



Experimental and Theoretical Investigation of the Thermal Performance of Passive Single-Slope Solar Stills in Arid Regions

Mammar Bouhelal ^{a,*}, Amar Rouag ^{b,c}, Abdelhamid Bouhelal ^d, Yousef Belloufi ^{b,e}

^a Laboratoire de Mécanique Appliquée et Systèmes Energétiques (LMASE), Faculty of Applied Sciences, Kasdi Merbah University, Ouargla, Algeria

^b Department of Renewable Energies, Faculty of Hydrocarbons, Renewable Energies, Earth and Universe Sciences, Kasdi Merbah University, Ouargla, Algeria

^c Laboratoire de Génie Energétique et Matériaux (LGEM), Mohamed Khider University of Biskra, Algeria

^d Laboratory of Green and Mechanical Development (LGMD), Ecole Nationale Polytechnique, Algiers, Algeria

^e Laboratoire de Génie Matériaux (LGM), Mohamed Khider University of Biskra, Algeria

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ABSTRACT

This paper presents an experimental and theoretical analysis of a passive single-slope solar still's performance for clean water production in the arid regions of Algeria (including El-Oued and Ouargla). The study focused on four typical days, which were analyzed numerically using NASA Surface Meteorology and Solar Energy (SSE) data to investigate seasonal performance. A parametric study on the most productive day was then conducted to evaluate the impact of varying parameters on the system's performance. The results show that the solar still's performance is highly influenced by solar radiation intensity and ambient temperature. Productivity in the summer was 1.5 times higher than in the other seasons. It has shown also that increasing the basin liner's absorptivity resulted in a 67.7% increase in efficiency. Additionally, the study found that when the water mass in the basin increases, the system's efficiency drops semi-linearly by about -0.12. This suggests that while increasing the water mass may provide more thermal storage, it negatively impacts the system's efficiency, likely due to slower heat transfer and evaporation processes.

1. INTRODUCTION

Approximately 97.5% of Earth's water is saltwater, with only 2.5% being freshwater, of which 80% is frozen in ice caps or combined as soil moisture (El-Dessouky & Ettouney, 2002). There is a great need

* Corresponding author, E-mail address: bouhelal.mammar@univ-ouargla.dz

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for clean drinking water, especially with the increase in population in the world and the insufficient current sources of clean water. Clean drinking water is necessary for daily consumption, industry, and agriculture (Kalogirou, 2023; Tiwari & Sahota, 2017). There are several water desalination techniques, the main ones being thermal desalination and membrane desalination (Duffie et al., 2020).

Membrane desalination relies on the use of permeable materials that allow water molecules to pass through while preventing the passage of salt. Pumps are necessary to push water through the membrane, which requires electrical energy in these systems (Sathyamurthy et al., 2017). On the other hand, thermal desalination, as the name suggests, relies on the evaporation and condensation of saltwater to obtain freshwater. Solar distillation is a technique that belongs to the category of thermal techniques and relies on the use of renewable sources (i.e. solar energy) for water distillation.

In theory, there are two types of solar distillation techniques: direct and indirect distillation systems. Direct solar distillation heats water directly from the sun, whereas indirect solar distillation uses a solar collector to transfer heat to a heat transfer fluid, which is then used to heat water in a second circuit (Duffie et al., 2020; El-Dessouky & Ettouney, 2002; Kalogirou, 2023; Tiwari & Sahota, 2017).

Generally, direct solar distillation is utilized for small amounts of water, whereas indirect solar distillation is used to create bigger amounts of freshwater. Solar distillation systems use two technologies: active (Badran et al., 2023) and passive (Keshtkar et al., 2020; Bouhelal et al., 2023). The primary distinction between these two systems is that active sun distillation utilizes an external energy source to initiate the distillation process, whereas passive solar distillation simply uses solar energy.

The most common and traditional method of obtaining fresh water from solar energy is to use a basin-type solar still. This method employs the sun to heat saltwater in a basin with a tilted glass panel. The water evaporates and condenses on the glass plate, generating drops that fall into a collector below, yielding fresh water. Basin-type solar stills are typically classified into two types: single-slope and double-slope (Sathyamurthy et al., 2017; Tiwari & Sahota, 2017). The single-slope solar still is the simplest and most often used in the world (Bouhelal et al., 2025).

Recent research demonstrates significant improvements in solar still performance with novel changes. El-Sebaey et al. (2022) developed a double-basin single-slope solar system that achieved 59.9% better productivity and 25% thermal efficiency than traditional designs, highlighting the importance of water depth optimization. Similarly, Nazari et al. (2019) improved a single-slope solar still by incorporating an external thermoelectric cooling channel on the glass cover and copper oxide (Cu_2O) nanofluid in the basin water. In comparison to a traditional solar still, this system improved freshwater productivity by up to 81%, energy efficiency by 80.6%, and exergy efficiency by 112.5 percent. Thermoelectric cooling raised the temperature difference between the basin water and the glass, increasing condensation, whereas the nanofluid increased the thermal conductivity of the basin water, improving performance even further. Economic research found a competitive cost per liter and a fair payback period, demonstrating the practicality of these improvements in arid, sun-rich environments.

Al-Mezeini et al. (2023) found that smaller water depths greatly increase productivity and thermal efficiency in single-slope solar stills, achieving up to 2.68 L/day and 30%, respectively, in Oman's desert climate. The installation of external reflectors enhanced these measures by increasing basin temperature, resulting in 3.075 L/day and 35% efficiency. Their findings also revealed that distillate quality meets potable water requirements, highlighting the practicality of simple, low-cost solar stills for freshwater production in sun-rich, water-scarce areas. These findings emphasize the importance of operational parameters and design optimizations on system performance.

Rahbar and Esfahani (2013) used a 2D CFD model and a unique productivity equation based on the Chilton-Colburn analogy to forecast single-slope solar still performance. The model precisely mimics

fluid flow, heat transfer, and mass transfer, allowing for the determination of optimal design parameters such as still length and glass-to-water distance. Validation against experiments verified its reliability, making it an effective tool for optimizing solar stills.

Estahbanati et al. (2016) studied the influence of internal reflectors (IRs) on single-slope solar stills using tests and an enhanced radiation model that takes into consideration solar radiation on all still walls. Experiments indicated that IRs increased water output by 16% in the summer and 41% in the winter, for an average annual gain of 34%. IRs on the front and side walls increased yield by around 18%, while rear wall reflectors increased it by 22%. The study also discovered that cloudiness affects infrared effectiveness, with the greatest influence under clear sky. Internal reflectors are a cost-effective and zero-energy solution for increasing solar still efficiency, particularly in places with high solar radiation and low cloud cover.

Altarawneh et al. (2017) conducted experimental and numerical studies on single slope, double slope, and pyramidal solar stills, concluding that a single slope still with a 30° south-facing tilt performs best annually. They found low water depth and sufficient insulation as critical criteria for increasing production and created a verified model that accounts for heat and mass transfer under real-world settings.

Malaiyappan et al. (2016) investigated the impact of basin materials (glass, galvanized iron, and aluminum) on single-slope solar still productivity. Their studies and CFD simulations revealed that aluminum basins produced the most freshwater due to superior thermal conductivity and heat storage. The study reveals that the choice of basin material has a significant impact on solar still efficiency.

