

Article

Experimental Performance Investigation of an Original Rotating Solar Still Design under Realistic Meteorological Conditions

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Abstract: This research article proposes a novel design of solar still; furthermore, it investigates, experimentally, its thermal and productivity performances, as well as its efficiency, under the realistic meteorological conditions of the city of Gafsa, Tunisia (34.4311° N, 8.7757° E), in terms of ambient temperature and solar irradiance. The novel proposed design presents a cylindrical solar still with a rotating transparent plastic (Plexiglass) cover, wiped continuously on the inner surface. A specific technological configuration of the evaporation and condensation compartments is elaborated. A real prototype is manufactured in order to carry out the performance experimental investigation. A performance comparison is carried out between the cylindrical transparent plastic cover rotating and it being fixed, for two experimentation days presenting slightly different meteorological conditions. The experimental water and plastic cover temperatures, the hourly and the cumulative water production, as well as the hourly efficiency are deeply quantified and interpreted.

Keywords: solar still; novel design; rotating cover; transparent plastic (Plexiglass); experimental investigation; thermal performance; water production performance; efficiency



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1. Introduction

The shortage of potable/drinking [1,2] water is increasingly becoming a major social health problem that affects hundreds of millions, or even billions of human beings around the world [3–8]. Indeed, this problem is partially handled by some technologies associated with water reuse and desalination [9,10]. Solar-powered desalination technologies [11–17] permit the sustainable supply of potable water and fossil energy saving. The sustainability of such desalination technologies is assessed in several interesting works [18–23]. The theory of solar stills is widely investigated in the literature. Some very interesting and relevant works are noticed about the history of solar stills and their basic principle design classifications [24–28], heat and mass transfer and thermodynamic [24–26], performance and productivity, cost reduction for various designs [27,28] and mathematical modeling [28]).

The literature of the past three years reveals several interesting experimental investigations on the performance of novel designs associated with solar-powered desalination systems. Jianwei Xiao, et al. [29] experimentally investigated, under different conditions, a bubbling humidification–dehumidification desalination system heated by concentrated solar irradiance (using a Fresnel lens). The system details, as well as the operating mode, are explained. Principal results show that the maximum and the cumulative freshwater

productivity reached 1.24 L/h/m^2 (at 980 W/m^2) and $5.61 \text{ L/m}^2/\text{day}$ (with a thermal efficiency of 69% in October in Beijing), respectively. The cost of the produced freshwater is around $0.027 \text{ \$/L}$. Erdem Cuce et al. [30] experimentally investigated (during one week in July) a novel solar distillation unit with a passive booster reflector and sensible energy storage. Neither thermal insulation nor a cooling system was considered (as a research work, Part 1). Principal results showed that the total water production is around 2197.4 mL . It was deduced that the water productivity strongly depends on the existence of an efficient cooling system, as well as thermal insulation. Pinar Mert Cuce et al. [31] extended the experimental investigation referenced in [25] to integrate thermal insulation and a cooling system (as a research work, Part 2, compared to Part 1). Technical details, for such extensions, were provided. Principal results showed that the average efficiency of water productivity is enhanced by 112.7% with a cumulative water production of around $1.34 \text{ L/m}^2/\text{day}$. Hui Xu et al. [32] experimentally investigated and numerically optimized a novel desalination system using a weak air compression process, under different operating parameters (seawater and moist air parameters). The proposed novel system presents a high heat recovery ratio. A gained output ratio equivalent is proposed as a new performance index in order to objectively assess the comprehensive performance from thermal and electrical energy. A particularly interesting result showing the gained output ratio equivalent for the proposed system is among the best record reported in similar research with a value up to 2.6. Hemin Thakkar, et al. [33] designed and experimentally analyzed an interesting small-scale desalination system using solar-powered air heating, packed-bed humidification and finned-type dehumidification. Principal results show yields of more than 30 L/day and 40 L/day when air flow rates are in the order of 0.06 kg/s and 0.12 kg/s , respectively. Hemin Thakkar et al. [34] carried out a comparative experimental analysis of the integration of a flash evaporator in a solar desalination system. All testing conditions are provided. Principal results show that the integrated flash evaporator system permit to obtain distillate water production in the order of 13.95 kg , as compared with 4.29 kg for conventional solar still. Mays Shadeed et al. [35] experimentally investigated the performance of a home-made continuous solar desalination unit (CSDU), under different weather and operational conditions. Principal results show that the maximum productivity reaches $13.20 \text{ L/m}^2/\text{day}$ for solar radiation of around $6.69 \text{ kWh/m}^2/\text{day}$. It is to note that the CSDU average productivity is three times higher than conventional solar stills. Alinford Samuel, et al. [36] designed and experimentally investigated an active solar still applicable to remote islands. The tested design can be simply seen as a passive double-slope solar still with a solar water heater, wicks and fin materials. Experiments conditions are detailed. Principal results show that the use of the proposed design permits the enhancement of the average daily productivity and the average day time hourly productivity by 147% and 245%, respectively, compared to the conventional passive solar still. Naseer T. Alwan, et al. [37] carried out an interesting experimental investigation and a cost analysis regarding the distillate water yield of a modified solar still compared to a commercial one, on 19 June, 17 July, 22 August and 15 September, under the meteorological conditions of the city of Ekaterinburg, Russia (56.84° N , 60.58° E). The proposed modified solar still presents an inside rotating hollow cylinder and it is integrated to a solar heater. Principal results show that the modified solar still permits reaching a 290–300% increase in distilled water production in June, and a 400% increase in other months, compared to a commercial solar still. One liter of the produced distilled water costs $0.0268 \text{ \$/L}$, compared to $0.0282 \text{ \$/L}$ for the conventional solar still. The quality of the distilled water meets the Russian and international quality standards associated with PH, TDS and EC. Naseer T. Alwan et al. [38] carried out another relevant experimental investigation and cost analysis of a modified solar still, compared to a conventional one. The two compared solar stills have identical dimensions and are tested under the same operating conditions in order to ensure a correct performance comparison. The suggested modified solar still is integrated to ultrasonic humidifier devices, placed within the water basin of the solar still. A cotton cloth is used to cover these devices in order to increase the evaporation surface area, reduce the dimension

between the water surface and the Plexiglass cover and avoid the spreading of produced fog. The main results show that the suggested solar still permits obtaining a daily yield 68% higher than the conventional solar still. Furthermore, the thermal efficiency of the suggested solar still is 1.1 times more than the conventional one (at 4:00 p.m.). Of note, also, is that the cost of the produced distilled water by the suggested solar still is 34.9% reduced, compared to the conventional solar still.

