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Research Article

Enhancing the Performance of Passive Solar Stills by Implementing Different Piping Water

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ABSTRACT

In this study, the impacts of incorporating a saltwater pipe in passive solar stills were experimentally examined. The copper pipe serves as a heating source for the brackish water both inside and outside the absorber area, utilizing natural convection and conduction heat transfer in the solar stills to heat the water and enhance the rate of evaporation. Three new configurations of water pipes were tested. The maximum hourly volume of water produced by the solar stills in July 2023 reached approximately 986gr/m^2. The results of the experiment show that the efficiency of freshwater production is highest when using the square pipe design in July. This design demonstrated superior productivity and efficiency compared to others. The presence of water pipes improved the temperature of the salt water within the solar stills' basin. The introduction of water pipes in the basin led to a 41.9% increase in distillate output in CSSWSP, a 41.5% increase in CSSWHP, and a 40.8% increase in CSSWRP compared to the productivity of traditional solar stills.

1. Introduction

Water is the foundation for all life on Earth and its continued existence. It is essential for humans, plant life, and animals. Despite covering approximately 70% of the Earth's surface, most of the water available is unsuitable for human consumption. Around 97% of the Earth's water is found in the oceans, while 2% is stored in glaciers and polar ice caps, and only 1% is in lakes, rivers, and groundwater [1, 2 , 3]. Although the quantity of available water is limited, it is sufficient for all living organisms. However, the increasing global population and rapid industrial development have led to water pollution, scarcity of water resources, limited freshwater availability, and uneven water distribution. Clean water access, freshwater desalination, transfer, and supply of water remain significant challenges in many arid regions worldwide [4, 5].

Some countries struggle to meet international health standards for drinking and agricultural water quality, such as Iraq, where drinking water quality is below par [6]. The most effective and economical way to convert salty water into fresh water is through a desalination method that utilizes solar energy. By harnessing the free heat from the sun, this process can be achieved efficiently. Various factors such as the design of a solar still, its location for testing, elevation, surrounding temperature, sunlight intensity,

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water level in the basin, material and shape of the glass cover, fluid heat capacity, wind speed, and certain weather conditions like dust all play a role in determining the speed of water production and the thermal efficiency of solar stills [7]. A self-sufficient solar desalination and purification system has been developed to produce drinking water from brackish water. This system operates on the simple principle of absorbing water from a stationary basin and utilizing the energy from the sun's rays to turn the water into steam. The steam then condenses back into water, resulting in purified water. These solar distillation units are primarily categorized into two basic types: passive, which do not require external energy consumption or generation [8, 9], and active, which utilize one or more external sources of power such as PVT systems, electric pumps, and others [10, 11, 12], Researchers have conducted numerous experimental and theoretical studies on both passive and active solar desalination systems [13, 14]. Various techniques have been explored to enhance the performance and output of solar stills, including the use of floating plates [15, 16], different wick materials [17, 18], energy storing materials [19], incorporation of fins [20], reflectors [21], vacuum tubes [22], integrated solar stills [23], multi-stage solar stills [24].

Most researchers have opted for absorber plates made of aluminum or galvanized iron sheets. For instance, a 1 mm thick black-painted aluminum sheet served as the absorber plate in a solar still, yielding a productivity of 3.77 l/m^2 on a sunny day [25]. In the other work [26] explored the use of a solar still coated with black paint on a 1 m^2 corrugated galvanized iron sheet to enhance heat retention. They found that the still achieved efficiencies of 47.14% in winter and 56.29% in summer. This research demonstrated the effectiveness of utilizing common, environmentally friendly materials to boost production. In a more recent study [27] various low-cost and eco-friendly substances such as molasses powder (MP), sawdust (SD), and rice husk (RH) were investigated for their ability to increase evaporation rates in solar stills. Additionally, bamboo straw (BS), banana leaf straw (BL), and rice straw (RS) were tested as absorbent materials on the glass lid to enhance condensation rates. Comparing the performance of these modified solar stills to conventional solar stills (CSS) under similar weather conditions, significant improvements were observed. The experimental results revealed that the solar still with sawdust (SSSD) achieved a notable increase in evaporation rate, surpassing that of CSS by 34.81%. Similarly, the solar still with rice straw (SSRS) displayed enhanced condensation performance, exceeding that of CSS by 51.88%. Subsequent investigations focused on combining sawdust and rice straw to further enhance both evaporation and condensation processes. The solar still with this combination (SSSDRS) demonstrated a substantial productivity increase of 62.88% compared to CSS, reaching 3633 ml/m^2. Ahmed et al. [28] conducted an experimental study on the impact of black wicks on the performance of tubular solar stills. In their research, they explored how using inexpensive cotton wicking materials affects the efficiency of tubular solar stills integrated into parabolic concentrating solar tracking systems. The study compared the results of tubular stills with and without wicks to evaluate the enhancements achieved by upgrading the equipment. The comparative analysis revealed that the performance of the device with wicks was superior, leading to a significant reduction in the cost of freshwater production. The utilization of black cotton wicks resulted in a 29.11% and 24.45% increase in the production and efficiency of stills, respectively, while also decreasing the manufacturing expenses of seawater desalination by 40.21%. The solar still equipped with a wick could produce 5.1 L/m^2 of desalted water at a significantly reduced cost. This daily output could effectively fulfill the water needs of an individual in a small isolated community for a day. Al Helal et al. [29]developed a numerical and experimental method to enhance a single-slope solar still's efficiency in producing freshwater in arid desert regions. The solar still achieved a maximum productivity of 5.5 kg/m^2. At the minimum air gap distance of 14 cm, the distillate production increased by approximately 23% with a reduction in the height from 1.5 to 0.5 cm. Negi et al. [30] conducted a study on the performance evaluation of a tilting wick single-slope solar still under different salt concentrations (0%, 2%, and 4%). The highest distillate yield was observed at a salt concentration of 2% due to the efficient trapping of salt particles in the wick pores, which accelerated evaporation. A 17.5% improvement in the overall distillate output was achieved at a salt concentration of 2%.

