ISSN 0003-701X, Applied Solar Energy, 2022, Vol. 58, No. 2, pp. 250–258. © Allerton Press, Inc., 2022.
Russian Text © The Author(s), 2022, published in Geliotekhnika, 2022, No. 2, pp. 330–340.

Experimental Investigation of a Single-Slope Basin Still with a Built-in Additional Flat-Plate Solar Air Collector

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Received September 24, 2021; revised November 3, 2021; accepted January 22, 2022

Abstract—Fresh water and environmental pollution are great challenges to the sustainable development of human society. and the distillation process solves this problem. The yield of distilled water for a single solar tank is still very low. In this work, experimental investigation into increases the evaporation of the stagnant basin water, an air solar collector was incorporated into the stagnant basin. A comparative investigation between conventional and modified solar stills the experiment is being carried out on specific days in February 2021 under the climatic conditions of Ouargla city (30°52′ N, 5°34′ E) to investigate the impact of solar still inside the wooden box coupled with a flat-plate solar air collector on daily productivity and thermal loss under outdoor climatic conditions. It was found that using the single slope solar still coupled with a flat plat solar air collector increases the daily productivity of the conventional by 6.13% and modified solar stills 36.33%. The change in heat loss from day to day is caused by a change in the ambient temperature and the effect of wind speed, and the lower the thermal loss, the higher the daily productivity for a conventional system, but for the modified, there is no effect on it.

Keywords: distillation, solar collector, heat loss, thermal infusion, solar radiation

DOI: 10.3103/S0003701X22020049

INTRODUCTION

Since the availability of fresh water has dwindled over time more children die from the lack of safe drinking water than virtually any other cause (particularly in the Third World). In 1950, the world's population was at 2.5 billion people; by 1999, it had passed 6 billion people; by 2025, it will surpass 8.3 billion people; andit will surpas 10.0 billion people by 2060 [1].

According to the OECD, 340 million people in 28 countries around the world are currently unable to have access to sufficient clean water. By 2025, that figure is expected to grow to almost 3 billion people in 52 nations. North Africa suffers from this problem. Among the proposed solutions, solar distillation has been proposed because it is economical and clean, thanks to its basic structure, and to the fact that it does not require a linked energy source [2].

Charles Wilson (1872) was the first scientist to develop a solar energy device to supply pure water in Chile. It had worked for more than 40 yr [3]. While the distillation utilizing the solar still is highly inefficient, new solutions are needed to increase production [4, 5].

Several theoretical and experimental studies have been conducted in the last 30 years to increase the productivity of Conventional Solar Stills (CSS) by increasing evaporation, heat storage, and lowering thermal losses [6–10]. Tiwari et al. [11, 12] conducted research on the current state of research on both passive and active solar still distillation systems. They claim that the only cost-effective way to deliver drinkable water is to use passive solar stills. An attempt to improve the thermal performance of a single basin solar still is to enumerate some of them using a v-corrugated absorber (VS BSS). In fact, a simple solar still design was proposed which is equipped with a corrugated absorber in the shape of the letter V and a built-in phase changing material (PCM) which allows melted wax to expand inside the storage tank through a net of tubes. Using varying water masses, the system is tested with and without the PCM. They also looked into using PCM to add wick to the corrugated plate. Because of its ease of storage, safety, and homogeneous melting, using the PCM results in a slight drop in daylight productivity but a significant improvement in overnight productivity [13].

Also, through a device consisting of a basin-type distiller with the unique feature of the basin liner being extended as an integrated solar collector accumulator with very simple characteristics, weekly and hourly assessments revealed that the basin-type distiller's daily production increased by about 70% [14].

Many experiments were conducted in order to improve the performance of solar distillation; the interest was to develop a condensing surface or an evaporation liner. We mention here without limitation the work done by Abu-Arabi et al. [15] where they lowered the temperature of the glass cover in order to obtain large amounts of productivity. The use of solar collectors and their incorporation into solar distillates ultimately leads to the improvement of the daily production of the distillation. Much research is now focused on improving the efficiency of solar still using this technology.

Much research is now focusing on improving the efficiency of solar stills by using enhancers such as solar collectors [16–19]. The possibility of using combined solar stills to improve solar distillation yield was examined. The results reveal that as the solar collector area of the helping device rises, so does the fresh water productivity [20]. Tiwari [21] The transient performance of a single basin solar still with a flat plate collector is shown. When there was a connection between the solar still and the flat plate collector the use of a small pump. For the water was cycled between the solar stills and FPSC. The average daily distilled water production was found to be 24% higher than that of a simple single basin solar still.

RAI et al. [22], carried out a study on a single solar basin that was still operating in various modes. For an uncoupled still, the fluctuation of daily distillate with water quantity and salinity was measured. The modes of thermosyphon and forced circulation were also investigated. According to their findings, the rate of daily distillation decreases as salt content rises. The addition of brackish water lowers the rate of evaporation by increasing surface tension. The best results were achieved in a single basin that was still connected to an FPSC with forced circulation. For regions where electrical power is expensive or unavailable, the thermosiphon mode should be used with a tiny dye in the basin water.