The aim of this work is to originally design, manufacture and experimentally test the thermal and the productivity performances of a solar still with a rotating transparent plastic (Plexiglass) cover, with an inner surface continuously wiped, under the meteorological conditions of the city of Gafsa, Tunisia (34.4311° N, 8.7757° E). Section 2 explains the solar still design in terms of originality and technical specifications. Section 3 presents the experimental statement in terms of the experimental prototype and experimental operating conditions. Section 4 presents the quantification and the discussion of the experimental results in terms of the proposed solar still thermal performances (water and cover temperatures) and productivity (hourly and cumulative water production), as well as efficiency in the function of the meteorological conditions (solar irradiance and ambient temperature). Section 5 concludes the main results.

2. Solar Still Design

2.1. Originality

The proposed original solar still design is depicted by Figure 1. The water desalination is based on the evaporation of saline water and then the condensation of the humid air thanks to coil cooling technology. The solar irradiance passes through a rotating cylindrical transparent plastic cover before being captured by two absorbers. One is flat and placed at the bottom of a saline water basin, while the other is curved and is located closely above the lower hemisphere of the cylindrical cover. A reflective surface is used to concentrate the solar irradiance towards the lower hemisphere side of the cover. The saline water is pumped from a feed tank to the still upper basin with a specific flow control, in order to maintain a constant saline water depth. The flat absorber irradiance permits the direct heating of the saline water in order to enhance the evaporation, while the curved absorber irradiance allows the heating and the drying of the air in order to improve its maximum moisture content. The radiated heat is trapped within the cylindrical cover thanks to the greenhouse effect. The almost dry air is humidified by the evaporated water vapor. The obtained humid air is then condensed when passing through the neighborhood of the cooling coil and is finally collected in a desalinated water basin. The bottom curved absorber is insulated from the desalinated water basin in order to prevent re-evaporation of the collected desalinated water. Furthermore, the inner surface droplets on the cover, created due to the condensation phenomenon, are continuously wiped towards the condensed water basin using a fixed wiper, as the cylindrical cover rotates. The desalinated condensed water collected on the still bottom basin is pumped towards an outlet desalinated water tank. Also, the continuous wiping of water droplets permits keeping the plastic cover transparent to solar irradiance. This will enhance the greenhouse effect and improve the solar still efficiency.

2.2. Technical Specifications

The proposed cylindrical solar still is divided into four parts in order to facilitate the collection of the condensed water. The cylindrical transparent plastic (Plexiglass) cover of the proposed cylindrical solar still has a diameter $D_c = 420$ mm, a height $h_c = 1620$ mm and a thickness $t_c = 2$ mm. The cover is rotated using a small DC 6V very low speed 1 rpm geared motor. The energy consumption of such a motor is negligible. Of note is that the changing of the rotation speed affects the thermal and water production performance of the proposed solar still design. This issue will be handled as research perspectives in the next research investigation. The absorbers are made of steel and painted black in order to enhance the absorption rate. The flat absorber, at the bottom of the saline water basin, has a length $L_{ab} = 1600$ mm, a width $W_{ab} = 220$ mm and a thickness $t_{ab} = 1$ mm.

The bottom curved absorber is a semi-cylinder with a diameter $D_{ab} = 400$ mm and height $h_{ab} = 1600$ mm. The saline water depth should be maintained constant as $d_{sw} = 20$ mm. The condenser compartment presents a helicoidal pipe cooling coil using saline water as the coolant. The pipe diameter is in the order of $D_p = 5$ mm. In order to both limit the cost of the manufacturing and prevent the rapid degradation of our solar still prototype in saltwater, the used steel is a commercial carbon steel but it is correctly painted using a first layer of rustproof paint and a second layer of commercial hygienic black paint to both enhance solar energy absorption rate and ensure a healthy desalinated water. This solution permits avoiding the use of expensive stainless steels.

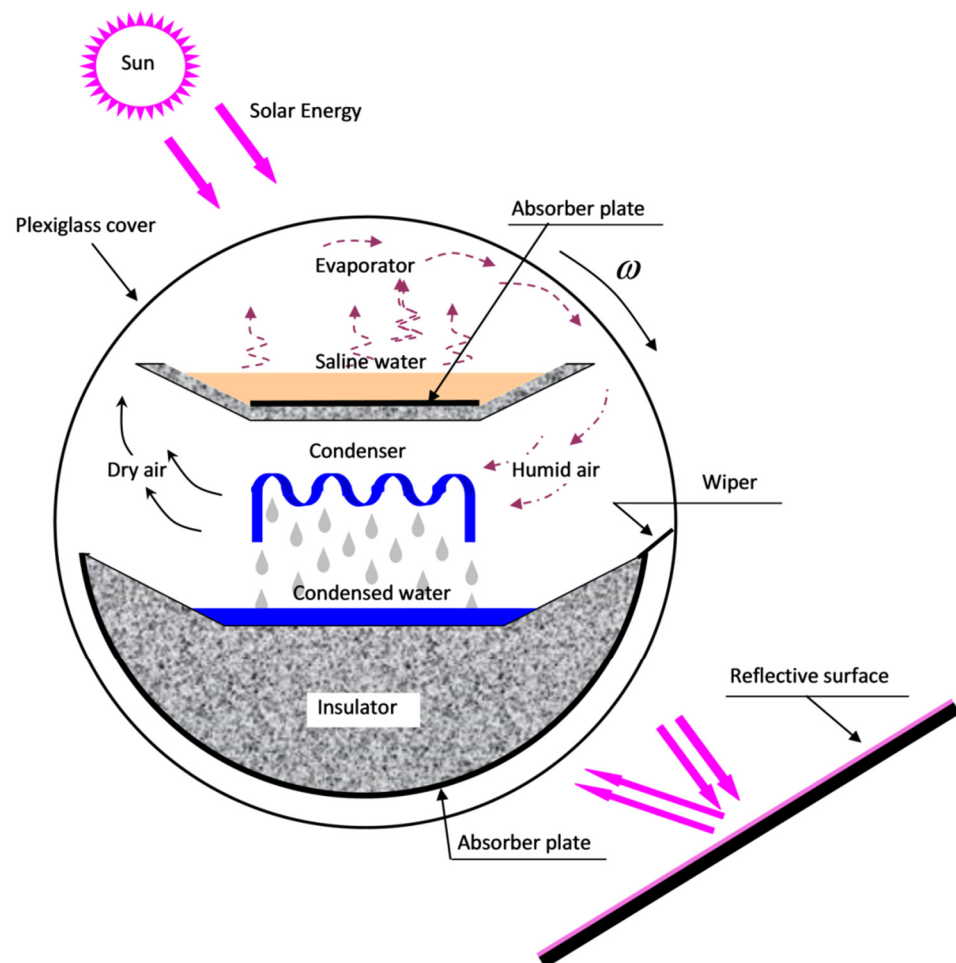


Figure 1. Original solar still design.

