A comparative assessment of innovative hemispherical solar distillers with cylindrical and conical fins: An experimental approach

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Research Article

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Abstract

Although the influence of fins on a basin's flat absorber will improve thermal performance and distillate production due to the increased heat transfer areas, many researchers are still interested in the problem of shading caused by fins, which reduces distiller productivity for some configurations of the fins designs. To obtain the best fin configurations that achieve the lowest shading effects and highest performance of hemispherical solar stills. The influences of absorbent cement layer with two types of fins (cylindrical and conical fins) with a diameter of 1.5 cm and a height of 3 cm at different gap spacing (3, 3.75, and 4.5 cm) were studied. To achieve these; three hemispherical solar stills were tested at same weather conditions, first is the conventional hemispherical still without fins (CHSWF) which represent the reference case. Second, is the cylindrical finned hemispherical still with gap spacing 3, 3.75, and 4.5 cm (CyFHS). Third, is the conical finned hemispherical still with gap spacing of 3, 3.75, and 4.5 cm (CoFHS). The results showed that, the cylindrical finned hemispherical still (CyFHS) productivity values are 5.55, 6.00, and 6.70 kg/m^2, respectively, while conical finned hemispherical still (CoFHS) productivity values are 6.20, 6.65, and 7.15 kg/m^2 at gap spacing of 3, 3.75, and 4.5 cm, respectively compared to 4.20 kg/m^2 that was produced by CHSWF. The results showed that the use of conical fins achieves the highest performance of hemispherical still as a result of reducing the effect of shading. Whereas, the best configuration that achieves the highest performance is the use of conical fins with a gap spacing of 4.5 cm, where the rate of improvement is 70.24% compared to CHSWF

Background

Countries play a variety of roles, including welfare and economic development. Water is one of the most basic human needs. Water scarcity and pollution are the most serious issues in developing countries [1–3]. The sea contains 97% of the world's saltwater, the polar region contains 2% of the world's water in the form of ice, and the remaining 1% of the water is accessible to humans and animals [4–6]. One of the main causes of people's health problems is contaminated water. Worldwide, water salinity has increased as a result of low rainfall. Water pollution is caused by the following factors. Population growth, urbanization, and industrialization are all factors. Solar distilled desalination is the most effective desalination technique for the production of drinking water in developing countries [7–9].

Manokar and Winston [10] investigated the differences between single basin SS made of acrylic with aluminum fins and single basin SS made of galvanized iron. The results showed that single basin acrylic SS with aluminum finned has daily productivity of 2640 mL/m^2/day, while single slope SS made of galvanized iron has daily productivity of 2340 mL/m^2/day.. Attia et al. [11] used iron fins of various lengths (1, 2, and 3 cm) and spacing in the absorber plate of 5 and 7 cm to increase the yield of a hemispherical distiller. The results showed that using fins in the absorber plate with length of 2 cm and spacing of 7 cm improves performance by 56.73%. Vaithilingam et al. [12] compared acrylic stainless steel with copper fins to acrylic stainless steel without copper fins. The acrylic SS with copper fin produced a maximum daily output of 5.08 kg, according to the findings. The maximum daily output of the acrylic SS without copper fins was 3.75 kg. At different water depths, Rajaseenivasan and Srithar [13] investigated theoretical and experimental SS performance with circular and square hollow fins covered by wick (1, 2, 3, and 4 cm). The results showed that the experimental analysis and theoretical values were in good agreement. Still yielded 4.55 and 4.25 kg/m^2 per day in square fins with and without wick covering, and 4.27 and 3.99 kg/m^2 in circular fins with and without wick covering, respectively, compared to 3.16 kg/m^2 in the conventional still. Total CO_2 emission mitigation ranges from 5.6 to 36.6 t for a still with square fin and wick covered, with a life span of 5 to 30 years. The effect of fins and internal reflectors on single slope SS performance was investigated experimentally by Bataineh and Abbas [14]. Internal reflectors performed better in the winter due to their high efficiency. The daily average increase in productivity on conventional still, still with fins, still with internal reflector, and still with fins and internal reflector, respectively, was 3.6428, 3.6445, 4.0965, and 4.6085 L/day/m^2. Tuly et al. [15] evaluated modified conventional stills for (fins, PCM, External condenser, and wick materials) cases. When compared to other stills, a solar still with an external condenser produced extremely high productivity (3.07 L/m^2). The productivity of a modified still with an external condenser was 24.79% higher than finned stills and 9.76% higher than conventional stills. The effect of fins on tubular solar still productivity was investigated experimentally by Sathyamurthy et al. [16]. Fins improved productivity; it was discovered that adding fins increased productivity by 0.65 L/m^2, compared to 0.55 L/m^2 for traditional tubular solar stills. External fins on passive solar still were investigated by Mohaisen et al. [17]. External fins improved distillate by 92.3%, according to the researchers. Its research revealed that these stills are cost-effective; the cost per liter for stills with external fins is 0.007 $/l, while the cost for still without fins is 0.0117 $/l. Panchal et al. [18] looked into the effect of fins (vertical and inclined (30°) on the productivity of traditional solar panels. Windchime pipes were recycled into fins. According to the findings, inclined finned SS produced (2.322 L/m^2), vertical finned SS produced (2.375 L/m^2), and traditional SS produced (1.873 L/m^2). A pyramid-shaped SS with hollow copper fins and PCM produced more energy than a pyramid-shaped SS with or without hollow fins, according to Kabeel et al. [19]. Stills with hollow copper fins and no PCM produced 5.75 L/m^2, while ordinary pyramid-shaped stills with no modifications produced 4.02 L/m^2, Shmroukh and Ookawara [20] found that a stepped SS with fins and inner and outer reflectors produced higher yields than a stepped SS without any modifications. The first one had productivity of 8.285 kg/m^2, which was 129% higher than plain stepped stills without any modifications (3.615 kg/m^2). Attia et al. [21] investigated the exergy/ thermal analysis of finned in acrylic solar stills at various saltwater depths (1 cm, 2 cm, and 3 cm). The exergy efficiency of the finned acrylic SS at 1 cm, 2 cm, and 3 cm is 3.83, 3.22, and 2.7%, respectively, according to the findings, while the thermal efficiency is 42.54, 37.92, and 31.2%. To improve hemispherical distiller performance, Attia et al. [22] used phosphate pellets with two concentrations of 1 and 2 percent. The use of phosphate pellets as a storage medium improved the hemispherical distiller's performance, according to the findings. When compared to a traditional hemispherical distiller, distiller productivity increased by 33.7 and 47.9% for 1 and 2% of phosphate pellets, respectively.