In general, numerous research studies and experiments have been carried out to enhance the production of potable water using solar stills. The experimental study utilized a passive solar still to boost freshwater output. During this research, a metal tube was inserted into the evaporation chamber, and three different designs were developed for the water tube, which facilitated the transfer of saltwater to the basin. The influence of each tube's shape on the solar still's productivity was examined and compared to that of a traditional solar still. This innovation was employed to delay the movement of saltwater into the basin and act as a heat source to warm the water as it entered. The use of straight-tube arrangements has been reviewed in various articles, but the indirect designs presented here offer specific initiatives to improve economics and solar thermal capture. The use of straight-tube arrangements has been reviewed in various articles, but the indirect designs presented here offer specific initiatives to improve economics and solar thermal capture.

2. Problem Statement

In Iraq, it is generally unsafe for individuals to drink water directly from the tap due to its unsuitability for consumption. Specifically, in the city of Al-Kufa, residents face water pollution caused by sewage, leading to the presence of contaminated water that poses health risks. Streams flowing through piles of rubbish, which residents claim have been accumulating and contaminating local water sources for over five years, exacerbate the issue. Laboratory analyses of this water revealed elevated levels of harmful elements and compounds like lead, zinc, cadmium, iron, and copper, surpassing permissible international levels. The city of Al-Kufa experiences frequent changes in meteorological conditions, situated at coordinates 32°00'00 N, 044°19'48 E, at an elevation of 22 meters above sea level. Salt percentage results from water sample testing are detailed in Table 1.

Table 1. Test results of the water from the Al-Kufa River in July 2023

Num.	Element/ molecule	River water (mg/l) or (ppm)	Natural proportions (mg/l) or (ppm)
1	TDS	2650	300 -1000
2	PH	8.3	6.5-8.5
3	Ca^{++}	429	200
4	Mg^{++}	289	30-50
5	Na^{+}	1225	20-175
6	K^{+}	110	10-12
7	SO_4^{--}	1323	250
8	PO_4^{--}	49.5	--
9	Cl^{-}	1250	25-200
10	NO_3^{-}	38	25-50
11	HCO_3^{-}	628	--
12	B	5	0.5
13	Cu^{++}	0.44	2
14	Ni^{++}	0.06	0.02
15	Pb^{++}	0.2	0.01
16	Fe^{++}	2	0.8
17	Zn	0.15	13.8-22.9
18	Cr	0.03	0.05
19	Cd	0.01	0.003
20	COD	79	--
21	BOD	63	--

Many city center residents opt to purchase mineral water from markets as an alternative. Consequently, there is an urgent need to propose a straightforward desalination system for individuals residing in remote areas of the city. This desalination system should be simple to produce, applicable, cost-effective, durable, and reliant on clean energy, specifically solar energy, which is available year-round.

2.1. Physical Model

The experiments, which were conducted in July 2023, utilized three modified single-slope solar stills (CSSWSP, CSSWHP, CSSWRP) to study the performance evaluation of solar stills as seen in Fig. 1.

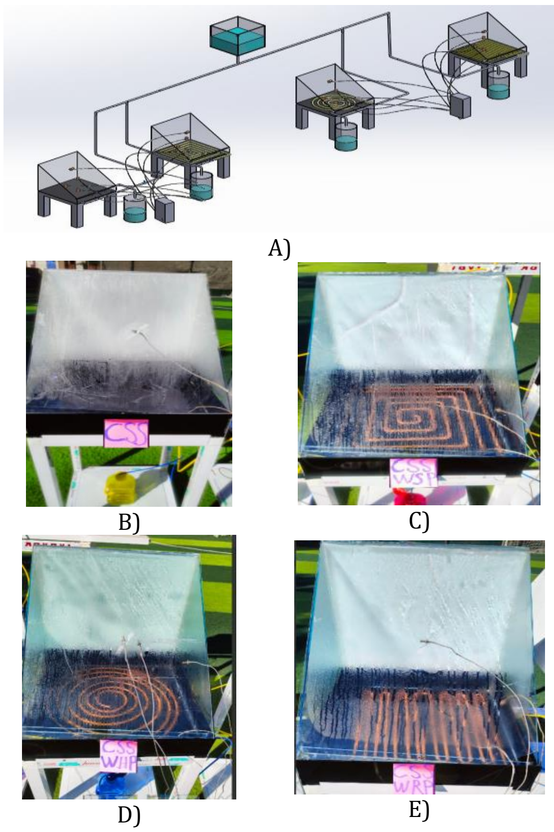


Fig. 1. The physical model of present study A) Four solar stills employed in the experiment; B) CSS; C) CSSWSP; D) CSSWHP; E) CSSWRP