The steel parts are joined by SMAW welding. The plexiglass cover is joined to the steel structure by a simple sealed mate in order to allow its sliding when it rotates. All the electrical parts (DC motor, DC pumps) are correctly plugged into appropriate electrical batteries using suitable electrical accessories. The feed saline water tank and desalinated water tank are connected to the solar still using appropriate flexible hoses.

The coolant is supplied at a low flow rate by a small DC 6 V water pump. Also, small DC 3V water pumps are used to ensure the saline water feeding, as well as the pumping of the collecting desalinated water towards an outlet tank. Of note, the saline water feeding can also be ensured by a gravity low flow rate (when the feeding tank is placed higher than the saline water basin) and the collecting of the condensed desalinated water can also be carried out by gravity (when the condensed water basin is slightly inclined). Thus, no significant energy consumption is required for ensuring the supply of the coolant, feed saline water, as well as the collecting of desalinated water. Table 1 summarizes the cost evaluation of the manufactured solar still prototype.

Table 1. Cost evaluation of the solar still prototype.

Parts	Cost (USD)
Steel parts	70
Paints (rustproof + hygienic)	43
Plexiglass cover and accessories	60
Insulator material	2.5
Condenser coil	6.5
Reflective mirror	15
Electrical parts and accessories	73
Tanks	30
Flexibles hoses	20
Manufacturing	90
Total	410

3. Experimental Statement

3.1. Experimental Prototype

A real prototype of the proposed novel solar still design is manufactured in order to test its performance under specific experimental operating conditions (Section 3.2). Figure 2 presents the considered real prototype.

**Figure 2.** Real prototype of the novel solar still design.

Figure 3 describes the test bench used to carry out the experimental investigation.

Table 2 summarizes the technical specifications of the different equipment used to measure the experimental data.

Table 2. Technical specifications of measurement equipment.

Equipment	Range	Accuracy	Error
Digital thermometer	−50 °C to 300 °C	0.1 °C	0.25%
Solarimeter	0 to 2000 W/m ²	1 W/m ²	5%
Calibrated flask	0 to 250 mL	5 mL	5%

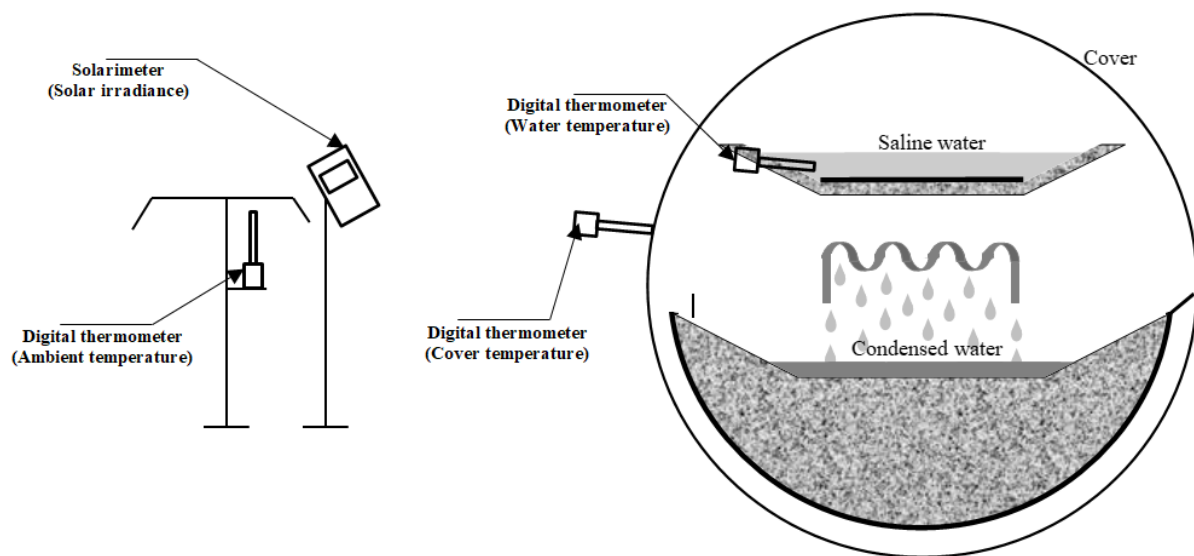


Figure 3. Measurement test bench.

3.2. Experimental Operating Conditions

The experimental investigation, applied for the considered novel solar still design, is carried out in the region of Gafsa, Tunisia (34.4311° N, 8.7757° E) under the meteorological conditions of the two experimentation days, 27 and 28 August 2021. For each experimentation day, a performance comparison is carried out between the cylindrical cover rotating and being fixed.

4. Experimental Results and Discussion

In order to easily assimilate the curves describing the experimental results, the curve evolutions are standardized such as: a dashed line refers to experimentation day 1; a solid line refers to experimentation day 2; a blue line refers to the experimentation with fixed cover; a red line refers to the experimentation with rotating cover; a filled circular marker refers to the water; an empty circular marker refers to the cover; a filled square marker refers to the solar irradiance (in black); and an empty square marker refers to the ambient temperature (in black).

4.1. Meteorological Conditions

The meteorological conditions, in terms of ambient temperature and solar irradiance, are measured for the two experimentation days (27 and 28 August 2021) as depicted by Figure 4.

The ambient temperature starts at 26.4°C and 26.3°C at 08:00, reaches its maximum of 36.6°C and 37.8°C , both at 14:00, and finally falls to 32°C and 33°C at 17:00, with an average in the order of 33.1°C and 33.7°C , for experimentation days 1 and 2, respectively. Thus, the ambient temperature is increased from day 1 to day 2 by 0.6° on average and 1.2° at the maximum.