By reviewing previous studies, it was found that the use of fins has a positive effect as it improves thermal performance and distillate production due to increased heat transfer areas. Many researchers are still interested in the problem of shading caused by fins, which reduces the distillation productivity for some configurations of fin designs. Therefore, this study is concerned with determining the best fin configuration that achieves the least shading effects and the highest performance of the solar stills. To obtain the best fin configurations that achieve the lowest shading effects and highest performance of hemispherical solar stills. The absorbent cement layer with two types of fins (cylindrical and conical fins) with a diameter of 1.5 cm and a height of 3 cm at different gap spacing (3, 3.75, and 4.5 cm) were suggested in this manuscript to obtain the best configuration of fins that achieves the highest productivity. To achieve these; three hemispherical solar stills were tested at same weather conditions, first is the conventional hemispherical still without fins (CHSWF) which represent the reference case. Second, is the cylindrical finned hemispherical still with gap spacing 3, 3.75, and 4.5 cm (CyFHS). Third, is the conical finned hemispherical still with gap spacing of 3, 3.75, and 4.5 cm (CoFHS). In May 2022, the experimental study was carried out in the geographical conditions of El Oued, Algeria (33.3683° N, 6.8674° E).

Experimental Methodology

Test-rig construction

Three hemispherical solar stills of similar dimensions were built in this experiment. One has conical fins, another has cylindrical fins, and the third is still a simple hemispheric as a reference. The diameter and height of the circular SS basin are 36 cm and 4 cm, respectively. Temperature differences between the basin and the atmosphere cause heat transmission loss from the still basin edges and bottom. To address this issue, it is insulated with a black silicon material. The SS top is encased in a 3 cm thick transparent cover. Figure 1 shows a photograph of a hemispherical distiller.

In the previous study, reasonable thermal energy storage materials of indeterminate shapes were used, such as gravel (Attia et al. [23]), quartz rock (Murugavel et al. [24]), graphite (Attia et al. [25]), red brick coated with cement (Kabeel et al. [26]), sand (Attia et al. [27]), and phosphate (Kabeel et al. [28]). To increase absorption and heat transfer area, cylindrical and conical cement fins with a height of 3 cm, a diameter of 1.5 cm, and different spacing (3, 3.75, and 4.5 cm) are made in the absorber plate. During the experiments, the saltwater in the basin is kept at 3 cm (maximum fin height). Table 1 lists the cement's characteristics.

As an absorbent material, a layer of cement with a thickness of 1 cm is placed at the bottom of the basin for better thermal conductivity. The basin has been dyed black to better absorb solar radiation energy. To improve heat transfer, cylindrical and conical fins attached to the sump liner were placed at the bottom of the basin to improve heat transfer. These fins are made of cement (the same material as an absorbent).

Table 1

Property of the cement

Properties	Values
Density, kg/m^3	1800
Thermal resistance, m^{2}K/W	0.011
Thermal conductivity, W/mK	1.4
Specific heat capacity, J/kgK	1000
Dimensions of fin, cm	1.5 (D) × 3 (H)

Figure 2 shows cylindrical and conical fins with the same height and diameter of 3 cm and 1.5 cm, respectively, at different spacing (3, 3.75, and 4.5 cm) and a water depth of 3 cm.

Experimental setup

To obtain the best fin configurations that achieve the lowest shading effects and highest performance of hemispherical solar stills. As a result, three modules are tested in the same way. Figure 3 shows the photo of the experimental setup. (CHSWF) is the traditional hemispheric still devoid of fins. Second, the cylindrical finned hemispherical spacing remains unchanged at 3, 3.75, and 4.5 cm (CyFHS for case 1, CyFHS for case 2, and CyFHS for case 3). Third, the conical finned hemispherical stills with a spacing of 3, 3.75, and 4.5 cm (CoFHS for case 1, CoFHS for case 2, and CoFHS for case 3) were tested for three days in a row as shown in Table 2. Figure 4 illustrates the different cases of test configurations. On three sunny days in May 2022, the cylindrical finned still and conical finned still of energy and exergy performance were investigated for the level of the basin saltwater at 3 cm. The data was extracted for 60 minutes, starting at 7:00 a.m. ending at 6:00 p.m.

Table 2

The different test configurations

Case		Method
Conventional	CHSWF	Conventional Hemispherical Still Without Fins
Case 1	CyFHS	Cylindrical Finned Hemispherical Still set at 3 cm gap spacing
Case 2	CyFHS	Cylindrical Finned Hemispherical Still set at 3.75 cm gap spacing
Case 3	CyFHS	Cylindrical Finned Hemispherical Still set at 4.5 cm gap spacing
Case 1	CoFHS	Conical Finned Hemispherical Still set at 3 cm gap spacing
Case 2	CoFHS	Conical Finned Hemispherical Still set at 3.75 cm gap spacing
Case 3	CoFHS	Conical Finned Hemispherical Still set at 4.5 cm gap spacing

Uncertainty analysis

The difference between the true and computed values, also known as an error, is what the uncertainty analysis is all about. Errors are systematic errors that can be calculated using the data book or calibration report for the instrument. Table 3 shows the equipment's operating range and precision.

