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Optimal configuration of a semi-corrugated basin with inverted solar concentrator for performance augmentation of hemispherical shaped solar distiller: a comparative experimental investigation

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ABSTRACT

This study aims to develop a novel design of hemispheric distillers that can achieve the highest performance improvement. To implement this idea, a semi-corrugated absorber basin combined with an inverted solar collector was utilized in order to augment the vaporization rates within the hemispheric distillation basin and thus improve the freshwater yield. The effects of three different pitch distances of the semi-corrugated basin (5, 8, and 12 cm) were investigated to figure out the finest pitch that maximizes the distillation yield of hemispheric distillation systems. To achieve these experimentally, two hemispherical distillers were designed, constructed, and examined, the first is a conventional hemispherical distiller (CHSD) and the second is the developed hemispherical distiller with a semi-corrugated absorber combined with an inverted solar collector (DHSD-SCA&ISC). Besides, three basins with a semi-corrugated absorber (with various pitches of 5, 8, and 12 cm) were designed and implemented for the developed hemispherical distiller. The practical tests were conducted over three consecutive days so that each case of DHSD-SCA&ISC was compared with CHSD. The results presented that the mutual utilization of the inverted solar collector and semi-corrugated basin with a pitch distance of 5.0 cm represents the optimized configuration in the distiller basin that yields the maximum freshwater product. At this case, the distilled product reached 9.54 L/m^2·d with an improvement percentage of 92.73% as compared to CHSD. Moreover, the daily energetic efficiency reached 77.29% with an enhancement percentage rate of 91.45% as compared to CHSD. In addition, the economic assessment findings indicated that the price per 1.0 L of distilled water was reduced by 36.0% compared to the CHSD.

Keywords: Hemispheric solar distiller; Semi-corrugated basin; Inverted solar collector; Optimal pitch distance; Comparative energic-exergic analyses; Enviroeconomic evaluation

1. Introduction

At present, the world's challenges of energy and drinking water issues are dramatically increasing due to the increasing growth of the earth's population and climate change [1,2]. The global crisis of drinkable water deficiency is one of the main challenges that meet developing countries worldwide as a result of the growing globe population, expanding

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irrigated agriculture, and increasing water consumption patterns [3]. Scientists are being researched to figure out innovative technologies and concepts for converting saltwater into freshwater to deal with the freshwater shortage trouble in remote regions [4,5]. Solar distillation is appraised as one of the vital ways used to maintain potable water from saltwater [6,7]. Owing to its unique advantages, water desalination using solar distillers (SD) is a straightforward and economical method for the desalination of salt water for producing potable water [8]. The concept of SD is mainly the saltwater included inside the distiller basin absorbs the solar heat and vaporizes to create a distilled vapor which raises and adjoining passes with the closed top glazier cover surface [9]. As a result of the temperature difference, it condenses and gathers in a collecting trough as a freshwater product. The SDs have diversified merits such as low cost, simplicity, easy manufacturing, no emissions, powered by renewable sources, and appropriateness to remote areas [10]. However, the SDs suffer from their low distillation yield [11]. Scholars are establishing numerous efforts to figure out methods for SDs production improvement; such as the glazier coverage cooling [12], the usage of sliding-wick belts [13], the optimizing the angle of inclination of the glass cover [14], the doping of nanoparticles in the seawater [15,16], the insertion of metal fins [17], phase change materials (PCM) [18], sensible storage materials [19], thermoelectric cooling materials [20], porous materials [18], PV/T waste heat recovery [21], tracked parabolic concentrators [22], hemispheric cover [23], nano-black paintings [24], integration of heat pipes [8], preheating basin seawater by solar water heaters [25,26], spraying feed nozzles [27], and rotative drums [28].

The inclusion of nanoparticles inside the basin of salt water has been proposed as a highly performance enhancer due to their unique thermal–physical characteristics, which assist in the augmentation of the vaporization rates of saltwater. Sharshir et al. [29] indicated experimentally that the utilization of 1.0% of copper oxide and graphite nanoparticles to 0.50 cm seawater deepness of traditional SD combined with glazier coverage cooling yielded an improvement in the distillation yield by 45% and 54%, respectively. In another work, the mutual use of a stepped solar distiller with 1.5% black carbon nanoparticles and linen wicks had higher distillation yield and lower freshwater cost by 80.60% and 47.20%, respectively, compared to conventional SD [15]. Thakur et al. [30] improved the heat transfer behavior and evaporation rates of the basin saltwater using ZnO and CuO nanoparticles within single-slope distiller. It was asserted that the distillation yield was increased by 41.60% and 30.4% utilizing CuO/water and ZnO/water nanofluids, respectively, relative to reference SD. Jathar and Ganesan [31] investigated the influence of glazier cover cooling in a multi-basin SD utilizing three various nanofluids; namely, Al_2O_3, MgO, and TiO_2 nanofluids. Two nanoparticle concentrations (0.20% and 0.10%) were utilized for all cases. It was found that the higher the nanoparticle concentration the maximum freshwater distillation yield. The distillation yield was enhanced by 19.10%, 28.40%, and 41.30% for TiO_2/water, Al_2O_3/water, and MgO/water nanofluids, respectively.