The solar irradiance starts at 504 W/m^2 and 546 W/m^2 , reaches its maximum of 982 W/m^2 at 13:00 and 994 W/m^2 at 12:00, and finally falls to 641 W/m^2 and 672 W/m^2 , with an average of 813 W/m^2 and 843 W/m^2 , for experimentation days 1 and 2, respectively. Thus, the solar irradiance is increased from day 1 to day 2 by 30 W/m^2 on average and 12 W/m^2 at the maximum.

4.2. Thermal Performance

The solar still thermal performance, in terms of water and cover temperatures, are measured for the two experimentation days (27 and 28 August 2021) in the cases where

the cylindrical cover is fixed or rotating. Figures 5 and 6 depict the thermal performance experimental results of the proposed solar still design for day 1 and day 2, respectively.

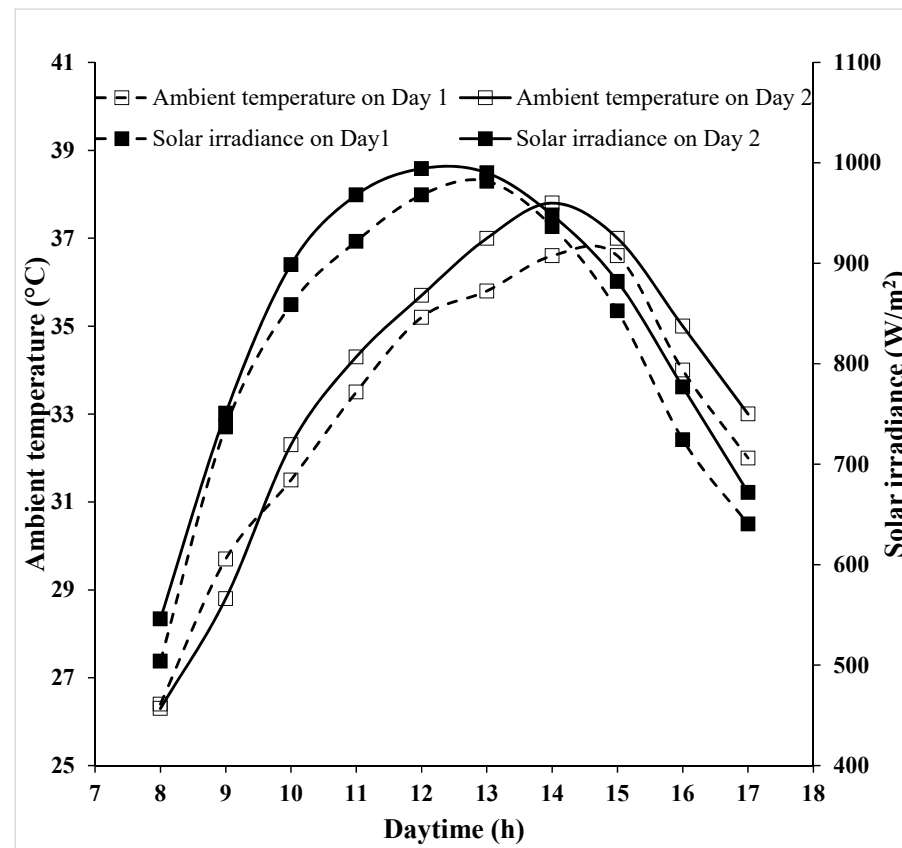


Figure 4. Meteorological conditions for 27 August (day 1) and 28 August (day 2) 2021.

During experimentation day 2, the cover temperature starts at 30 °C and 29.5 °C at 08:00, reaches its maximum of 56.5 °C and 59 °C, both at 14:00, and finally falls to 49.8 °C at 17:00, with an average in the order of 49.2 °C and 49.7 °C, where the cover is fixed and rotating, respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the cover temperature by 0.5° on average (from 49.2 °C to 49.7 °C) and 2.5° at the maximum (from 56.5 °C to 59 °C).

The water temperature starts at 32.7 °C and 33.6 °C at 08:00, reaches its maximum of 63.8 °C and 67.2 °C, both at 14:00, and finally falls to 55.2 °C and 56.7 °C at 17:00, with an average in the order of 54.9 °C and 56.6 °C, where the cover is fixed and rotating, respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the water temperature by 1.7° on average (from 54.9 °C to 56.6 °C) and 3.4° at the maximum (from 63.8 °C to 67.2 °C).

This increase in cover temperature, from a fixed or rotating cover, is expected. In fact, the cover rotation with a moderate speed (not too high nor too low) permits all of the cover portions to be intensively and quickly heated up, principally by convection and radiation, when passing in the lower region, very close to the curved absorber and the reflector. Moreover, the cover is further heated up by conduction since the temperature difference between the lower and higher portions of the cover is enhanced. Also, the increase in water temperature, from a fixed or rotating cover, is expected. In fact, the increase in the cover temperature enhances the greenhouse effect within the solar still. Thus, the saline water temperature is further increased.