The goal of this research is to enhance the evaporation rate. The experimental results of the modified stills were compared with those of the conventional solar still CSS. Solar distillation was also carried out with the consideration of a heat exchanger in this study, using three different water pipe arrangements as depicted in Fig. 1 (A, B, C, D, and E. The dimensions of the solar stills were 50*50*50 cm and featured innovative designs incorporating saltwater tubes, a square tube, a helical tube, and a rectangular tube for water transfer to the solar stills. The diameter of the tube was 1.9 cm. Among these designs, the use of square, helical (concentric circles), and rectangular pipe arrangements results in a longer time for water to reach high temperatures and rate of evaporation compared to straight pipes. Furthermore, these arrangements function as heat sources for heating the water during transportation, as illustrated in Fig. 1.

2.2. The Experimental Tools

Six K-type thermocouples, accurate to within 0.16 degrees Celsius, are strategically placed within the solar still to monitor the temperature of the salt water, vapor, ambient area, glass surfaces, and condenser. All thermocouples are connected to a digital temperature meter with a precision of 0.1 degrees Celsius. Throughout the experiment, a solar intensity meter with a resolution of ±2 W/m^2 is employed to measure daily fluctuations in solar irradiance on the glass covering. Additionally, an anemometer is utilized to track variations in wind speed in the surrounding environment with an accuracy of ±0.15 meters. Calibration bottles are utilized for daily productivity measurements, and brine volume is quantified using a wall-attached scale within the solar still. Detailed components of the instrument are illustrated in Table 2.

Table 2. The characteristics of the experimental tools

Apparatus	Accuracy	Range	Uncertainty (%)
Digital temperature Display	± 0.11 °C	0–200°C	± 1.168
K- thermocouple	± 0.16 °C	0--200°C	± 0.386
Thermometer	± 0.12 °C	0–100°C	± 0.293
Intensity meter	± 2 W/m2	0–1000 W/m2	± .1.395
Gaging vessel	± 10 ml	0–1000 ml	± 9.799
Anemometer Cup-type	± 0.15 m/s	0–15 m/s	± 8.615

Due to the overlap of errors in the table above and the necessary repetitions in the experiments, the calculation error has been minimized.

3. Governing Equations

The fluid present in the space is identified as moist air possessing the characteristics of ideal gases. Considering the natural convection within solar stills, the Rayleigh number is below 10^7, making the laminar flow theory suitable. To calculate the thermal efficiency, the following equation from [1] can be used:

$$\eta = \frac{\sum \dot{m_i} * l_v}{\sum I_d A_b * \Delta t} \quad (1)$$

where I_d, L_v, and $\dot{m}_i$ are the solar intensity, the water's latent heat of evaporation, and mass flow rate of brine, in that order. In addition, A_b and Δt are basin area and time interval, respectively. The water yield of the solar still as:

$$q_t = \dot{m} L_v \quad (2)$$

where η represents the thermal efficiency, $\dot{m}$ is the water production rate, I_v is the average solar radiation intensity on the pool, while q_t is the total heat transfer.

For cost analysis, a method is utilized to assess the economic viability of the proposed technology from[1,10]. The funds recovery factor (FRF) is defined as:

$$FRF = \frac{i(i+1)^y}{(i+1)^{y-1}} \quad (3)$$

where i and y are the lending bank's interest rate and the life of a solar still, respectively.

The fixed annual cost (FYC) is computed as follows:

$$FYC = FRF * M \quad (4)$$

where M is the highest cost. The drowning fund factor (DFF) is calculated using the following equation:

$$DFF = \frac{i}{(i+1)^{y-1}} \quad (5)$$

The yearly salvage value (YSV) is calculated as:

$$YSV = DFF * d \quad (6)$$

where d is the salvage value of the solar still. The annual repair procedure cost (YRC) may be estimated using

$$YRC = 0.15 FYC \quad (7)$$

The term yearly cost (YC) refers to the following:

$$YC = FYC + YRC - YSV \quad (8)$$

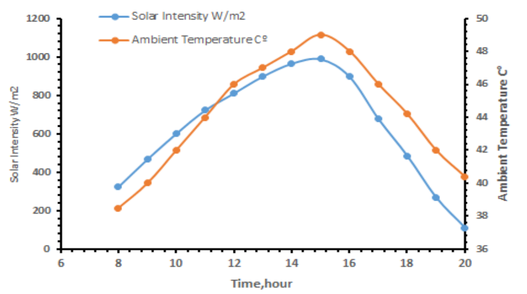
The parameter of the price per liter (PPL)is achieved as:

$$PPL = \frac{YC}{P} \quad (9)$$

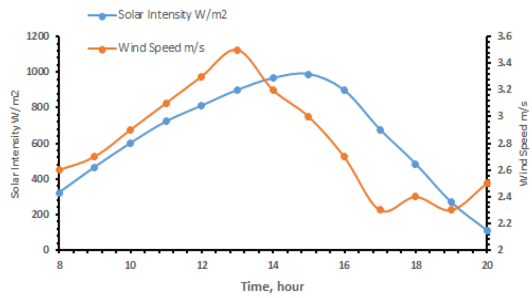
where p is the yearly production average.

4. Results and Discussion

Figure 2 illustrates the weather conditions in Kufa City on July 1st, 2023. Figure 2A demonstrates how the ambient temperature is affected by the intensity of sunlight, with a peak at 3 pm and temperatures ranging between 38 and 49 degrees Celsius.



(A)



(B)

Fig. 2. The hourly variations of A) solar intensity and ambient temperature; B) solar intensity and wind speed on July 1st, 2023

The intensity of radiation forms a nearly spherical shape, reaching a peak of 989 W/m² at 3:00 pm. Figure 2B shows the daily fluctuations in sunlight intensity and wind speed. Rapid fluctuations in ambient temperature coincide with changes in wind velocity around noon.

Figure 3 displays the daily temperature fluctuations of water (T_W), glass (T_g), vapor ($T_{vap.}$), condenser ($T_{cond.}$), and the environment ($T_{amb.}$). Between 8:00 am and 3:00 pm, the temperature gap between the water and glass widens, resulting in accelerated water evaporation and heightened water yield. In July, the maximal water volume produced by solar stills was around 986 grams per square meterby 3:00 pm. The recommended sunlight exposure hours are from 8:00 am to 8:00 pm. The peak yield of fresh water during July occurs between 1:00 pm and 4:00 pm, aligning with the highest solar radiation at noon, followed by a temperature decline.

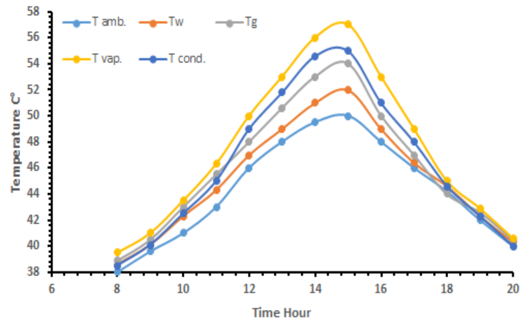
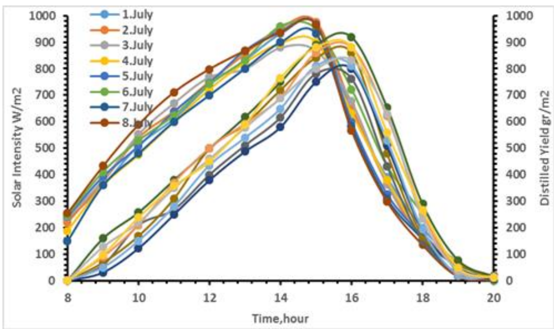


Fig. 3. Hourly temperature differences of water (T_w), glass (T_g), vapor (T_{vap}), condensation (T_{cond}), and ambient (T_{amb}) on July 1st, 2023.

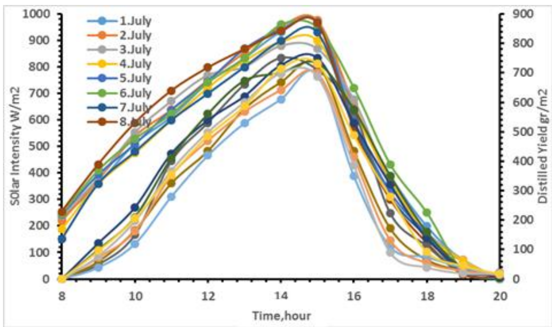
Furthermore, the solar still with a square tube generated the highest quality water due to increased solar radiation exposure, leading to faster evaporation compared to other solar stills with shorter helical and rectangular tubes. This extended exposure of the square tube to solar radiation enhanced the heating of the saltwater, allowing for prolonged absorption of heat from the sun's rays on the absorber part and the tube within the solar still.

Figure 4 illustrates the hourly sunlight intensity and its influence on distilled water production. The figure highlights the impact of hourly sunlight intensity on distilled water production throughout the day, analyzing four different configurations over an 8-day period in July 2023. The study also examines the effects of tube design on solar still output, specifically SSWSP, CSSWHP, CSSWRP, and CSS configurations. Results from the experiments indicate that the use of a square pipe is the most effective in freshwater production during July. It is apparent that water production is greater in the square pipe compared to the rectangular pipe, which in turn produces more than the helical pipe.

