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Modeling and Experimental Study of a Water Solar Collector Coupled to Optimized Solar Water Still

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ABSTRACT

This work presented the modeling and the experimental study of a water solar collector coupled with an optimized solar still developed in order to boost fresh water produced in a solar distillation system. The desalination process is currently operated under the climatological conditions of Sfax, Tunisia. To numerically simulate the water solar collector, we developed a dynamic model based on heat and mass transfer from the water solar collector. The obtained set of ordinary differential equations was converted to a set of algebraic system of equations by the functional approximation method of orthogonal collocation. The aim of this study was to present the mathematical model and experimental study of this water solar collector.

1. Introduction

Solar energy heaters are heat exchangers that convert incoming solar energy into internal energy of the transport medium, in this case seawater. The function of the solar heater within the distillation unit is to toast the incoming swab water to a determined temperature that will allow the operation of the evaporator unit and the separation of faded fresh water from thick swab-rich water. The water solar heater, object of this study, is one of five factors (air solar collector, water solar collector, and humidifier, solar still SS and inner condenser) of an optimized solar still system shown in Figure 1.

The solar desalination system is grounded on the air humidification and dehydration principle. Fresh water is one of the high rudiments responsible for life on earth. The SS is a simple system and provident process using solar energy to produce fresh water. But the productivity of the conventional SS system is veritably law. Several designs and a lot of study have been developed to meliorate the productivity of solar stills. A SS system was tested with an energy storehouse media at its base by Naim and El Kawi [1]. The performance of a solar still system with different size sponger cells placed in the receptacle water was studied experimentally by Abu-Hiljeh and Rababa'h [2] and Murugavel

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and Srithar [3] presented an experimental study of an optimized SS with different depth of water in the receptacle and different wick accoutrements like cotton cloth and sponger distance. Yadav and Yadav [4] studied the SS by incorporating reversed absorber asymmetric line- axis emulsion parabolic collector and concluded that the distillate affair was increased in comparison to conventional SS.

This is because the SS entered solar energy both from top and nethermost performing in increased temperature difference between water face and glass cover. The colorful factors affecting the productivity of a solar still coupled with a solar heater and the influence of inclination of water heater of conventional SS system were optimized by Tanaka and Nakatake [5] presented an experimental study of an active solar still integrated with a solar water collector and plant that the maximum increase in the yield was over to 33. Arslan [6] introduced a new model of heat and mass transfer of a tubular SS system. They plant that, the heat balance of the sticky air and the mass balance of the water vapor in the sticky air were formulized for the first time Zaki *et al.,* [7] and Sakthivel *et al.,* [8] presented an experimental study of a modified SS system by adding jute cloth in perpendicular position in the middle of the receptacle and another row of jute cloth attached to the still wall. A vertical shaft rotating by a small wind turbine and inclined SS were integrated in the main device of solar still system as a mongrel system of distillation were studied by Eltawil and Zhengming [9]. They plant that the inclined water still produced advanced affair yield than that of the SS main device by roughly 29.17. Arslan [6] delved the performance of colorful designs of active SS under an unrestricted cycle mode experimentally and concluded that the indirect box active SS design produced loftiest overall diurnal edge. Also, El-Sebaii *et al.,* [10] delved a new fine model to study the thermal performance of the SS with phase change material. El-Zahaby *et al.,* [11] presented a new conception of a SS coupled to a flashing chamber to meliorate the fresh water yield. Bacha and Zhani [12], Zarzoum *et al.,* [13-15], and Boukhriss *et al.,* [16] designed a new SS with an energy storing material in the water receptacle to extend the operation of the distiller at night. They also integrated a water and air solar heater and a separate condenser that coupled to the SS system to meliorate the productivity. Arslan [6] and Abdel-Rehim and Lasheen [17] developed a rotating shaft with vertical axis introduced near to the water face of the absorber of SS system to meliorate the diurnal productivity.

They coupled this SS to an electrical motor to rotate the shaft. They plant that this new design of the SS was bettered by 5.5 in July, 5 in June, and 2.5 in May. Badran and Al-Tahaineh [18] delved SS adding glasses on the interior walls and coupled with a solar collector experimentally.

This work presented a fine modeling and an experimental study of the water solar heater coupled with the optimized SS in Sfax, Tunisia.

