Hemispherical Solar Distiller With Truncated Circular Cone-Shaped Reflector Mirrors (TCC-RM)

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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°, 15°, 20°, 25°, 30°, 35°, 40° and 45° 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° inclination angle achieve the maximum cumulative yield of 8.35 L/m² with an improvement of 42.74% compared to THSD. While the utilization of TCC-RM with the inclination angles by 30°, 35°, 20°, 40°, and 15° achieves the cumulative yield of 7.9, 7.3, 7.05, 6.67, 6.6 L/m² compared with 5.85 L/m² for THSD. On the contrary, adjusting the inclination angle of TCC-RM at 10°, and 45° 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 economics analysis its recommended to utilized TCC-RM with a 25° inclination angle to achieve the highest performance and minimum distillate cost of hemispherical solar distillers.

1. 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 (Attia et al., 2021a,b; Prasad et al., 2021; Essa et al., 2021; Abdullah et al., 2021; Kabeel et al., 2017). 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 (Kabeel et al., 2018; Attia et al., 2021d,e,f; Sharshir et al., 2020; Kabeel et al., 2020; Kabeel and Abdelgaied, 2017, 2019). 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; Attia et al., 2021g; 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 (Bellila et al., 2021; Abd Elbar and Hassan, 2020a,b,c; Abd Elbar et al., 2019a,b; Abd Elbar et al., 2018) 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. (2021i) 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 yield 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%. while freshwater yield was low compared to solar still with flat plate collector only. 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.

2. 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. Figure 1 shows the schematic view of hemispherical solar distillers.

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 ($\theta = 10, 15, 20, 25, 30, 35, 40$ 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 Figure 2.

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°, 15°, 20°, 25°, 30°, 35°, 40°, and 45° 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.

Thermocouples by $\pm 0.1^\circ\text{C}$ 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 $\pm 10 \text{ W/m}^2$ accuracy was used to record and log solar radiation. A graduated cylinder with $\pm 1 \text{ mL}$ 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	$\pm 0.1^\circ\text{C}$	0.08°C
Solar power meter	0-1999 W/m ²	$\pm 10 \text{ W/m}^2$	5.78 W/m ²
Graduated cylinder	0–500 mL	$\pm 1 \text{ mL}$	0.5 mL

3. 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);

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

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

4. 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 [3][4]. 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[5][6]. As a result, evaluating the still temperatures provides a clear picture of the still performance.

4.1. Hemispherical Solar Still temperatures

Figures 4, 5, 6, and 7 illustrates the temperature variations with time of the proposed hemispherical solar Distillers components and the corresponding ambient temperature and solar rays within tested days. Figure 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 figure 5. Furthermore, figure 6 illustrate 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 figure 7.

As indicated from these figures (4:7), 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 (4:7) 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 12pm, it is noticed that the maximum values of all components for the proposed systems were obtained three hours later at 15pm. 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.

Figure 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 figure 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 10° has a negative effect on the water temperature values. However, using the TCC-RM with 15° enhanced the maximum water temperature by 2.78% compared with THSD due to increasing the incident solar radiation on HSS area.

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 figure 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° inclination angle has the maximum condensation rate compared with other corresponding systems.

Figure 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 results 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 figures (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.

The impact of using TCC-RM with inclination angles of 40, and 45 degrees on traditional THSD temperatures is shown in Figure 7. It can be concluded from figure 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 figures (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. Which means that HSD-TCC-RM25 has the maximum evaporation rate, and then maximum freshwater productivity.

4.2. Hemispherical Solar Distillers Freshwater Yield

Figure 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. Figure 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. Figure 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 traditional THSD.

Figure 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 figure 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° , which achieves the maximum accumulated freshwater yield between all other HSS proposed systems.

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

4.3. Daily Efficiency

Figure 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.

5. 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 capital recovery factor (CRF) is calculated as follows (Attia et al., 2021i);

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

Additionally, fixed annual cost (FAC) is calculated as follows (Attia et al., 2021i);

$$FAC = P \times (CRF) \quad (4)$$

Where, P is a distiller fixed cost.

Sinking fund factor (SFF) is calculated as follows (Attia et al., 2021i);

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

Also, salvage value (S) is calculated as follows (Attia et al., 2021i);

$$S = 0.17 \times P \quad (6)$$

and annual salvage value (ASV) is calculated as follows (Attia et al., 2021i);

$$ASV = S \times (SFF) \quad (7)$$

The annual maintenance cost (AMC) is calculated as follows (Attia et al., 2021i);

$$AMC = 0.05 \times (FAC) \quad (8)$$

The total annual cost (TAC) is calculated as follows (Attia et al., 2021i);

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

Then, the distilled cost per liter (CPL) is calculated as follows (Attia et al., 2021i);

$$\text{CPL} = \text{TAC} / \text{M} \quad (10)$$

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 ($\theta = 10, 15, 20, 25, 30, 35, 40$ and 45 with vertical).

Cost analysis of all distillers is shown in Table 5. 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° is 0.771DZD (\$ 0.0057).