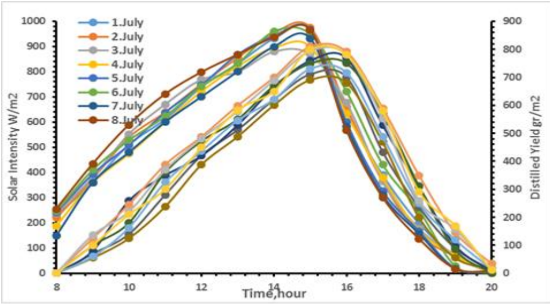
Figure 5 demonstrates the impact of ambient temperature on the production of distilled water across 8 test days in July, using four solar stills and three different pipe configurations. The temperature and wind speed data for these days are also included. Figure 6 illustrates the relationship between hourly freshwater production and wind speed over the same 8-day period. The temperature and wind speed data for these days are also included.



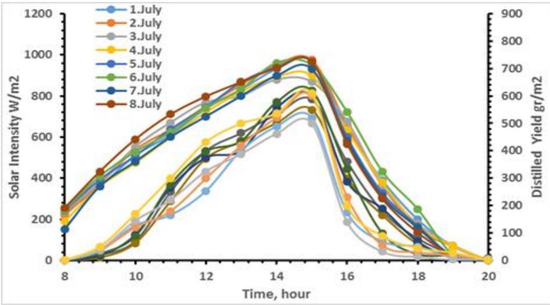
(A) CSSWSP design



(B) CSSWHP design

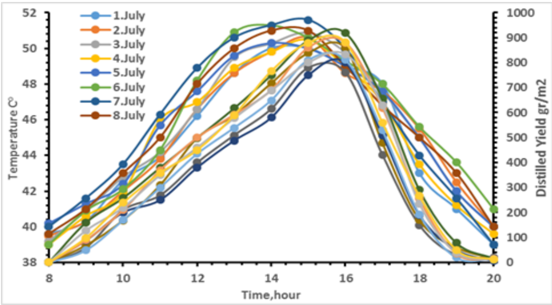


(C) CSSWRP design

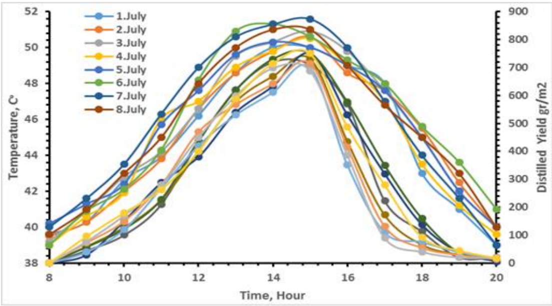


(D) CSS design

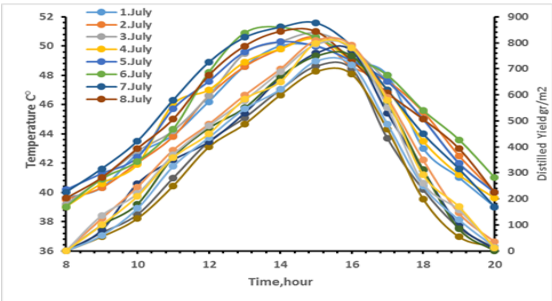
Fig. 4. The hourly impact of sunlight intensity on distilled production was observed over an eight-day experimental period in July for four desalination design