Augmentation of the evaporation area of the saltwater basin is another tool for increasing the heat transport rates from the basin surface to the saltwater; thus, augmenting the freshwater distillation rates. Up to now, diversified studies have investigated the influence of utilizing a corrugated basin on the distillation yield of solar stills. Omara et al. [32] implemented an experimental study on single slope SD with corrugated, finned, and conventional flat absorber basins. It was declared that the distillation yield of the finned and v-corrugated distiller was improved by 40% and 21%, respectively compared to the reference flat basin distiller, at 5.0 cm saltwater depth. Shalaby et al. [33] yielded a 12.0% increase in the distillation yield with the deployment of single slope SD with a v-corrugated absorbent embedded with rewarded PCM container. A pyramidal solar distillatory with a v-corrugated basin and PCM was manufactured and tested by Kabeel et al. [34]. It was drawn that the utilization of v-corrugated basin and PCM achieved an enhancement in the cumulative freshwater output and daily energy efficiency of the pyramidal SD by 87.0% and 88%, respectively over the traditional SD. Two tubular SDs with three different saltwater basin configurations (smooth flat and semicircular corrugated) were experimentally studied by Elshamy and El-Said [35]. The heat transfer behaviour of the two distillers was assessed based on energic, exergic, and economic analyses. They declared that the distillation yield of the corrugated semicircular tubular distiller was enhanced by 26.50% compared to the smooth flat tubular distiller with an improvement in exergic and energic efficiencies of 23.7% and 26.0%, respectively. Katekar and Deshmukh [36] modulated the traditional single slope SD by using a corrugated stepped basin. The findings revealed that the corrugated stepped SD had a daily distillation yield of 3.39 kg/m^2 as compared to 1.37 kg/m^2 for tradtional sigle slope SD. Hammad et al. [37] carried out an experimental investigation to improve the distillation yield of a single-slope SD. It utilized a corrugated basin with rewarded paraffin wax container to augment the vaporization area for efficacious heat transport of saltwater. It was found that the energic efficiency and accumulated distillation yield of the modified distiller were improved by 72.70% and 63.57%, respectively, compared to the reference distillatory.

Some works have been seeking to enhance the freshwater yield of the solar distillers utilizing different shapes of metal fins fitted to the surface of the saltwater basin. Abdelgaied et al. [38] researched the influence of utilizing hollow circular and square fin configurations on the performance of the tubular distillation system and compared them with the reference tubular free of fins. It was shown that an improvement in the tubular distillatory product by 33% and 47.3% for the hollow circular and square fins, respectively. Modi and Jani [39] utilized circular and square fins integrated with the saltwater basin to improve the performance of the double slope distillatory. The findings showed that the usage of circular fins improved the distillery distillation yield by 54.2% compared to the square fins at 10 mm saltwater depth. Alatawi et al. [40] analyzed the combined impact of utilizing wicked vertical fins and trough parabolic collector on the tubular solar still performance. They showed that the distillation yield and energic effectiveness were ameliorated by 45.0% and 41.10%, respectively.

The summarized literature indicates that various attempts have been established to promote the potable water production of conventional SDs. The outlined findings inferred that the enhancement of performance of the distiller is attained by: (a) Doping nanoparticles inside the basin saltwater due to their unique thermal-physical characteristics; (b) Augmentation of the evaporation area of the saltwater basin using v-corrugated basins for increasing the heat transport rates from the basin surface to the saltwater; (c) Inserting different shapes of metal fins fitted to the surface of the saltwater basin; (d) Integration rewarded PCM container to promote the heat source availability to augment the distiller's nocturnal product.

Researchers are still seeking out cost-efficient methods to augment the thermo-economic performance of SDs because of the limitation of low distillation yields. Therefore, the novelty of this work attempts in developing an improved hemispheric solar distiller that could provide a significant amount of freshwater using an optimized semi-corrugated shaped basin integrated with rewarded inverted solar collector, which has rarely been studied in the survey. In this present paper, an innovative design of a hemispheric solar distiller incorporating a semi-corrugated absorber basin and integrating an inverted solar heater is presented. The inverted solar collector is a curved transparent reflector embedded with an internal solar concentrator in which the sun rays reflect on the rewarded surface of the circular basin of the hemispheric distiller as displayed in Fig. 1. This low-cost concept is utilized to reduce the backward thermal losses and further improve the vaporization rates of salt water inside the basin. Furthermore, to obtain the optimized pitch of semi-corrugated absorbers that is combined with an inverted solar collector, we studied three various pitches of semi-corrugated absorbers (5, 8, and 12 cm). As a result, the objectives of this research can be pointed out as follows:

- Assessment experimentally of the impact of utilization of semi-corrugated shaped basin embedded rewarded inverted solar collector within the hemispheric distiller to augment freshwater production.
- Two hemispherical distillers are designed, constructed, and tested, the first is a conventional hemispherical distiller (CHSD) as a reference and the second is the developed hemispherical distiller via semi-corrugated absorber combined with an inverted solar collector (DHSD-SCA&ISC).
- To obtain the optimized pitch of the proposed semi-corrugated absorber, three basins with a semi-corrugated absorber (with various pitches of 5, 8, and 12 cm) are designed and implemented for the developed hemispherical solar distillers (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm).
- The practical tests are conducted over three consecutive days, to compare the performance of these three different configurations of developed hemispherical solar distillers (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC

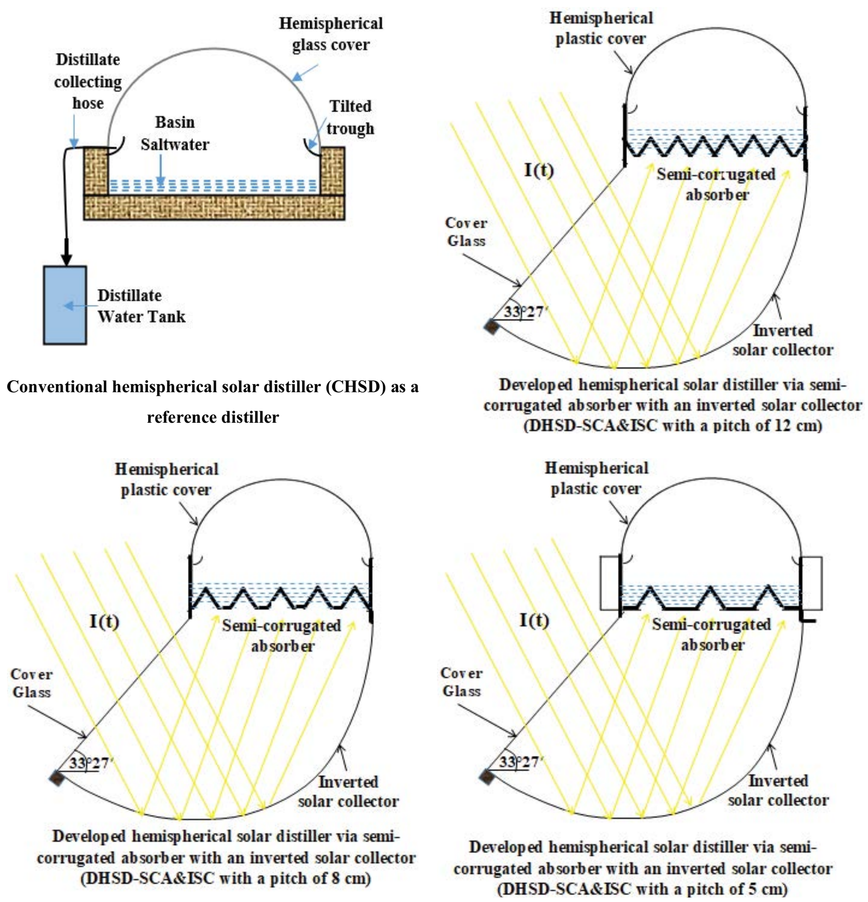

Fig. 1. A 2D portrayal of the experimental models.

with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm) with the CHSD under same weather of the ElOued, Algeria (33.37°N, 6.85°E).

- In addition, an energic–exergic analyses of the four studied hemispheric distillers are developed to find out the daily freshwater productivity and energy daily efficiency. Besides, a cost analysis is established to appreciate the cost per distillate liter for the four hemispheric distillers.

2. Experimental methods

2.1. Experimental system description

The experimental set-up includes two combined efficacious modulations made to the design of hemispherical solar distillers which aims to fulfill the finest performance improvement. These modifications are the semi-corrugated absorber combined with an inverted solar collector in order to boost the evaporation rates within the distiller basin and thus improve its yield. To obtain the optimized pitch of semi-corrugated absorbers that was combined with an inverted solar collector, we studied the three various pitches of semi-corrugated absorbers (5, 8, and 12 cm). To achieve these aims, we constructed the experimental test rig containing two hemispherical distillers that were designed, built, and tested, the first is a CHSD as a reference still and the second is a developed hemispherical distiller via semi-corrugated absorber combined with an inverted solar collector (DHSD-SCA&ISC). Also, to obtain the optimized pitch of semi-corrugated absorbers, three basins with a semi-corrugated absorber (with various pitches of 5, 8, and 12 cm) were designed and implemented for the developed hemispherical solar distillers (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm). Fig. 1 shows the two-dimensional drawing of the conventional distiller (CHSD) as a reference distiller and three developed hemispherical solar distillers via a semi-corrugated absorber combined with an inverted solar collector (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm).

Fig. 2 shows the basin configurations of the three developed hemispherical solar distillers via a semi-corrugated absorber combined with an inverted solar collector (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm). The basins of the semi-corrugated absorber are constructed from mild steel that is 2 mm thick, has a height of 31 mm, and has an angle of 90° between any two tops or bottoms. The corrugated triangle of each basin is designed with an angle of inclination of 60o, with a horizontal base of 4 cm and a height of 1.75 cm. For the first basin of the developed hemispherical solar distiller, the pitch of the semi-corrugated absorber has been set at 5 cm (DHSD-SCA&ISC with a pitch of 5 cm). For the second basin of the developed hemispherical solar distiller, the pitch of the semi-corrugated absorber has been set at 8 cm (DHSD-SCA&ISC with a pitch of 8 cm). For the third basin of the developed hemispherical solar distiller, the pitch of the semi-corrugated absorber has been set at 12 cm (DHSD-SCA&ISC with a pitch of 12 cm). A 0.1-m-long iron leg supported the inverted absorber collector, which was mounted on it. Use is made of a cover glass that is 3 mm thick, 0.51 m long by 0.41 m wide, and tilted 33° horizontally toward the south. Aluminum foil sheets are used to cover the inner and side walls of the inverted absorber, where sunlight reflects off of them and

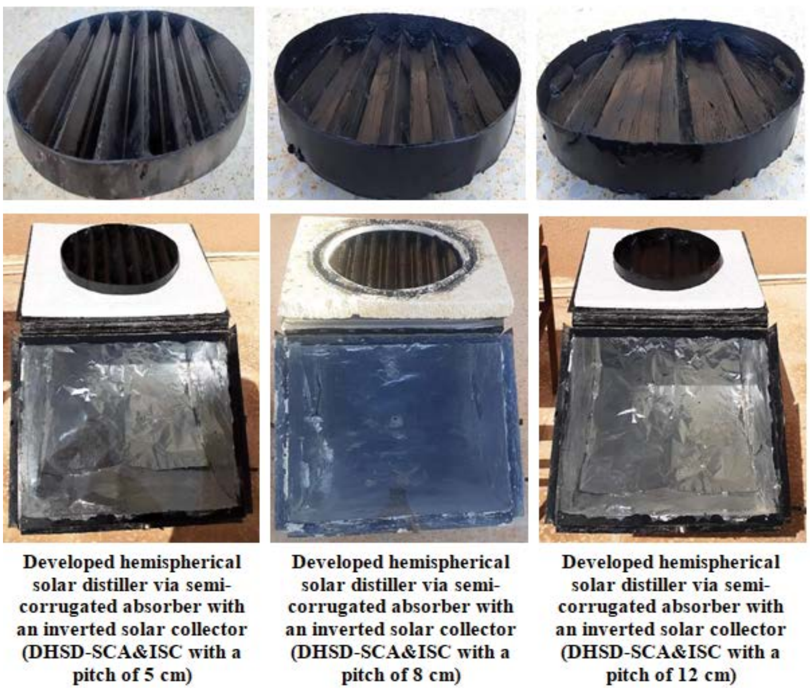

Fig. 2. A photograph of the basins of the developed hemispherical solar distiller via a semi-corrugated absorber combined with an inverted solar collector.

