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Analyzing Environmental Influences on New Structure of Solar Still Productivity: An Experimental Study in Basrah Iraq

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Abstract

Solar desalination uses solar radiation to convert saline or seawater into clean water and is increasingly crucial due to growing pollution from industrial and automotive sources. Although solar stills offer a sustainable solution, they face challenges in terms of production efficiency. This study presents a new structural design for solar stills, which incorporates advanced insulation materials, a well-designed distillate channel, and an inclined base to enhance productivity. The research explores how different climatic conditions such as wind speed, solar radiation, and atmospheric humidity affect solar still performance. Seven experimental setups were evaluated, comparing traditional inclined stills with advanced closed-loop systems. The results demonstrated that closed-loop systems improved productivity by 28.6% compared to open-loop systems. Additionally, moderate wind speeds increased productivity by 20.82%, while partial cloud cover and light rain decreased productivity by 52.15% and 12.9%, respectively. However, light rain also enhanced condensation efficiency by cooling the glass surface. This study highlights the importance of incorporating environmental factors into the design and optimization of solar still systems for improved performance.

Keywords: Close Loop Incline Solar Still (CLISS), Environmental factors, Continuous flow, Passive solar.

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1. Introduction

Pure water is extracted from saline or sea water using solar radiation in a process known as solar desalination. The growth of the automotive and industrial sectors has led to pollution of the air, water, and land, which puts human health at risk. Water pollution is one of the main types of pollution, and most nations are working to generate clean, high-quality drinking and cooking water that is free of pollutants. Thus, the significance and necessity of pure and clean drinking water became apparent to researchers worldwide. While researchers have developed several methods for cleaning water, the use of renewable energy in water distillation has opened up a new and effective area for investigation. As a sustainable water desalination method, solar stills show great promise.

However, the limited application of solar stills is due to their low production rates. Increasing the output rate per unit basin area has been a major objective in the development of this technology. The output can be increased by enhancing the temperature differential between the basin water and the glass cover, as the temperature difference is the main driving force for water evaporation in solar stills. Several modifications have been made to enhance performance based on the temperature difference effect on daily productivity. Sakthivel et al. [1] studied the effect of adding absorber material such as jute, which increased efficiency by 20% by providing a large evaporation surface for a single-slope solar still. Akash et al. [2] investigated the effects of cover tilt angles, water depth, and input water salinity. They found that tilting the cover to match the latitude of the study region, reducing water depth, and lowering salinity enhanced distilled water productivity. Tiwari et al. [3] examined the effect of optimal cover tilt for summer and winter conditions, finding that productivity increases with greater inclination in winter and decreases in summer. Naim et al. [4] explored the impact of adding charcoal as an absorber medium, which improved productivity by 15%. In another study, Naim et al. [5] added a phase change energy storage mixture (PCESM), further enhancing overall productivity. Abdallah et al. [6] investigated the addition of two different absorber materials: coated and uncoated porous media (metallic wiry sponges) and black volcanic rocks. They concluded that potable water collection rates were 28%, 43%, and 60% for coated sponges, uncoated sponges, and black rocks, respectively. Tanaka and Nakatake [7], Khalifa and Ibrahim [8], and Tanaka [9] studied the impact of reflector tilt angles. Badran [10] analyzed the effects of different operational techniques. Singh et al. [11] provided analytical expressions for water and glass temperature and productivity as functions of climatic and design parameters. Singh et al. [12] examined the effects of glass cover inclination and water depth on productivity. Rai et al. [13] investigated the effects of water mass in the basin, salinity, floating black jute cloth, thermosyphon circulation, and forced circulation. Akash et al. [14] examined the use of different absorbing materials such as black rubber, black ink, and black dye. Velmurugan et al. [15] compared different passive enhancements on productivity, concluding that productivity increased by 15.3%, 29.6%, and 45.5% with the addition of sponges, wicks, and fins, respectively. Sakthivel et al. [16] studied the effect of increasing the evaporation area by adding jute cloth. This was examined both experimentally and theoretically using Dunkle's equation. The study concluded that productivity increased by 20% and efficiency by 8%. This type of improvement is considered one of the cheapest and most widely available, in addition to maintaining water quality. Alshqirate et al. [17] studied the effect of adding natural fibers on the productivity of a pyramid solar still, comparing it to a traditional system without fibers. The natural fibers improved the evaporation rate by increasing the surface area exposed to sunlight, which in turn increased productivity. The study achieved a productivity of 5160.8 g/m^2, representing a 44.5% increase over the traditional system. Arunkumar et al. [18] conducted a practical study in Jordan to investigate the effect of design variations on productivity, including spherical solar still, pyramid solar still, hemispherical solar still, double basin glass solar still, concentrator coupled single slope solar still, tubular solar still, and tubular solar still coupled with pyramid solar still. The spherical solar still exhibited a productivity of 2300 mL/m^2/day. This type absorbs solar radiation from all directions due to its spherical glass, increasing the absorbed quantity and condensation surface area, thus enhancing productivity. The concentrator coupled single slope solar still achieved 2600 mL/m^2/day. The double basin glass solar still yielded 2900 mL/m^2/day. Here, water evaporates in the upper basin due to latent heat from condensation in the lower part, ensuring productivity even during nighttime. The pyramid solar still and the hemispherical solar still produced 3300 and 3659 mL/m^2/day respectively, reach due to increased surface area. While the tubular solar still reached 4500 mL/m^2/day and the tubular solar still coupled with pyramid solar still recorded the highest productivity of 6928 mL/m^2/day. Feilizadeh et al. [19] studied the impact of changing the height, length, and width of a simple solar still. They developed a radiation model that includes the effect of the walls on the solar radiation reaching the water. For the first time, the model separately considered the components of diffuse and direct solar radiation, which were previously neglected, leading to less accurate results. They found that increasing the height of the walls led to a decrease in efficiency, concluding that the optimal height should be less than 0.1 meters. On the other hand, increasing the length of the still reduced the shading from the side walls, thus increasing efficiency. Regarding the width, increasing it improved productivity up to an optimal point, after which it gradually decreased. This optimal point varies with different seasons, but generally, the best width-to-length ratio is about 0.4. Sharshir et al. [20] conducted a study to improve the performance of wick solar stills by varying the aspect ratios while maintaining the same areas and materials of the device. They tested three different models and concluded that the solar still with medium dimensions had the best performance. This system was tested with three different wick materials: cotton cloth, cotton towel, and jute cloth. The results showed that cotton cloth wicks were the best due to their superior capillary action. Additionally, top and bottom reflectors, as well as reflectors with cooling, were tested. The results indicated that the productivity of type *B* increased by 16.31% and 22.41% compared to types *A* and *C*, respectively. When using cotton cloth, the productivity increased by 19.17% and 24.14%, respectively. Adding reflectors with cotton cloth increased productivity by 37.99% and 39.96%, respectively. Finally, applying cooling to the external glass surface increased productivity by 30.59% compared to type A. In conclusion, the use of cotton cloth, reflectors, and external cooling for the type *B* model increased freshwater productivity and energy efficiency by 52.36% and 58.5%, respectively. Keshtkar et al. [21] proposed a novel procedure for transient numerical modeling of solar stills without using fixed temperatures as boundary conditions. Instead, instantaneous environmental conditions were employed. Additionally, they dispensed with the use of multi-phase approaches and utilized coupling species equations with the energy equation through a user-defined function. This method was applied to both traditional passive and multi-stage active solar stills. The study indicated that increasing the number of stages to 6 had no effect. Hafs et al. [22] conducted modeling and simulation of a single slope solar desalination system with a phase change material (PCM) thermal energy storage system. The active system was created by linking the passive solar desalination system with a parabolic trough collector (PTC) via a heat exchanger as an external heat source. For each system, they studied both flat and corrugated basin surfaces (rectangular, triangular, and spherical) and compared their productivity. They concluded that the productivity of the conventional system with a corrugated rectangular surface increased by approximately 109% and 42% compared to the traditional system and the system with a flat absorber with storage, respectively. It was found that the solar system integrated with PTC and modified with different absorber shapes achieved higher freshwater productivity, reaching 15.39 and 15.01 kg/m²/day compared to 2.37 and 2.11 kg/m^2/day for the passive system using rectangular and spherical absorbers, respectively. Consequently, the improvement percentage in the developed active system was about 549.36% and 611.37%, respectively. Aghakhani et al. [23] explored heating and cooling under normal conditions and under vacuum pressure ranging from 60 to 120 kPa. The productivity of a single slope solar still was analyzed using two-dimensional numerical simulation. The most significant improvement observed was 152.69% after cooling the glass and heating the water. Moreover, basin water heating, operational pressure reduction, and glass cover cooling are found to enhance performance by 112.72 %, 31.82 %, and 27.16%, respectively