Table 3

Instrument errors and range

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

Results And Discussions

Experiments were carried out in three cnescutive days in May, 2022 atthe University of El Oued in Algeria. The readings were taken hourly from 7:00 a.m. to 6:00 p.m.

The effectiveness of a hemispheric solar still is influenced by solar intensity and ambient temperatures. As a result, hourly readings of the experiment's solar intensity and ambient temperature are required. During experimentation test hours, Fig. 5 depicts the variation in ambient temperatures and solar intensity. The solar intensity increases until midday on each of the three test days, then gradually decreases as time passes until reaches to lowest point of sunset. Around 1:00 p.m., the highest recorded temperature of ambient was also reached. This means test locations are subjected to the same climatic and weather conditions, they can be compared more precisely.

The performance of the hemispherical solar still (CHSWF) is compared to that of the cylindrical hemispherical solar still (CyFHS) and the conical hemispherical still (CoFHS) with fins spaced differently (3, 3.75, and 4.5 cm).

Figure 6 depicts a change in water temperature for the three distinct configurations of CyFHS and CoFHS on May 13, 14, and 15.

The maximum temperature of the water basin appears to increase as the distance between fins evolves. At about 2:00 p.m., the maximum water basin temperatures of CHSWF, CyFHS (Case 1), CoFHS (Case 1), CyFHS (Case 2), CoFHS (Case 2), CyFHS (Case 3), and CoFHS (Case 3) are 55, 58, 61, 58, 65, 65, and 67, respectively.

From 7:00 a.m. to 6:00 p.m. on May 13, 14, and 15, Fig. 7 shows the change in yield for various configurations. The hourly variance of collected water production rises as the fin spacing of the cylindrical and conical hemispherical continues to rise. The daily cumulative distillate yields for CHSWF, CyFHS (Case 1), CoFHS (Case 1), CyFHS (Case 2), CoFHS (Case 2), CyFHS (Case 3), and CoFHS (Case 3) are 4.2, 5.55, 6.2, 6, 6.65, 6.7, and 7.15 L/m^2/day, respectively.

The accumulated daily yield for the three test configurations is shown in Fig. 8, with the maximum daily yield of 7.15 L/m^2 achieved when the fins spacing is 4.5 cm in CoFHS (Case 3). Figure 9 shows the daily yield enhancement due to using CyFHS and CoFHS at different fins spacing, it is seen that the maximum daily yield increase of 70.24% compared to CHSWF is achieved when fins spacing is 4.5 cm in CoFHS (Case 3).

Table 4

Commulative daily yield comparisons by changing the fins spacing of cylindrical and conical hemispherical still (3, 3.75, and 4.5 cm)

Day	Solar Still	Daily yield (l)	Improvement rate (%)
13-05-2022	CHSWF	4.20	-
	CyFHS (Case 1)	5.55	32.14
	CoFHS (Case 1)	6.20	47.62
14-05-2022	CHSWF	4.20	-
	CyFHS (Case 2)	6.00	42.86
	CoFHS (Case 2)	6.65	58.33
15-05-2022	CHSWF	4.20	-
	CyFHS (Case 3)	6.70	59.52
	CoFHS (Case 3)	7.15	70.24

Based on the fin spacing, Fig. 10 depicts the efficiency of CyFHS and CoFHS. The average efficiency of hemispherical distillers CyFHS and CoFHS increases as the fins spacing increases because the efficiency of hemispherical distiller dependent on yield and water temperature. CHSWF, CyFHS (Case 1), CoFHS (Case 1), CyFHS (Case 2), CoFHS (Case 2), CyFHS (Case 3), and CoFHS (Case 3) have average efficiency ratings of 37.15, 48.95, 54.47, 52.95, 58.33, 58.86 and 62.72%, respectively. Figure 11 shows the enhancement in daily efficiency due to using CyFHS and CoFHS at different fins spacing, it is seen that the maximum daily efficiency enhancement of 68.08.% compared to CHSWF is achieved when fins spacing is 4.5 cm in CoFHS (Case 3).

Economic Evaluation

Table 5 shows the payback period of the CHSWF, CyFHS (Case 1), CyFHS (Case 2), CyFHS (Case 3), CoFHS (Case 1), CoFHS (Case 2), and CoFHS (Case 3) for modules with cylindrical and conical fins at various spacings, based on the overall cost of manufacturing, operating cost, and maintenance cost (3, 3.75 and 4.5 cm). The payback period for CHSWF, CyFHS (Case 1), CyFHS (Case 2), CyFHS (Case 3), CoFHS (Case 1), CoFHS (Case 2), and CoFHS (Case 3) is 36, 28, 26, 23, 25, 23 and 21 days, respectively, to recover the whole cost.

