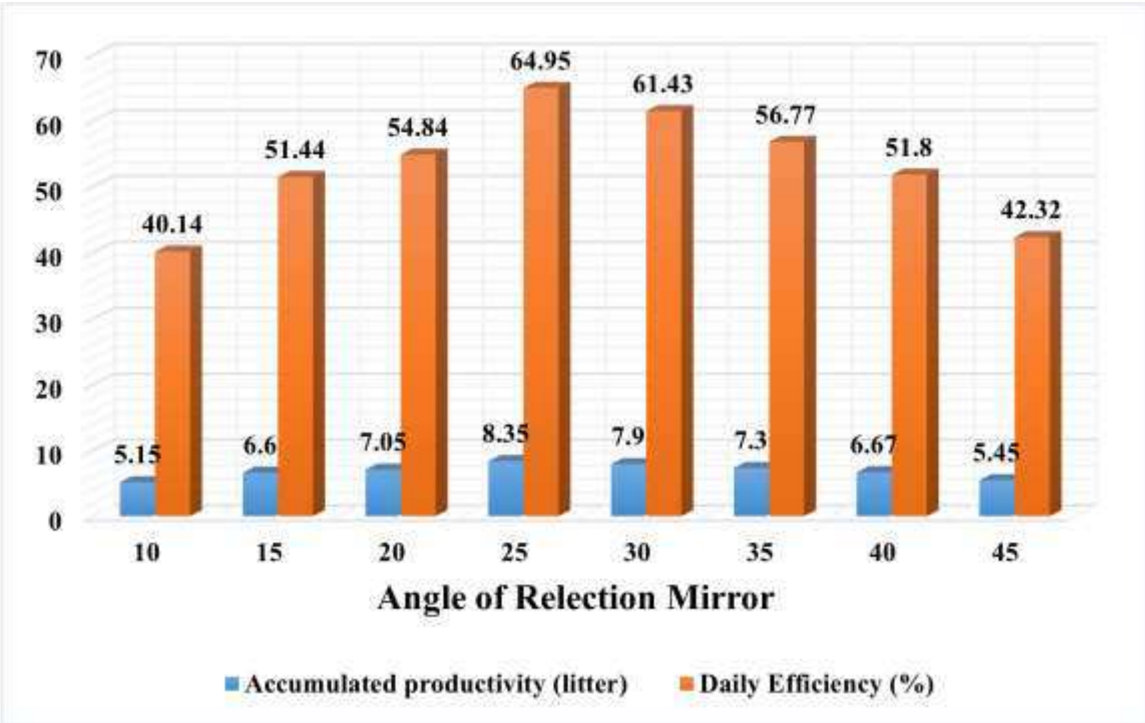


Fig. 10. Variation of cumulative yield and daily efficiency with angle of TCC-RM

Economic Evaluation

For calculate the cost of one-liter of freshwater produced by distillers. We analyze and tabulate the cost details of hemispherical solar distiller's devices with and without truncated circular cone-shaped reflector mirrors (TCC-RM) inclination angle in Table 3.

Table 3: Effective costs analysis of components.

(1$=135.33 DZD)

	THSD		HSD-TCC-RM	
Material	Cost (DZA)	Cost ($)	Cost (DZA)	Cost ($)
Cover plastic	2000	14.787	2000	14.787
Reflective mirror	-	-	2000	14.787
Box of wooden	6500	48.0285	6500	48.0285
Accessories and workforce	500	3.6945	500	3.6945
Maintenance	50	0.3694	50	0.3694
Total cost per m^2	9050	66.8704	11050	81.6484

The economic study was carried out to calculate the cost of distillate per liter (CPL) based on the equations mentioned by Attia et al., (2021c) as follows:

The capital recovery factor (CRF) is calculated as follows:

$$CRF = \frac{\mathrm{i}(i+1)^n}{(i+1)^n - 1} \tag{3}$$

Additionally, fixed annual cost (FAC) is calculated as follows:

$$FAC = P \times (CRF) \tag{4}$$

where, P is a distiller fixed cost.

Sinking fund factor (SFF) is calculated as follows:

$$SFF = \frac{i}{(i+1)^n - 1} \tag{5}$$

Also, salvage value (S) is calculated as follows:

$$S = 0.17 \times P \tag{6}$$

Annual salvage value (ASV) is calculated as follows:

$$ASV = S \times (SFF) \tag{7}$$

The annual maintenance cost (AMC) is calculated as follows:

$$AMC = 0.05 \times (FAC) \tag{8}$$

The total annual cost (TAC) is calculated as follows:

$$TAC = FAC + AMC - ASV \quad (9)$$

Then, the distilled cost per liter (CPL) is calculated as follows:

$$CPL = TAC / M \quad (10)$$

where, M is the average distillate yield per yearly.