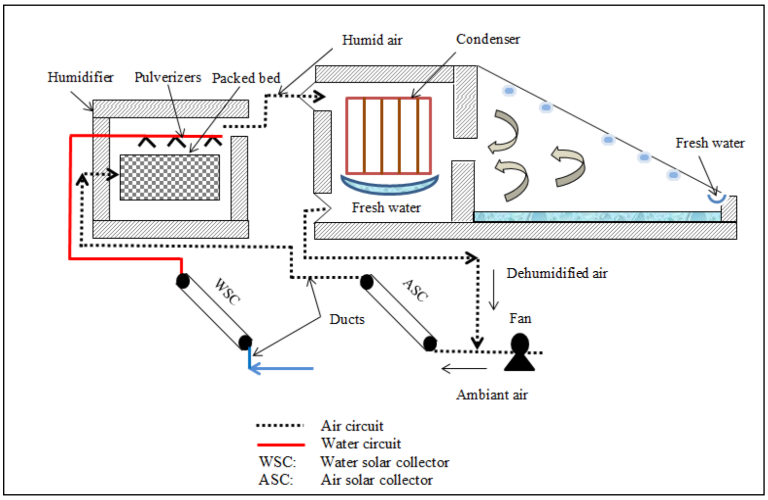

Fig. 1. A schematic diagram of the experimental setup

2. Materials and Methods

2.1 Collector Design and Equipment

Utmost liquid collectors use a distance-and- tube absorber with the tubes in front of, before, or as an integral part of the distance. The water solar heater device used by the present desalination prototype consists of 6 collectors 2 m in length and 1 m in range. The water solar heater uses a distance – and- tube, in bobby material, absorber with the tubes as an integral part of the distance; the inner periphery of the tubes is 10 mm and the external bone is 12 mm. The air gap between the absorber and the glass cover is 0.1 m. The hinder and sides aloneness was handed by polyurethane to reduce heat loss. A silicon sealant was used between the different factors of the water solar collector to insure sequestration from the terrain. The measured variables in the trials reported in this paper include bay and outlet water temperatures, ambient temperature and the solar irradiation incident on the field collector aero plane. The air and water solar collectors were instrumented with Pt100 thermostats with a sensibility of 0.3799 Ω/ °C for measuring the outlet and the bay water and ambient temperatures. The Pt 100, which measured the ambient temperature, was kept in a sanctum to cover the detector from direct sun. A pyranometer, with 1 delicacy and12.29 µV/ Wm2 sensibility, was used to measure the total solar irradiation placed in a vertical aero plane conterminous to the collector.

All detectors, calibrated before use to determine the examinations sensibility, were connected to a data accession system (type Agilent 34970A). During trial, all the parameters were measured and recorded every 1 min for over to 500 mn. All measures started at 800 a.m. The solar desalination system under study differs from the preliminarily explored bones by using a humidifier, on the one hand, and a field of tenement- plate air solar collector and a field of tenement- plate water solar collector, on the other, which makes the system more flexible and increases the fresh water product. Sea or brackish water, preheated in the condensation palace of the solar still by the idle heat of condensation, and hotted in the water solar collector, is pulverized into the humidifier. Due to heat and mass transfers between the hot water and the heated air sluice in the humidifier in case of working in open air circle coming from the condensation the ultimate is loaded by humidity. To increase the exchange face and the hearthstone time of air and water inside the solar still to increase the heat and mass transfer, and later ameliorate the product of the brackish system, and thus to raise the rate of air humidification, a packed bed was implanted in the palace of the humidifier. The impregnated wettish air is also transported toward the condensation palace where it comes in contact with a face the temperature which is lower than the dew point of the wettish air. The condensed water was collected from the bottom of the condensation palace of the solar still, while the Neptune (the salty water exiting the humidifier) at the bottom of the humidifier will be moreover reclaimed and combined with the feed result at the entry point or rejected in case of saltiness rates increase. The detailed descriptions of the solar still main factors are as follows. Utmost liquid collectors use a distance-and- tube absorber with the tubes in front of, before, or as an integral part of the distance. The water solar collector device used by the present distillation prototype consists of 2 collectors 2 m in length and 1 m in range.

The water solar collector uses a distance and tube, in bobby material, an absorber with the tubes as an integral part of the distance; the inner periphery of the tubes is 10 mm and the external bone is 12 mm. The air gap between the absorber and the glass cover is 0.1 m. The hinder and sides aloneness was handed by polyurethane to reduce heat loss. A silicon sealant was used between the different factors of the water solar collector to insure sequestration from the terrain Srivastava and Joseph [19].