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

6. 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:

- (1) The use of truncated circular cone-shaped reflector mirrors (TCC-RM) within the hemispherical solar distillers increases the distillate yields.
- (2) optimal inclination angle of truncated circular cone-shaped reflector mirrors (TCC-RM) is 25 degrees with vertical, the corresponding improvement percentage is 42.74%.
- (3) 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.

(4) 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.

(5) The truncated circular cone-shaped reflector mirrors (TCC-RM) reflects the solar energy falling into the distilled basin water and increases its heating.

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

Abbreviations

THSD	Traditional Hemispherical Solar Distiller
HSD-TCC-RM10	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 10°
HSD-TCC-RM15	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 15°
HSD-TCC-RM20	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 20°
HSD-TCC-RM25	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 25°
HSD-TCC-RM30	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 30°
HSD-TCC-RM35	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 35°
HSD-TCC-RM40	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 40°
HSD-TCC-RM10	Hemispherical Solar Distiller with Truncated Circular Cone-Shaped Reflector Mirrors inclination angle 45°

Declarations

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

Authors Contributions

Author's full name Authors Contributions

- 1 *Mohammed El Hadi Attia*, Experimental work, , Writing - original draft, preparation.
- 2 *Abd Elnaby Kabeel*, Conceptualization, Writing - Review & 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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References

1. Abd Elbar AR, Yousef MS, Hassan H (2019a) Energy, exergy, exergoeconomic and enviroeconomic (4E) evaluation of a new integration of solar still with photovoltaic panel. J Clean Prod 233:665–680
2. Abd Elbar AR, Hassan H (2020a) Energy, exergy and environmental assessment of solar still with solar panel enhanced by porous material and saline water preheating. J Clean Prod 277:124175
3. Abd Elbar AR, Hassan H (2020b) Enhancement of hybrid solar desalination system composed of solar panel and solar still by using porous material and saline water preheating. Sol Energy 204:382–394
4. Abd Elbar AR, Hassan H (2020c) An experimental work on the performance of new integration of photovoltaic panel with solar still in semi-arid climate conditions. Renew Energy 146:1429–1443
5. Abd Elbar AR, Hamdy Hassan H (2019b) Experimental investigation on the impact of thermal energy storage on the solar still performance coupled with PV module via new integration. Sol Energy 184:584–593

6. Abd Elbar AR, Hamdy Hassan SOokawara. A numerical study on the effect of the heat sink as condenser on the performance of passive solar still 2018:256–9.
<https://doi.org/10.1109/ICREGA.2018.8337589>
7. Abdullah AS, Omara ZM, Essa FA, Younes MM, Shanmugan S, Abdelgaied M, Amro MI, Kabeel AE, Farouk WM (2021) Improving the performance of trays solar still using wick corrugated absorber, nano-enhanced phase change material and photovoltaics-powered heaters. *Journal of Energy Storage* 40:102782
8. Abdelgaied M, Zakaria Y, Kabeel AE, Essa FA (2021a) Improving the tubular solar still performance using square and circular hollow fins with phase change materials. *Journal of Energy Storage* 38:102564
9. Abdelgaied M, Harby K, Eisa A (2021b) Experimental investigation on the performance improvement of tubular solar still using floating black sponge layer. *Environ Sci Pollut Res* (2021).
<https://doi.org/10.1007/s11356-021-13187-z>
10. Abdelgaied M, Harby K, Eisa A (2021c) Performance improvement of modified tubular solar still by employing vertical and inclined pin fins and external condenser: an experimental study. *Environ Sci Pollut Res* 28:13504–13514
11. Attia MEH, Kabeel AE, Abdelgaied M, El-Maghlany WM, Bellila A (2021a) Comparative study of hemispherical solar distillers iron-fins. *J Clean Prod* 292:126071
12. Attia MEH, Kabeel AE, Abdelgaied M, El-Maghlany WM, Driss Z (2021b) Enhancement the performance of hemispherical distiller via phosphate pellets as energy storage medium. *Environ Sci Pollut Res* 28:32386–32395
13. Attia MEH, Kabeel AE, Bellila A, Manokar AM, Sathyamurthy R, Driss Z (2021d) A comparative energy and exergy efficiency studies of hemispherical and single slope solar stills. *Environ Sci Pollut Res* 28:35649–35659
14. Attia MEH, Driss Z, Kabeel AE, Alagar K, Athikesavan M, Sathyamurthy R (2021) e Phosphate bags as energy storage materials for enhancement of solar still performance. *Environ Sci Pollut Res* 28:21540–21552
15. Attia MEH, Kabeel AE, Abdelgaied M, Essa FA, Omara ZM, 2021f Enhancement of hemispherical solar still productivity using iron, zinc and copper trays, *Solar Energy* 216; 295–302
16. Attia MEH, Karthick A, Manokar AM, Driss Z, Kabeel AE, Sathyamurthy R, Sharifpur M (2021g) Sustainable potable water production from conventional solar still during the winter season at Algerian dry areas: energy and exergy analysis. *J Therm Anal Calorim* 145:1215–1225
17. Attia MEH, Kabeel AE, Abdelgaied M, Abdelaziz GB (2021i) A comparative study of the effect of internal reflectors on a performance of hemispherical solar distillers: Energy, exergy, and economic analysis". *Sustain Energy Technol Assess* 47:101465
18. Badran OO (2007) Experimental study of the enhancement parameters on a single slope solar still productivity. *Desalination* 209:136–143