Environmental factors also play a significant role in the performance of solar stills. Variations in sunlight intensity, ambient temperature, humidity, and wind speed can all influence the rate of water evaporation and condensation. Solar stills can achieve higher productivity in regions with high solar radiation, while in cooler or cloudy regions, their efficiency may decrease.

This research will focus on the effect of environmental factors on the hourly and daily productivity of solar stills. Specifically, examine passive and continuous flow types of solar stills to clarify the effect of these variables over 8 hours. To facilitate the flow process, the still was tilted at an angle proportional to the latitude of the city of Basrah, where the testing was conducted, which is 30°.

The experiment was conducted in the Basrah region (30.4959_N, 47.8195_E), southern Iraq, inside the Engineering Technical College at the Southern Technical University during the period from March 18th to March 30th, 2024. The readings were taken from 9:00 a.m. to 5:00 p.m. each day under different climatic conditions. Temperature variations were recorded every second by a Data Logger system connected to PV power equipment. Figure 1 illustrates the schematic representation of the solar distillation unit incorporating PV powered recirculation.

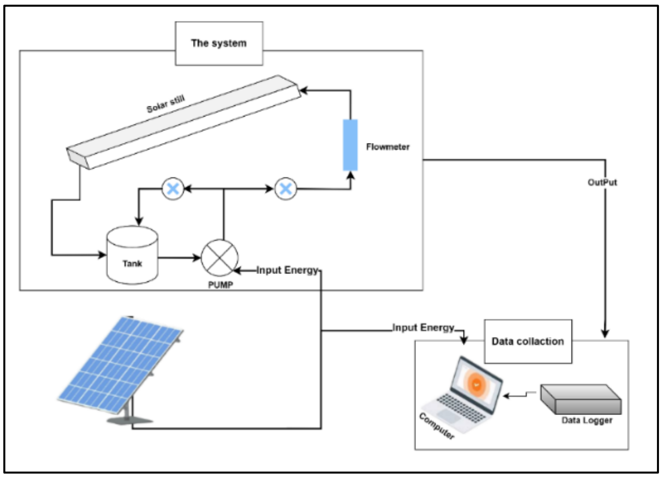


Fig. 1 Schematic for Closed-Loop Inclined Solar Still (CLISS) design.

2. Detail of proposed design

The following experimental components were used in this work:

2.1. Wooden box

A wooden box is open at the top and enclosed with a glass layer. Within its base lies a black iron sheet, strategically designed to facilitate water passage.

2.2. Basin line

The solar still's main component captures incident radiation penetrating through its glass cover. The basin line is designed to withstand exposure to hot saline water, exhibit high absorbance of solar radiation, resist accidental punctures, and facilitate easy repair in case of damage (potentially from shattered glass) such as iron sheets. To enhance absorbance, a standard non-glossy black paint was applied as illustrated in Fig. 2.

Fig. 2 The basin photograph.

2.3. Glass cover

This study utilized window glass as a transitive cover. Silicon rubber was selected as the sealing material for the glass cover due to its effectiveness in establishing secure contact with various surfaces. The choice of sealant is crucial for ensuring optimal performance, as it not only secures the cover to the frame but also accommodates any thermal expansion or contraction among different materials, thereby enhancing the system's overall efficiency.

2.4. Saline water reservoir

A thermally insulated tank, lined with glass wool is situated below the system. It receives the unevaporated hot water from the solar still through gravitational force and reintroduces the water back into the system using a PV panel pump as illustrated in Fig. 3.

Fig. 3 The photograph of the saline water reservoir.

2.5. Photovoltaic recirculation system (PV panel pump)

The PV recirculation system is comprised of a pump responsible for circulating hot water from the reservoir back to the solar still. This system is integrated with a solar setup, including PV panels and a hybrid OREX solar inverter. Furthermore, lithium iron phosphate batteries 12AV are utilized to store excess energy for utilization during periods of limited sunlight as shown in Fig. 4.

Fig. 4 PV panel component (a) photovoltaic cells, (b) lithium iron phosphate battery, and (c) hybrid solar inverter OREX.

2.6. Insulating material

In this study, efforts were made to minimize heat losses from both the storage tank and the pipeline by employing insulating materials. The insulation materials employed in this study include glass wool insulation utilized for insulating the storage tank. Additionally, pipe insulation was used to insulate the connecting pipes as illustrated in Fig. 5.

2.7. The distillate channel

The distillate channel functions to collect condensate from the lower edge of the glass cover and transport it to an external graduated flask. This channel consists of two parts: the first part is inside the distillation unit, shaped as a plate extending for a certain distance parallel to the glass surface to capture as many water droplets as possible without losses. This is connected to an external tube, which represents the second part, whose sole function is to transport the water from the collection plate to the graduated flask.

(a) Glass wool. (b) Pipe insulation.

Fig. 5 Insulation materials.