heats the plate of the distiller's corrugated basin, which in turn heats the saltwater in the basin for better vaporization. The wheels of the standing of VHSD-ISTR are installed to easily adapt the modified hemispheric distiller in the south orientation. A 3.0 mm thick glazier coverage (0.40 m width and 0.50 m length) was utilized to cover the interface of the inverted solar collector and inclined horizontally at an angle of 33°, (ElOued latitude, Algeria 33.37 N). To minimize the heat lost from the distiller, the exterior of the basin is lined with 50 mm thick polystyrene that has a lower thermal conductance coefficient of 0.028 W/K·m. The photographic view of the conventional hemispherical distiller (CHSD) and developed hemispherical distiller via a semi-corrugated absorber combined with an inverted solar collector (DHSD-SCA&ISC) are shown in Fig. 3.

2.2. Experimental procedure

The practical tests were conducted over three consecutive days, to compare the performance of these three different configurations of developed hemispherical solar distillers (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm) with the reference distiller (CHSD) under same weather conditions. In order to get an optimized pitch of a semi-corrugated absorber that was combined with an inverted solar collector to realize the best distillers yield. During the experimentation tests, the mass of basin water in all cases of hemispherical solar distillers was kept constant at 17 kg/m^2. The measured data are recorded for 12 h from 7:00 AM–7:00 PM on September 2022. The experimentation test location is the El Oued, Algeria climate (33.37°N, 6.85°E).

Table 1
Technical characteristics of measuring tools

Measurement device	Accuracy	Range	Uncertainty
Thermocouples	±2.50%	0–100°C	±1.443%
Pyranometer	±3.0 W/m^2	(0–2,000) W/m^2	±1.732%
Vane anemometer	±0.30 m/s	0–30 m/s	±0.173%
Graduated beaker	±1.0%	0–500 mL	±0.577%

The accumulated distilled water in beakers is measured by using an enumerated measuring cylinder. The various component temperatures of distillers were measured utilizing K-type thermocouples. The thermocouples were placed at the absorber, saltwater basin, and inner surfaces of the glass cover. A thermocouple was also used to measure the ambient temperature. Also, the intensity of solar rays was measured by employing a solar meter. These observations are recorded from 7:00 AM–7:00 PM on an hourly basis.

2.3. Uncertainty analysis

Table 1 illustrates the accuracy, range, and errors of measuring instruments. Technical characteristics of measuring tools utilized in the experiments are clearly listed in Table 1, namely, the standard ranges, accuracies, and uncertainties of the measurement instruments. From the available manufacture's accuracies of the measuring tools, the uncertainty of each measuring device (U) can be computed using its corresponding accuracy (ε) as given [41]:

$$U = \frac{\varepsilon}{1.723} \quad (1)$$

The overall uncertainty percentage of the conducted experiments can be calculated using Eq. (2) in terms of the uncertainty of each measuring device [41]:

$$U_t = \sqrt{\left[U_1^2 + U_2^2 + U_3^2 + \ldots + U_n^2\right]} \quad (2)$$

So, the percentage of overall uncertainty fulfilled for the conducted measurements is 2.33%.

2.4. System performance

The effectiveness of the four cases of hemispherical stills is assessed by applying energy analyses for calculation and comparison of the daily energy efficacy of the four investigated stills. Daily thermal efficiency of CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm was calculated as:

Fig. 3. A photograph of experimental test-rig.

$$\eta_{\text{daily.th}} = \frac{\sum \dot{m}_{\text{dw}} h_v}{\sum I(t) A_{\text{ab}} \times 3{,}600} \times 100, (\%) \quad (3)$$

where $\dot{m}_{\text{dw}}$ is hourly distilled yield (kg/m²·h); A_{ab} is absorption area (m²); $I(t)$ is the intensity of solar rays (W/m²); T_w is water basin temperatures (°C), and h_v is latent heat (J/kg) which was calculated as:

$$h_v = 10^3 \left[\begin{array}{c} 2501.9 - 2.40706 T_w + 1.192217 \times 10^{-3} T_w^2 \\ -1.5863 \times 10^{-5} T_w^3 \end{array} \right] \quad (4)$$

Daily exergy efficiency η_{ex} is calculated as given [35]:

$$\eta_{\text{ex.}} = \frac{\sum \text{Ex}_{\text{out}}}{\sum \text{Ex}_{\text{in}}} \quad (5)$$

Input exergy to a basin Ex_{in} is computed as [35]:

$$\text{Ex}_{\text{in}} = A_a \times I(t) \left[1 - \frac{4}{3} \times \left(\frac{T_a + 273.15}{6{,}000} \right) + \frac{1}{3} \times \left(\frac{T_a + 273.15}{6000} \right)^4 \right] \quad (6)$$

Output exergy from a basin Ex_{out} is calculated as [35]:

$$\text{Ex}_{\text{out}} = h_{e,w-g} \times A_a \times \left(T_{\text{bw}} - T_g \right) \times \left(1 - \frac{T_a}{T_{\text{bw}}} \right) \quad (7)$$

Evaporative heat transfer coefficient $h_{e,w-g}$ is calculated as [35]:

$$h_{e,w-g} = 16.273 \times 10^{-3} \times h_{c,w-g} \times \left(\frac{P_{\text{bw}} - P_g}{T_{\text{bw}} - T_g} \right) \quad (8)$$

Convective heat transfer coefficient $h_{c,w-g}$ is calculated as [35]:

$$h_{c,w-g} = 0.884 \times \left[\left(T_{\text{bw}} - T_g \right) + \frac{\left(T_{\text{bw}} + 273.15 \right) \times \left(P_{\text{bw}} - P_g \right)}{\left(268900 - P_{\text{bw}} \right)} \right]^{(1/3)} \quad (9)$$

3. Results and discussion

The performance of the developed hemispheric solar distiller system is directly influenced by the sun's intensity and the climatic environment. As a result, the experiment calls for hourly measurements of the weather temperature and intensity of solar irradiation. During the experiment's test hours, Fig. 4 displays the hourly variation in solar intensity and the surrounding temperature. The radiation intensity increases up till noontime on the three test days before gradually decreasing the rest of the day up till it reaches its minimal level just before sunset. Around 15:00, the maximal measured surrounding air temperature was attained. This suggests that since the test configurations are all impacted by the same climatic and environmental factors, more precise comparisons may be made between them.