Baimbetov et al. (2024) created a sophisticated computational model using heat balance equations and the Runge-Kutta method to evaluate single-slope solar still productivity throughout different Caspian region cities. The model takes into account local climate differences such as solar irradiation, ambient temperature, water depth, and insulation. Tehran had the highest yearly productivity (1760 kg/m²) and efficiency (53%), while cooler cities showed lesser performance. The study found that the ideal basin water depth (~2 cm) and insulation thickness (4-9 cm) for continental climates. It also shown economic viability, with distilled water prices as low as USD 0.024/kg in Baku. These findings confirm the model's correctness and highlight the significance of environmental adaptability and design optimization for solar stills in various locales.

Despite significant advances in the design and optimization of single-slope solar stills—ranging from nanofluid enhancements and thermoelectric cooling to reflective surface integration and material selection—there is still a significant lack of field-validated performance data for these systems in North African desert climates, particularly Algeria. Most research use laboratory conditions or simulations calibrated to other geographic regions, which limits the generalizability of their conclusions. Furthermore, parametric models frequently overlook seasonal performance variations and the combined effect of various interacting variables such as basin mass and glazing characteristics. This creates a gap in the region-specific experimental validation and modeling required to design solar distillation systems for Algeria's arid southern zones such as El-Oued and Ouargla.

Southern Algeria is characterized by a unique combination of exceptionally high solar energy potential and severe water scarcity, which makes it particularly suitable for solar-driven desalination technologies. The Saharan regions of Algeria, including El-Oued and Ouargla, benefit from average annual global solar irradiation levels exceeding 2,000 kWh·m⁻²·year⁻¹, placing them among the most favorable areas worldwide for solar energy exploitation (Stambouli et al., 2012). At the same time, Algeria faces critical water stress, with renewable freshwater availability falling below 500 m³ per capita per year, a level classified as absolute water scarcity according to widely accepted water stress indicators

(Ait-Aoudia & Berezowska-Azzag, 2016). This combination of abundant solar resources and acute water scarcity strongly motivates the development and assessment of passive solar still systems for sustainable clean water production in southern Algeria.

This paper aims to present an experimental and numerical investigation of the thermal performance of a single-slope solar still under arid climatic conditions in Algeria, with a focus on the El-Oued and Ouargla regions. An experimental campaign was conducted on a single clear day, 25 November 2024, in the Guemar area (El-Oued), and the measured data were used exclusively to validate a transient numerical model based on energy balance equations.

After validation, the numerical model was applied purely in simulation mode to analyze the performance of the solar still under seasonal climatic conditions. For this purpose, four typical days (21 March, 21 June, 21 September, and 21 October) were selected, and the corresponding meteorological data were obtained from the NASA Surface Meteorology and Solar Energy (SSE) database. Furthermore, a parametric study was conducted numerically on the most productive day (21 June) to investigate the influence of key design and operating parameters, such as basin water mass and absorptivity, on system performance.

2. EXPERIMENTAL SETUP

The widely recognized single-slope solar still is distinguished by its straightforward design and affordability, making it an accessible option for DIY (Do It Yourself) construction. The proposed domestic passive single-slope solar still is assembled using four wooden planks: two trapezoidal pieces measuring 16.5 cm by 8.5 cm by 2.5 cm, one square piece of 16.5 cm by 16.5 cm by 2.5 cm, and another square piece of 8.5 cm by 8.5 cm by 2.5 cm. Additionally, a larger wooden base measuring 55 cm by 55 cm supports the structure. The internal dimensions of the box are set at 14 cm by 6 cm by 50 cm. These wooden parts are precisely cut and joined together using specialized wood adhesive, with screws providing added stability. The dimensions of the proposed system are presented in Fig. 1.

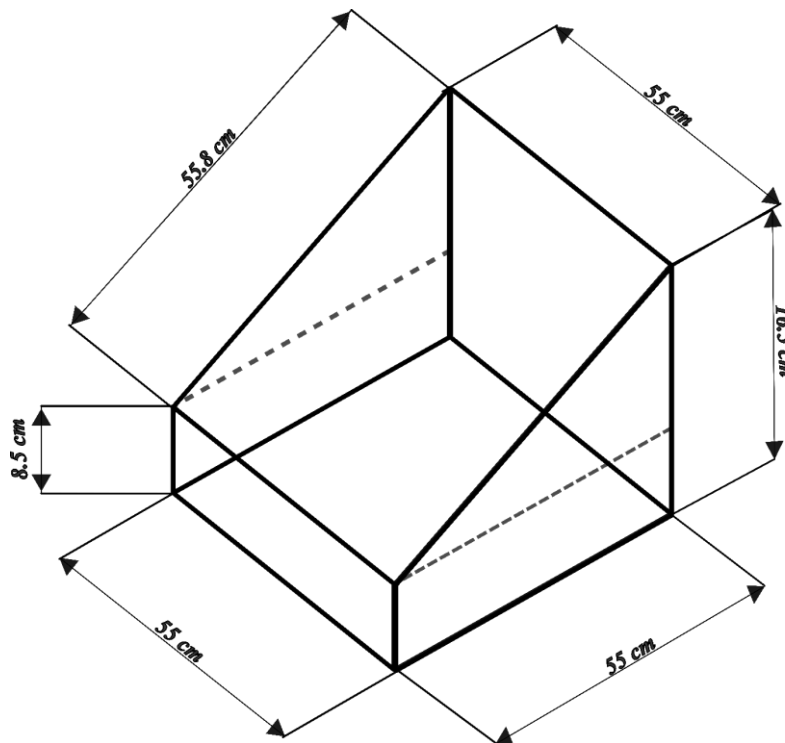


Fig 1. Sketch of a constructed solar still with dimensions.

To improve solar heat absorption, the inner surfaces of the distiller were coated with two layers of matte black paint for even coverage. A thick waterproof layer of black silicone sealant was then applied to enhance water resistance and thermal insulation. For external surfaces, a white reflective coating was used to reduce heat absorption from ambient sunlight, thereby decreasing thermal losses and increasing efficiency. The insulation material used for the solar still was red wood, coated with a white reflective coating to reduce thermal losses. The thermal conductivity of the red wood is approximately $0.12 \text{ W/m}\cdot\text{K}$, and the insulation thickness was set at 5 cm, as previously mentioned.

Two holes were drilled into the side panels of the wooden structure to insert the collection tube, which passes through these openings. About one-third of a PVC tube, measuring 60 cm in length and 2.5 cm in diameter, was cut to facilitate water droplet collection from beneath the glass cover. The entire distiller is sealed with a glass pane of 55 cm by 55 cm and 0.3 cm thickness. One end of the collection tube was sealed with a waterproof cap to prevent leaks, while the other end was connected to a storage tank to collect the distilled water continuously. The fully assembled solar still is shown in Fig. 2.



Fig 2. Fully assembled single-slope solar still with integrated water collection system.

Figure 3 displays the placement of Type K thermocouples within the system, which are used to monitor temperatures of the water, the interior surface of the glazing, and the external surface, providing essential data for assessing system performance.