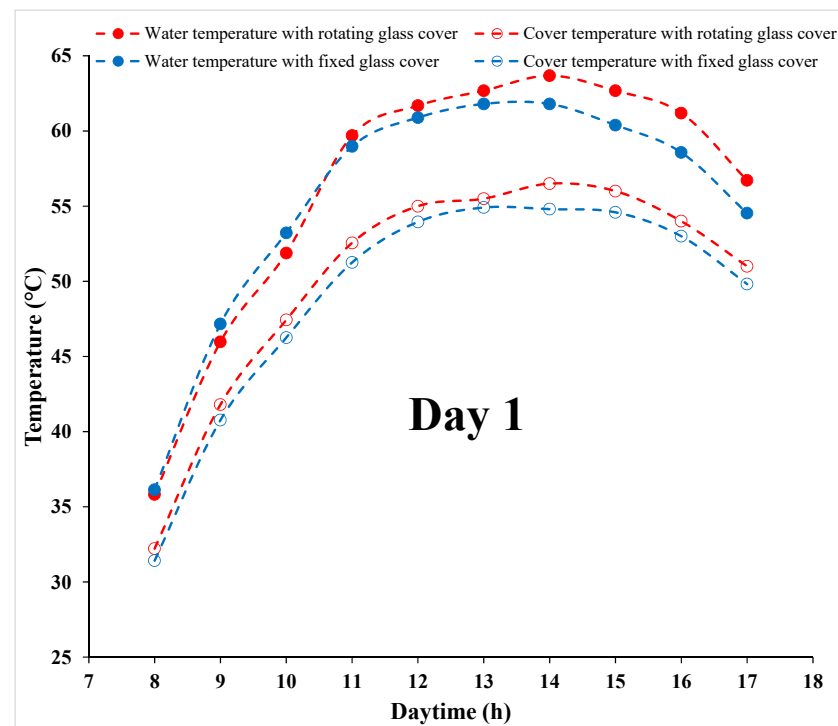


Figure 5. Water and cover temperature on 27 August 2021 (day 1) where the cylindrical cover is fixed or rotates. During experimentation day 1, the cover temperature starts at 31.4 °C and 32.2 °C at 08:00, reaches its maximum of 54.9 °C at 13:00 and 56.5 °C at 14:00, and finally falls to 49.8 °C and 51 °C at 17:00, with an average in the order of 49.1 °C and 50.2 °C, where the cover is fixed and rotating, respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the cover temperature by 1.1° on average (from 49.1 °C to 50.2 °C) and 1.6° at the maximum (from 54.9 °C to 56.5 °C). The water temperature starts at 36.1 °C and 35.8 °C at 08:00, reaches its maximum of 61.8 °C at 13:00 and 63.7 °C at 14:00, and finally falls to 54.5 °C and 56.7 °C at 17:00, with an average in the order of 55.4 °C and 56.2 °C, where the cover is fixed and rotating, respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the water temperature by 0.8° on average (from 55.4 °C to 56.2 °C) and 1.9° at the maximum (from 61.8 °C to 63.7 °C).

As the ambient temperature and the solar irradiance increase from day 1 to day 2 (Section 4.1), the cover temperature of the rotary cover still is decreased by 0.5° (from 50.2 °C to 49.7 °C) on average and increased by 2.5° (from 56.5 °C to 59 °C) at the maximum. Thus, it can be deduced that the cover temperature is decreased by 0.83° and increased by 2.08° for each 1° of ambient temperature, as well as decreased by 0.017° and increased by 0.2° for each 1 W/m² of solar irradiance, based on the meteorological average and maximum values, respectively. Also, the water temperature of the rotary cover still is increased by 0.4° (from 56.2 °C to 56.6 °C) on average and by 3.5° (from 63.7 °C to 67.2 °C) at the maximum. Thus, it can be deduced that the water temperature is increased by 0.67° and by 2.92° for each 1° of ambient temperature, as well as by 0.013° and 0.292° for each 1 W/m² of solar irradiance, based on the meteorological average and maximum values, respectively.

4.3. Productivity

The solar still productivity, in terms of hourly and cumulative water production, is measured for the two experimentation days (27 and 28 August 2021), where the cylindrical cover is fixed or rotates. Figures 7 and 8 depict the hourly and cumulative water productivity, respectively, for both day 1 and day 2.

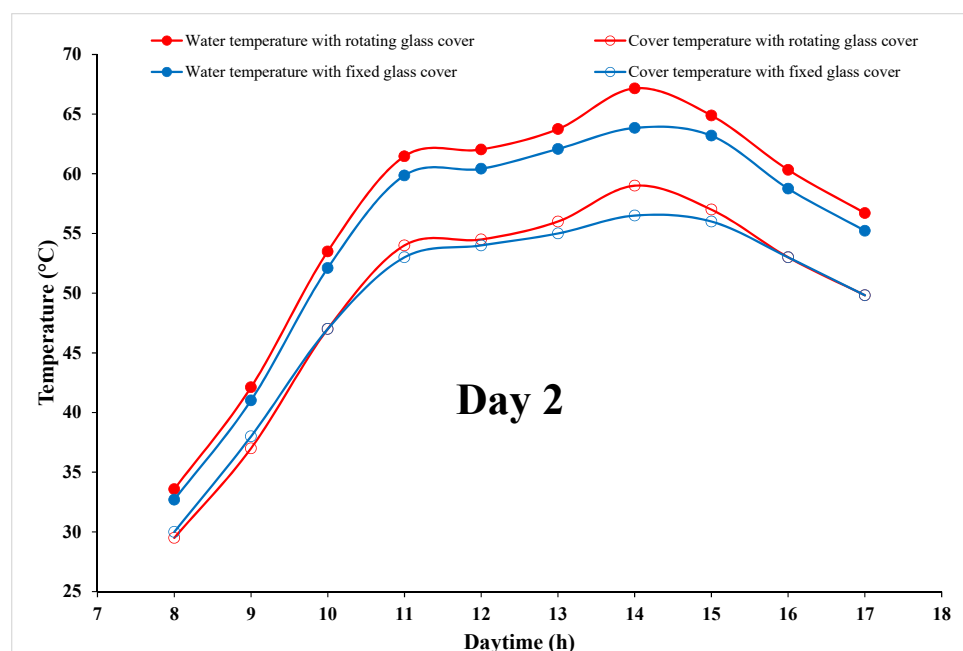


Figure 6. Water and cover temperature on 28 August 2021 (day 2), where the cylindrical cover is fixed or rotates.