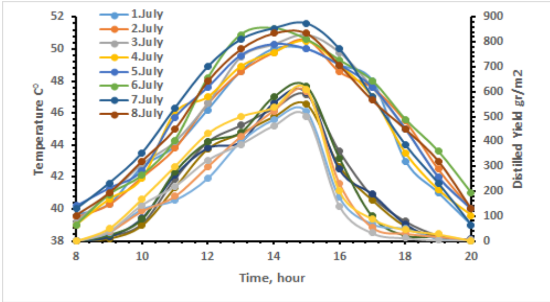
(A) CSSWSP design



(B) CSSWHP design

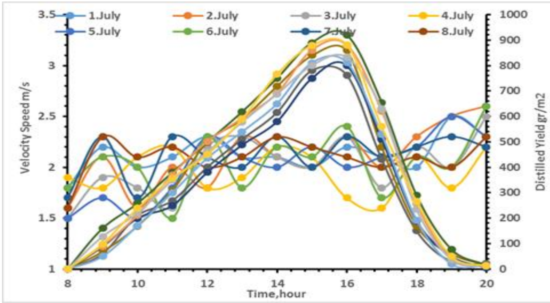


(C) CSSWRP design

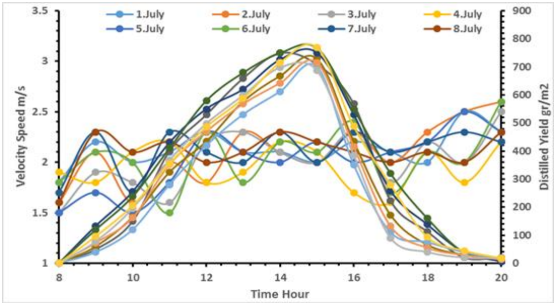


(D) CSS design

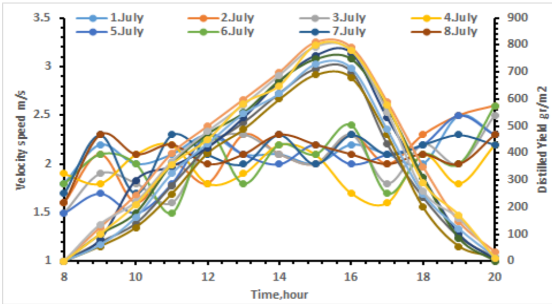
Fig. 5. The hourly impact of environmental temperatures on the distilled output was observed over eight experimental days in July, for four desalination design



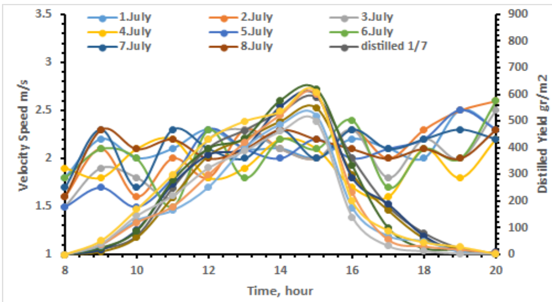
(A) CSSWSP design



(B) CSSWHP design



(C)CSSWRP design

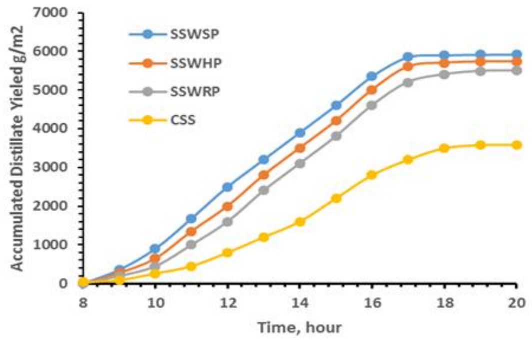


(D) CSS design

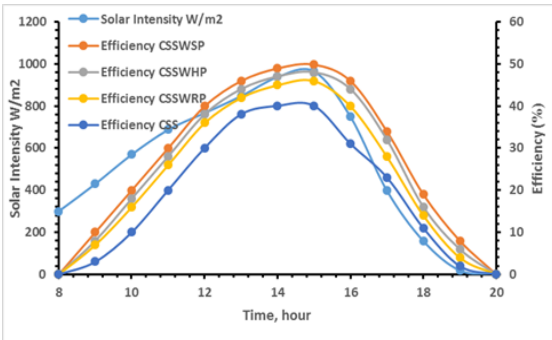
Fig. 6. The hourly effect of wind speed on distilled production during an eight-day experiment in July over eight experimental days in July, for four desalination designS

In Figure 7A, the graph illustrates the total water production for CSSWSP, CSSWHP, CSSWRP, and CSS in July. It is evident that the solar-powered still with a square water pipe produces the greatest amount of freshwater. Figure 7B depicts the hourly effectiveness of CSSWSP, CSSWHP, CSSWRP, and CSS, showing peak efficiency at 3:00 pm when solar radiance is at its highest. Water productivity reaches its peak at 4:00 pm, corresponding to the peak sunlight intensity at 3:00 pm and highest thermal efficiency.

As solar illumination decreases, efficiency drops to zero by 8:00 pm. Additionally, the highest amount of freshwater is produced at 7:00 pm as water production increases from 8:00 am to 7:00 pm. The latent heat of water at 5:00 pm exceeds that at 6:00 pm due to higher sunlight intensity at 5:00 pm compared to 6:00 pm.



(A)

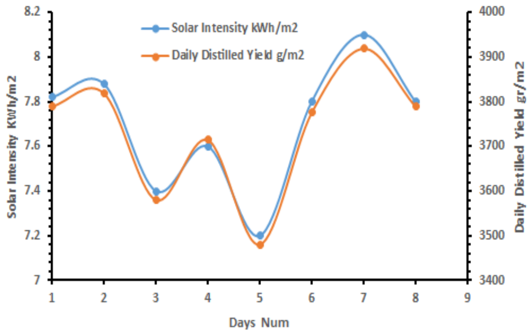


(B)

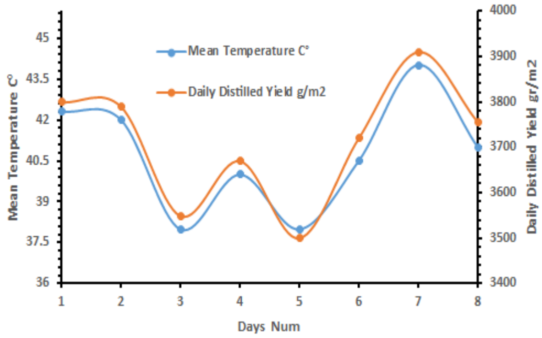
Fig. 7. Hourly changes in A) Total water yield from CSSWSP, CSSWRP, CSSWHP, and CSS; B) Effectiveness of portable CSSWS

The changes in daily solar intensity and daily distillate yield over an eight-day experimental period are depicted in Fig. 8A. Through practical experiments conducted over the course of eight days, it was observed that the direction of the produced freshwater mirrors the trend of solar radiation throughout the day. This outcome illustrates a clear correlation between the volume of distilled water and solar energy.