2.2 Dynamic Modeling Approaches

The water solar collector can be viewed as a multivariable system with several input and affair signals. Figure 2 presents the air solar collector input/affair illustration as a function of time. It displays the external variables that would affect the water solar collector as the solar radiation, I (t), and ambient temperature, T_{amb} (t), and the collector input signals, videlicet the air inflow rate, mama (t), and temperature, T_{we} (t), as well as the affair signal which is the water temperature, T_{ws} (t). Both I (t) and T_{amb} (t) are considered as disquiet because of their aleatorygeste during the time.

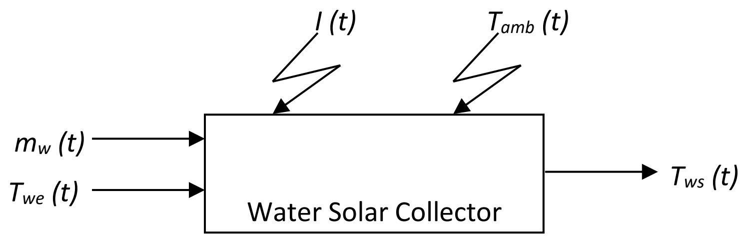

Fig. 2. Water solar collector input/output bloc diagram

The aero plane solar detector can be described by two different models. The first model is formed by an equation of the partial derivations. The alternate, be composed of two equations coupled to the partial derivations binding the temperature of the fluid to that of the absorber.

The flat plate water solar collector is constituted of an absorber of a blockish shape made up of resembling channels in bobby, a glass cover and an insulator. The hypothetical's used in developing the model are listed below:

(a) The water haste of is invariant, thus the air original state depends only on one side x.
(b) The area of the absorber plate and air are considered equal.
(c) The absorber plate and water have the same temperature at any point.
(d) The water temperature remains under 100 °C point.

Since there are no mass or attention changes, the system can be modeled solely from energy balances on the bulk temperature of the unit and the outlet temperature of the water from the system [20,21].

The energy balance equation for the system formed by the absorber and water for a slice of the collector with a range of l, a length of dx and a face of ds, is the coming one (The volume of energy accumulated by the absorber and water millions) = ((the volume of energy entered by a face absorber element, dA, during a dt time) - (the volume of energy gained by water) - (the overall Losses toward the outside)).

Mathematically, this can be expressed as

$$\left(MC\right)_g \frac{dA}{A} dT_w = I\,\tau_v \alpha_{pl}\, dt\, dA - Qw - Qloss_{pl-amb} \tag{1}$$

With

$$\left(MC\right)_g = M_w C_w + M_{pl} C_{pl}$$

$$Qw = m_w C_w dT_w dt$$

$$Qloss_{pl-amb} = U_{loss}\left(T_{pl} - T_{amb}\right) dt\, dA$$

The Eq. (1) can be written as:

$$\left(MC\right)_g \frac{dA}{A} dT_w = I\tau_v \alpha_{pl}\, dt\, dA - m_w C_w dT_w dt - U_{loss}\left(T_{pl} - T_{amb}\right) dt\, dA \quad (2)$$

It can also be further simplified as:

$$\frac{\partial T_w}{\partial t} = \frac{1}{\delta}\left(-m_w \xi \frac{\partial T_w}{\partial x} - T_w + f\left(t\right)\right) \quad (3)$$

With

$$\xi = \frac{C_w}{U_{loss} l} \; ; \; \delta = \frac{\left(MC\right)_g}{U_{loss} A} \; ; \; f\left(t\right) = \frac{\tau_v \alpha_{pl} I\left(t\right)}{U_{loss}} + T_{amb}\left(t\right)$$

The attained fine model for the solar heater allows the determination, for the solar intensity variable situations and ambient temperature T_{amb}, of the fluid immediate temperature at any point of the collector as a function of the command, geometrical and physical parameters (inflow rate, collector area, material and inclination angle of the heater) (Figure 3). It should be noted that the fluid temperature and inflow rate at the heater outlet are the two parameters with the most significant impact on the product of the SS system as they are the input parameters of the distillation module. The distributed parameter character of these models requires the use of a reduction model system to gain doable approximation of the result for the system equation gusted [22-24].