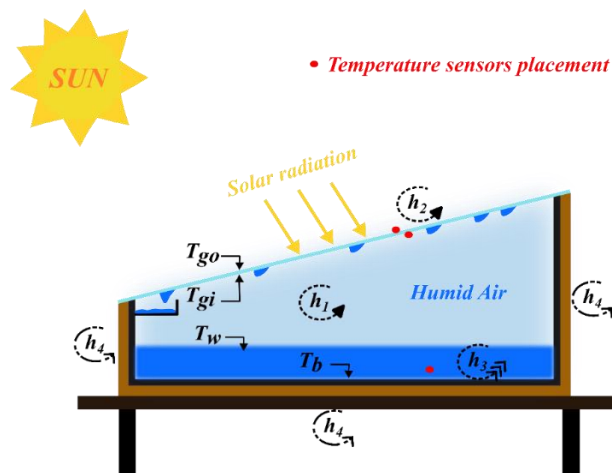


Fig 3. Schematic diagram showing the placement of Type K thermal sensors and heat transfer coefficients in the solar still mode.

The proposed system was experimentally evaluated on 25 November 2024 under clear sky conditions in the Guemar region, located in the El-Oued district of southern Algeria. Measurements were conducted throughout the day, from 07h10 to 17h00, spanning a total of ten hours, with data acquisition intervals of 30 minutes. The temperatures of the ambient air, basin water, and inner and outer glass cover surfaces were measured using Type K thermocouples with a measurement accuracy of $\pm 0.2\% \pm 0.7^\circ\text{C}$. Table 1 presents the measured parameters, which include ambient air temperature, inner and outer glass cover temperatures, and basin water temperature. This single experimental campaign was carried out solely for numerical model validation.

Table 1. Measured temperature data of the solar still system.

Time	Ambient Temperature, T_a ($^\circ\text{C}$)	Inner Glass Temperature, T_{gi} ($^\circ\text{C}$)	Outer Glass Temperature, T_{go} ($^\circ\text{C}$)	Water Temperature, T_w ($^\circ\text{C}$)
07h10	14.2	14.1	15.3	22.8
07h40	11.3	14.5	13.2	20.1
08h10	11.9	15.1	13.5	18.4
08h40	12.3	17.3	15.8	17.6
09h10	14.6	21.2	18.1	20.9
09h40	16.6	24.1	20.8	24.5
10h10	18.2	27.6	23.0	29.1
10h40	19.5	31.4	25.4	33.6
11h10	20.7	34.9	28.2	37.6
11h40	22.4	38.6	29.4	42.8
12h10	23.2	41.7	30.9	46.2
12h40	23.6	43.4	32.2	48.5
01h10	25.7	45.1	32.3	50.0
01h40	25.1	45.9	31.5	50.4
02h10	24.5	44.3	31.3	48.7
02h40	25.3	41.7	30.6	46.1
03h10	24.1	40.8	30.1	44.7
03h40	21.9	37.1	29.1	41.5
04h10	19.7	33.3	27.7	36.6
04h40	22.1	28.4	23.6	35.1
05h10	20.4	24.8	21.5	28.9

3. MATHEMATICAL MODEL

This section presents a transient mathematical model developed to describe the heat and mass transfer processes occurring within the single-slope solar still. The model is based on coupled energy balance equations applied to the main system components, namely the basin water, inner glass cover, outer glass cover, and basin liner. The governing equations account for solar energy absorption, convective, radiative, and evaporative heat transfer mechanisms, as well as conductive heat losses to the ambient environment. The primary unknowns of the model are the time-dependent temperatures of the basin water (T_w), inner and outer glass covers (T_{gi} , T_{go}), and basin liner (T_b), which are solved simultaneously to evaluate the thermal behavior and productivity of the solar still.

The assumptions made for the thermal analysis of a typical single-slope solar still are stated as follows:

1. The temperatures are uniform in space and vary only with time.
2. The thermal capacitance of the glass cover and basin liner is neglected, as their thermal masses are relatively small compared to that of the basin water, which dominates the transient thermal behavior of the solar still. Consequently, thermal energy storage is considered only in terms of the water mass.
3. The surface areas of the glass cover and basin are assumed to be equal.
4. The sides and bottom of the solar still are equipped with thermal insulation.

- **For inner glass cover**

As presented in Fig.3, the energy balance for inner glass cover states that the heat gained by the inner glass surface from solar absorption and convection with the water equals the conductive heat transferred through the glass to the outer surface. Thus, the energy balance for the inner glass cover can be expressed as follows (Tiwari & Sharma, 1991; Yadav & Prasad, 1991):

$$\alpha_g I(t) + h_1(T_w - T_{gi}) = \frac{k_g}{L_g}(T_{gi} - T_{go}) \quad (1)$$

where: $I(t)$ is the intensity of solar radiation at time t , α_g is the absorptivity of glass cover, T_w is the water temperature in basin, T_{gi} is the inner glass temperature, T_{go} is the outer glass temperature, T_w is the water temperature, k_g is the thermal conductivity of the glass, L_g is the thickness of glass cover, h_1 is the total internal heat transfer coefficient from the water surface to the glass cover, calculated by:

$$h_1 = h_{r,1} + h_{c,1} + h_{evap} \quad (2)$$

where:

$h_{r,1}$ is the radiative heat transfer coefficient from water to inner glass cover, it can be calculated by (Tiwari & Sahota, 2017):

$$h_{r,1} = \varepsilon_{eff} \sigma \left[(T_w + 273)^2 - (T_{gi} + 273)^2 \right] (T_w + T_g + 546) \quad (3)$$

$h_{c,1}$ is the convective heat transfer coefficient from water to glass cover, it can be estimated by (Badran & Abu-Khader, 2007):

$$h_{c,1} = 0.884 \left[(T_w - T_{gi}) + \frac{(P_w - P_{gi})(T_w + 273)}{268.9 \times 10^3 - P_w} \right]^{1/3} \quad (4)$$

h_{evap} is the evaporative heat transfer coefficient from water to glass, approximated as:

$$h_{evap} = 16.273 \times 10^{-3} \times h_{cw} \frac{(P_w - P_{gi})}{(T_w - T_{gi})} \quad (5)$$

In the equation (3), σ is the Stefan-Boltzmann constant, which has a value of $5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$, and ε_{eff} is the effective emissivity of the water surface and it is a dimensionless parameter that represents the ratio of the actual emissivity of the water surface to the emissivity of a blackbody. It is typically assumed to be 0.9 for a water surface. It can be calculated by:

$$\varepsilon_{eff} = \left(\frac{1}{\varepsilon_g} + \frac{1}{\varepsilon_w} - 1 \right)^{-1} \quad (6)$$

where ε_g and ε_w are respectively the emissivity of glass and water.