Table 5

Economic analysis of the distillers CHSWF, CyFHS (Case 1), CyFHS (Case 2), CyFHS (Case 3), CoFHS (Case 1), CoFHS (Case 2) and CoFHS (Case 3)

	CHSWF	CyFHS			CoFHS		
		Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
Capital cost (DZD)	9000	9000	9000	9000	9000	9000	9000
The price of Cement (DZD)	-	200	180	160	150	130	110
Maintenance cost (DZD)	50	50	50	50	50	50	50
Total cost (DZD)	9050	9250	9230	9210	9200	9180	9160
Productivity ((kg/m^2/day)	4.20	5.55	6.00	6.70	6.10	6.65	7.15
The cost per liter of distilled water on the market (DZD)	60	60	60	60	60	60	60
The price of daily water production (DZD)	252	333	360	402	366	399	429
Payback period (Day)	36	28	26	23	25	23	21

(1$=132.78 DZD, 1€=156.03 DZD)

Conclusion

In this study, hemispherical solar stills with an absorbent layer of cement (1 cm) were compared to cylindrical and conical fins with a diameter of 1.5 cm and a height of 3 cm at different spacing (3, 3.75, and 4.5 cm). Results prove that cylindrical and conical fins are important in performance enhancement.

- Due to the shading effect in solar distillers, the effect of cylindrical and conical fins on performance is dependent on their spacing.
- CyFHS (Case 1), CyFHS (Case 2), and CyFHS (Case 3) have respective collective yields of 5.55, 6.00, and 6.70 L/m^2/day; CoFHS (Case 1), CoFHS (Case 2), and CoFHS (Case 3) have respective collective yields of 6.20, 6.65, and 7.15 L/m^2/day.
- CyFHS (Case 1), CyFHS (Case 2), and CyFHS (Case 3) have respective daily efficiencies of 48.95, 52.95, and 58.85%; CoFHS (Case 1), CoFHS (Case 2), and CoFHS (Case 3) have respective daily efficiencies of 6.20, 6.65, and 7.15%.
- With the best configuration of CyFHS (Case 3) with 4.5 cm spacing, cylindrical fins improve distiller productivity and efficiency up to 59.53, 58.85%.
- With the best configuration of CoFHS (Case 3) with 4.5 cm spacing, conical fins improve distiller productivity and efficiency up to 70.24, 68.06%.
- The relationship between the spacing of fins and the total number of fins should be optimized according to the recorded test results to avoid the shading effect.

- The payback period required to recover CHSWF is 36 days, this period is equal to 23 days for CyFHS (Case 3) and to 21 days for CoFHS (Case 3).

In a hemispherical distillation with a positive reinforcing contribution, cement fins are inexpensive. Fins, especially conical ones, should be spaced widely to avoid vignetting during installation.

Nomenclature

CHSWF	**Conventional Hemispherical Still Without Fins**
CyFHS (Case 1)	Cylindrical Finned Hemispherical Still set at 3 cm gap spacing
CyFHS (Case 2)	Cylindrical Finned Hemispherical Still set at 3.75 cm gap spacing
CyFHS (Case 3)	Cylindrical Finned Hemispherical Still set at 4.5 cm gap spacing
CoFHS (Case 1)	Conical Finned Hemispherical Still set at 3 cm gap spacing
CoFHS (Case 2)	Conical Finned Hemispherical Still set at 3.75 cm gap spacing
CoFHS (Case 3)	Conical Finned Hemispherical Still set at 4.5 cm gap spacing

Declarations

-Ethical Approval

Not applicable

-Consent to Participate

Not applicable

-Consent to Publish

Not applicable

-Authors Contributions

No.	**Author's full name**	**Authors Contributions**
1	*Mohammed El Hadi Attia*	Formal analysis and investigation, Writing - original draft preparation.
2	*Abd Elnaby Kabeel*	Conceptualization, Writing - Review & Editing.
3	*Mohamed Abdelgaied*	Conceptualization, Methodology, Writing - Review & Editing.
4	*Moataz M. Abdel-Aziz*	Conceptualization, Methodology, Writing - Review & Editing.

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-Competing Interests

No competing interests

-Availability of data and materials

Not applicable

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Figures

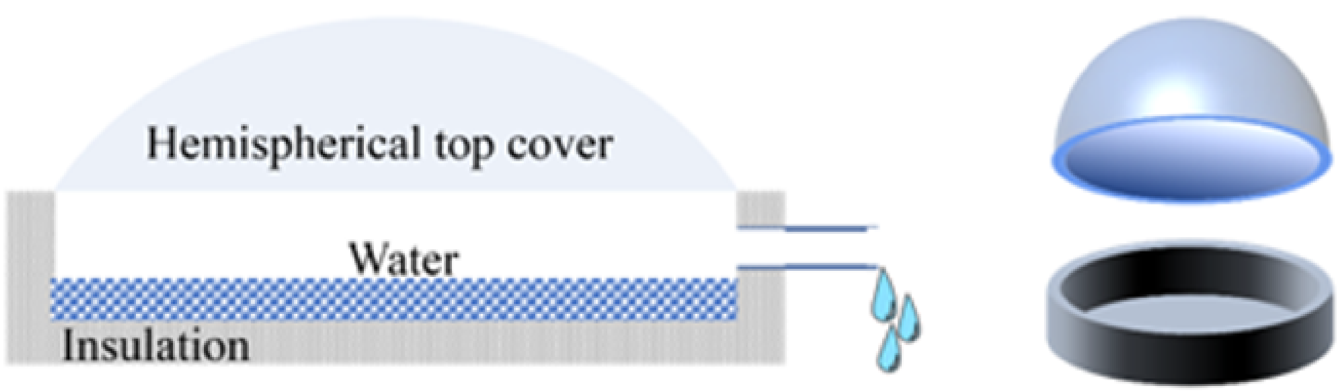

Figure 1

View of the hemispherical solar distiller

Figure 2

View of the cylindrical and conical fin (heights 3 cm and diameters 1.5 cm)