The daily distillate production of a solar still connected to a flat-plate solar energy collector in circulation mode is higher than that of an uncoupled still [21]. Also, using the natural circulation effect inside the still, an experimental strategy is offered to improve the performance of a traditional solar still. The concept is to use a rectangular natural circulation loop attached to the back side of the still to generate air flow. Because of the air convection formed inside the still, convective heat transfer is significantly boosted. By doubling the glass cover and employing an external passive condenser, the thermosiphon effect can be achieved [23]. A problem arose in the solar stills, which is the loss of heat, and many scientists tried to solve the problem. Where each of Faramarz et al. [24] Materials are used to preserve waste heat, and the study's numerical results show that the solar still without PCM storage has a better energy and exergy performance, with a maximum value of energy and exergy efficiency of 76.69 and 6.53%, respectively, for a typical sunny day. While the maximum energy and exergy efficiency of the solar still with PCM for a semi-cloudy day sample is 74, 35 and 8.59%, respectively, semi-cloudy days are preferred due to their better energy and exergy performance. In addition, the performance of a solar still was investigated using sand and servo thermal medium oil (heat transfer oil) as a passive storage material beneath the basin liner for waste heat conservation [25, 26]. Meteorological factors, on the other hand, have an impact on thermal losses [27, 28]. In this study, we try to exploit the waste heat from the solar still through its presence inside a wooden box attached to a flat solar collector with air flowing inside it maintains the temperature of the parts of the distiller.

Moreover, Dev and Tiwari [29] derived an expression for instantaneous gain efficiency and instantaneous loss efficiency with the help of empirical data from (Dev et al., 2011) for climate.The case of Muscat, Oman in the months of June and July 2009 and in this solar system one additional element has been introduced which is that the curved inverter is placed under one passive slope basin of solar energy for better heating, the system has glass cover at 23 deg angle, basin area of 1 m^2 and depth Basin water 0.01 m. The analysis was compared with P-SSSS in the same climatic conditions and the results were good. The instantaneous gain efficiency and instantaneous loss efficiency of P-IASSS and P-SSSS were found to be 34.6, 11.6, 48 and 21.9%, respectively for the 0.01 m basin water depth in solar distillation.

The research in this paper aims to reduce and reduce waste heat. This is achieved by placing the solar still inside a wooden box, which is attached to a flat-air solar collector. Where the latter leaks hot air currents, that flow very slowly inside the box to maintain a constant temperature of some parts of the distillation apparatus. Salt water and distilled water were compared using single-slope solar stills. According to complaints, the Ouargla region has a higher salt content in its water than the other regions of south Algeria.

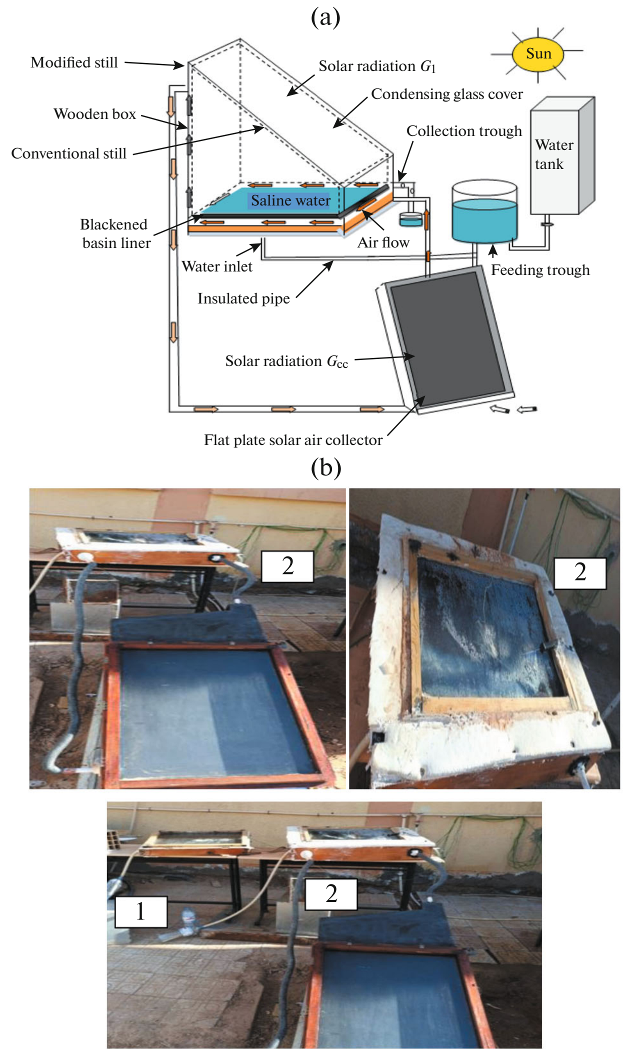

Fig. 1. (a) Schematic diagram of the single slope solar still. (b) Photograph of the solar still.