In equations (4) and (5), P_w and P_{gi} are the partial pressures of water vapor at the water surface and the inner glass surface, respectively. They are calculated based on the water and glass temperature by (Badran & Abu-Khader, 2007; Tiwari & Sahota, 2017):

$$P(T) = \exp \left(25.317 - \frac{5144}{T + 273} \right) \quad (7)$$

• For outer glass cover

The energy balance for the outer glass cover equates conductive heat transfer through the glass to convective heat loss from the outer surface to the ambient air. The energy balance for the outer glass cover can be expressed as:

$$\frac{k_g}{L_g} (T_{gi} - T_{go}) = h_2 (T_{go} - T_a) \quad (8)$$

h_2 is the total external heat transfer coefficient from glass to ambient, calculated by:

$$h_2 = h_{r,2} + h_{c,2} \quad (9)$$

where, $h_{r,2}$ is the radiative heat transfer coefficient from glass to atmosphere, calculated by:

$$h_{r,2} = \frac{\varepsilon_g \sigma [(T_{go} + 273)^4 - (T_{sky} + 273)^4]}{(T_{go} - T_a)} \quad (10)$$

T_{sky} is the temperature of sky, calculated by:

$$T_{sky} = 0.0552 T_a^{1.5} \quad (11)$$

$h_{c,2}$ is the convective heat transfer coefficient from glass to atmosphere, it can be estimated by (Badran & Abu-Khader, 2007):

$$h_{c,2} = 5.7 + 3.8V \quad (12)$$

where V is the wind speed. For the El Oued region, the annual wind speed is 4.9 m/s (Bouhelal & Smaili, 2021).

- **For water temperature**

The energy balance equation for the mass of water in the basin of the solar still represents the relationship between the heat gained from the inner glass cover and the heat lost to the surrounding environment, as well as the rate of change of the temperature of the water. This equation is expressed as (Badran & Abu-Khader, 2007; Tiwari & Sahota, 2017; Yadav & Prasad, 1991; Yadav & Yadav, 1998):

$$m_w c_w \frac{dT_w}{dt} + h_1(T_w - T_{gi})A_b = h_3(T_b - T_w)A_b \quad (13)$$

where A_b is the surface area of the water in the basin, T_b is the basin liner temperature, m_w is the mass of water in the basin, c_w is the specific heat of water, h_3 is the natural convective heat transfer coefficient from basin to water, estimated using the correlation (Bergman et al., 2011):

$$\begin{cases} Nu_{water} = 0.1 \times Ra^{1/3} & \text{for } Ra > 10^7 \\ Nu_{water} = 0.54 \times Ra^{\frac{1}{4}} & \text{for } Ra \leq 10^7 \end{cases} \quad (14)$$

where $Nu_{water} = h_3 L^* / k_{water}$ is the Nusselt number for water, and Ra is the Rayleigh number, defined as:

$$Ra = \frac{g\beta(T_b - T_w)L^{*3}}{\nu\alpha} \quad (15)$$

where g is the gravitational acceleration, $\beta = 1/T_{avg}$ is the thermal expansion coefficient, α is the thermal diffusivity of water, ν is the kinematic viscosity of water, L^* is the characteristic length of the still, defined as the ratio of the basin area to its perimeter (Badran & Abu-Khader, 2007), i.e., $L^* = A_b/P_b$.

- **For basin liner**

The energy balance equation for the liner of the basin represents the relationship between the heat absorbed from the sun by the basin liner, the heat lost from the water surface by natural convection, and the heat lost from the basin liner to the surrounding environment. This equation is expressed as:

$$\alpha_b I(t) = h_3(T_b - T_w) + h_4(T_b - T_a) \quad (16)$$

where h_4 is total heat transfer coefficient from the basin liner to ambient, calculated by (Tiwari & Sahota, 2017):

$$h_4 = \frac{1}{\left(\frac{L_{ins}}{k_{ins}} + \frac{1}{h_{r,4} + h_{c,4}}\right)} \quad (17)$$

L_{ins} and k_{ins} are the thickness and the conductivity of the insulation, $h_{r,4}$ and $h_{c,4}$ are the radiative and convective heat transfer coefficients from the basin to atmosphere. The $h_{r,4}$ coefficient is calculated by:

$$h_{r,4} = \frac{\varepsilon_b \sigma \left[(T_b + 273)^4 - (T_{sky} + 273)^4 \right]}{(T_b - T_a)} \quad (18)$$

where ε_b is the emissivity of the basin liner. The convective heat transfer coefficients from the basin to atmosphere $h_{c,4}$ is estimated using the following correlation (Bergman et al., 2011):

$$\begin{cases} \text{Nu}_{\text{air}} = 0.664 \times \text{Re}_{\text{air}}^{1/2} \times \text{Pr}_{\text{air}}^{1/3} & \text{for } \text{Re}_{\text{air}} \leq 10^5 \\ \text{Nu}_{\text{air}} = 0.037 \times \text{Re}_{\text{air}}^{0.8} \times \text{Pr}_{\text{air}}^{1/3} & \text{for } \text{Re}_{\text{air}} > 10^5 \end{cases} \quad (19)$$

In this study, Maple mathematics software (Thota, 2012) was used to obtain the governing differential equation for water by substituting Eqs. (1), (8), and (16) into Eq. (13):

$$\frac{dT_w}{dt} + \alpha T_w = \beta I(t) + \gamma T_a(t) \quad (20)$$

where:

$$\alpha = \frac{A_b}{c_w m_w} \left[h_1 \left(1 - \frac{L_g h_1 h_2 + h_1 k_g}{(L_g h_1 + k_g) h_2 + h_1 k_g} \right) - h_3 \left(\frac{h_3}{h_3 + h_4} - 1 \right) \right] \quad (21)$$

$$\beta = \frac{A_b}{c_w m_w} \left[\frac{h_1 (L_g h_2 \alpha_g + k_g \alpha_g)}{(L_g h_1 + k_g) h_2 + h_1 k_g} + \frac{h_3 \alpha_b}{h_3 + h_4} \right] \quad (22)$$

$$\gamma = \frac{A_b}{c_w m_w} \left[\frac{h_1 h_2 k_g}{(L_g h_1 + k_g) h_2 + h_1 k_g} + \frac{h_3 h_4}{h_3 + h_4} \right] \quad (23)$$

The discretized form of the Eq. (20) using the finite difference method can be written as follows:

$$T_w^{t+1} = T_w^t + \Delta t (-\alpha T_w^t + \beta I(t) + \gamma T_a(t)) \quad (24)$$

where $\Delta t = 0.1$ s represents the time step.

Moreover, Eqs. (1), (8) and (16) result in, respectively

$$T_{gi}^t = \frac{(T_a(t) k_g + L_g (\alpha_g I(t) + h_1 T_w^t)) h_2 + k_g (\alpha_g I(t) + T_w^t h_1)}{(L_g h_1 + k_g) h_2 + h_1 k_g} \quad (25)$$

$$T_{go}^t = \left(-\alpha_g I(t) - h_1 (T_w^t - T_{gi}^t) \right) \frac{L_g}{k_g} + T_{gi}^t \quad (26)$$

and

$$T_b^t = \frac{\alpha_b I(t) + h_4 T_a(t) + h_3 T_w^t}{h_3 + h_4} \quad (27)$$

Equations. (24), (25), (26) and (27) represent the explicit expressions for the temperatures of the water mass (T_w), inner glass cover (T_{gi}), outer glass cover (T_{go}) and basin liner (T_b) of the still, respectively.