Figure 3

Photo of the experimental setup

Figure 4

Photo of different cases of test configuration

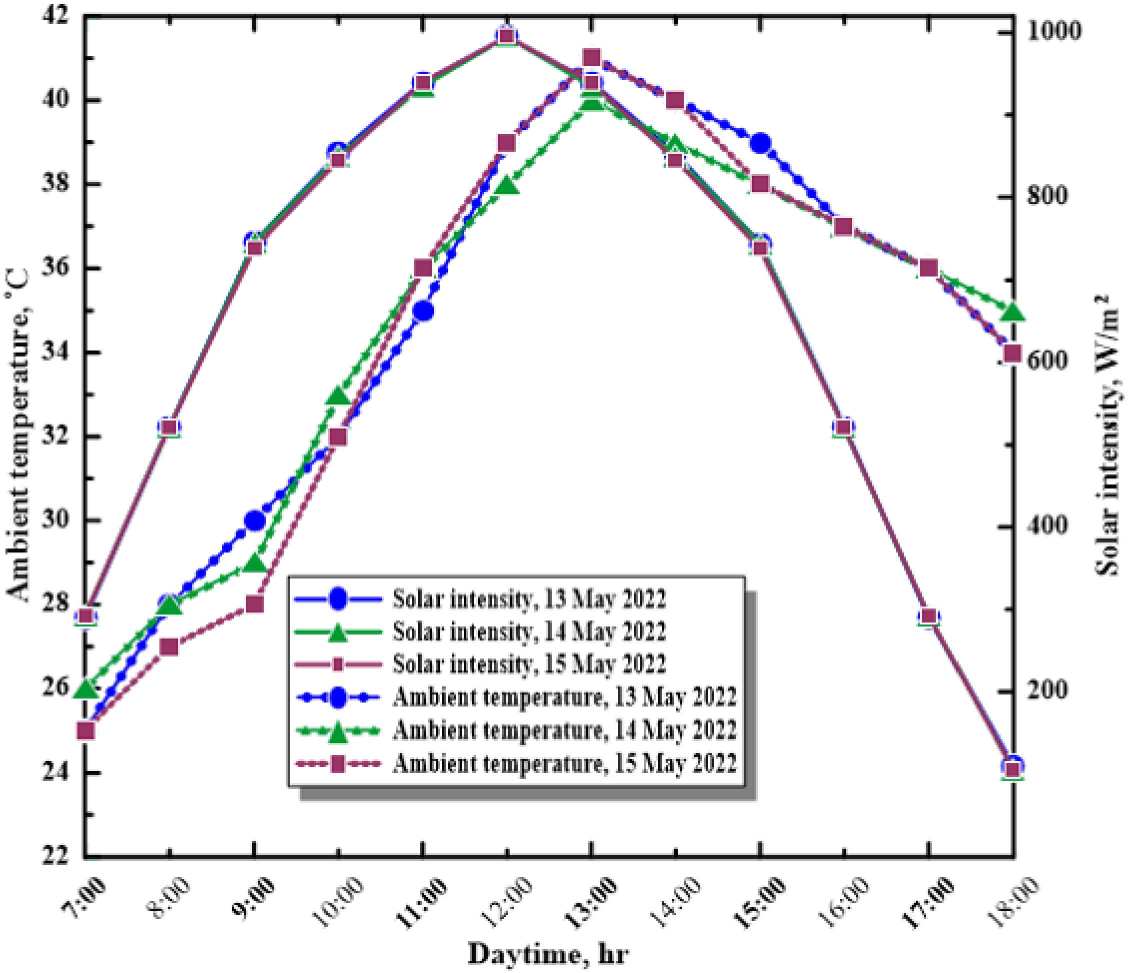

Figure 5

Solar intensity and temperature throughout a day

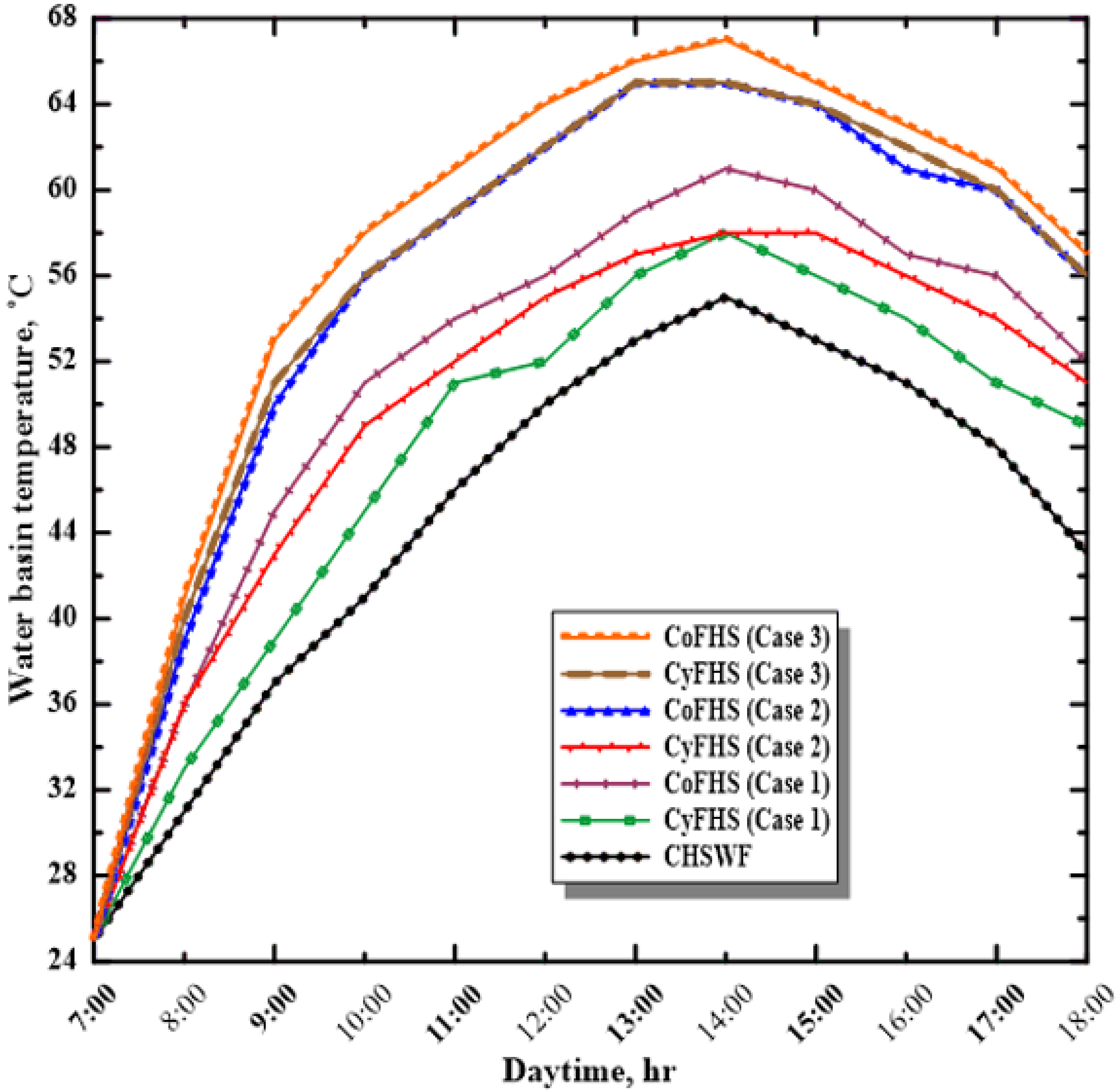

Figure 6

Hourly variation of water temperature throughout the day for CyFHS and CoFHS test configurations