Table 4 present Daily productivity of hemispherical solar distillers use truncated circular cone-shaped reflector mirrors (TCC-RM) with different inclination angle (θ = 10°, 15°, 20°, 25°, 30°, 35°, 40° and 45° with vertical).

The price of distilled water per liter in Algeria market is 60 DZD ($ 0.4436), but the price of distilled water product per liter from THSD (reference unit) is 0.906 DZD ($ 0.0067) and product from hemispherical solar distillers with truncated circular cone-shaped reflector mirrors (TCC-RM) at inclination angle equal to 25^{o} is 0.771DZD ($ 0.0057), Table 5.

Table 4. Daily productivity of hemispherical solar distillers with/without TCC-RM.

Distiller types	**Accumulative productivity, L/m^2 day**
THSD	5.85
HSD-TCC-RM10	5.15
HSD-TCC-RM15	6.60
HSD-TCC-RM20	7.05
HSD-TCC-RM25	8.35
HSD-TCC-RM30	7.90
HSD-TCC-RM35	7.30
HSD-TCC-RM40	6.67

Table 5: Cost analysis of all distillers.

	THSD	HSD-TCC-RM10	HSD-TCC-RM15	HSD-TCC-RM20	HSD-TCC-RM25	HSD-TCC-RM30	HSD-TCC-RM35	HSD-TCC-RM40	HSD-TCC-RM45
N (year)	10	10	10	10	10	10	10	10	10
I (%)	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
CRF	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
P ($)	66.87	81.65	81.65	81.65	81.65	81.65	81.65	81.65	81.65
S ($)	11.37	13.88	13.88	13.88	13.88	13.88	13.88	13.88	13.88
FAC ($)	14.04	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15
SFF	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
ASV ($)	0.455	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555
AMC ($)	0.702	0.858	0.858	0.858	0.858	0.858	0.858	0.858	0.858
TAC ($)	14.287	17.453	17.453	17.453	17.453	17.453	17.453	17.453	17.453
M (L/m^2 year)	2135.3	1879.8	2409	2573.3	3047.8	2883.5	2664.5	2434.6	1989.3

Conclusion

In this paper, study the effect of truncated circular cone-shaped reflector mirrors (TCC-RM) inclination angle on hemispherical distiller's performance and obtain the optimal inclination angle. The yield of solar hemispherical distillation at the conditions of brine depth of 1 cm was studied, under the weather conditions of El Oued-Algeria city. The following points can be summarized from the experimental work:

- The use of truncated circular cone-shaped reflector mirrors (TCC-RM) within the hemispherical solar distillers increases the distillate yields.
- Optimal inclination angle of truncated circular cone-shaped reflector mirrors (TCC-RM) is 25 degrees with vertical; the corresponding improvement percentage is 42.74%.
- Whenever the tilt angle is greater than 25°, the productivity decreases, and the improvement percentages are 35.04, 24.79, 14.02, and -6.84% at tilt angles of 30, 35, 40, and 45° with vertical, respectively.
- Whenever the angle of inclination was less than 25°, the productivity also decreased, and the improvement rates were 20.51, 12.82, and -11.97% at inclination angles of 20, 15, and 10 degrees with vertical, respectively.
- Based on the data of cumulative yield, daily efficiency, and the economic analysis it's recommended to utilize TCC-RM with a 25º inclination angle to achieve the highest performance and minimum distillate cost of hemispherical solar distillers.

We recommend using the truncated circular cone-shaped reflector mirrors (TCC-RM) with an ideal tilt angle of 25° with vertical.

Nomenclature

THSD	Traditional Hemispherical Solar Distiller
HSD-TCC-RM10	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 10º
HSD-TCC-RM15	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 15º
HSD-TCC-RM20	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 20º
HSD-TCC-RM25	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 25º
HSD-TCC-RM30	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 30º
HSD-TCC-RM35	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped

	Reflector Mirrors inclination angle 35^o
HSD-TCC-RM40	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 40^o
HSD-TCC-RM10	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 45^o

Declarations

Ethical Approval

Not applicable

Consent to Participate

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Consent to Publish

Not applicable

Authors Contributions

Author's full name Authors Contributions

1 *Mohammed El Hadi Attia,* Expermental work, , Writing - original draft*,* preparation.

2 *Abd Elnaby Kabeel,* Conceptualization, &Editing.Supervisor

3 *Mohamed Abdelgaied,* Conceptualization, Methodology, Writing -,Review & Editing.

4 Ayman Refat Abd Elbar, Formal analysis and investigation. Writing -Review & Editing.

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