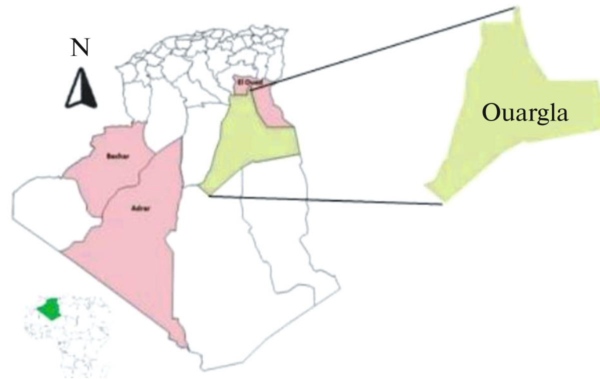

Fig. 2. Geographical location of Ouargla city.

MATERIALS AND METHODS

Solar Still Description

This experiment was based on two distillater. The first conventional solar still, and the second one is modified. A cross sectional view and photograph passive solar still on a single slope Fig. 1 depicts the system in natural mode (a and b respectively). The typical solar still has a surface area of 0.324 m^2, whereas the single slope, solar still, and flat plate collector have a surface area of 1.345 m^2. The flat plate collector is connected to a single slope solar still in such a way that hot air from the collecting plate enters the wooden box through the natural circulation circle. The glass cover is 4 mm thick and level, with a 15° angle to the solar still basin [30, 31]. The water depth is 0.015 m. It entails slowly pouring saline water into the basin to maintain the water depth. The single-slope solar panel is still pointing south. To have a high absorptive of solar energy, the bottom surface of the solar still was painted black and resistant to temperatures of up to 600°C.

Experimental Setup

The experimental work was performed at the Lab. New and renewable energy development in arid and Saharan areas, LENREZA, Ouargla, Algeria (30°52′ N, 5°34′ E) Department of Physics, Faculty of Mathematics and Material Sciences, University of Ouargla, Algeria in the month of February in the 2021. From 8:15 a.m to 5:15 p.m, water productivity was measured with a 1h intervals during all the experiment. The city of Ouargla, is facing (Fig. 2) and has a total area of 211 980 km^2. Its climate is arid, and it is in the middle of the desert where the average temperature during the hottest months exceeds 45°C and the relative humidity does not exceed 19% [32]. Figure 1 shows the experiment where four positions selected to measure the temperature using thermocouple (glass cover—basin—Solar collector (inlet—outlet)). Solar energy travels through the glass cover, is absorbed by the black plate, and then transferred to the seawater in the still evaporation basin.

The vapor is transmitted to the glass, where it condenses. The water steam is separated from the air vapor by continuous circulation, evaporation and condensation, generating a thin liquid coating that trickles down due to gravity. and most of the research conducted on solar distillates aims indicates that in seasons characterized by high air temperatures, the productivity rate of these distillates is high, which indicates that the air temperature factor has a direct impact on the yield of distillation, in contrast productivity decreases in cold seasons. To solve this problem, we have resorted to providing the natural conditions for the solar still by raising the temperature of the environment surrounding the still so that it appears to work in the summer climate. The process consists in placing the device inside a wooden box to isolate this effect.