2.8. *Inclined structure*

As previously indicated, the proposed system involves recycling water and tilting the distillation unit externally by constructing an inclined base. The base is made of hollow galvanized iron, with a base area matching that of the distillation unit and a specified height at the rear, angled appropriately for the study location. Figure 6 illustrates the final design of the external base for the system.

Fig. 6 Inclined base structure.

The lower part of the base was added for two reasons: first, to increase the height of the system to optimize its position for maximum solar radiation absorption, and second, for structural engineering purposes. All components connected to the distillation unit are fixed to the base, facilitating easier transportation and movement while providing greater protection against breakage.

Additionally, the technical specifications of the solar still are shown in Table 1.

2.9. *Thermocouples distribution*

The K-type thermocouple was used to measure temperatures from various locations within the system, with a margin of error within the range of ± 0.9 °C for temperature measurements between 1 °C and 110 °C. Ten sensors were installed at fixed intervals on the inner walls of the distillation unit: four sensors were evenly distributed on the upper surface of the basin, four on the inner surface of the glass, one inside the thermal tank, and one external sensor to measure the ambient temperature, as illustrated in Fig. 7. Heat-resistant silicone was used to secure the sensors in the specified locations. The pre-programmed thermocouple data logger was connected to a PV panel system for self-sustained operation and to a personal computer to record temperatures at regular intervals of one second.

This version maintains the core information while removing the reference to the sensor length.

Table 1. The technical specifications of the solar still.

Specification	Item	Value	Unit
Basin	Length	150	cm
	Width	50	cm
	Thickness	1.5	mm
Wooden box	Length	160	cm
	Width	60	cm
	Height	10	cm
	Thickness	10	mm
Glass	Thickness	5	mm
	Average transmissivity	0.88	m^2/s
Reservoir	Capacity	25	L
Structure	Length	160	cm
	Width	60	cm
	Height	142	cm
	Thickness	1	cm
	Angle	30	degree
Distillate channel	Length	3	cm
	Width	60	cm
	Diameter	0.25	in
Glass wool	Thickness	3	cm
	Thermal conductivity	0.030-0.050	W/m°C
Pipe Insulation	Thickness	1	cm
	Thermal conductivity	0.03-0.045	W/m°C
PV panel system	Power $_{pump}$	370	W
	Maximum Power $_{PV1}$	270	W
	Maximum Power $_{PV1}$	170	W

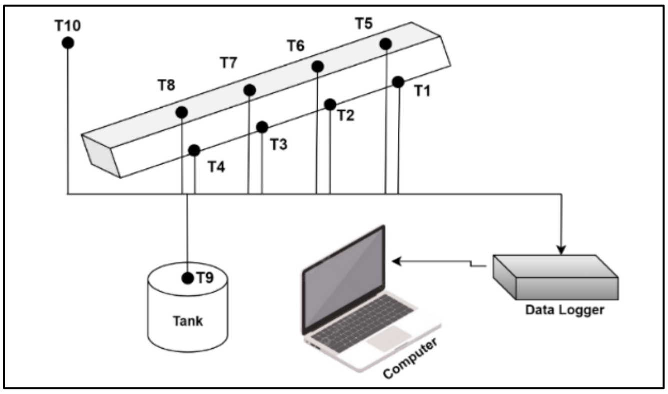


Fig. 7 Thermocouples location.

2.10. *Measuring devices*

In this section, all types of equipment used for measurement are explained below and shown in Fig. 8.

1. Multi-channel data logger

The MPD-580 multi-channel data logger, with 32 channels and an accuracy of (± 0.2%), was used in the experiment to record instantaneous temperatures. K-type thermocouple sensors were placed in various positions, as previously described. The (MDCS Data Analysis) software, which supports a multi-channel data recorder with an optical USB connection, was used to log test results and transfer them to a computer for further analysis. The impact of temperature changes on the system during operation was demonstrated by displaying the results

2. Solar power meter

The TES-1333 solar power meter device was utilized to measure the total solar radiation received by the solar still, positioned perpendicular to the inclined glass surface at a 30° angle. The features and capabilities of the TES-1333 solar power meter device is outlined in Table 2. Additionally, the amount of solar radiation was measured and recorded every hour during the testing procedure.

Table 2. TES-1333 specifications.

Character	Value	Unit
Maximum value	2000	W/m^2
Accuracy	± 0.5	%
Angular accuracy	Less than 60	degree
Sampling time	Approx. 0.4	second

3. Flowmeter

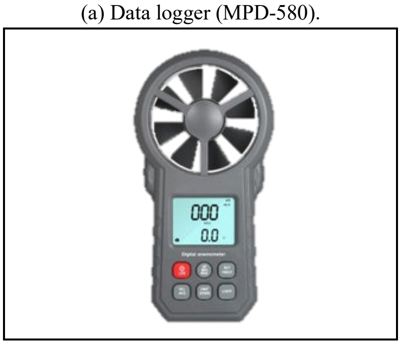
To determine the volumetric flow rate of the heat transfer fluid (water) and to study various flow rates with higher precision, two flow meters were used: one for flow rates less than 7 LPM, with a range of (1-8) LPM, and the other for flow rates greater than 7 LPM, with a range of (2-18) LPM.

4. Wind speed

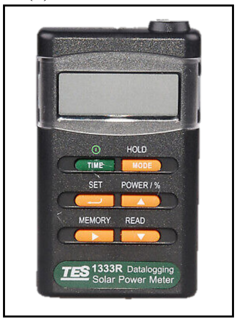
An electronic anemometer was employed as the instrumentation for measuring wind speed. Throughout the experiment, wind speeds ranged between (2-10) m/s. The kind of measuring anemometer is (Ragova Weather station RG-0189), and the accuracy is (± 0.03) m/s.

(a) Data logger (MPD-580).

(b) Water flow meter.



(c) Wind speed meter.



(d) Solar power meter.

Fig. 8 Measuring equipment used in this study.

3. Experimental validation

The experiment was conducted on days between March 18 and March 30, 2024, in Basrah, Iraq. The CLISS was inclined at an angle of 30° from the horizontal, corresponding to the latitude of Basrah. Figure 9 shows a photograph of the entire experimental setup.

Temperatures of the glass cover, basin, and storage tank are monitored by sensors (thermocouples) placed at various points. Hourly measurements of production for different cases were compared with theoretically calculated values to validate the thermal model.

Fig. 9 Closed-Loop Inclined Solar Still (CLISS) design.

4. Statistical analysis

4.1. Correlation coefficient (r)

Once predicted values are validated against experimental data, the relationship between predicted and experimental values is illustrated using a statistical measure called the coefficient of correlation. This coefficient can be assessed using the following formula [24].

$$r = \frac{N\sum Y_i X_i - \left(\sum X_i\right)\left(\sum Y_i\right)}{\sqrt{N\sum X_i^2 - \left(\sum X_i\right)^2}\sqrt{N\sum Y_i^2 - \left(\sum Y_i\right)^2}} \quad (1)$$

4.2. Root mean square of percent deviation (e)

Experimental values are utilized for prediction, and the accuracy of these predictions is verified against experimental data. The agreement between predicted values and experimental results can be quantified using the root mean square percent deviation [24].