The rate of distillate output per unit area of the basin ($\dot{m}_e$) and the thermal efficiency (η) can be mathematically expressed respectively as (Tiwari & Sharma, 1991; Yadav & Prasad, 1991; Yadav & Yadav, 1998):

$$\dot{m}_e = \left(\frac{h_{evap} (T_w - T_{gi})}{L_v} \right) \times 3600 \quad (28)$$

and

$$\eta = \frac{\dot{M}_e L}{(A_b \sum I(t)) \Delta t} \times 100 \quad (29)$$

where h_{evap} is the evaporative heat transfer coefficient from water surface to glass cover, L_v is the latent heat of vaporization, and $\dot{m}_e$ is the daily distillate output per unit basin area.

4. MODEL VALIDATION

4.1 Validation with Yadav & Prasad (1991)

To validate the mathematical model presented above, the operating conditions and parameters used by Yadav & Prasad (1991) were adopted. The parameters used, including constant heat transfer coefficients and other relevant factors, are presented in Table 2. Additionally, Fig. 4 illustrates the variation of solar irradiation and ambient air temperature as a function of time. The basin water temperature distribution, calculated using Eq. (24) with parameters and climate conditions as described in Table 2 and Fig. 4 (left), is presented in Fig. 4 (right). The mass of water and the absorptivity of glass are respectively $m_w = 25$ kg and $\alpha_p = 0.7$. The results obtained indicate good agreement between the calculated and Yadav's numerical data, with the two curves being identical. The maximum relative error does not exceed 3%, demoting the powerful of the proposed theoretical model.

4.2 Validation with present measurements

Additional validation was performed using experimental data from the proposed solar still system located in Guemar, El Oued region, on November 25, 2024. The estimated solar irradiation and measured ambient temperature used as inputs for the numerical model are shown in Fig. 5. The experimental error has been determined using the sensibility of thermocouple sensors. Fig. 6 compares the measured and predicted temperatures over time. Both datasets follow a similar pattern, showing an increase in water temperature from early morning, reaching a peak around midday, followed by a gradual decrease in the late afternoon. The numerical model effectively captures the overall trend with high accuracy, although slight underprediction is noted during the early morning hours. The maximum relative error is less than 5.6%.

Table 2. Parameter values used for the validation of the solar still model (Yadav & Prasad, 1991).

Parameter	Symbol	Value
Area of the basin liner	A_b	1.0 m^2
Heat capacity of water	c_w	4190 J/kg
heat transfer coefficient from water surface to glass cover	h_5	$8.55 \text{ W/m}^2\text{°C}$
heat transfer coefficient from water surface to glass cover	h_1	$22.52 \text{ W/m}^2\text{°C}$
heat transfer coefficient from glass surface to ambient	h_2	$50.0 \text{ W/m}^2\text{°C}$
heat transfer coefficient from surface of basin liner to ambient	h_3	$135.05 \text{ W/m}^2\text{°C}$
heat transfer coefficient from bottom surface of still to ambient	$h_{c,4}$	$6.27 \text{ W/m}^2\text{°C}$
Thermal conductivity of insulation	k_{ins}	$0.04 \text{ W/m}^2\text{°C}$
Thickness of insulation	L_{ins}	0.05 m
Latent heat of vaporization	L_v	$2.297 \cdot 10^6 \text{ J/kg}$

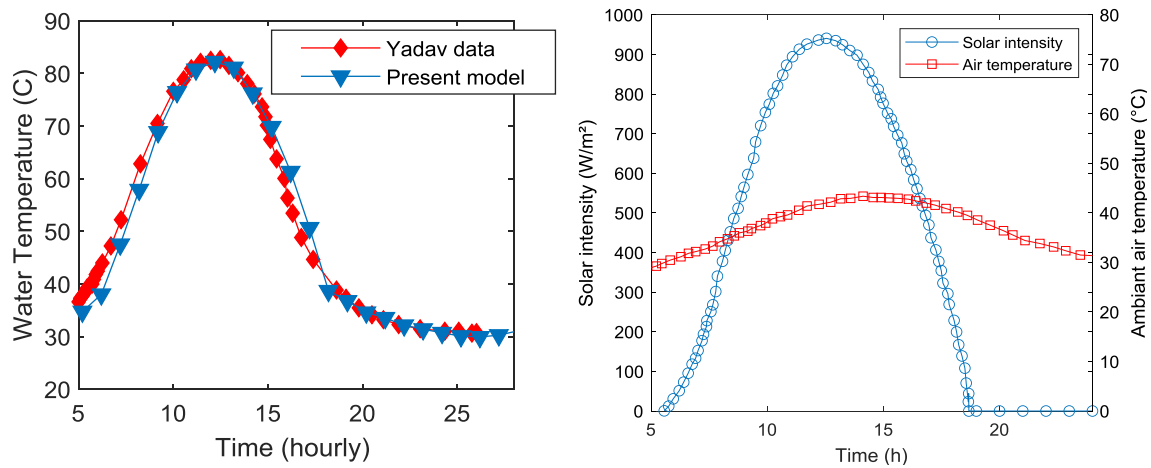


Fig 4. Comparison of the water temperature distribution between the actual model and Yadav & Prasad results (right), and hourly variation of the solar intensity and ambient temperature used by Yadav & Prasad (1991) (left).

The uncertainty in the measured temperatures is governed by the thermocouple accuracy ($\pm 0.2\% \pm 0.7$ °C). This measurement uncertainty was considered when evaluating the agreement between experimental data and numerical predictions; the reported deviations fall within an acceptable range relative to the sensor accuracy.

During the experimental validation conducted on 25 November 2024, the solar irradiation used as an input to the numerical model was obtained from the NASA Surface Meteorology and Solar Energy (SSE) database, corresponding to the geographical coordinates of the Guemar (El-Oued) region. This dataset provides hourly averaged solar radiation values derived from long-term satellite observations and validated atmospheric models, and it has been widely used in solar thermal studies. The accuracy and consistency of this data source make it suitable for representing the incident solar radiation during the validation day.

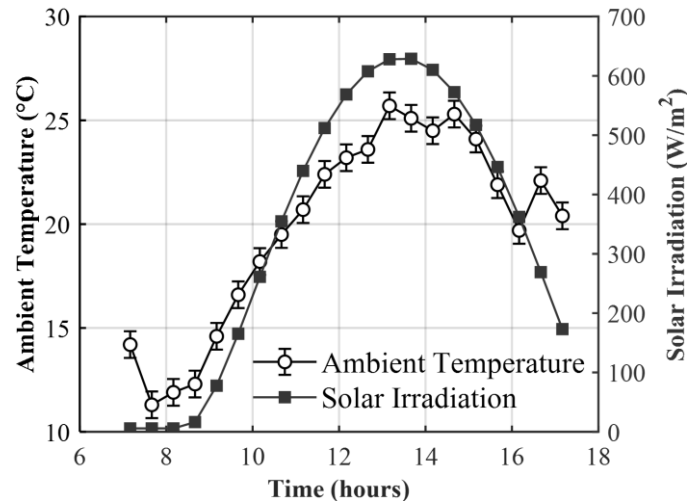


Fig 5. Measured ambient temperature and estimated solar irradiation profiles over time at Guemar, El Oued region on 25/11/2024, for solar still validation.