The trend suggests that distillation is more reliant on solar radiation than ambient temperature, as evidenced in Fig. 8B. Figs. 8C and 8D further elaborate on the disparities in daily solar intensity, daily efficiency, and daily average ambient temperature. The daily efficiency closely mirrors both daily solar radiation and average ambient temperature. Notably, on the seventh day of the experiment when maximum daily solar intensity is recorded, there is also a peak in daily average ambient temperature and daily efficiency.



(A)



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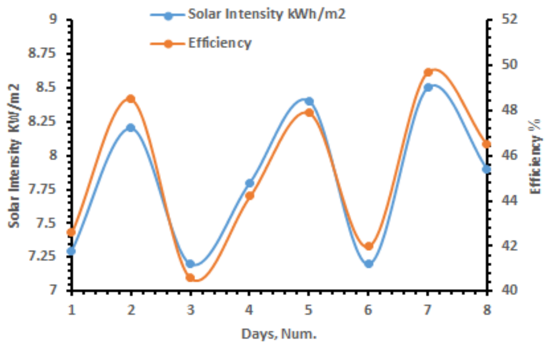
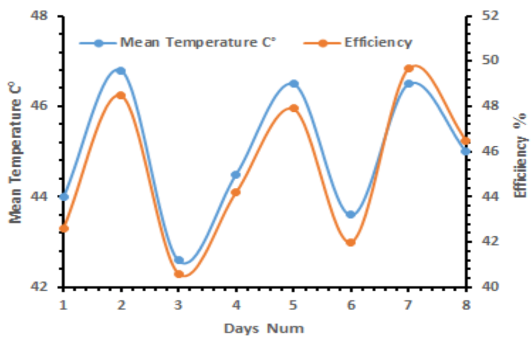


(C)



(D)

Fig. 8. Variations in solar intensity, average temperature, daily water yield, and efficiency of CSSWSP during the eight days of experiments

The hourly efficiency, calculated using Equations (10) and (11), has been graphed for CSS and three water pipe designs in comparison with the hourly efficiency of a solar still tested in Karbala City, Iraq by [31], as depicted in Figure 9.

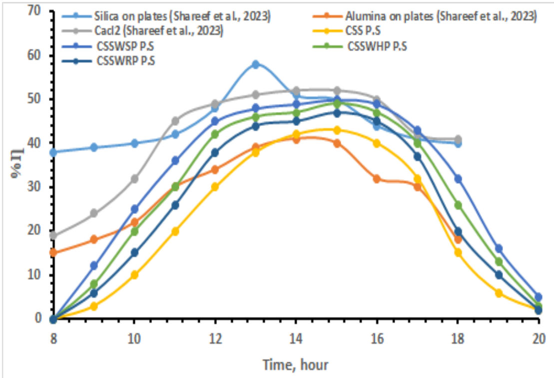


Fig. 9. Hourly variations in efficiency as compared to the findings of [31]

They calculated the productivity and performance increase of the solar still, as well as its thermal efficiency, based on verification data from July, as presented in Table 3. CSSWSP demonstrates the highest productivity and efficiency when compared to CSSWHP, CSSWRP, and CSS. Systematic sustainability assessments are employed to gauge environmental impacts, with a life cycle assessment examining the production process, procedures, and eventual disposal of the product over a 20-year span.

The expenses for all components utilized in the distillation system are detailed in Table 4, encompassing cutting and stamping services. The glass piece significantly impacts the overall cost. Table 5 presents a comparison of various designs of solar collectors, including modified and conventional types, showcasing the manufacturing costs for square, helical, and rectangular tube panels. The assessment demonstrates that the CSSWSP design is a more economical choice. Furthermore, the thermal efficiency of the experimental setup was examined across different altitudes and locations. Table 6 reveals that the thermal efficiency is competitive when contrasted with other solar distillation systems.