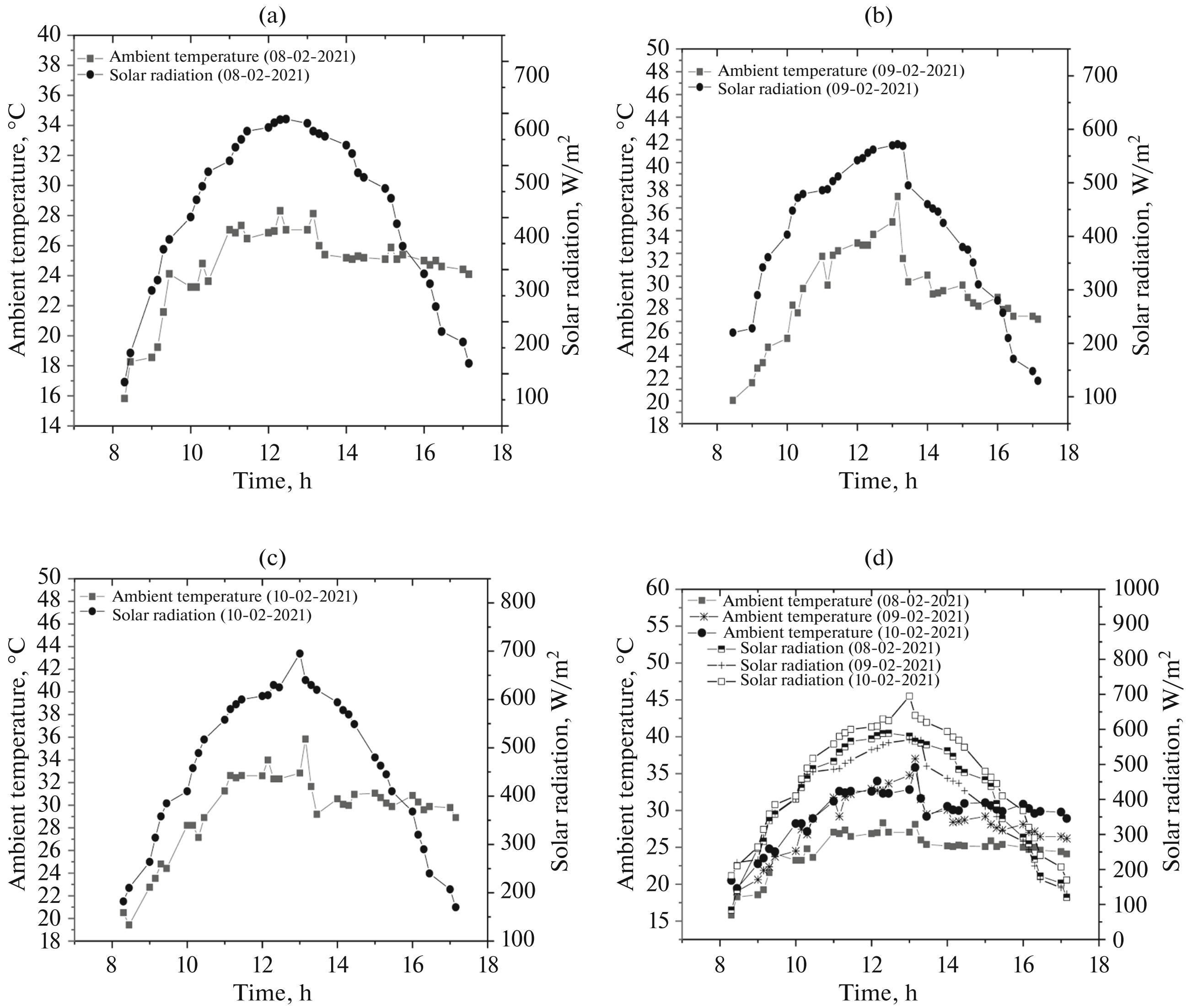

Fig. 3. Hourly change of ambient temperature and solar radiation for single slope stills of the day of the experiment in February 2021.

EQUATIONS FOR MODELING SINGLE SOLAR STILLS WITH ENERGY BALANCE

The statements bellow has been taken into account when creating energy balance equations for various components of a single slope solar still.

(1) The system is operating in a quasi-steady state.

(2) The tubing connecting the solar still to the flat plate collector is completely insulated.

(3) Simplifications:

• We neglect the heat transfer by connecting to the sidewalls. This is due to the thickness and quality of the wood insulating.

• Ignoring the rays reflected by water is due to the fact that the reflectivity is low compared to the absorbance.

• Ignoring the existence of heat loss between the Insulation under the basin and the environment is due to the equal external temperature of the insulator and the environment.

Writing energy balance Eqs. (1)–(3) for various elements of a single-slope solar still:

— Energy conservation equation glass

$$m_g C_g \frac{dT_g}{dt} = \alpha_g G_t + \left(Q_{ev,w-g} + Q_{r,w-g} + Q_{c,w-g}\right) - Q_{r,g-a} - Q_{c,g-a}.$$

— Energy conservation equation water

$$m_w C_w \frac{dT_w}{dt} = \tau_g \alpha_w G_t + Q_{c,b-w} - \left(Q_{ev,w-g} + Q_{r,w-g} + Q_{c,w-g}\right)\frac{A_g}{A_w}.$$

— Energy conservation equation the basin.