19. Bellila A, Attia MEH, Kabeel AE, Abdelgaied M, Harby K, Soli J (2021) Productivity enhancement of hemispherical solar still using Al₂O₃-water based nanofluid and cooling the glass cover, *Applied Nanoscience*, 2021, <https://doi.org/10.1007/s13204-021-01677-y>
20. Boubekri M, Chaker A (2011) Yield of an improved solar still: numerical approach. *Energy Procedia* 6:610–617
21. Chandrika VS, Attia MEH, Manokar AM, Márquez FPG, Driss Z, Sathyamurthy R (2021) Performance enhancements of conventional solar still using reflective aluminum foil sheet and reflective glass mirror: energy and exergy analysis. *Environmental Science and Pollution Research*. 2021. <https://doi.org/10.1007/s11356-021-13087-2>
22. Essa FA, Omara ZM, Abdullah AS, Shanmugan S, Panchal H, Kabeel AE, Sathyamurthy R, Athikesavan MM, Elsheikh A, Abdelgaied M, Saleh B (2021) Augmenting the productivity of stepped distiller by corrugated and curved liners, CuO/paraffin wax, wick, and vapor suctioning. *Environ Sci Pollut Res* (2021). <https://doi.org/10.1007/s11356-021-14669-w>
23. Hiroshi T (2010) Monthly optimum inclination of glass cover and external reflector of a basin type solar still with internal and external reflector. *Sol Energy* 84:1959–1966
24. Kabeel AE, Abdelgaied M, Eisa A (2018) Enhancing the performance of single basin solar still using high thermal conductivity sensible storage materials. *Journal of cleaner production* 183:20–25
25. Kabeel AE, Sathyamurthy R, Manokar AM, Sharshir SW, Essa FA, Elshiekh AH (2020) Experimental study on tubular solar still using Graphene Oxide Nano particles in Phase Change Material (NPCM 's) for fresh water production. *J Energy Storage* 28:101204
26. Kabeel AE, Abdelgaied M (2019) Performance enhancement of a photovoltaic panel with reflectors and cooling coupled to a solar still with air injection. *J Clean Prod* 224:40–49
27. Kabeel AE, Teamah MA, Abdelgaied M, Abdel Aziz GB (2017) Modified pyramid solar still with v-corrugated absorber plate and PCM as a thermal storage medium. *J Clean Prod* 161:881–887
28. Kabeel AE, Abdelgaied M (2017) Performance enhancement of modified solar still using multi-groups of two coaxial pipes in basin. *Appl Therm Eng* 118:23–32
29. Khechekhouche A, Kabeel AE, Benhaoua B, Attia MEH, El-said EMS (2020) Traditional Solar distiller improvement by a single external refractor under the climatic conditions of the El Oued region, Algeria. *Desalination Water Treatment* 177:23–28
30. Manokar AM, Winston DP (2017) Experimental analysis of single basin single slope finned acrylic solar still. *Materials Today: Proceedings*, 4(8), 7234-7239
31. Prasad AR, Attia MEH, Al-Kouz W, Afzal A, Manokar AM, Sathyamurthy R (2021) Energy and exergy efficiency analysis of solar still incorporated with copper plate and phosphate pellets as energy storage material", 2021, *Environmental Science and Pollution Research*. <https://doi.org/10.1007/s11356-021-14080-5>
32. Sharshir SW, Elkadeem MR, Meng A (2020) Performance enhancement of pyramid solar distiller using nano fl uid integrated with v-corrugated absorber and wick: An experimental study. *Appl Therm Eng* 168:114848

33. Thakur AK, Sharshir SW, Ma Z (2021) Performance amelioration of single basin solar still integrated with V-type concentrator: Energy, exergy, and economic analysis. *Environ Sci Pollut Res* 28:3406–3420
34. Tanaka H (2009) Experimental study of a basin type solar still with internal and external reflectors in winter. *Desalination* 249:130–134
35. Tanaka H, Nakatake Y (2006) Theoretical analysis of a basin type solar still with internal and external reflectors. *Desalination* 197:205–216
36. Tanaka H, Nakatake Y (2007) Improvement of the tilted wick solar still by using a flat plate reflector. *Desalination* 216:139–146
37. Tanaka H, Nakatake Y (2009) Increase in distillate productivity by inclining the flat plate external reflector of a tilted-wick solar still in winter. *Sol Energy* 83:785–789

Figures

Figure 1

The schematic view of the hemispherical solar distiller design.

Figure 2

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

Figure 3

The pictorial view of the hemispherical solar distillers actual experimental.

Figure 4

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

Figure 5

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

Figure 6

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

Figure 7

Temperature Variations of THSD compared with HSD-TCC-RM at inclination angles of 40 and 45 degree

Figure 8

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

Figure 9

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

Figure 10

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