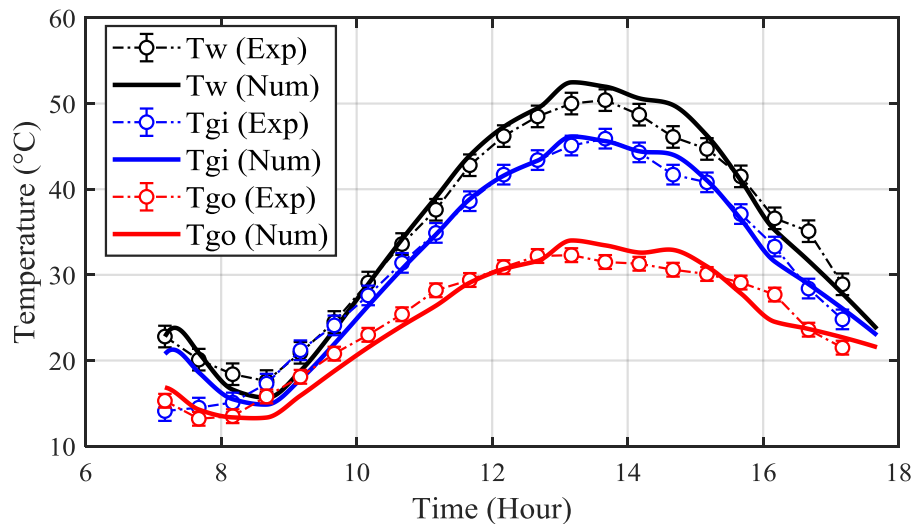


Fig 6. Comparison of experimental and numerical temperatures over time for the solar still at Guemar, El Oued Region on 25/11/2024.

It should be noted that this validation is based exclusively on experimentally measured data from 25 November 2024, whereas the seasonal performance analyses presented in Section 5 were carried out using NASA Surface Meteorology and Solar Energy (SSE) data.

5. RESULTS AND DISCUSSION

5.1 Simulation

In this study, the validated numerical model was used to simulate the performance of the solar still for four typical days (namely, 21/03/2022, 21/06/2022, 21/09/2022, and 21/10/2022) under different weather conditions for the region of Ouargla with a latitude and longitude of 31.95 and 5.316667, respectively. The meteorological data for these days were obtained from the NASA Surface meteorology and Solar Energy (SSE) model (Whitlock et al., 2000), which combines a variety of sources, including meteorological station observations, satellite measurements, and atmospheric models. The model then

uses this data to estimate the solar radiation and meteorological parameters at any location on Earth. Figure 7 depicts the fluctuations in solar irradiation intensity and ambient temperature across these typical days. The maximum solar irradiation on March 21, 2022, June 21, 2022, September 21, 2022, and October 21, 2022 was 787.20, 1011.40, 870.45, and 777.33, respectively.

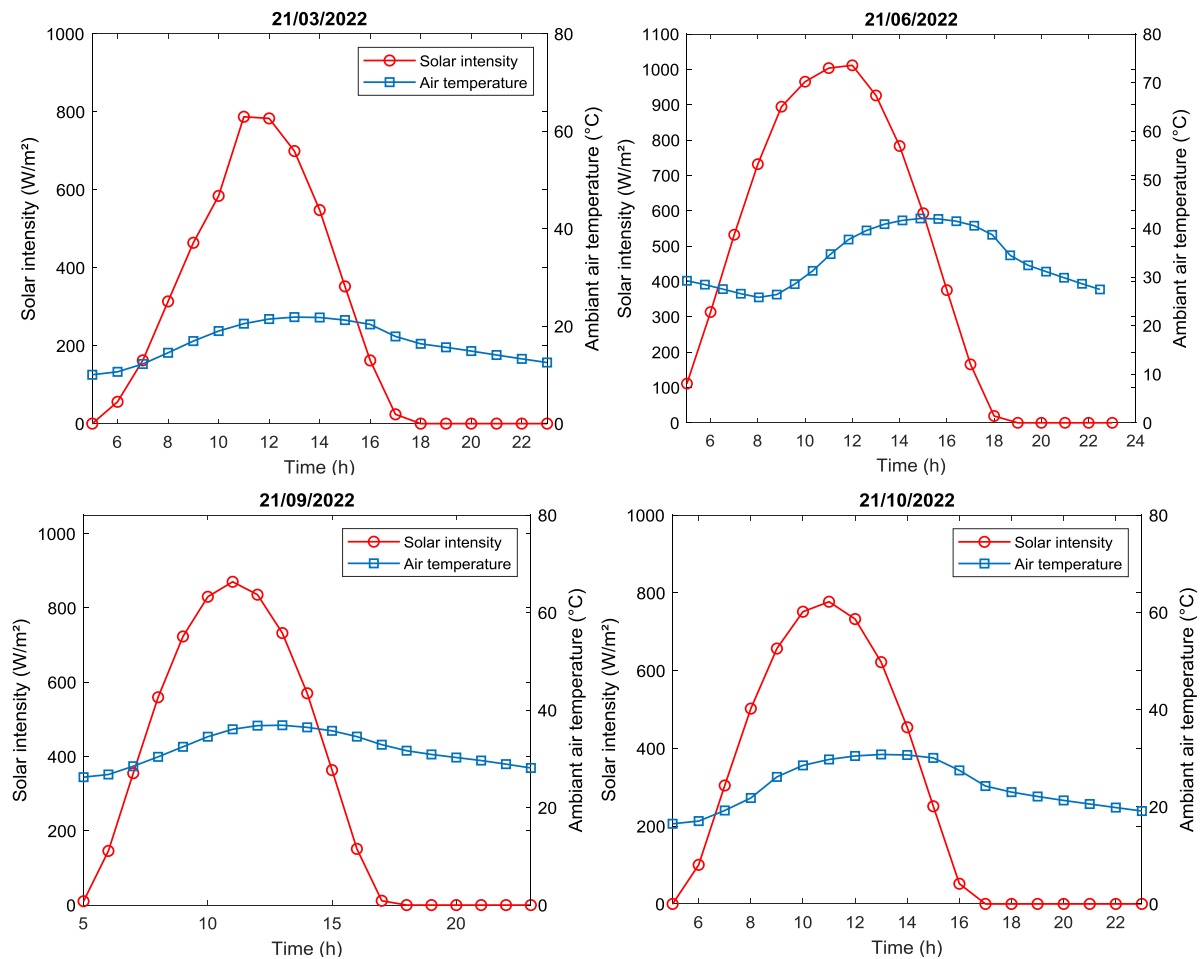


Fig 7. Variation of the solar intensity and the ambient temperature for the selected days.

The temperatures of the basin water, mean glasses cover, and basin liner have been calculated using Eqs. (24-27) based on the operating conditions of the four selected days presented in Fig. 7. Table 2 provides the parameters used in these calculations, including the heat transfer coefficients, which were assumed to be constants in this study. The same values used by (Yadav & Prasad, 1991) and presented in table 1 were utilized, as the variation of these coefficients was deemed negligible and having the same order of magnitude as reported by (Kalogirou, 2023).

Figure 8 shows the distribution of the water, glass cover and basin for the four studied days. Based on the results presented in Fig 8, it can be inferred that the temperature distributions conform to the shape of solar irradiation, and the maximum temperatures rise in proportion to the intensity of solar irradiation.