The experimentation tests were conducted for three consecutive days in September 2022, to illustrate the influences of a semi-corrugated absorbent that combined with an inverted solar collector on the basin water temperature of developed hemispherical solar distillers. Fig. 5 presents the diurnal changes in basin saltwater temperatures during the test configurations (CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm). It is evident that the saltwater basin temperatures of DHSD-SCA&ISC with a pitch of 5 cm are more than that of other developed hemispherical solar distillers. The maximum basin water temperature was recorded at approximately 3:00 PM, which reached 71, 78, 77, and 75ºC for CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm, respectively. Also, as shown in Fig. 6, the temperatures difference between the water basin and cover varies between 1°C–17°C, 1°C–24°C, 1°C–23°C, and 1°C–21°C for CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm, respectively. These results presented that the combination of a semi-corrugated absorber with an inverted solar collector represents a good choice which causes to raises the water basin temperature, thus improving the evaporation rate, and then improving the distillate productivity. Further, the usage of an inverted solar collector makes an additional solar heat source by concentrating more solar flux onto the semi-corrugated surface, which

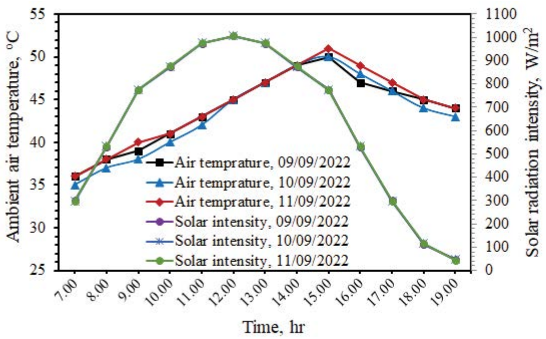

Fig. 4. Diurnal variations in solar rays intensity and weather temperature throughout the testing days of the hemispheric distillers.

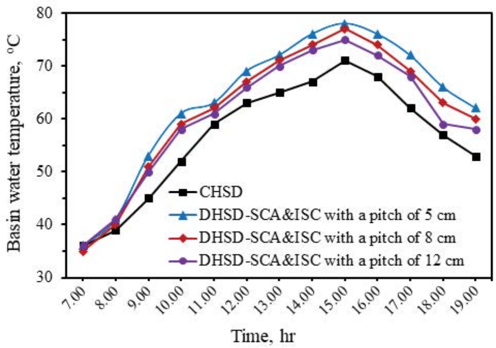

Fig. 5. Diurnal variations in saltwater basin temperatures for CHSD and DHSD-SCA&ISC with various pitch distances.

results in boosting the water temperature and minimizing the heat losses of the modified hemispherical still. Hence, the temperatures of the basin and saline water in DHSD-SCA&ISC were larger than that of CHSD. In addition, as can be seen from the results presented in Figs. 5 and 6, the water basin temperature increases with reduces the pitch of the semi-corrugated absorber that was combined with an inverted solar collector. These are mainly because of the increase in the heat transfer area, as well as the rise in the intensity of absorbed solar rays by decreasing the pitch of the semi-corrugated absorbent basin of the distiller.

Fig. 7 demonstrates the diurnal changes in the basin absorbent temperature between the inversed solar collector and the distillation basin. It is evident that the absorber temperature between the inversed solar collector and the distillation basin of the developed hemispherical solar distillers via a semi-corrugated absorbent basin combined with an inverted solar collector (DHSD-SCA&ISC) depends on the pitch of the semi-corrugated absorbent geometry. As declared in Fig. 7 the basin absorbent temperatures were various between 36°C–80°C, 35°C–78°C, and 36°C–77°C for DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm, respectively. These results showed that the maximum absorber temperature was recorded for DHSD-SCA&ISC with a pitch of 5 cm. These results presented that the developed hemispherical solar distiller (DHSD-SCA&ISC with a pitch of 5 cm) represents an optimal configuration that achieved the highest distiller yield.

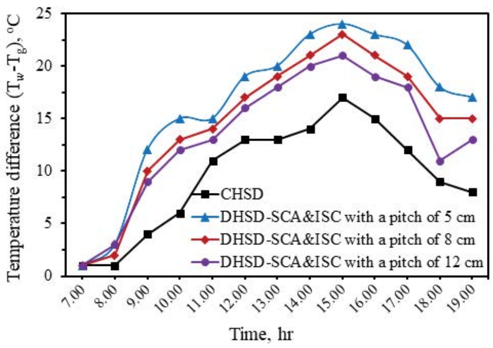

Fig. 6. Diurnal changes in temperature difference between the saltwater basin and cover for CHSD and DHSD-SCA&ISC with various pitch distances.

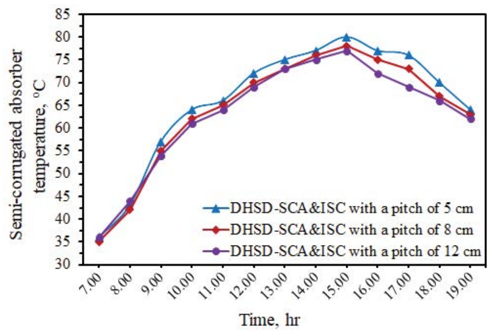

Fig. 7. Hourly variation of the semi-corrugated absorber temperature for three developed hemispherical solar distillers.