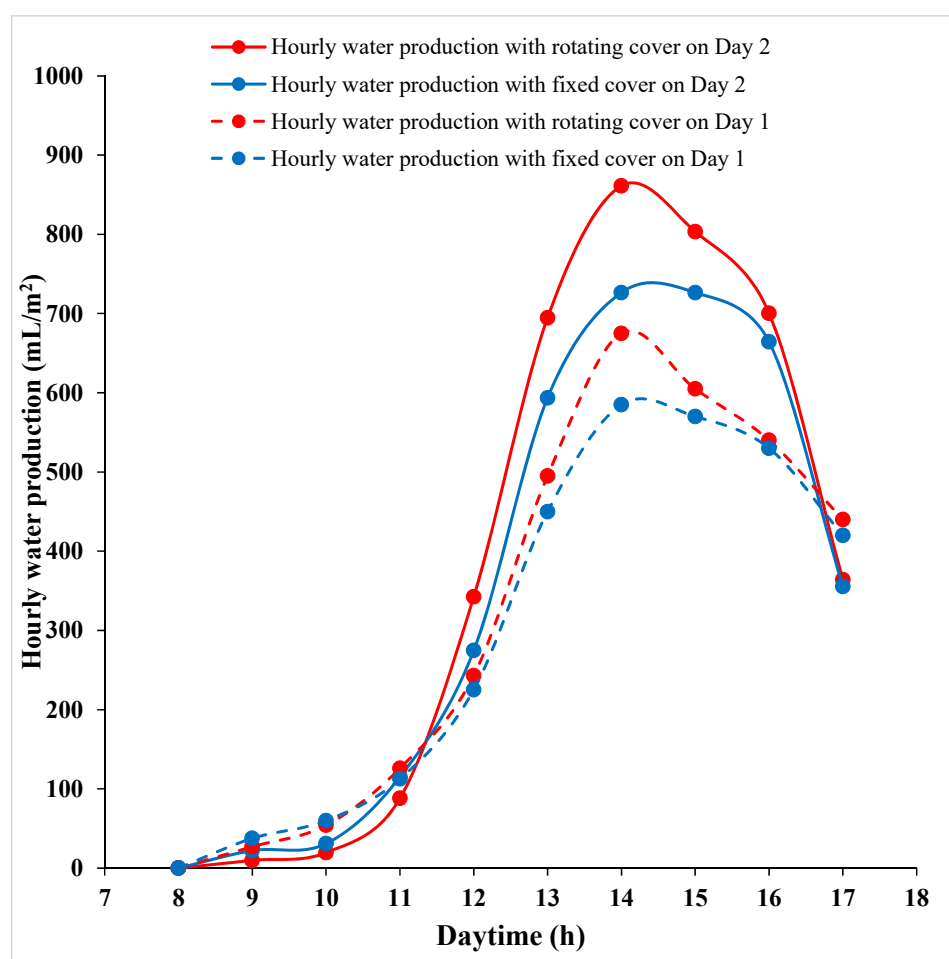


Figure 7. Hourly water production for 27 August (day 1) and 28 August (day 2) 2021, where the cylindrical cover is fixed or rotates.

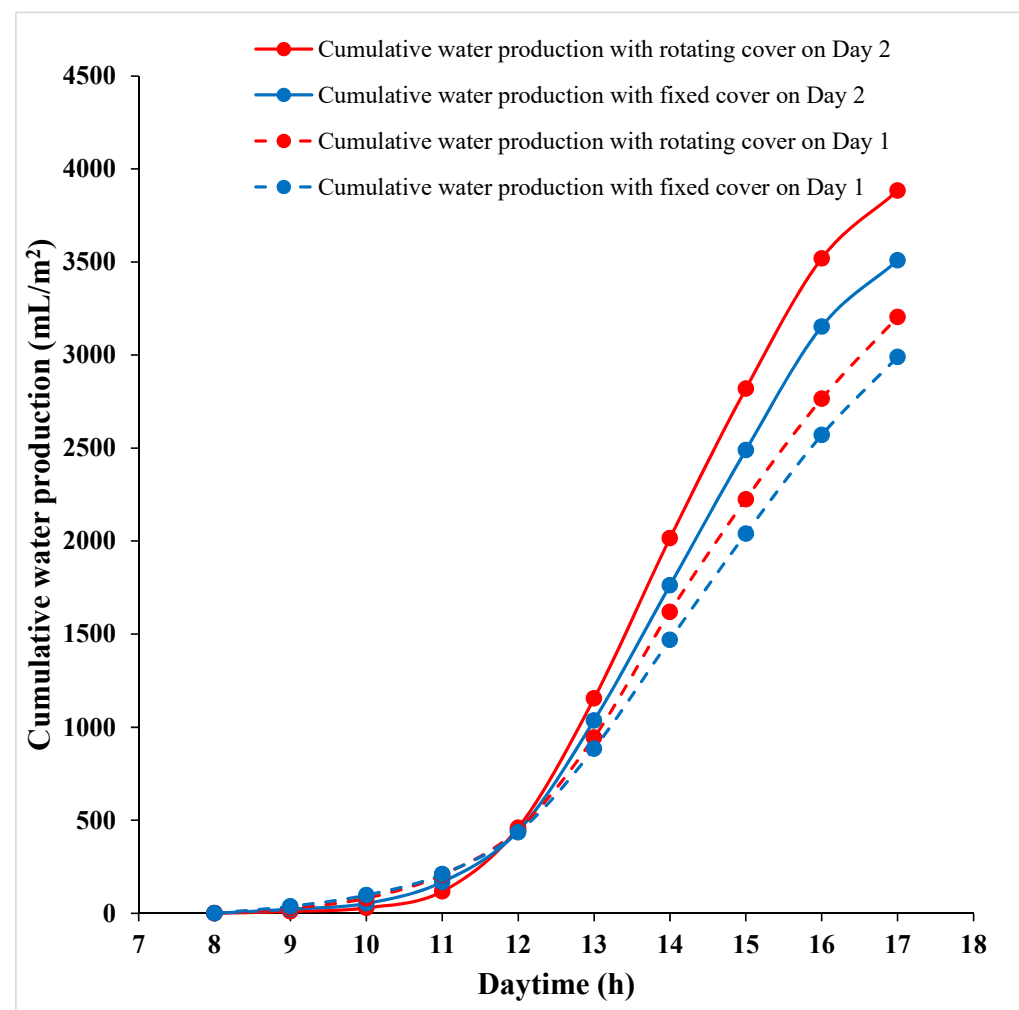


Figure 8. Cumulative water production for 27 August (day 1) and 28 August (day 2) 2021, where the cylindrical cover is fixed or rotates.

During experimentation day 1, the hourly water production obviously starts at 0 mL/m²/h at 08:00, reaches its maximum of 585 mL/m²/h and 675 mL/m²/h, both at 14:00, and finally falls to 420 mL/m²/h and 440 mL/m²/h at 17:00, with an average in the order of 299 mL/m²/h and 320.5 mL/m²/h, where the cover is fixed and rotating, respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the hourly water production by 21.5 mL/m²/h on average (from 299 mL/m²/h to 320.5 mL/m²/h) and 90 mL/m²/h at the maximum (from 585 mL/m²/h to 675 mL/m²/h).

During experimentation day 2, the hourly water production obviously starts at 0 mL/m²/h at 08:00, reaches its maximum of 725 mL/m²/h and 860 mL/m²/h, both at 14:00, and finally falls to 355 mL/m²/h and 365 mL/m²/h at 17:00, with an average in the order of 350.9 mL/m²/h and 388.4 mL/m²/h, where the cover is fixed and rotating respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the hourly water production by 37.5 mL/m²/h on average (from 350.9 mL/m²/h to 388.4 mL/m²/h) and 135 mL/m²/h at the maximum (from 725 mL/m²/h to 860 mL/m²/h).