Figure 9 illustrates the variations in collected water in the solar still over four days of testing, which also represents its production. The graph clearly illustrates that the solar still's productivity grows dramatically over the summer season, particularly on June 21, 2022, when solar radiation intensity is at its peak. In contrast, production remained practically constant on the other study days, 21/03/2022, 21/09/2022, and 21/10/2022, when solar radiation intensity is significantly lower. Notably, production in June was 1.5 times that of March, September, and October, demonstrating a substantial relationship

between solar radiation intensity and system performance. The graph also shows that, as expected, the higher the solar radiation, the more water accumulated in the still, showing that periods of higher solar radiation are best for increasing clean water production. This shows that seasonal fluctuations in solar radiation have an important role in determining the overall efficiency and output of solar stills, with the summer months offering the best conditions for water distillation.

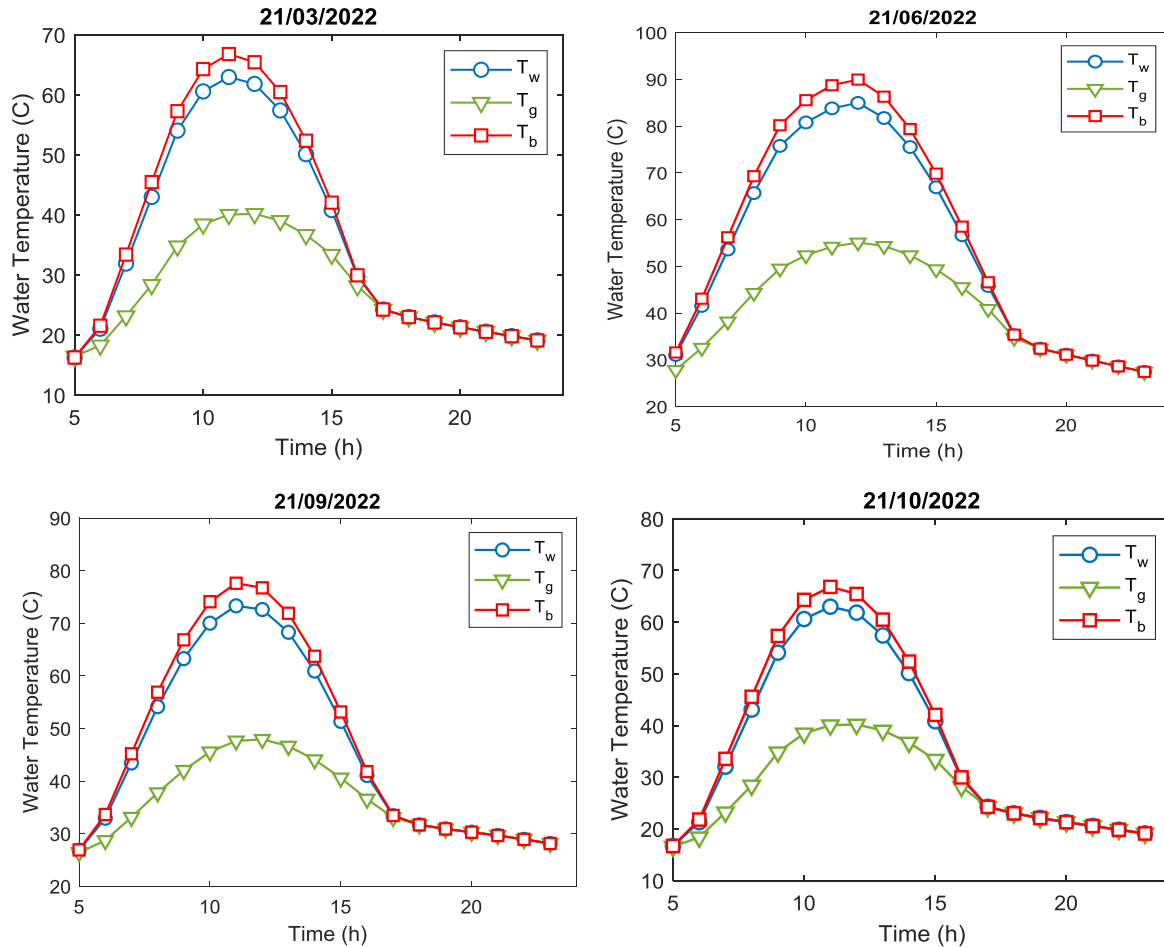


Fig. 8. Variation of the temperature of water, glass, and basin liner for the selected days.

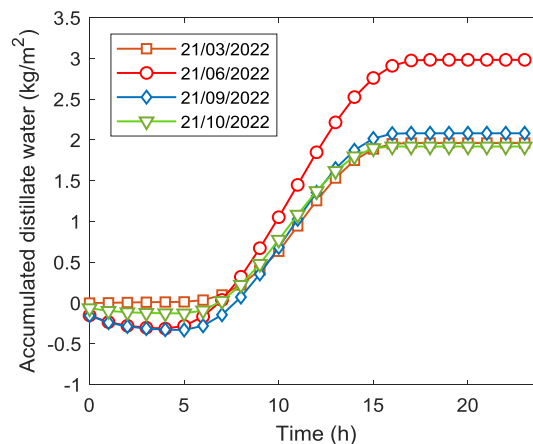


Fig 9. Productivity of the solar still distribution for the selected days.

In order to assess the absolute performance of the proposed system, the obtained productivity levels were compared with benchmark studies reported under similar Saharan climatic conditions. For instance, (Khechekhouche et al., 2021) reported a daily freshwater production of approximately $3.15 \text{ kg} \cdot \text{day}^{-1}$ for a conventional single-slope solar still operating under El-Oued climatic conditions. Similarly, (Khechekhouche et al., 2020) observed a productivity of about $3.41 \text{ L} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ for a conventional still in the same region, which increased to $4.84 \text{ L} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ when an external refractor was employed. These comparisons indicate that the productivity achieved in the present study is within the typical range reported for passive solar stills in arid southern Algerian climates, confirming the competitiveness and practical relevance of the proposed configuration.

5.2 Parametric Study

To assess the performance of the solar still in the Ouargla region, a parametric analysis was undertaken on the most effective day (21/06/2022), with a focus on two key parameters: the mass of water in the basin and the absorptivity of the basin liner. Figs 10 and 11 show the distributions of the daily efficiency (or yield), calculated using Eq. (28), for different values of water mass (ranging from 20 to 100 kg) and basin absorptivity (ranging from 0.4 to 0.75, which are practical). Fig. 10 shows that when the water mass in the basin increases, the system's efficiency drops semi-linearly by about -0.12% per unit increase in water mass. This suggests that, while increasing the water mass may provide more thermal storage, it also affects the overall efficiency of the system, presumably due to slower heat transport and evaporation processes.

The nearly linear decrease in thermal efficiency with increasing basin water mass can be attributed primarily to the thermal inertia of the water layer. As the water mass increases, a larger amount of energy is required to raise the water temperature, leading to a proportional delay in temperature rise and evaporation rate under similar solar input conditions. Within the investigated range, heat transfer coefficients and loss mechanisms remain relatively unchanged, resulting in an approximately linear relationship rather than a nonlinear response dominated by heat transfer resistance.