The root mean square of the percent deviation is given by:

$$e = \sqrt{\frac{\sum (e_i)^2}{N}}$$

$$e_i = \left[\frac{X_i - Y_i}{X_i}\right] * 100\% \quad (2)$$

4.3. Standard error (error)

The standard error is calculated to estimate the variability of sample data around the expected value. It measures how much the measured values in a sample deviate from the expected or average value, providing insight into the accuracy of predictions or estimates derived from the sample [24].

$$Error = \left[\frac{\sum (Y_i - aX_i - b)}{N-2} \right]^{\frac{1}{2}} \quad (3)$$

Where,

$$a = \frac{N\sum X_i Y_i - (\sum X_i)(\sum Y_i)}{N\sum X_i^2 - (\sum X_i)^2} \quad (4)$$

$$b = \frac{(\sum X_i^2)(\sum Y_i) - \sum Y_i X_i (\sum X_i)}{N\sum X_i^2 - (\sum X_i)^2} \quad (5)$$

$$Y = aX + b \quad (6)$$

Where *Xi* represents theoretical or predicted value, *Yi* represents experimental value, and *N* is the number of observations.

Table 3 presents the range of errors for various instruments used throughout the experiment.

Table 3. Various instruments' error analysis.

Devices	Root Mean Square	Coefficient of correlation	error	accuracy
Thermocouple	2.03	0.999	0.969	± 0.4%
flow meter	3.24	0.999	0.096	-
Solar Power Meter	0.84	0.9999	1.379	± 0.5%
data logger type	-	-	-	± 0.2%
Wind speed	-	-	-	-

5. Results and discussions

Given the climatic conditions of the experiment's location, various weather situations were considered, including clear skies, wind speeds dynamically controlled within the range of (2 to 5) m/s, partial cloud cover with dry conditions, and partial cloud cover with light rain.

The study focuses on analyzing systems including wind speed, solar radiation variation, and atmospheric humidity, comparing them with a traditional setup. In the traditional setup, an inclined still operated with a water recirculation system integrated with a solar-powered recirculation pump under a clear sky condition. This pump conveyed water from an insulated heat reservoir to the still. The research aimed to assess how environmental factors influence the system's performance.

Seven different setups were considered for comparison, including:

I. Close loop inclined still under clear skies as a conventional system.
II. Conventional system under high-speed wind.
III. Conventional system under, partial cloud cover with dry conditions.
IV. Conventional system under partial cloud cover with light rain

Based on previous research, the chosen flow rate is determined to be 11 liters per minute, and the saline water content in the tank is also determined to be 15 liters, based on the best value obtained from previous work.

5.1. Effect of circulation on inclined solar still

When comparing the conventional inclined distillers with an open-loop to a closed-loop system of the same type, it becomes evident that the recirculation process affects the water temperature inside the distiller. This alteration resembles a preheating process for the water, consequently enhancing the system's productivity.

To validate this concept, readings were taken from previous work. Then, a practical experiment was conducted to verify the hypothesis. The productivity of both open and closed-loop systems was compared at a flow rate of 1 LPM. The results showed that productivity increased by 28.6% during 8 hours of daytime operation. Figure 10 illustrates the hourly and accumulative productivity for both systems.

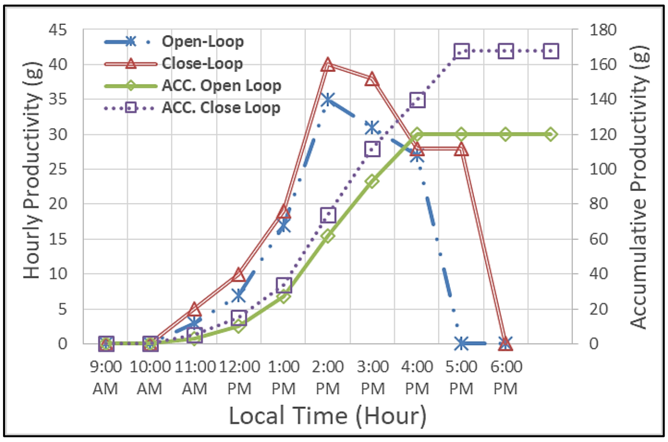


Fig. 10 Hourly, and accumulative production for open, and close loop inclined solar still (CLISS).

5.2. Effect of solar radiation with ambient temperature

The effect of solar radiation in conjunction with ambient temperature on solar stills is a critical aspect of their performance and efficiency. Solar radiation is the primary energy source driving the distillation process in solar stills, while ambient temperature influences the overall heat transfer dynamics within the system.

When solar radiation interacts with the glass cover of the solar still, it penetrates through and heats the basin containing saline or impure water. This heating causes the water to evaporate, leaving behind impurities, and the vapor rises, condensing on the cooler surface of the glass cover. The condensed vapor then drips down into a collection channel as purified water.

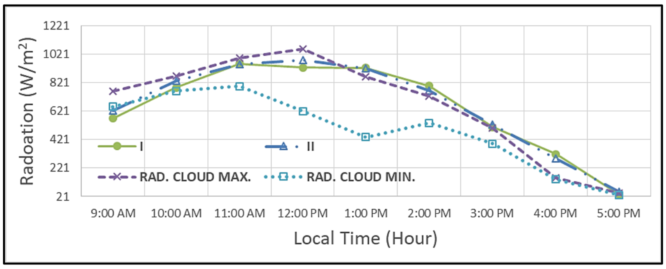
The ambient temperature surrounding the solar still affects several key factors:

Condensation rate: Ambient temperature also influences the rate of condensation of water vapor on the glass cover. Cooler ambient temperatures can cause the glass cover to be colder, promoting more rapid condensation of vapor into liquid water. However, excessively low ambient temperatures may lead to reduced condensation rates or even freezing of the condensate, impacting overall water production.

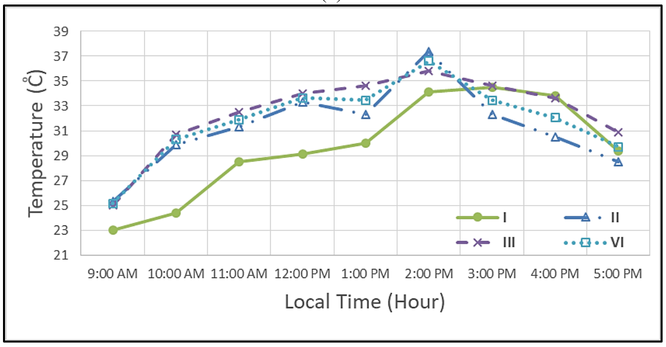
Productivity: The combined effect of solar radiation and ambient temperature influences the productivity value of solar stills throughout the day. Peak solar radiation hours typically coincide with higher ambient temperatures, resulting in increased water production during these periods. However, productivity may vary depending on factors such as cloud cover, humidity, and the specific design of the solar still.