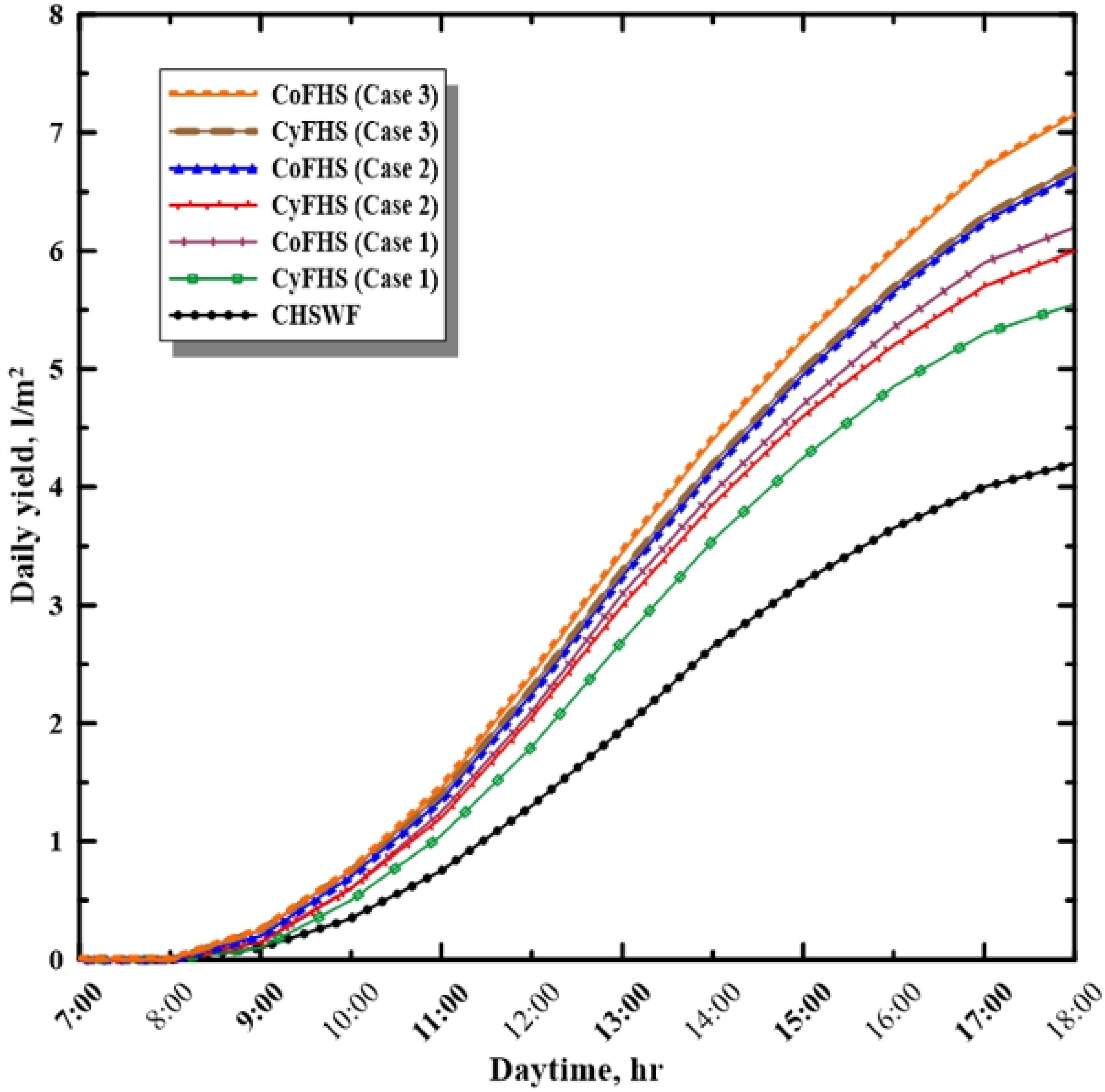

Figure 7

Daily yield throughout the day for CyFHS and CoFHS test configurations

Figure 8

Daily yield for different cases of CyFHS and CoFHS