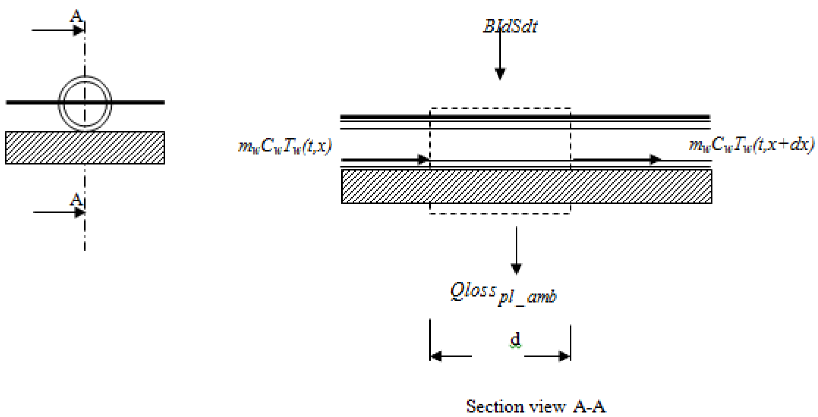

Fig. 3. Thermal energy balance of differential section of solar water collector (one–temperature case)

2.3 Models Approximation of the Solar Collector

The logical result of Eq. (1) is insolvable and it must be discretized to gain approximate. The system of finite differences has been used relatively considerably in the history, but it generally requires a large number of discretization points and results in a similarly large set of Ordinary Differential Equations (ODE).

On the other hand, the Orthogonal Terms Method (OCM) approximates the result by a polynomial trial function, and the performing set of ODE is frequently vastly lower. Presently, the expression system is veritably extensively used in chemical and biotechnological engineering problems [25].

The set of Partial Differential Equations (PDE) is converted to an ODE using the OCM system with the boundary condition

$$\frac{dT_{wi}}{dt}=\frac{1}{\delta}\left[-m_w\xi\left(\sum_{j=1}^{N+1}l_{ij}T_{wj}-l_{i0}T_{we}\right)-T_{wi}+f\left(t\right)\right] \tag{4}$$

Where i=1, 2, 3, ………. N+1.

2.4 Experimental Study of the Water Solar Collector

The measured climatic conditions; solar radiation and ambient temperature T_{amb} for a typical day in august (summer time) in the megacity of Sfax, Tunisia are presented independently in Figure 4. This figure shows an hourly variation of solar radiation and T_{amb}. This day is characterized by clear sky conditions. From this figure, we can see that the maximum solar radiations value is at 1 pm for this hitch experimental days also decreases. It's seen that during the day from daylight to evening, the solar radiation and T_{amb} increase gradationally and reaches a maximum value between around noon period and also decreases. Solar radiation and T_{amb} relate to meteorological conditions which affect the SS performance of the water solar heater. The hourly variations of solar radiation and water solar heater outlet temperature T_w are shown in the Figure 5, Figure 6 and Figure 7 in function of time; show the response of the heater outlet temperature in function of solar radiation during the day. Thus, it can be seen from those hitch figures that when the solar radiation intensity presents a temporal change, a residual hesitancy of the heater outlet temperature T_w follows fleetly [23,24].

Also, water outlet temperature T_w exactly follows the geste of the solar radiation. The maximum solar flux value presented in those numbers is recorded between (Noon and 1 pm) and the outlet water temperatures T_w (75 °C-77 °C) reach their maximum values. After 2 pm, the hitch temperatures begin to drop because of the drop of the quantum of solar radiation falling on the SS-a shadow effect due to a drop of energy quantum. Thus, the heater presents a good response time to any climatic disturbance. It is clear from those numbers that the temporal variations of water solar heater temperatures T_w have the same trends as those of the solar radiation. These results mentioned that the solar radiation during the day has a lesser influence on the thermal performance of the water solar heater than the ambient air temperature T_{amb}. This would be useful to optimize the functioning of the water solar heater by integrating a regulation algorithm grounded on rainfall conditions during system work.

For the high solar radiation intensity, the good response time of the air solar heater leads to an increase in the thermal performance of the water solar heater and also the product of the SS. But for low value, the rapid-fire response of the heater to solar oscillations may be an insufficiency for the SS [26-28].