Table 3. The performance of the SSWRP, SSWSP, SSWHP, and CSS set-up

Solar still type	Water production g/m2	Thermal efficiency %	Rate of improvement %
CSSWSP	5920	49.6	41.9
CSSWHP	5735	49.1	41.5
CSSWRP	5686	48.5	40.8
CSS	3590	39.6	---

Table 4. Price of fabricated modified and conventional solar stills

Element	Price in US dollar
Thermal silicon paste	6
Sheet of glass 3 m^2	23
Cutting and sealing works	7
Black paint	9
Total	45

Table 5. Cost of producing the current project and others

Ref.	Daily water production cost $\$/m^2$
[1]	0.006
[5]	0.15
[8]	0.025
[32]	1.93
[33]	29.5
Present work CSSWSP	0.020
Present work CSSWHP	0.18
Present work CSSWRP	0.15
Present work CSS	0.13

Table 6. The thermal efficiency of the current study is compared to that of various studies in various areas

Ref.	Town, Nation	Height	Position	Efficiency
[1]	Mashhad, Iran	995 *m*	36° 18′ 56.12 N and 59° 34′ 4.66 E	43
[2]	Al Kufa Najaf, Iraq	30 *m*	32 ∘ North, 44 ∘ East	60
[34]	Gafsa-Tunisia	290 *m*	34.42 North, 8.78 East	12.9
[35]	Yozgat, Turkey	1335 *m*	34.48 North,30.86 East	37
[36]	Mansoura, Egypt	12 *m*	31V North, 31° East	7.9
[37]	Greater Noida, India	201 m	27.7 North, 77 East	45
[38]	Istanbul, Turkey	40 *m*	29.65 North, 42.09 East	28
[39]	Assiut, Egypt	70 *m*	27.11 North, 31.10 East	40.7
[40]	Kafrelsheikh, Egypt	17 *m*	31.6Nourth, 30.57 East	50
[41]	Valsad, India	13 m	20° North, 72° East	26.8
[42]	Buldana, India	277 *m*	28.21 North, 74.28 East	38.15
[43]	Tamilnadu, India	138 *m*	11°North, 77° East)	42
[44]	Bundara, Victoria, Australia	319 *m*	58 south, 23 East	49.9

[45]	Borg Al-Arab, Egypt	28 *m*	30.1° North, 29.1° East	75
Current Work CSSWSP	Al Kufa ,Najaf, Iraq	30 *m*	32° North, 44° East	49.6
Current Work CSSWHP	Al Kufa ,Najaf, Iraq	30 *m*	32° North, 44° East	49.1
Current Work CSSWRP	Al Kufa ,Najaf, Iraq	30 *m*	32° North, 44° East	48.5
Current Work CSS	Al Kufa ,Najaf, Iraq	30 *m*	32° North, 44° East	39.6

5. Conclusions

In this current study, four solar stills were designed, fabricated, and tested on recommended days in July 2023 under the climatic conditions of Al-Kufa, situated at an altitude of 30 meters and at coordinates 32°N, 44°E. The main results from the experiments can be summarized as follows:

- The maximum hourly water yield from all solar still designs in July was around 986 gr/m^2, recorded at 3:00 pm.
- The highest amount of fresh water during the day occurs between 1:00 pm and 4:00 pm, aligning with peak solar radiation at noon, followed by a decrease in temperatures thereafter.
- Experimental findings indicate that the square pipe method yields the most effective freshwater production.
- CSSWSP shows superior productivity and efficiency when compared to CSSWHP, CSSWRP, and CSS.
- The evaluation suggests that the cost of implementing the CSSWSP design is cost-effective in comparison to others.
- Thermal efficiency was assessed across various altitudes and locations, revealing favorable results in comparison to other solar still designs.
- Productivity is directly linked to solar radiation, temperature, and wind speed, with wind having a lesser impact due to limited water mass in the basin.
- The presence of water pipes enhances the temperature of saltwater within the solar still basin.
- Implementing water pipes in the basin results in a 41.9% increase in distillate production in CSSWSP, 41.5% in CSSWHP, and 40.8% in CSSWRP compared to CSS productivity.

Nomenclature

CSS	Conventional Solar Still
CSSWSP	Conventional Solar Still with Square Pipe
CSSWHP	Conventional Solar Still with Helical Pipe
CSSWRP	Conventional Solar Still with Rectangular Pipe
a	Standard uncertainty
u	Accuracy of instrument
m_c	Hourly distillate yield on condenser wall [kg/hr]
m_d	Daily distillate yield [kg/day]
m_i	Hourly distillate yield [kg/hr]
I	Initial cost
I_d	Daily averaged solar irradiation [W/m^2]
I_i	Hourly solar intensity [W/m^2]
AM	Before noon
PM	After noon
η	Efficiency
$U(\eta)$	Maximum combined uncertainty for the device efficiency
FRF	Funds recovery factor
i	Lending bank's interest rate
y	Life of a solar still
FYC	Fixed annual cost
M	Highest cost
DFF	Drowning fund factor
YSV	Yearly salvage value
d	Salvage value of the solar still
YRC	The annual repair procedure cost
YC	Yearly cost
PPL	Evaluate the price per litter
P	Yearly production average
T_{amb}	Ambient temperature [K]
T_g	Glass temperature [K]
T_w	Wall temperature [K]
T vap	Vapour temperature [K]
T cond.	Condenser temperature

Subscripts

amb	Ambient
c	Condenser wall
d	Daily

g	Glass cover
i	Hourly
E	East
N	North

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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Authors Contribution Statement

Zainab Majeed shabra: Material preparation; Data collection; Analysis; Writing – Original Draft.

Javad Abolfazli Esfahani: Material preparation; Data collection; Analysis; Writing – Review; Supervision.

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