Understanding the intricate relationship between solar radiation and ambient temperature is essential for designing efficient solar still systems tailored to specific environmental conditions.

An experimental study was conducted under three distinct climatic conditions. The first condition simulated a high-speed wind day, the second represented a partly cloudy day, and the third simulated a cloudy day with light rain. These conditions were all compared to a clear, sunny day. Each of these conditions allowed for the observation of how solar radiation and ambient temperature variations affect the performance of the solar still system. Figure 11 shows the actual and average value of radiation and ambient temperature for different cases.



(a)



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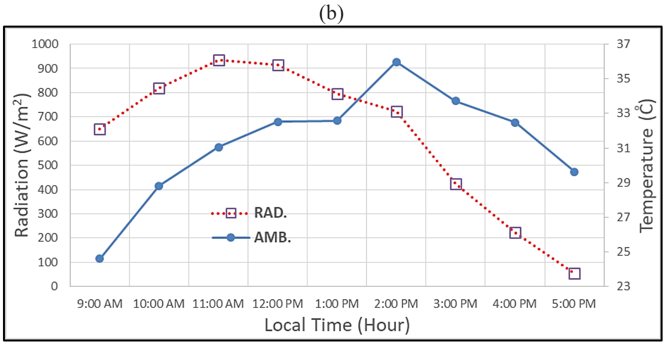


(c)

Fig. 11 (a) Radiation value for each case. (b) Ambient temperature value for each case. (c) Average hourly ambient and solar radiation during the experiments.

5.3. Effect of wind speed variation

The effect of wind speed on solar stills is an important factor that can significantly influence their performance and efficiency. Wind speed affects various aspects of the solar still operation, including heat transfer, overall productivity, and system stability.

Heat Transfer: Wind can enhance convective heat transfer by carrying heat away from the glass surface of the solar still, which can lead to faster condensation of the evaporative potable water.

Productivity: The impact of wind speed on the productivity of solar stills depends on various factors such as the design of the system, ambient temperature, and relative humidity. In some cases, moderate wind speeds can improve productivity by preventing the formation of boundary layers and enhancing heat transfer.

System Stability: Wind can affect the stability and integrity of the solar still structure. Strong winds may cause structural damage or displacement, especially if the solar still is not securely anchored or if it is poorly designed to withstand wind loads.

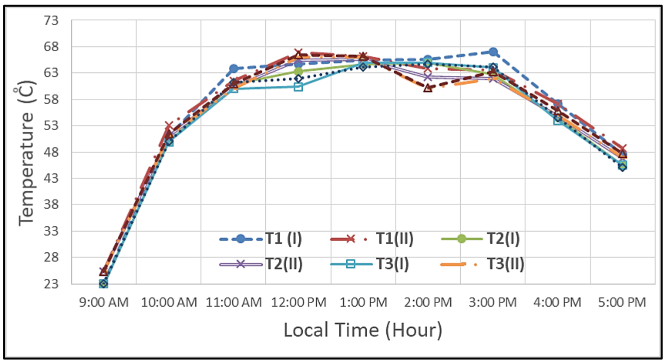
Overall, while moderate wind speeds can have beneficial effects on the operation of solar stills, excessively high wind speeds may negatively impact their performance. Therefore, it is essential to consider wind speed conditions when designing and operating solar still systems to optimize their efficiency and productivity.

To investigate the effects of wind speed on solar still performance, an experimental study was conducted under two different wind speed conditions: relatively low and relatively high. These experiments aimed to assess how varying wind speeds impact heat transfer, evaporation, condensation, and overall productivity in solar stills.

5.3.1. Variations of various temperatures inside the still

Figure 12 illustrates the fluctuations in various temperatures within the distillation unit throughout the experiment for both the current condition and the traditional setup. It is noteworthy that in Fig. 12(a), which represents the basin temperature distribution, the temperature of the absorber plate is notably higher. When the experiment was conducted with the weir absorber plate, it was found that the maximum temperature of 65.5°C was reached at 1:00 p.m. in system (I).

Figure 12(b) represents the glass, tank, and ambient temperature distributions along the systems. Based on the observation of temperature distribution, it is noted in Fig. 12(b), that the glass temperatures in system (II) were lower due to an increased rate of heat transfer from the glass surface, resulting in differing productivity between the two systems.



(a)

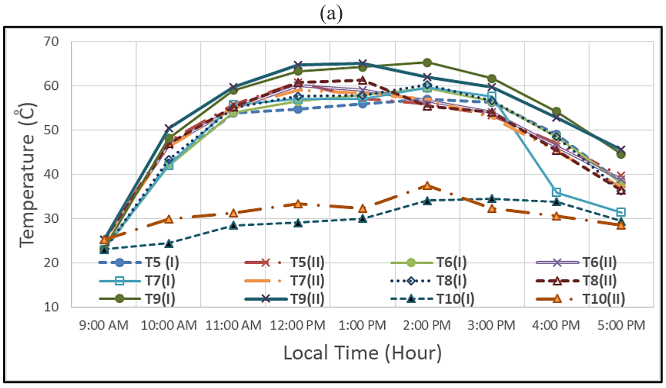


Fig. 12 Distribution of temperature levels for different locations.

5.3.2. Effect of glass and water temperature deference variation

As mentioned earlier, the temperature difference between the glass and the water is considered the driving force behind the operation of the system, and the greater this difference, the higher the productivity. Figure 13 illustrates this concept relatively. It is observed from the figure that system (I) begins with higher temperature difference rates because solar radiation falls directly on the system without dispersion or reduction due to high wind speeds. However, after some time, the glass surface temperature of system (I) starts to rise due to the decreased heat exchange rate between the glass surface and the surrounding air. In contrast, system (II) exhibits a higher heat transfer rate between the glass and the surrounding air as a result of higher wind speeds.

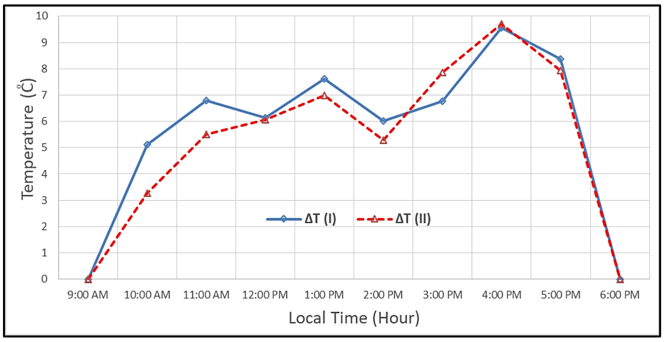


Fig. 13 The difference in temperature between the water and the glass for System (I) and System (II).