Fig. 8 demonstrates the influences of the pitch distance on semi-corrugated hemispheric still on the hourly distilled product. As seen in Fig. 8, the maximal hourly product reached 0.8, 1.15, 1.08, and 1.02 L/m²·h for CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm, respectively. As demonstrated in Fig. 9 the cumulative productivity reached 4.95, 9.54, 8.49, and 7.85 L/m²·d for CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm, respectively. These results presented that the combination of a semi-corrugated absorber with an inverted solar collector (DHSD-SCA&ISC with a pitch of 5 cm) represents a good design configuration that achieves the highest performance.

Table 2 and Fig. 9 compare the cumulative distillate yield of a conventional hemispherical distiller (CHSD) and three suggested developed hemispherical solar distillers (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm) and their improvement. As shown in this table the cumulative distillate yield of CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm,

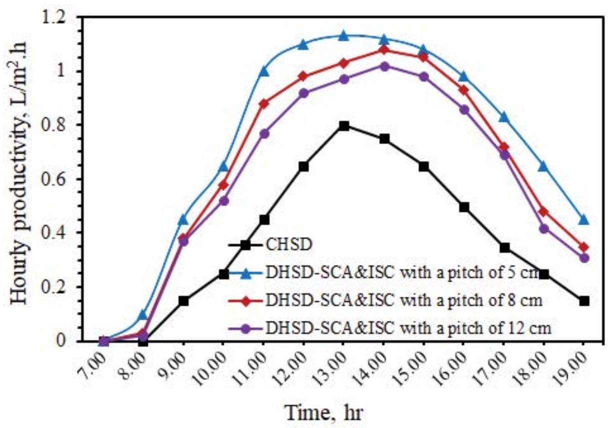

Fig. 8. Hourly variations of distillate yield of CHSD and DHSD-SCA&ISC with various pitch distances.

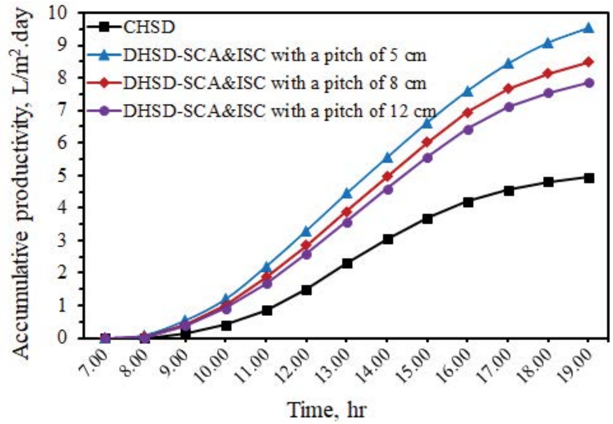

Fig. 9. Cumulative distillate yield of CHSD and DHSD-SCA&ISC with various pitch distances.

Table 2
Comparison of the cumulative yield and corresponding improvement rates of the developed hemispheric solar distillers in this work

Date of the experiment	Daily yield, kg/m²				Distillation yield Improvement (%)
	CHSD	DHSD-SCA&ISC with a pitch of 5 cm	DHSD-SCA&ISC with a pitch of 8 cm	DHSD-SCA&ISC with a pitch of 12 cm	
09-09-2022	4.95	9.54	–	–	92.73
10-09-2022	4.95	–	8.49	–	71.52
11-09-2022	4.95	–	–	7.85	58.59

and DHSD-SCA&ISC with a pitch of 12 cm reached 4.95, 9.54, 8.49, and 7.85 L/m²·d, respectively. The productivity improvement for DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC reached 92.73%, 71.52%, and 58.59%, respectively, when compared to CHSD. This superiority in distilled water yield is due to the higher basin brackish water temperature and evaporation rates of DHSD-SCA&ISC with various pitch distances compared to CHSD as previously explained. More specifically, the inclusion of a semi-corrugated basin augmented significantly the freshwater product by ameliorating the vaporization rates by providing more heat transport surface area in the absorbent basin. Further, the usage of an inverted solar collector acts as an extra heat solar source by concentrating more solar irradiation onto the outer surface of the corrugated absorbent, which increased the water temperature and minimized the back heat losses of the developed hemispheric stills of several pitch distances. So, the rates of freshwater productivities of DHSD-SCA&ISC of several pitch distances (12, 8, and 5 cm) were much larger than that of TFBHD. Moreover, the hindmost outputs of the DHSD inferred that the maximal daily distilled productivities of the DHSD are attained by the usage of semi corrugated basin with a pitch distance of 5.0 cm, followed by semi corrugated basin with a pitch distance of 8.0 cm, and the lowest daily distilled productivities of the DHSD are produced by the usage of semi corrugated basin with a pitch distance of 12.0 cm, respectively. This is principally due to the increment in the absorption surface area with the decrement in the pitch space of the semi corrugated, and thus promotes the vaporization areas and heat transfer rates from the semi corrugated basin to basin saltwater, which in turn augments the distilled freshwater production.

The daily efficacy of the CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm are contrasted in Fig. 10. The daily thermal efficiency ratings of DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm are 77.29%, 68.69%, and 63.69%, respectively, in comparison to CHSD daily efficiency of 40.37%. These results indicate efficiency gains of 91.45%, 70.15%, and 57.77%, respectively.