In contrast, Fig. 11 shows a significant positive association between solar still efficiency and basin liner absorptivity. As the basin's absorptivity increases, so does its efficiency, with a significant increase of around +67.7% recorded at higher absorptivity levels. This demonstrates the importance of the basin liner's material properties in maximizing the thermal performance of the solar still. A higher absorptivity permits the system to collect more solar energy, boosting its ability to heat water and induce evaporation, thus improving the distillation process. These findings indicate that adjusting both the water mass and the material qualities of the basin liner can considerably improve the efficiency and productivity of solar stills, making them a more viable solution for water desalination in arid places such as Ouargla.

The efficiency of the solar still increased linearly by approximately 67.7% as the absorptivity of the basin liner was increased from 0.4 to 0.75. This improvement highlights the significant impact of absorptivity on performance, with practical values for the basin liner absorptivity ranging between 0.4 and 0.75, where the optimal performance was observed at a value of 0.7. The R^2 value for the Fig 10 curve is 0.12%.

Although the general trends observed in this parametric study are consistent with previous investigations, the present results provide quantitative insight into the relative sensitivity and magnitude of key parameters under Saharan climatic conditions, which have been less extensively documented in the literature.

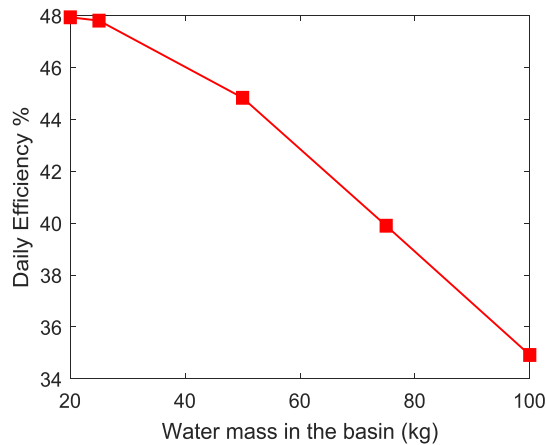


Fig 10. Effect of the mass water in the daily efficiency of the solar still.

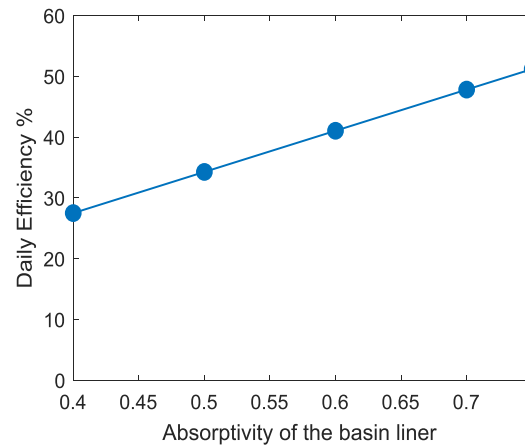


Fig 11. Effect of the basin liner absorptivity on the daily efficiency of the solar still.

6. CONCLUSION

This study investigated the thermal performance of a passive single-slope solar still for clean water production in Algeria's arid regions (El-Oued and Ouargla). Experimental and theoretical studies have been carried out to explore the thermal performance of the system in the studied desert regions for clean water production. The goal of this research was to assess the viability of solar stills as a solution to water scarcity in dry places, as well as to understand how solar intensity and ambient temperature affect system performance. The study simulated the performance of the solar still on four typical days (21/03/2022, 21/06/2022, 21/09/2022, and 21/10/2022).

The obtained key results can be summarized as follows:

- Solar productivity remained very variable due to seasonal solar radiation fluctuations. On June 21, 2022, the solar still's productivity was 1.5 times more than in March, September, and October. This illustrates the system's susceptibility to seasonal variations in solar intensity.
- The thermal profiles of the basin water, inner glass cover, and basin liner showed a strong association with solar radiation intensity, with the highest temperatures occurring during peak solar radiation hours. The daily temperature distributions tracked the oscillations in solar radiation, demonstrating the system's responsiveness to environmental changes.
- A parametric analysis on June 21, 2022, revealed that increasing the water mass in the basin resulted in a slight decrease in the system's efficiency by approximately 0.12% for every kg increase in water mass. Increasing the basin liner's absorptivity increased system efficiency by 67.7%, highlighting the importance of material qualities in enhancing solar still performance.
- The numerical model was tested using experimental data from the Guemar region, which revealed excellent agreement between anticipated and observed data, with a maximum relative error of less than 5.6%.

This study confirms the practicality of single-slope passive solar stills as a cost-effective and sustainable method of producing clean water in dry locations, particularly in Algeria's southern zones. The findings underscore the relevance of environmental factors, particularly solar radiation and ambient temperature, in determining system performance. Furthermore, material selection, such as the absorptivity of the

basin liner, is critical in boosting solar still efficiency. Validating the theoretical model with practical data improves the approach's reliability for future solar still design and optimization.

Based on the findings through this study, the following practical design recommendations are proposed: 1) The optimal water depth should range from 20 to 100 kg, with the best efficiency observed at mid-levels. 2) The absorptivity of the basin liner significantly impacts efficiency, with values around 0.7 providing optimal performance. These adjustments, along with proper placement in high solar radiation areas, can enhance the still's effectiveness in producing clean water in arid climates.

From a practical perspective, large-scale deployment of low-cost passive solar stills appears to be the most realistic and immediately applicable direction for southern Algeria, given the region's abundant solar resources, limited infrastructure, and socio-economic constraints. While advanced enhancement techniques such as nanofluids and thermoelectric cooling offer promising efficiency improvements, their implementation may be more suitable as longer-term research directions due to cost, maintenance, and operational complexity. Future research should therefore prioritize field trials and scalability assessments of passive solar still systems, complemented by economic feasibility analyses to support sustainable deployment in off-grid communities.

NOMENCLATURE

A_b	Surface area of basin liner. [m^2]	h_2	Heat transfer coefficient from glass surface to ambient. [$W/m^2.K$]
C_w	Specific heat of the water. [$J/Kg.K$]	h_3	Convective heat transfer coefficient from surface of basin liner to ambient. [$W/m^2.K$]
I	Intensity of solar radiation falling on glass cover of still. [W/m^2]	h_4	Convective and radiative heat transfer coefficient from bottom surface of still to ambient. [$W/m^2.K$]
L_{ins}	Thickness of insulation. [m]	h_{evap}	Evaporative heat transfer coefficient from water surface to glass cover. [$W/m^2.K$]
L_0	Latent heat of vaporization. [J/Kg]	k_{ins}	Thermal conductivity. [$W/m.K$]
T_a	Air ambient temperature. [K]	$\dot{m}_e$	Hourly distillate output per unit basin area. [$Kg/m^2.h$]
T_b	Temperature of the basin liner. [K]	m_w	Mass of the water in the basin of the solar still. [Kg]
T_g	Temperature of the glass cover. [K]	t	Time. [s]
T_w	Temperature of water in the still. [K]	α_p	Absorptivity of the basin liner.
h_b	Heat transfer coefficient from the basin liner to the surrounding environment. [$W/m^2.K$]	η	Efficiency of the solar still.
h_1	Heat transfer coefficient from water surface to glass cover. [$W/m^2.K$]		

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