5.3.3 Effect of the wind speed on hourly and daily output

Figure 14 illustrates the hourly and accumulative productivity of both systems. Figure 14(a) shows that the hourly productivity of the system with relatively higher speed (II) is greater than that of the system with a relatively lower speed.

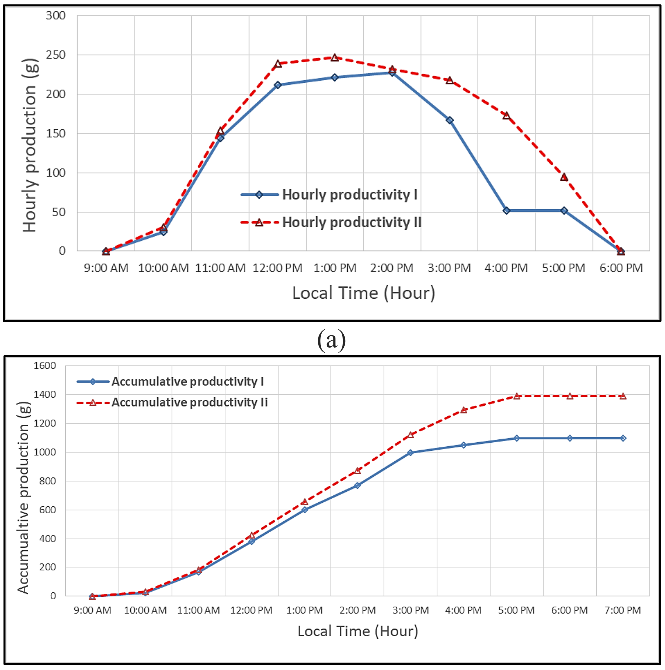


Fig. 14 (a) Hourly productivity. (b) Daily productivity for (II), (I) systems.

This difference becomes more pronounced during and after peak hours due to the thermal storage of the glass and the reduced heat exchange with the atmosphere, as mentioned in the previous section. The same concept is reflected in the accumulative productivity shown in Fig. 14(b).

5.3.4. Comparison of experimental and theoretical values

When comparing the experimental results with those obtained from Duncles' equation, it is evident that the productivity behavior is similar, with only slight differences. This theoretical comparison has been computed and validated, as shown in Fig. 15.

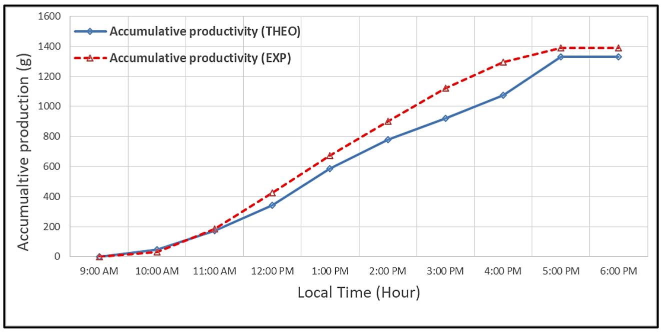


Fig. 15 Comparison between the experimental and theoretical values for system (II).

5.4. Effect of partial clouding

The effect of partial clouding on the solar distiller can have tangible impacts on its performance. Here are some of the effects that may occur:

Reduction in productivity efficiency: When clouds are partial, they may diminish the amount of sunlight reaching the solar distiller. This can reduce the efficiency of generating evaporation by the solar distiller.

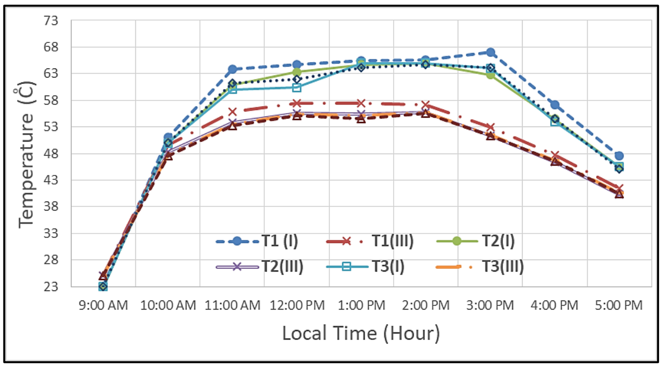
Reduction in effective operational period: In the case of frequent partial cloud cover, the process of energy generation or water heating may intermittently halt, as the system may require time to regain full performance after the passage of clouds.

5.4.1. Variations of various temperatures inside the still

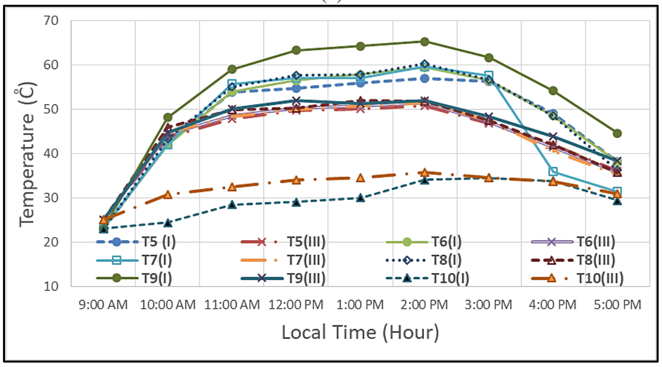
Figure 16 illustrates the fluctuations in various temperatures within the distillation unit throughout the experiment for both the current condition and the traditional setup. It is evident from Fig. 16(a) that the basin temperatures for system (I) are significantly higher than those for system (III). This decrease is logical due to the reduction in the initial energy of the system, represented by solar radiation, as a result of partial cloud cover. The same conclusion can be drawn from Fig. 16(b).

5.4.2. Effect of glass and water temperature deference variation

As in the previous case, the temperature difference is an important factor for the system. Figure 17 illustrates the difference in temperature variation between system (I) and system (III), where the decrease in temperature difference for system (III) is attributed to the reduction in solar radiation.



(a)



(b)

Fig. 16 Distribution of temperature levels for different locations.