The daily exergy efficacy of the CHSD, DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm are presented in Fig. 11. The daily exergy efficiency ratings of DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm are 9.73%, 7.36%, and 5.92%, respectively, in comparison to

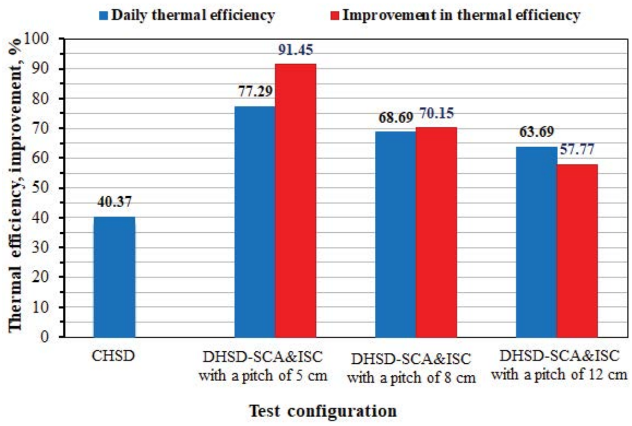

Fig. 10. Daily thermal efficiency of CHSD and DHSD-SCA&ISC with various pitch distances.

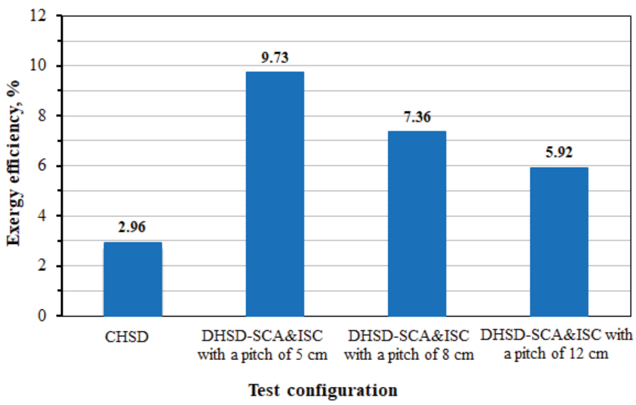

Fig. 11. Daily exergy efficiency of CHSD and DHSD-SCA&ISC with various pitch distances.

CHSD daily exergy efficiency of 2.96%. These results indicate the inverted solar collector combined semi-corrugated basin with the finest pitch distance of 5.0 within the hemispheric distillers represents a good design configuration that achieves the highest exergy efficiency.

4. Comparative assessment of distilled yield of the current study with other previous still designs

The production of distilled water from the current study and various published still designs are compared in Table 3. The single slope SS with circular hollow fins can increase daily productivity by a maximum of 43.86% as reported by Jani and Modi [39]. On the other hand, the hemispherical SS with a flat absorber basin increases daily productivity by a minimum of 14.30%, as yielded by Attia et al. [42]. The percentage increase in daily productivity from developed hemispherical solar distillers in the current study at different pitch distances (5, 8, and 12 cm) between the semi-corrugated absorber is obtained as 92.73%, 71.52%, and 58.59%, respectively. The accomplished enhancements in the daily yield of the studied hemispheric still integrated with an inverted solar collector and semi-corrugated basin revealed a very good daily yield compared to those produced by other previous designs of solar stills.

5. Cost analysis

The cost analysis findings and details of the CHSD and three suggested developed hemispherical solar distillers (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of

Table 3
Comparison of the increase in daily productivity compared to the present study

References	Design of distiller	Proposed modification	Daily productivity (L/m²·d)	Percentage increase in daily productivity (%)
[39]	Single slope	- Circular hollow fins	1.49	43.86
		- Square hollow fins	0.94	38.49
[29]	Single slope	1.0% graphite nanoparticle	4.00	54.00
		1.0% CuO nanoparticles	3.76	45.0
[33]	Single slope	Paraffin wax container and corrugated basin	3.76	12.00
[35]	Tubular	Semicircular corrugated basin	4.30	26.47
[38]	Tubular	- Hollow square fins	5.52	33.00
		- Hollow circular fins	6.11	47.30
[43]	Tubular	Parabolic concentrator	4.71	25.050
[34]	Pyramid	V-corrugated basin with PCM storage bed	6.60	86.40
[42]	Hemispherical	- Iron flat trays	4.40	14.30
		- Iron V-corrugated trays	5.50	42.85
Present study	Developed hemispherical solar distiller	- DHSD-SCA&ISC with a pitch of 5 cm	9.54	92.73
		- DHSD-SCA&ISC with a pitch of 8 cm	8.49	71.52
		- DHSD-SCA&ISC with a pitch of 12 cm	7.85	58.59

Table 4
Cost analysis of the components of DHSD-SCA&ISC with various pitch distance

Description amount	CHSD	DHSD-SCA&ISC (5 cm)	DHSD-SCA&ISC (8 cm)	DHSD-SCA&ISC (12 cm)
Fabrication and materials cost (DZD)	9,000	9,000	9,000	9,000
Price of an inverted solar collector (DZD)	–	1,400	1,400	1,400
Price of the semi-corrugated basin (DZD)	–	700	600	500
Capitalized total investment cost (DZD)	9,000	11,100	11,000	10,900
Yearly discounting rate (%)	12	12	12	12
Lifetime of the distiller (y)	10	10	10	10
Capitalized recovery factor	0.17698	0.17698	0.17698	0.17698
Yearly fixed cost (DZD)	1,592.86	1,964.52	1,946.83	1,929.13
Maintenance/operating cost (DZD)	477.857	589.357	584.048	578.738
Annual salvage cost (DZD)	102.571	126.504	125.365	124.225
Total yearly cost (DZD)	1,968.14	2,427.38	2,405.51	2,383.64
Daily produced water (kg/m²·d)	4.95000	9.54000	8.49000	7.85000
Annual water product (L/m²·y)	1,336.50	2,575.8	2,292.3	2,119.5
Price of 1.0 L of distilled water (DZD/L)	1.47261	0.94237	1.04938	1.12462
Price of 1.0 L of distilled water ($/L)	0.010971	0.008378	0.007818	0.007021
Market cost of 1.0 L distilled water (DZD/L)	60	60	60	60
Discounted payback period (d)	31	19	22	23

(1$ = 134.23 DZD, 1€ = 154.48 DZD)

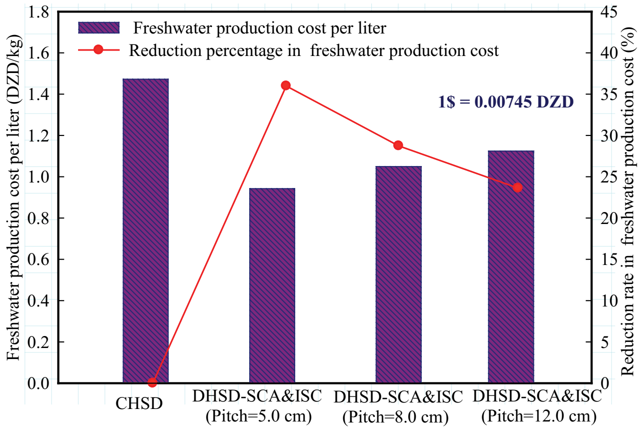

Fig. 12. Price of 1.0 L of distilled water of CHSD and DHSD-SCA&ISC with various pitch distances.