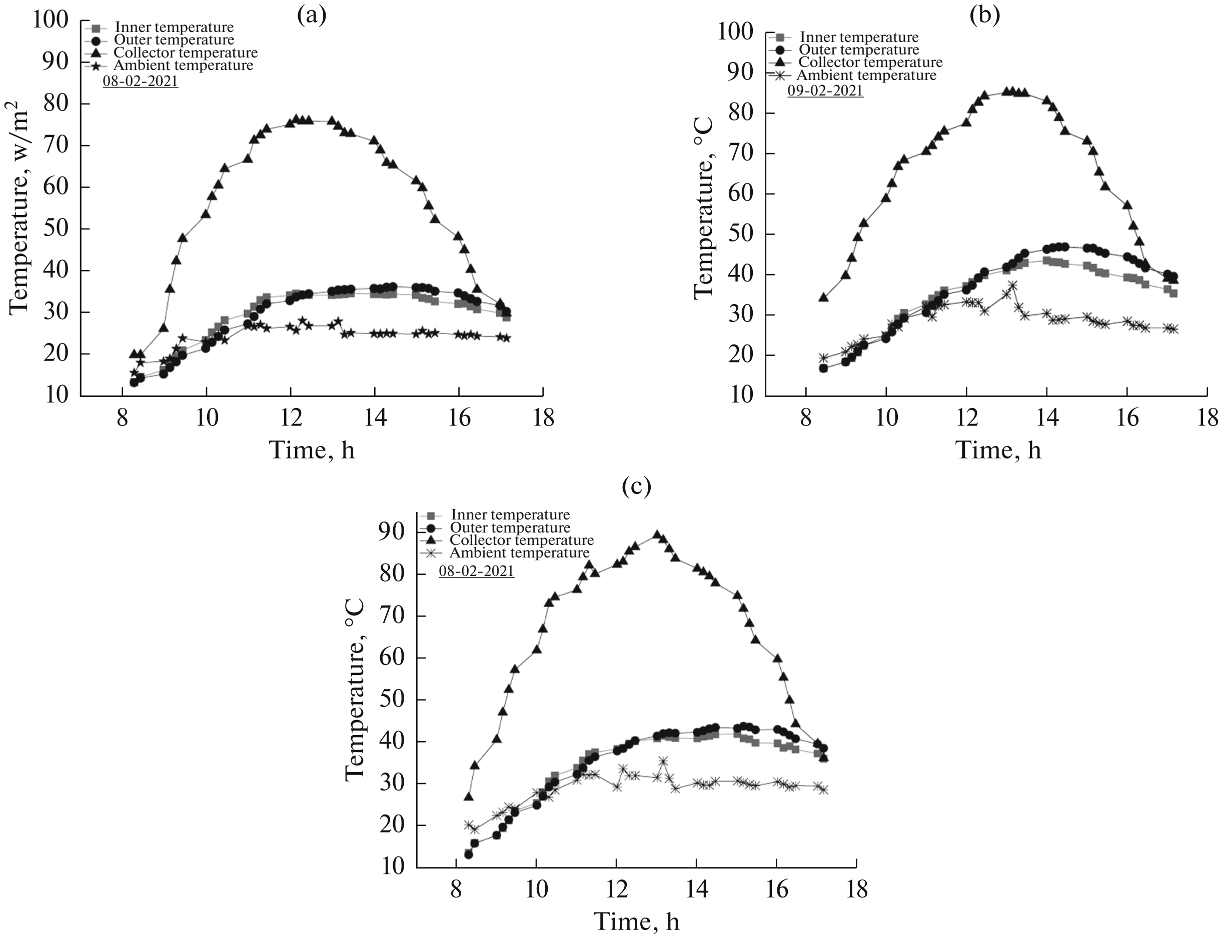

Fig. 4. Variations in ambient temperature, as well as inner and outer and collector temperatures, hourly.

In Conventional Solar Still

$$m_b C_b \frac{dT_b}{dt} = \tau_g \tau_w \alpha_b G_t - Q_{ev} - Q_{c,b-w} - Q_{loss\text{-}b_1}.$$

In Modifier Solar Still with Collector

$$m_b C_b \frac{dT_b}{dt} = \tau_g \tau_w \alpha_b G_t + Q_{ev} - Q_{c,b-w} - Q_{loss\text{-}b_2}.$$

DISCUSSION OF THE RESULTS

Experiments were carried out in order to better understand the performance of the solar still when used in conjunction with the solar air collector. The environmental variables employed in the modeling, such as solar radiation and ambient temperature, are shown in Fig. 3 the day of the experiment in February 2021. Figure 3a was ambient temperature 28.3°C and February 8 and the solar radiation 589 W m^{-2}. The ambient temperature in February 9 is 37°C and solar radiation 572 W m^{-2} (Fig. 3b). The ambient temperature in February 10 is 35.8°C and the solar radiation 695 W m^{-2} (Fig. 3c). Figure 3d shows the total of ambient temperature and the solar radiation.

Figure 4 shows that ambient temperature, inner and outer temperature, and collector temperature for the month of February 2021 daily experiments of slope solar stills. Figure 4a: the temperature high of the collector is 57.0°C and inner temperature 29.8°C and outer temperatures 30.0°C. Figure 4b: the collector temperature is 67.1°C and inner temperature 35.1°C and outer temperatures 35.8°C. Figure 4c: the collector temperature is 65.3°C and inner temperature 34.9°C and outer temperatures 36.4°C.

Collector temperature higher because effect the solar radiation and ambient temperature .and also temperature of the inner and outer are equally on February 9 for modified still.

Figure 5 shows the variance in conventional thermal loss and the modified still in three days: the difference was large, the thermal loss of the conventional still by 136.59 W and the modified still 62.00 W (Fig. 5a); the difference is 102.52 and 61.20 W (Fig. 5b); the difference is 48.22 and 28.16 W (Fig. 5c).