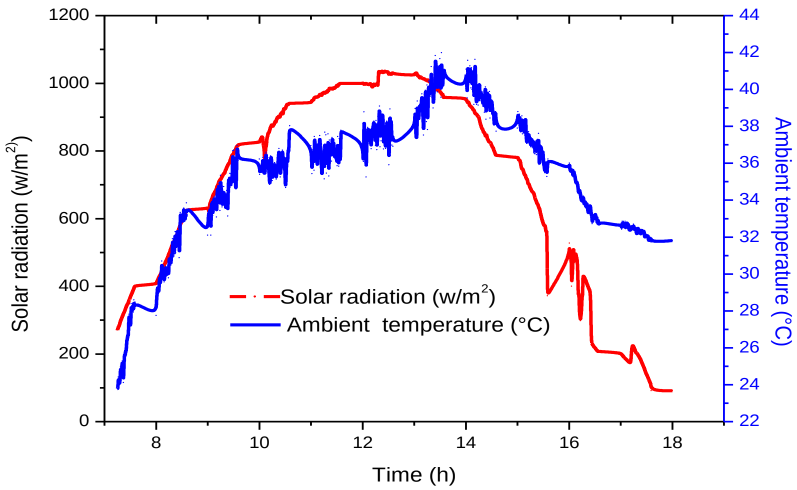

Fig. 4. Hourly variations of the solar radiation and the ambient temperature T_{amb} with local time (19.08.2022)

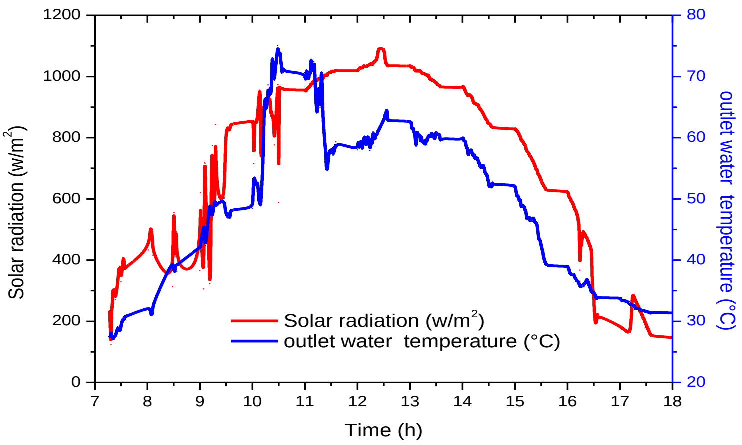

Fig. 5. Hourly variations of the solar radiation and the outlet water temperature T_{ws} with local time (17.08.2022)

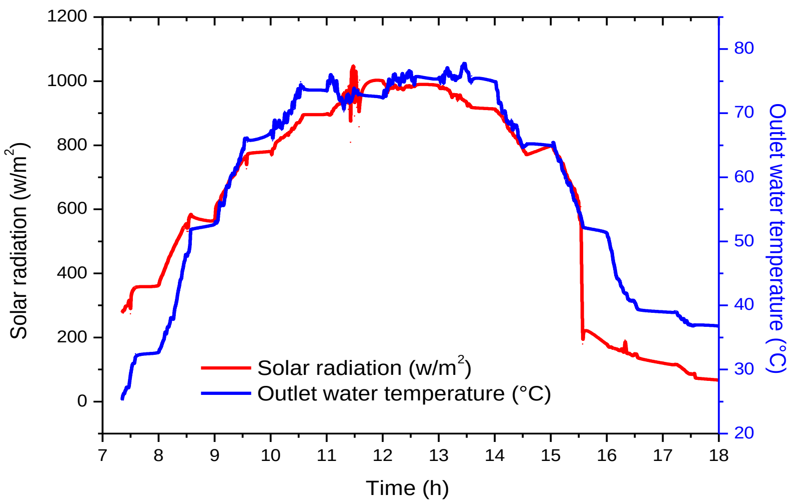

Fig. 6. Hourly variations of the solar radiation and the outlet water temperature T_{ws} with local time (01.09.2022)

Hourly variations of the solar radiation and the water solar heater outlet temperature T_{ws} and of the air solar heater outlet temperature T_a shown in Figure 7 and Figure 8 in function of time show the response of the heater system outlet temperature to the solar radiation natural change during daylight hours. In fact, it can be seen from these numbers that when the solar radiation intensity exhibits a temporal change, a residual hesitancy of the heater outlet temperature follows fleetly. It was noticed that the air T_a and water outlet temperature T_{ws} exactly follow the geste of the solar radiation. The maximum solar flux value shown in those numbers is recorded between (noon and 1 pm), while the outlet air temperature T_a (76 °C-83 °C) and the outlet water temperature T_{ws} (75 °C-77 °C) reach their maximum values [29,30].

After 2 pm the hitch temperatures begin to drop because of the dwindling the quantum of solar radiation falling on the SS-a shadow effect due to a drop of energy [26,27,31].