As the ambient temperature and the solar irradiance increase from day 1 to day 2 (Section 4.1), the hourly water production of the rotary cover still is increased by 67.9 mL/m² (from 320.5 mL/m² to 388.4 mL/m²) on average and by 185 mL/m² (from 675 mL/m² to 860 mL/m²) at the maximum. Thus, it can be deduced that the hourly water production is increased by 113.17 mL/m² and by 154.17 mL/m² for each 1° of ambient temperature, as

well as by 2.26 mL/m² and 15.42 mL/m² for each 1 W/m² of solar irradiance, based on the meteorological average and maximum values, respectively.

During experimentation day 1, the cumulative water production obviously starts at 0 mL/m²/day at 08:00 to reach its maximum of 2990 mL/m²/day and 3205 mL/m²/day at 17:00, where the cover is fixed and rotating, respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the cumulative water production by 215 mL/m²/day (from 2990 mL/m²/day to 3205 mL/m²/day).

During experimentation day 2, the cumulative water production obviously starts at 0 mL/m²/day at 08:00 to reach its maximum of 3510 mL/m²/day and 3885 mL/m²/day at 17:00, where the cover is fixed and rotating respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the cumulative water production by 375 mL/m²/day (from 3510 mL/m²/day to 3885 mL/m²/day).

The increase in water production, from a fixed or rotating cover, is expected. In fact, the increase in cover temperature will naturally induce the enhancement of the greenhouse effect within the solar still. The relative humidity of the feed dry air is reduced. The saline water temperature is increased. Thus, the saline water evaporation is intensified and the amount of collected condensed water is increased.

As the ambient temperature and the solar irradiance increase from day 1 to day 2 (Section 4.1), the cumulative water production of the rotary cover still is increased by 680 mL/m² (from 3205 mL/m²/day to 3885 mL/m²/day). Thus, it can be deduced that the cumulative water production is increased, by 1133.33 mL/m²/day for each 1° of ambient temperature, as well as by 22.67 mL/m²/day for each 1 W/m² of solar irradiance, based on the meteorological average values.

4.4. Efficiency

The solar still performance is assessed based on the hourly efficiency η_h , expressed as the ratio of the output evaporation energy associated with the hourly desalinated water yield to the hourly input solar energy:

$$\eta_h = \frac{m_w \times H_{evap}}{(A \times I) \times 3600} \times 100 \quad (1)$$

With:

η_h : Hourly efficiency

m_w : Hourly water production

H_{evap} : Latent heat of evaporation

A : Projected area of the solar still

I : Solar irradiance

The latent heat of evaporation H_{evap} of water [39,40] at the water temperature T_w is expressed as:

$$H_{evap} = \left(2501.9 - 2.40706 \times T_w + 1.192217 \times 10^{-3} T_w^2 - 1.5863 \times 10^{-5} \times T_w \right) \times 10^3 \quad (2)$$

Figure 9 depicts the hourly solar still efficiency for both day 1 and day 2, where the cylindrical cover is fixed or rotates.

During experimentation day 1, the hourly efficiency obviously starts at 0% at 08:00, reaches its maximum of 48% and 56%, both at 16:00, and finally falls to 43% and 35% at 17:00, with an average in the order of 24% and 26%, where the cover is fixed and rotating, respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface, permits increasing the hourly water production by 2% on average (from 24% to 26%) and 8% at the maximum (from 48% to 56%).

During experimentation day 2, the hourly efficiency obviously starts at 0% at 08:00, reaches its maximum of 49% and 61%, both at 14:00, and finally falls to 45% and 35% at 17:00, with an average in the order of 26% and 30%, where the cover is fixed and rotating, respectively. Thus, the use of a rotating cover, continuously wiped on the inner surface,

permits increasing the hourly water production by 4% on average (from 26% to 30%) and 12% at the maximum (from 49% to 61%).

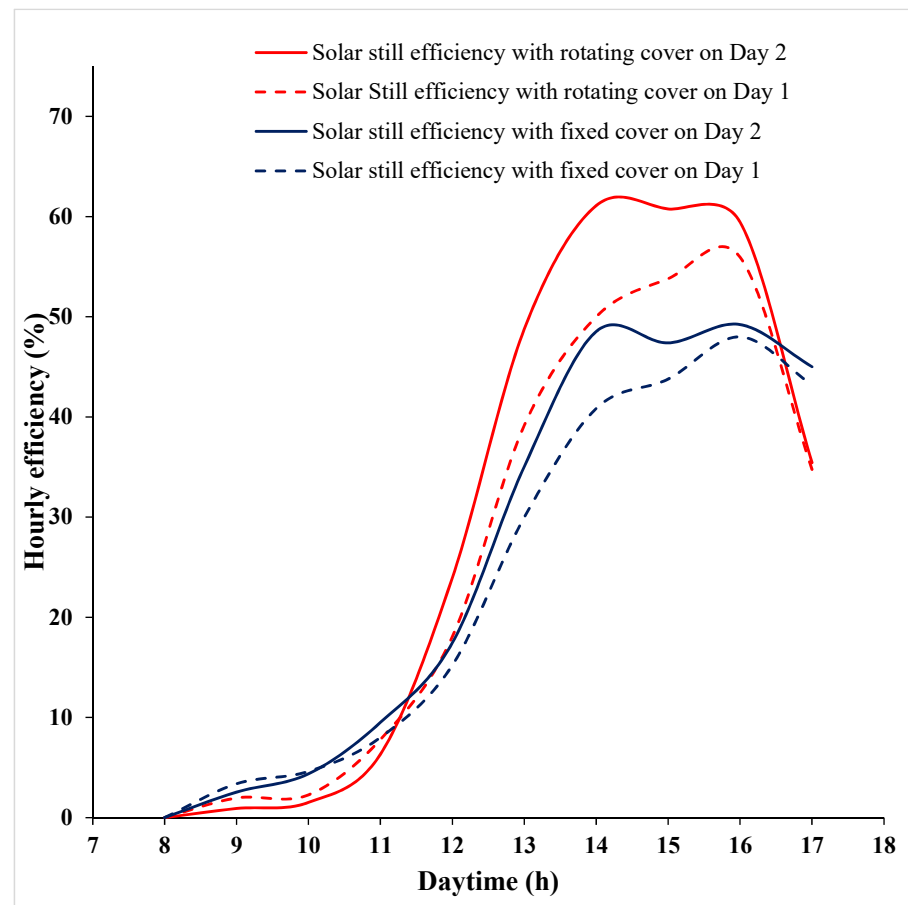


Figure 9. Solar still efficiency for 27 August (day 1) and 28 August (day 2) 2021, where the cylindrical cover is fixed or rotates.