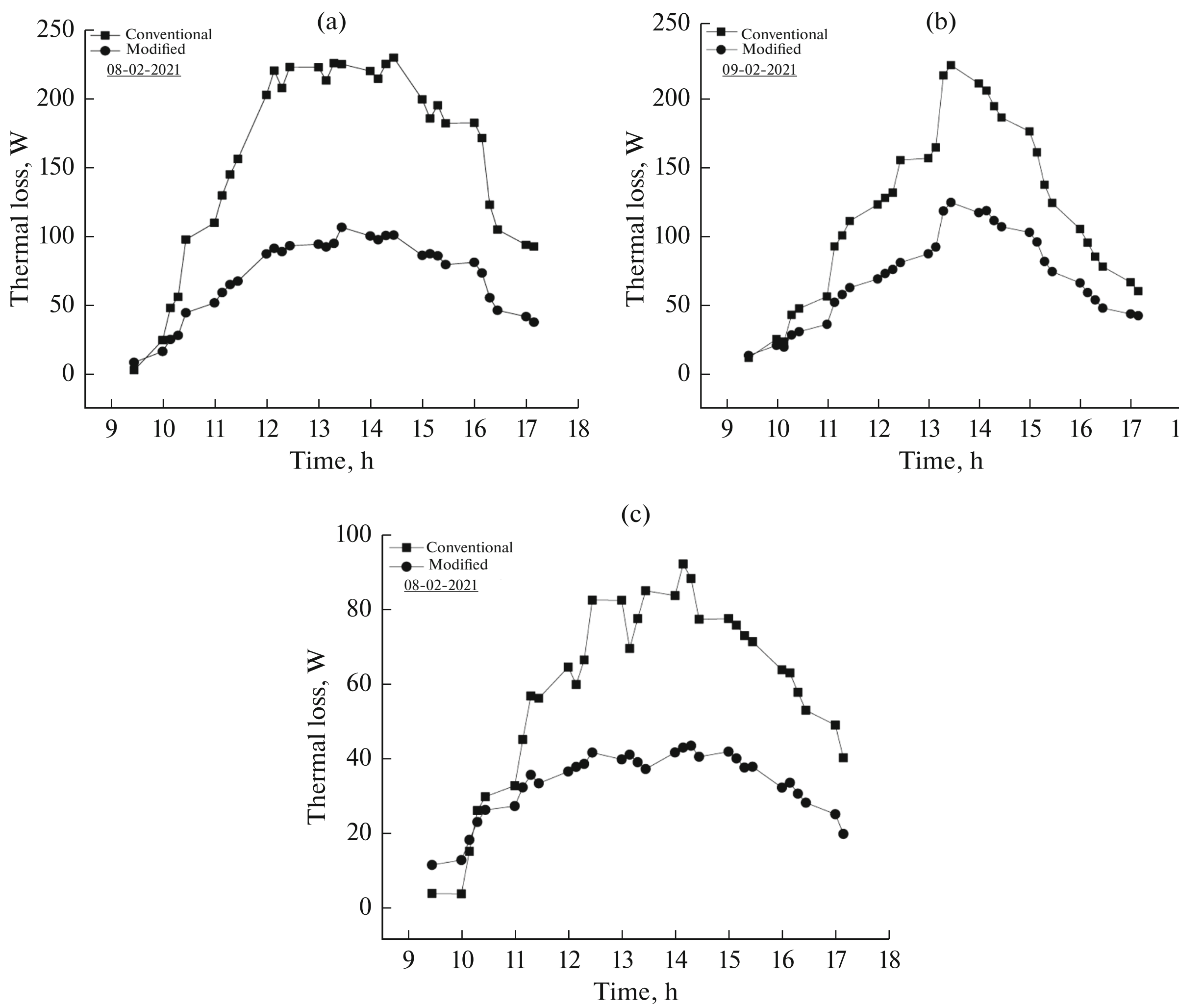

Fig. 5. Differences of thermal losses in conventional and modified.

The change in heat loss from day to day is caused by a change in the ambient temperature and wind speed. Lower ambient temperature increased the heat loss in conventional solar still compared to the modified still because exploitation of thermal loss. On the other hand, heat loss at the beginning of the day due to the rising of elements the solar still.

Figure 6 shows the expected variation in the rate of water production of the conventional still and modified still. Fig. 6a: Where the productivity has grown substantially and clearly of the modified still over the conventional still 0.383 to 1.437 kg/m^2.

Figure 6b: From 8 to 12, there was an increase in the modified still, but by a small percentage, before increasing dramatically from 0.983 to 2.270 kg/m^2.

Figure 6c: From 8 to 11:15, the increase in modified still and conventional is almost identical and after that, the increase in modified is much compared to conventional 1.183 to 2.154 kg/m^2. It can be observed that the hourly yield for modified still is higher than conventional. Fig. 6d shows the total of water production modified still.