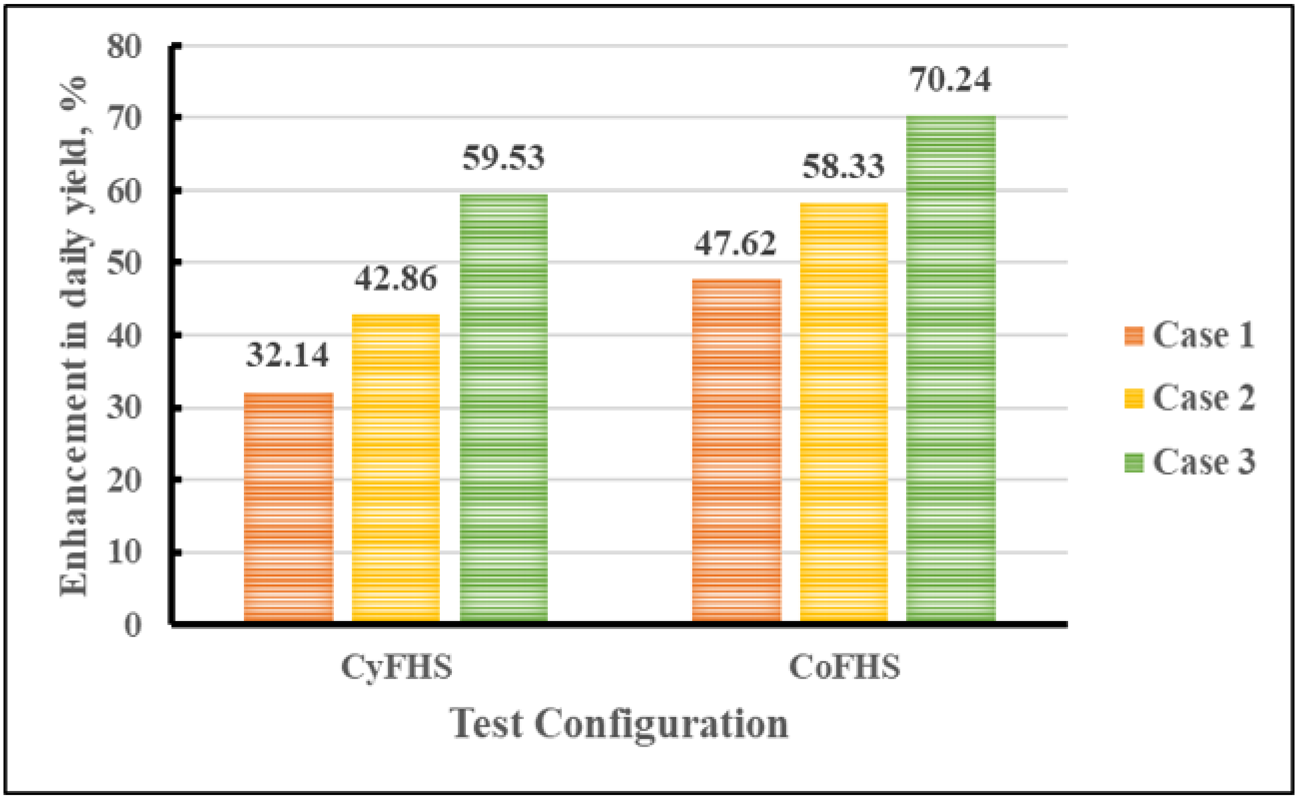

Figure 9

Daily yield enhancement for different cases of CyFHS and CoFHS

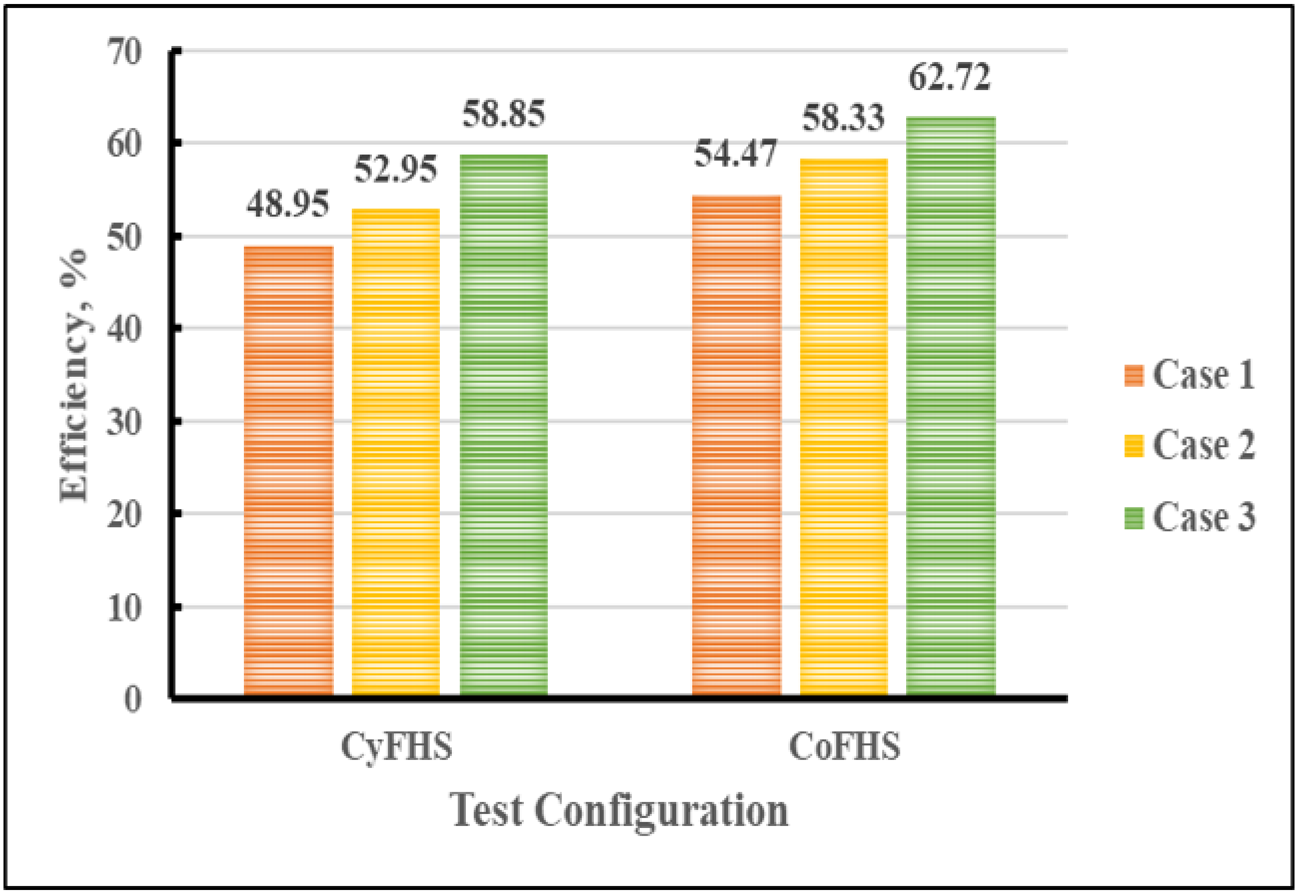

Figure 10