As the ambient temperature and the solar irradiance increase from day 1 to day 2 (Section 4.1), the hourly efficiency of the rotary cover still is increased by 4% (from 26% to 30%) on average and by 2% (from 56% to 61%) at the maximum. Thus, it can be deduced that the hourly efficiency is increased by 6.67% and by 1.67% for each 1° of ambient temperature, as well as by 0.13% and 0.16% for each 1 W/m^2 of solar irradiance, based on the meteorological average and maximum values, respectively.

4.5. Summary of the Major Experimental Results

As it is depicted by Table 3, the major experimental results, in terms of initial, final and maximum values of temperatures, solar irradiance, water production and efficiency measurement sets are categorized based on their specification (ambient, cover, water, solar still, hourly or cumulative), day measurement (day 1 or day 2) and cover type (fixed, rotating or not applicable). Principal statistical parameters, in terms of the average (mean) value and standard deviation, are associated with each set of measurements.

Table 3. Major experimental results.

Set of Measurement (Unit)	Specification	Day	Cover Type	Initial Value	Final Value	Maximum Value	Average (Mean) Value	Standard Deviation
Temperature (°C)	Ambient	Day 1	Not Applicable	26.4	32	36.6	33.1	3.29
Temperature (°C)	Ambient	Day 2	Not Applicable	26.3	33	37.8	33.7	151.38
Temperature (°C)	Cover	Day 1	Fixed	31.4	49.8	54.9	49.1	7.80
Temperature (°C)	Cover	Day 2	Fixed	30	49.8	56.5	49.2	8.20
Temperature (°C)	Cover	Day 1	Rotating	32.2	51	56.5	50.2	9.11
Temperature (°C)	Cover	Day 2	Rotating	29.5	49.8	59	49.7	235.99
temperature (°C)	Water	Day 1	Fixed	36.1	54.5	61.8	55.4	258.90
temperature (°C)	Water	Day 2	Fixed	32.7	55.2	63.8	54.9	1124.03
Temperature (°C)	Water	Day 1	Rotating	35.8	56.7	63.7	56.2	1218.17
Temperature (°C)	Water	Day 2	Rotating	33.6	56.7	67.2	56.6	1542.48
Solar irradiance (W/m ²)	Ambient	Day1	Not Applicable	504	641	982	813	157.12
Solar irradiance (W/m ²)	Ambient	Day2	Not Applicable	546	672	994	843	7.68
Water production (mL/m ² /h)	Hourly	Day1	Fixed	0	420	585	299	3.74
Water production (mL/m ² /h)	Hourly	Day2	Fixed	0	355	725	350.9	8.72
Water production (mL/m ² /h)	Hourly	Day1	Rotating	0	440	675	320.5	9.48
Water production (mL/m ² /h)	Hourly	Day 2	Rotating	0	365	860	388.4	10.35
Water production (mL/m ² /day)	Cumulative	Day 1	Fixed	0	2990	Not Applicable	NA	10.79
Water production (mL/m ² /day)	Cumulative	Day 2	Fixed	0	3510	Not Applicable	NA	304.44
Water production (mL/m ² /day)	Cumulative	Day 1	Rotating	0	3205	Not Applicable	NA	351.18
Water production (mL/m ² /day)	Cumulative	Day 2	Rotating	0	3885	Not Applicable	NA	1369.95
Hourly efficiency (%)	Solar still	Day 1	Fixed	0	43	48	24	19.33
Hourly efficiency (%)	Solar still	Day 2	Fixed	0	45	49	26	21.04
Hourly efficiency (%)	Solar still	Day 1	Rotating	0	35	56	26	22.85
Hourly efficiency (%)	Solar still	Day 2	Rotating	0	35	61	30	26.50

5. Conclusions

An original cylindrical solar still with a rotating transparent plastic (Plexiglass) cover, continuously wiped on the inner surface, is designed, manufactured and experimentally tested in terms of thermal performance, water production and efficiency, under the realistic meteorological conditions of Gafsa, Tunisia (34.4311° N, 8.7757° E). Of note, the proposed design uses a condenser as well as two absorbers: one is flat and emerged in the saline water while the other is curved and placed above the lower hemisphere of the cylindrical cover. An insulator is used to avoid undesirable condensed water evaporation due to the heat released by the bottom absorber. Since all design details, in the current technological arrangement, are strongly dependent, it is highly recommended for water desalination developers not to ignore any design details if they are willing to investigate and further develop the proposed design. The rotation of the cover permits considerably enhancing the thermal performance, the water production and the efficiency of the proposed solar still design. The cover temperature is decreased by 0.83° and increased by 2.08° for each 1° of ambient temperature, as well as decreased by 0.017° and increased by 0.2° for each 1 W/m² of solar irradiance, based on the meteorological average and maximum values, respectively. The water temperature is increased by 0.67° and by 2.92° for each 1° of ambient temperature, as well as by 0.013° and 0.292° for each 1 W/m² of solar irradiance, based on the meteorological average and maximum values, respectively. The hourly water

production is increased by 113.17 mL/m²/h and by 154.17 mL/m²/h for each 1° of ambient temperature, as well as by 2.26 mL/m²/h and 15.42 mL/m²/h for each 1 W/m² of solar irradiance, based on the meteorological average and maximum values, respectively. The cumulative water production is increased, by 1133.33 mL/m²/day for each 1° of ambient temperature, as well as by 22.67 mL/m²/day for each 1 W/m² of solar irradiance, based on the meteorological average values. The hourly efficiency is increased by 6.67% and by 1.67% for each 1° of ambient temperature, as well as by 0.13% and 0.16% for each 1 W/m² of solar irradiance, based on the meteorological average and maximum values, respectively. The effects of the rotation velocity and the condenser cooling capacity remain unsolved in the current research work. These issues will be handled as research perspectives in the next research investigations.

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Nomenclature

A	Projected area of the solar still (m ²)
D	Diameter (mm)
H	Latent heat (J/kg)
h	Height (mm)
I	Solar irradiance (W/m ²)
L	Length (mm)
m	Water production (kg) in relation with hourly water production (mL/m ² /h) and cumulative (daily) water production (mL/m ² /day)
T	Temperature (°C)
t	Thickness (mm)
W	Width (mm)
η	Efficiency (%)
Subscript	
ab	Absorber
$evap$	Evaporation
h	Hourly
p	Pipe
c	Cover
sw	Saline water
w	Water

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