12 cm) are analyzed and tabulated in Table 4. The cost analysis formulation reported by Thakar et al. [44] is considered in this research. As presented, a 31-d payback period is necessary to reclaim the total cost of CHSD. However, a payback period is necessary to reclaim the total cost of the developed hemispherical solar distillers (DHSD-SCA&ISC with a pitch of 5 cm, DHSD-SCA&ISC with a pitch of 8 cm, and DHSD-SCA&ISC with a pitch of 12 cm) were reduced to 19 d, 22 d, and 23 d, respectively. The outcomes demonstrated in Table 4 of cost calculations concluded that the cost of 1.0 L of distilled water is estimated to be 0.94237, 1.04938, 1.12462, and 1.47261 DZD/L for DHSD-SCA&ISC 5.0 cm pitch, DHSD-SCA&ISC 8.0 cm pitch, DHSD-SCA&ISC 12.0 cm pitch, and CHSD, respectively. This refers to the decrement in the price of 1.0 L of distilled water for the hemispheric solar stills with semi-corrugated absorber and inerted solar heater is decreased by 36.0%, 28.74%, and 23.63%, respectively, compared to that of CHSD, when the pitch distances are 5, 8, and 12 cm, respectively, as highlighted in Fig. 12. Moreover, it also can be inferred that the cost of 1.0 L of distilled water produced by the proposed hemispheric distillation system is very competitive to the Algerian desalination market which significantly lower than the price of 1 L of mineral distilled water in the Algerian desalination market (60 Algerian dinars).

6. Conclusions

The current work attempts to figure out the effect of the pitch distance of a semi-corrugated absorber basin on the performance of the hemispheric solar distiller. Three basins with a semi-corrugated absorbent (with various pitches of 5, 8, and 12 cm) were designed and implemented for the developed hemispherical distiller to figure out the finest pitch that maximizes the distillation yield of hemispherical solar distillers. For further enhancement, an inverted solar collector was implemented with the rewarded surface of the semi-corrugated basin to minimize the back heat losses and further improve the vaporization rates of salt water inside the basin. The key results can be highlighted as follows:

- The mutual utilization of the inverted solar collector combined semi-corrugated basin with a pitch distance of 5.0 cm represents the optimized configuration in the still basin that yields the highest freshwater yield of the hemispheric distillers.
- The distilled yield of the conventional hemispheric solar distiller (CHSD) gave 4.95 L/d·m^2, whereas the amalgamation of the inverted solar collector combined semi-corrugated basin enhanced the freshwater product to 9.54, 8.49, and 7.85 L/d·m^2, for various pitch distances of 5.0, 8.0, and 12.0 cm, respectively.
- The amelioration in the daily distilled showed up 92.73%, 71.52%, and 58.59%, over the CHSD, for different pitch distances of the semi-corrugated basin of 5.0, 8.0, and 12.0 cm, respectively.
- The daily energetic efficiency of the modified hemispheric stills utilizing the inverted solar collector combined semi-corrugated basin reached 77.29%, 68.69%, and 63.69%, for different pitch distances of a semi-corrugated basin of 5.0, 8.0, and 12.0 cm, respectively, compared to 40.37% attained by the CHSD. These results indicate an enhancement in the energy efficiency of 91.45%, 70.15%, and 57.77%, for different pitch distances of the semi-corrugated basin of 5.0, 8.0, and 12.0 cm, respectively.
- The daily exergetic efficiency of the modified hemispheric stills utilizing the inverted solar collector combined semi-corrugated basin obtained as 9.73%, 7.36%, and 5.92% for several pitch distances of a semi-corrugated basin of 5.0, 8.0, and 12.0 cm, respectively, compared to 2.96% yielded by the CHSD.
- The outputs of the economical assessment asserted that the utilization of the inverted solar collector combined semi-corrugated basin with a pitch distance of 5.0 declined the price per 1.0 L of the distilled water by 36.0% over the CHSD.
- It can be proposed that the inverted solar collector combined semi-corrugated basin with the finest pitch distance of 5.0 within the hemispheric distillers represents a good design configuration that achieves the highest distilled yield and maximal energic-enviro-economic performance of the hemispheric distillation systems.

Nomenclature

Abbreviations

CHSD	—	Conventional hemispherical solar distiller
DHSD-SCA&ISC	—	Developed hemispherical solar distiller with a semi-corrugated absorbent combined with an inverted solar collector
DZD	—	Algerian dinar
SD	—	Solar distiller
PCM	—	Phase change materials

Symbols

A_{ab}	—	Absorber basin area, m^2
$I(t)$	—	Solar irradiation, W/m^2
h_v	—	Evaporation latent heat, kJ/kg
T_a	—	Ambient temperature, °C
T_s	—	Sun temperature, °C

T_w	—	Temperature of basin water, °C
$\dot{m}_{dw}$	—	Hourly water product, kg/h
U_t	—	Overall uncertainty percentage, %
$\eta_{daily,th}$	—	Thermal daily efficiency, %
$\eta_{daily,ex}$	—	Exergy daily efficiency, %

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