Which could be owing to the thermal loss exploited by the solar still temperature conservatism. On the other hand, the decrease in productivity is due to the decrease in ambient speed, which contributes to the lack of cooling of the glass, i.e. the lack of condensation.

A difference in water production from day to day in the experiment for the modified because to a difference in temperature between the inner and the outer but at February 9 are equally of the inner temperature and outer resulted in an increase in productivity.

When comparative water production between the conventional still in summer and modified still in winter. It was found that the production on modified 2.270 kg/m^2 and the conventional 3 kg/m^2 on June 25, 2020. So the production of conventional in summer are equally the production of modified in winter.

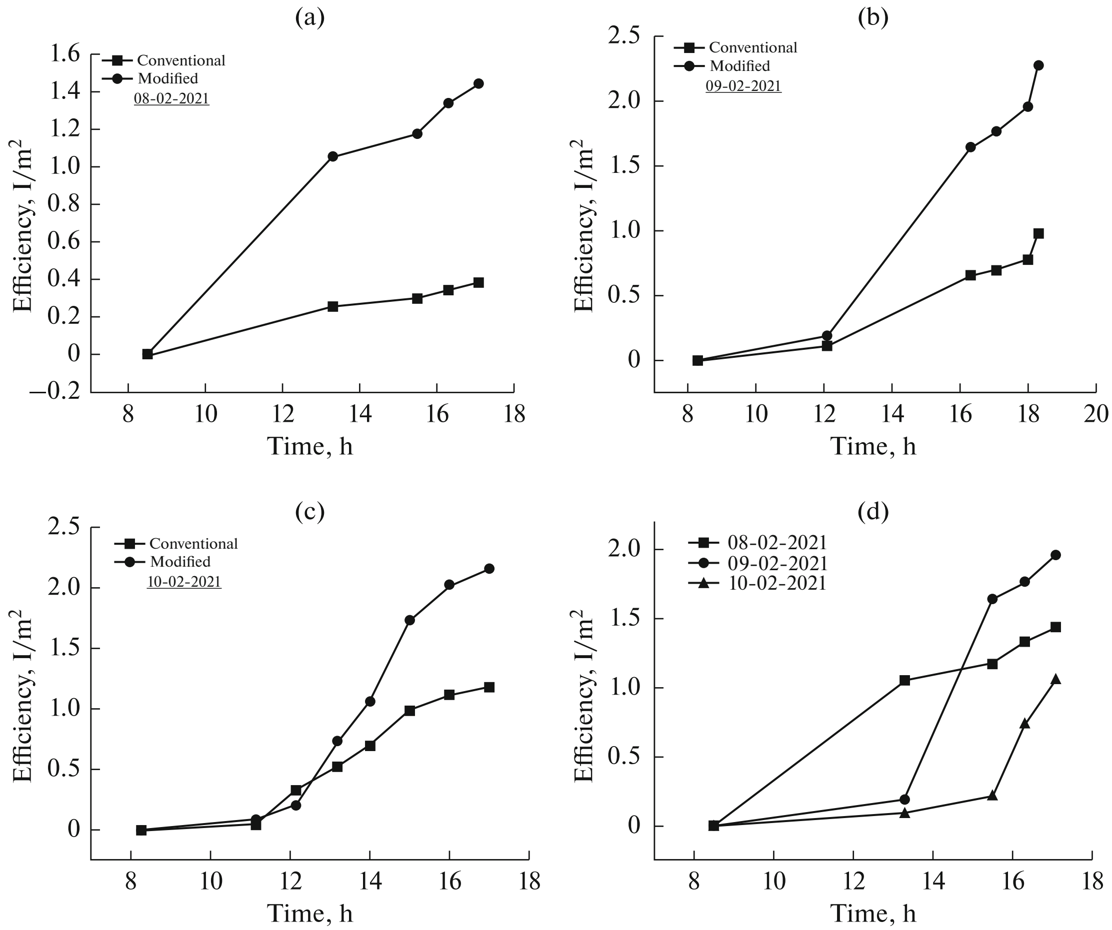

Fig. 6. Hourly fluctuations in ambient temperature and water productivity rate predicted and measured during the month of February 2021.