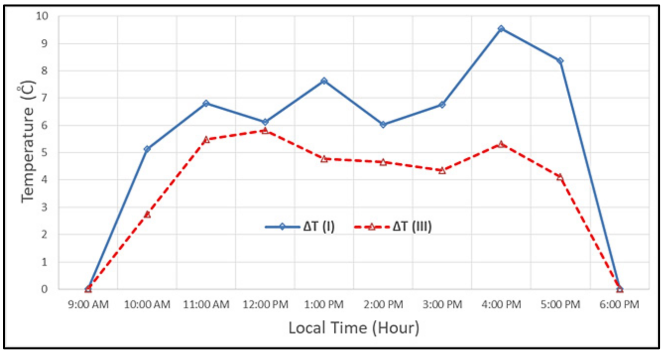


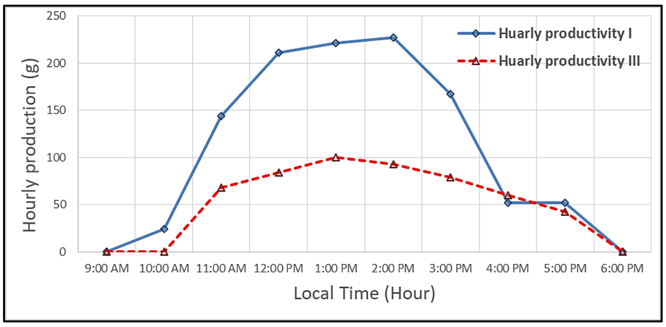
Fig. 17 The difference in temperature between the water and the glass for System (I) and System (III).

5.4.3. *Effect of partial clouding on hourly and daily output*

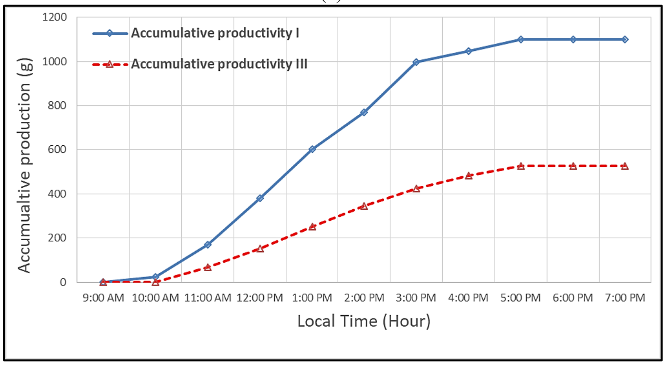
As evident in Fig. 18, both the hourly productivity in Fig. 18(a) and the accumulative productivity in Fig. 18(b) has decreased by more than half due to partial cloud cover. This figure demonstrates that the most significant factor affecting system productivity is solar radiation. Therefore, studying the region and climate is crucial before implementing such systems.

5.4.4. *Comparison of experimental and theoretical values*

The theoretical comparison, as depicted in Fig. 19, demonstrates that the productivity behavior is largely similar between the experimental results and those obtained from Duncles' equation, with minor discrepancies.



(a)



(b)

Fig. 18 (a) Hourly productivity. (b) Daily productivity for (III), (I) systems.

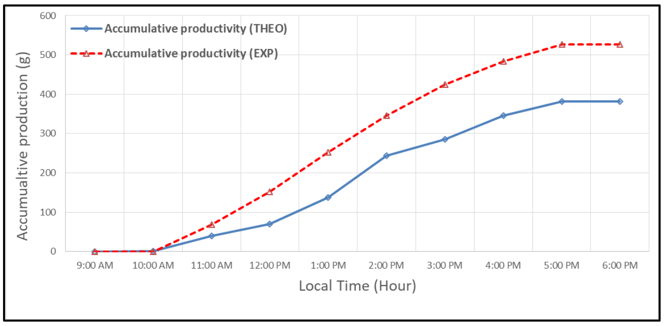


Fig. 19 Comparison between the experimental and theoretical values for system (III).

5.5. *Effect of light rain*

The impact of light rain on the productivity of solar stills can be multifaceted and depends on several factors. Here are some points indicating how light rain affects the performance of solar stills:

System Cooling: Light rain may cool down the system and the outer surface of the solar still. This may help prevent the system from overheating during hot days, thereby improving the efficiency of condensation later on.

Glass Cleaning: Light raindrops can clean the upper surface of the glass of the solar still, removing dirt, dust, and impurities that may obstruct the passage of light and reduce condensation efficiency.

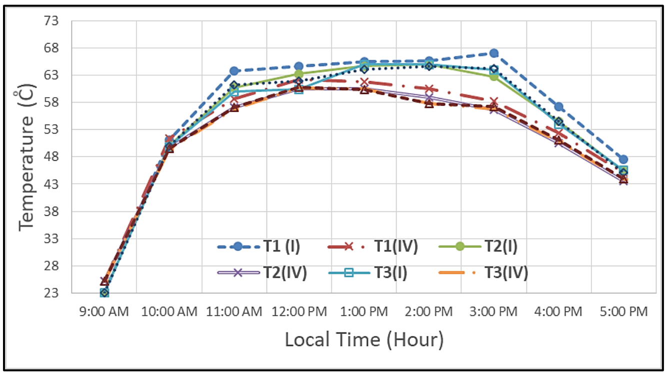
Reduced Air Movement: When wind speed is low due to light rain, the level of heat exchange between the glass surface and the surrounding air decreases. This leads to an increase in the temperature of the glass surface, reducing the effectiveness of the condensation process and thus lowering the productivity of the solar still.

It is worth noting that the impact of light rain on the productivity of solar stills can vary significantly and depends on the design of the still and the general weather conditions at the location.

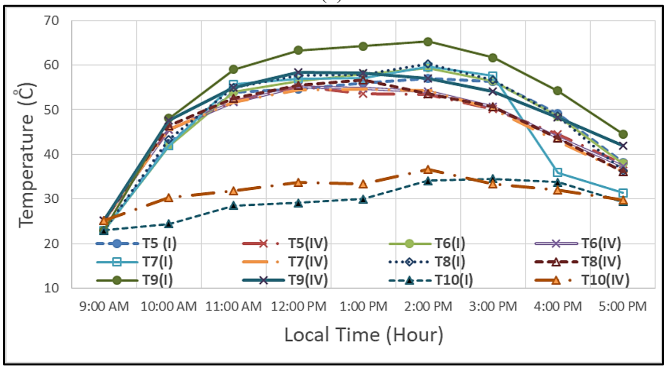
The experimental investigation explored the productivity of solar stills under two weather conditions: partial cloud cover with dry air and partial cloud cover with humid air and light rain.

5.5.1. Variations of various temperatures inside the still

Through Fig. 20, observe that the effect of light rain with partial shading is somewhat similar to dry shading in terms of reducing temperatures, but to a lesser extent than the dry condition, as evident in Figs. 20(a) and 20(b).



(a)



(b)

Fig. 20 Distribution of temperature levels for different locations.

5.5.2. Effect of glass and water temperature deference variation

Figure 21 delineates the variance in temperature difference between system (I) and system (IV), where the reduction in solar radiation contributes to the diminished temperature variance in system (IV). This is further evidenced by the impact of rain falling on the glass, which lowers its temperature. Hence, we note that the temperature difference in the fourth case is more favorable than in the third case.