Thus, the heater system presents a good response time to any climatic disturbance. On the other hand, the outside values of both air and water outlet temperatures T_a and T_w were attained in between 12 and 2 pm, and also dropped gradationally. It is clear from the numbers that the temporal variations of water and air solar heater temperatures T_{ws} and T_a have the same trends as those of the solar radiation. These results indicate that solar radiation has a lesser influence on the thermal performance of the water and air solar heater system than the ambient air temperature. This would be useful to optimize the functioning of the water and air solar heater system by integrating a regulation algorithm into the system grounded on the rainfall conditions.

For the high solar radiation intensity, the good response time of the air solar heater system leads to an increase in the thermal performance of the air solar collector and also the product of the SS. Still, for low solar radiation intensity, the rapid-fire response of the heater system to the solar oscillations may be an insufficiency for the SS [21,22,32].

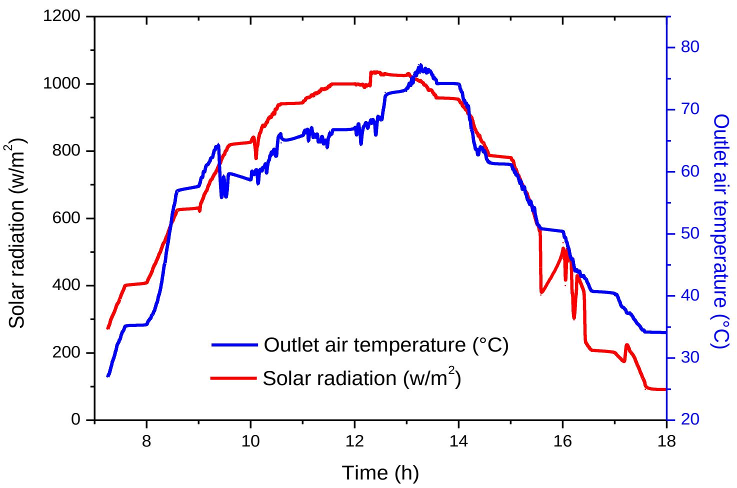

Fig. 7. Hourly variations of the solar radiation and the outlet air temperature T_a with local time (17.08.2022)

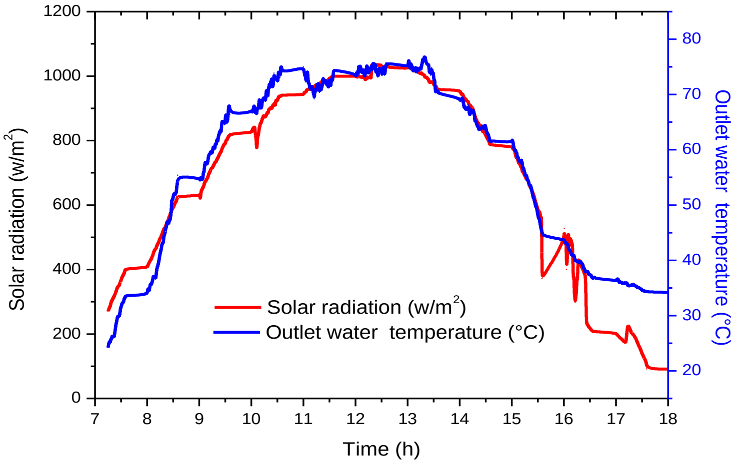

Fig. 8. Hourly variations of solar radiation and outlet water temperature T_{ws} with local time (19.08.2022)

3. Conclusion

The work presented in this article focuses on a theoretical and experimental study of a solar water heater coupled with a new dynamic mode solar still. The results of this study are an important contribution to the enrichment of the literature concerning work on desalination by distillation.

The simulator allowed us to predict the behavior of the solar still and solar water collector according to the variations of internal variables of the system and according to metrological variations.

The effects of integrating the different modules on the system performance have been studied. For all configurations, modeling of the system and simulation of its behavior have been successfully carried out on the basis of and the approach of mass balances.

The results obtained show the influence of external factors and internal parameters on the operating characteristics of the solar still, in particular production and performance. In particular, there is an increase in the global solar irradiation which remains the most influential parameter leads to an increase in these characteristics.

The solar still has been theoretically modeled and tested for different energy storage materials and different water depths. The maximum values of the production rate, the temperature of the water and the glass the temperature varies inversely with the heat capacity pond water and other materials used in the pond. The increase in the heat capacity of the basin makes it possible to reduce the total production of distilled water.

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