NOMENCLATURE

A	area, m^2
C_p	(J/(kg K)) specific heat at constant pressure
D	distance (m)
G	solar radiation, W/m^2
H	heat transfer coefficient (HTC) basin, $W/(m^2\,K)$
K	thermal conductivity, W/m °C
L	length of the flat plat solar air, m
M	mass, kg
Q	heat transfer rate (HTR), W/m^2
T	temperature, K
T	time, s
V	wind speed, m/s
U	overall heat loss, $W/(m^2\,K)$

Subscripts

A	ambient
B	basin
C	convection
R	radiation
Ev	evaporative
G	glass
Sky	actual of the planetarium
Box	wooden box
Iso	insulator
Coll	collector
Loss-b	thermal loss of conduction
v	volume, m^3
w	Water

Greek symbols

ε	emissivity
α	absorptivity

τ	transmissivity
ρ	reflectivity
σ	Stefan–Boltzmann constant (5.6697 × 10^8, W/(m^2 K^4))

Abbreviations

FPAC	Flat Plat Solar Air Collector
CSS	Conventional Solar Still

CONCLUSIONS

The followings are Some of the Conclusions We Have Reached

The aquarium's simple solar energy has been modified with an air solar collector to increase its productivity. To obtain the distilled water yield, different experiments were performed for the above-mentioned modification. The experimental results showed that the average daily production was higher when using this technique. The maximum deviation between the two models was about 50%. Productivity increased from 0.983 to 2.270 kg/m^2.

In comparison to conventional still, the thermal loss of a single slope with the collector is reduced. Lower ambient temperature increased the heat loss in conventional solar still compared to the modified because exploitation of thermal loss and at the coldest ambient air temperatures, the overall heat loss coefficient is highest.

The production of conventional in summer are equally the production of modified in winter and difference in water production from day to day in the experiment for the modified still because to a difference in temperature between the inner and the outer and height of water production at February 9 are equally of the inner temperature and outer.

Appendix A

In Eqs. (1)–(3) different heat transfer and heat transfer coefficients are follows:

$$Q_{r,w-g} = h_{r,g-a} A_g (T_g - T_{sky}),$$

where $h_{r,g-a} = \varepsilon_g \sigma (T_g^4 - T_{sky}^4) = 0.9\sigma (T_g^4 - T_{sky}^4)$,

$$T_{sky} = T_a - 6,$$

$$Q_{c,g-a} = h_{c,g-a} A_g (T_g - T_a),$$

$$h_{c,g-a} = 2.8 + 3V, \quad V \le 5 \text{ m/s},$$

$$Q_{r,w-g} = \varepsilon_w \sigma (T_w^4 - T_g^4) = 0.9\sigma (T_w^4 - T_g^4),$$

$$Q_{c,w-g} = h_{c,w-g} A_g (T_w - T_g),$$

$$h_{c,w-g} = 0.884 \left[(T_w - T_g) + \frac{(P_w - P_g)(T_w + 273.15)}{268.9 \times 10^3 - P_w} \right]^{1/3},$$

$$Q_{ev,w-g} = h_{ev,w-g} A_b (T_w - T_g),$$

$$h_{ev,w-g} = 16.273 \times 10^{-3} h_{c,w-g} \frac{p_w - p_g}{T_w - T_g},$$

$$Q_{c,b-w} = h_{c,b-w} A_b (T_b - T_w),$$

$$h_{c,b-w} = 0.54 \frac{K_w \mathrm{Ra}^{1/4}}{L_w}, \quad 10^4 < \mathrm{Ra} < 10^7.$$

In conventional solar still

$$Q_{ev} = Q_{r,b-a} + Q_{c,b-a},$$

$$Q_{r,b-a} = \varepsilon_{iso} \sigma (T_b^4 - T_a^4) = 0.11\sigma (T_b^4 - T_a^4),$$

$$Q_{c,b-a} = h_{c,b-a} (T_b - T_a),$$

$$Q_{loss\text{-}b_1} = U_{b_1} (T_b - T_a),$$

where,

$$U_{b_1} = \left(\frac{e_1}{k_1} + \frac{e_2}{k_2} + \frac{e_3}{k_3} \right)^{-1}.$$

Then

$$Q_{loss-Total1} = Q_{r,g-a} + Q_{c,g-a} + Q_{loss1} + Q_{r,b-a} + Q_{c,b-a}.$$

In modifier solar still with collector

$$Q_{r,b-a} = \varepsilon_{iso} \sigma (T_b^4 - T_{coll_{(moy)}}^4) = 0.11\sigma (T_b^4 - T_{coll_{(moy)}}^4),$$

where,

$$T_{coll_{(moy)}} = \frac{T_{coll1} + T_{coll2}}{2},$$

$$Q_{c,b-a} = h_{c,b-a} (T_b - T_{coll_{(moy)}}),$$

$$Q_{loss\text{-}b_2} = U_{b_2} (T_b - T_{coll_{(moy)}}),$$

where,

$$U_{b_2} = \left(\frac{e_1}{k_1} + \frac{e_2}{k_2} + \frac{e_3}{k_3} \right)^{-1}.$$

Then

$$Q_{loss\text{-}Total_2} = Q_{r,g-a} + Q_{c,g-a}.$$

The following are the saturated vapour pressure expressions as a function of temperature (°C).

$$P(T) = \exp\left(25.317 - \frac{5144}{T + 273.15}\right).$$

FUNDING

The General Directorate for Scientific Research and Technological Development (DGRST).

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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