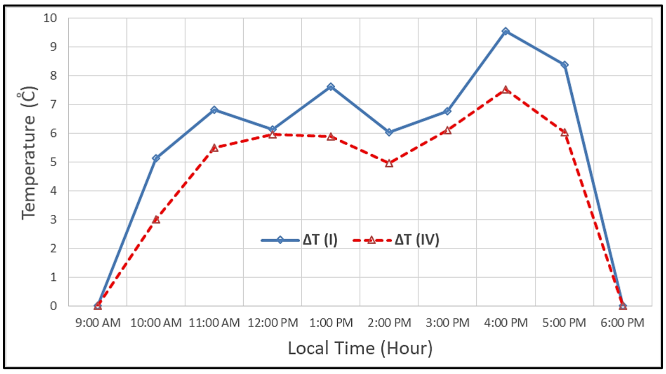
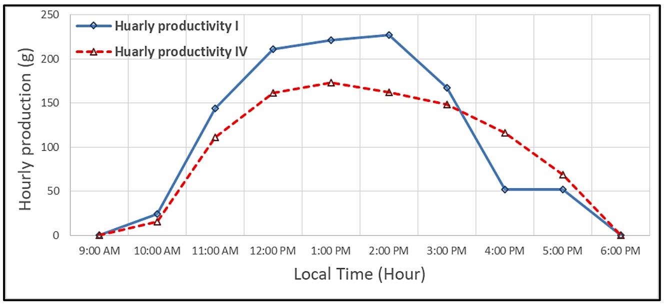


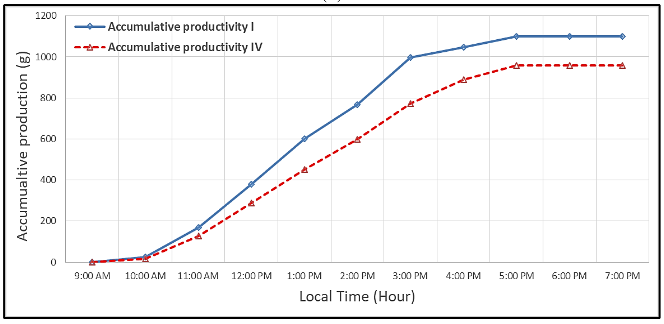
Fig. 21 The difference in temperature between the water and the glass for systems (I) and (IV).

5.5.3. Effect of the light rain on hourly and daily output

As depicted in Figs. 22(a). and 22(b), it is evident that productivity, whether on an hourly or cumulative basis, decreases due to fluctuations. However, it is important to note the distinction between dry and wet fluctuations. It is shown that light rain leads to a relative improvement in productivity due to the cooling effect on the glass, which increases temperature differentials and consequently enhances productivity. Nonetheless, the impact of both conditions is less than that of a clear day.



(a)



(b)

Fig. 22 (a) Hourly productivity. (b) Daily productivity for systems (I), and (IV).

5.5.4. Comparison of experimental value and theoretical values

The theoretical comparison, illustrated in Fig. 23, indicates a close alignment in productivity patterns between the experimental findings and the outcomes derived from Duncles' equation, albeit with slight variations.

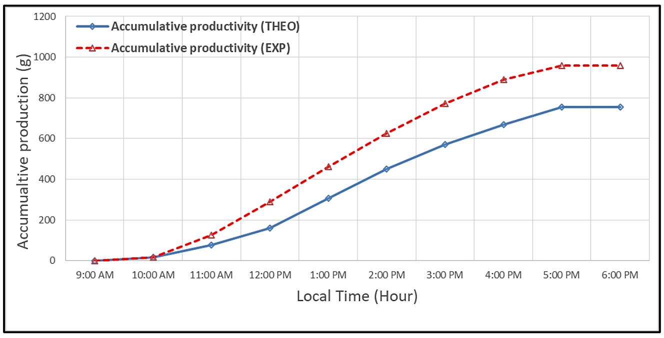
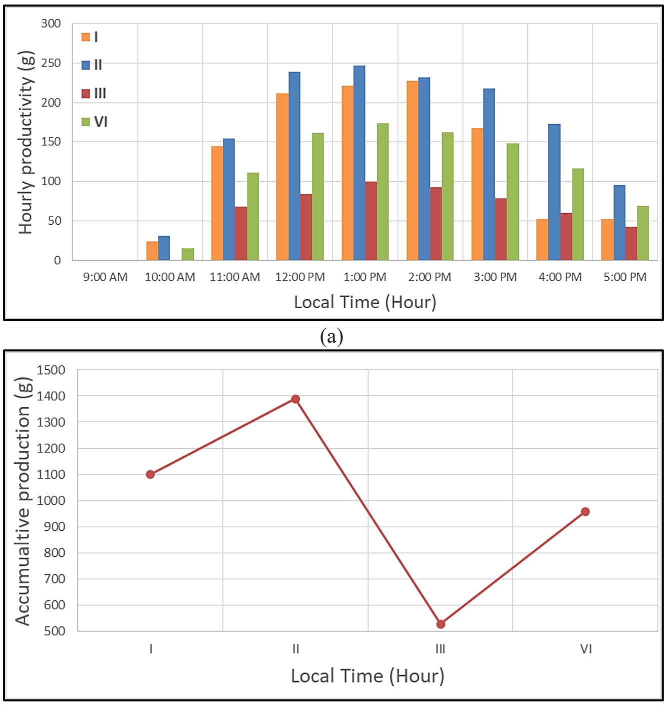


Fig. 23 Comparison between the experimental and theoretical values for system (IV).

5.6. Effect of various conditions on hourly and daily output

From Fig. 24(a), observe the difference in hourly productivity for each of the four systems, and it is evident that the second system, characterized by high wind speed, achieved higher productivity due to the cooling effect on the glass resulting from increased heat transfer coefficient. This concept appears clearer in Fig. 24(b). The enhancement by high wind speed effect in the accumulative productivity was 20.82% while the reduction by the partial cloud was 52.15% and 12.9% for dry and light rain respectively.



(b)

Fig. 24 (a) Hourly productivity. (b) Daily productivity for all systems.

6. Conclusions

In conclusion, this study delved into the intricate dynamics of solar stills, focusing on the effects of various environmental conditions such as the effect of wind speed, light rain, and solar radiation on their productivity. Through a comprehensive experimental investigation conducted in Basrah, Iraq, it was revealed that these factors significantly influence the performance of solar still systems.

Furthermore, the study highlighted the importance of circulation systems in solar stills, with closed-loop systems demonstrating notable improvements in productivity compared to open-loop configurations by 28.6%. The impact of wind speed on solar stills was also examined, with moderate wind speeds being conducive to enhanced heat transfer and productivity by 20.82%.

Moreover, the study explored the influence of light rain on solar still productivity, revealing that while it may lead to fluctuations, light rain can have a beneficial cooling effect on the glass surface, thereby improving productivity to some extent the reduction by partial cloud was 52.15% and 12.9% for dry and light rain respectively.

Overall, this research contributes that the second system, characterized by high wind speed, achieved higher productivity due to the cooling effect on the glass resulting from increased heat transfer coefficient.

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