The efficiency for different cases of CyFHS and CoFHS

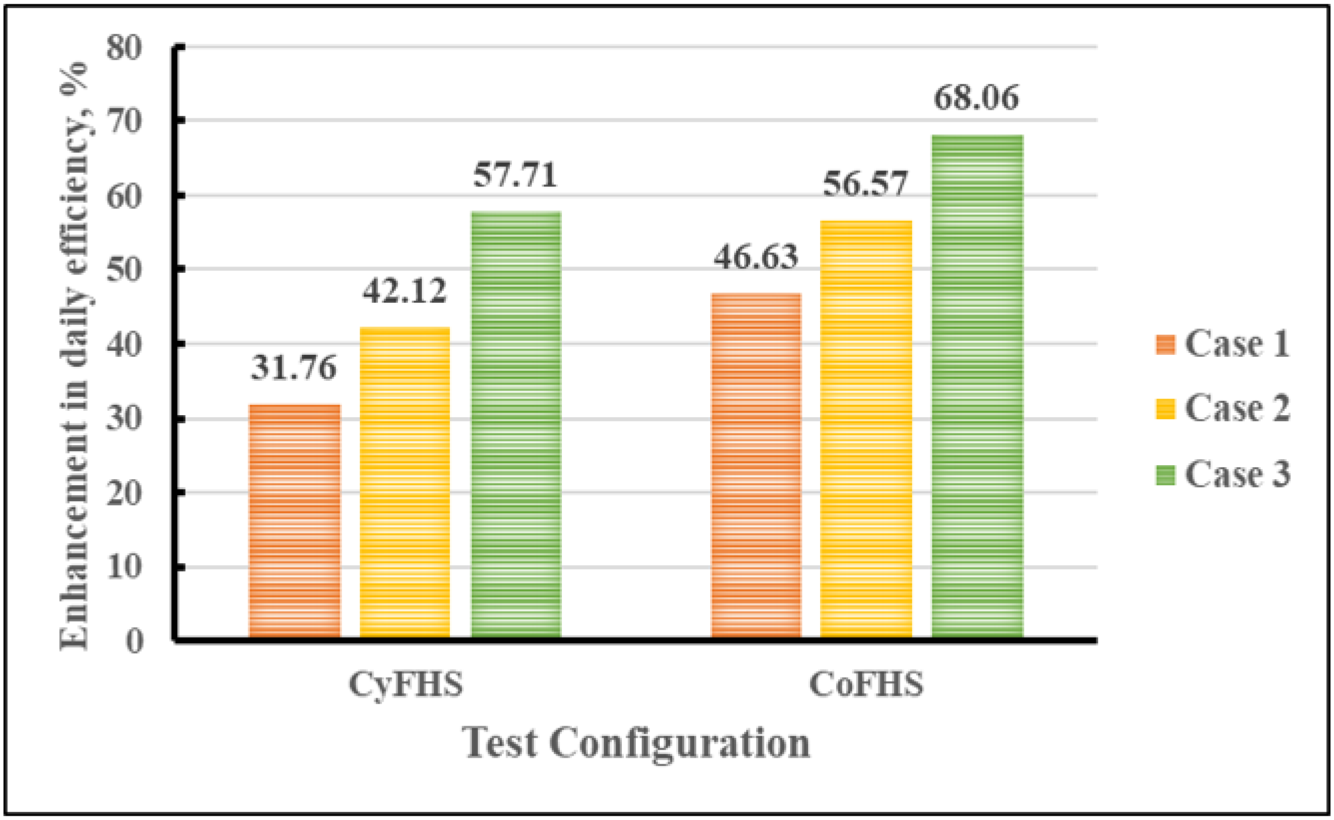

Figure 11

The enhancement in daily efficiency for different cases of CyFHS and CoFHS