Journal of Technology Research (JTR)
Volume 1, Issue 1, (2023), pp 094-101, ISSN 3005-639X

Experimental Study of Innovative Design for Solar Still Desalination

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Received: 03-09-2023 | Accepted: 25-11-2023 | Available online: 15-12-2023 | DOI:10.26629/jtr.2023.08

ABSTRACT

Solar still is a cost-effective and sustainable desalination process since it uses abundant solar energy to lower energy-related expenditures. For the first time, this study provides a new concept of free water production employing Solar Still with a built-in parabolic trough collector (PTC). The suggested solution is based on integrating a conventional solar still (CSS) and a PTC supported by an absorbent plate that serves as a thermal storage medium for the systems. The effect of integrating PTC on conventional single slope solar still as well as performance is being explored experimentally. The results show that the maximum cumulative productivity per hour for the seven-hour work period is 921 ml, and the highest overall productivity is 2451 ml and the maximum efficiency per hour of the modified Solar Still 44.9 %.

Keywords: Solar still, PTC, productivity.

دراسة تجريبية للتصميم المبتكر لتحلية المياه بالطاقة

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ملخـــــــص البحـــــــث

لاتـزال عملية تحليـة المياه بالطاقـة الشمسـية عمليـة فعالـة مـن حيـث التكلفـة ومسـتدامة لأنهـا تسـتخدم طاقـة شمسـية وفيـرة لخفـض النفقـات المتصـلة بالطاقـة. ولأول مـرة، تقـدم هـذه الدراسـة مفهومـًا جديـدًا لإنتـاج الميـاه المجـاني باسـتخدا المقطـر الشمسـي المـدمج مـع المجمـع الشمسـي مـن نـو ع القطـع المكـافئ. يعتمـد الحـل المقتـرح علـى دمـج المقطـر الشم سـي التقليـدي مـع المجمـع الشمسـي مـن نـوع القطـع المكـافئ مـد عـوم بلوحـة ماصـة تعمـل كوسـيط تخـزين حـراري للنظـام. تمـت ا لدراسـة العمليـة لتـأثير دمـج المجمـع الشمسـي مـن نـوع القطـع الـم كـافئ علـى المقطـر الشمسـي احـادي الميـل وكـذلك كفـاءة النظـام. تظهـر النتـائج أن الحـد الأقصـى للإنتاجيـة التراكميـة فـي السـاعة لفتـرة العمـل التـي تبلـغ سـبع سـاعات هـي 921 مـل، وأع لـى إنتاجيـة إجماليـة هـي 2451 مـل والحـد الأقصـى للكفـاءة فـي السـاعة للمقطـر الشمسي المطور 44.9%

الكلمات الدالة: المقطر الشمسي، المجمع الشمسي من نوع القطع المكافئ، الإنتاجية.

1. INTRODUCTION

With the rapid rise of the world's population and accelerated industrial development, freshwater scarcity has become a major global crisis and human challenge..[1] The fossil fuel depletion as well as the environmental damage caused by their combustion, has fueled the search for alternative energy sources.[2]
As a result, the only solution is to desalinate the saline water through different methods such as reverse osmosis (RO), humidification-dehumidification (HDH), electrodialysis (ED), and multiple effect evaporation (MEE) [3]
Solar energy has a significant impact on human needs. Solar energy is an infinite source of energy that can be used to generate electrical power, solar desalination, [4,5] air heating, and so on.
Solar energy is the most commonly used alternative as a renewable energy source in a desalination system [6,7]. Solar energy is the most popular type of renewable energy because of its advantages such as higher power density and reliability, as well as lower level of noise compared to other alternatives [8], and many countries have large future investment plans for developing their solar energy facilities [9].
Solar desalination is a technique that uses solar energy to produce distillate water. This method is used by a solar still (SS), which is a simple device. It is a simple box-type device that uses evaporation and condensation to desalinate water [10,11]. Per m2 per day, a solar still (SS) can produce 1-1.5 L of distillate water. The SS distillate output is lower due to various parameters such as losses generated, SS design and configuration parameters, and materials used to manufacture the SS. As a result, increasing the daily distillate yield of SS becomes necessary. [12].
Solar still is a cost-effective and sustainable desalination approach 54ecause it uses abundant solar energy for its operation, lowering energy-related costs.

In addition, using solar energy to desalinate seawater reduces co2 emissions. In comparison to other desalination methods, solar still has a simpler construction with fewer components [13].
To improve the performance of solar stills, researchers have tested constructional modifications such as stepped type, inclined wick, pyramid, tubular stills, and external heating sources such as reflectors, PV/T collectors, and external concentrators [14].
The parabolic trough collector (PTC) is a type of linear concentrating solar collector that works in the temperature range of 150-400 OC [15,16]. A parabolic trough collector is primarily composed of a parabolic trough mirror and a receiver in the reflector's focal line to absorb the reflected radiation from the sun. The heat transfer fluid (HTF) flows through the receiver absorbs the concentrated radiation and convert it to thermal energy [17]

A. *Improvement of evaporation within the solar still*

In general, solar still relies on the evaporation and condensation processes. Solar energy is used to evaporate the brine inside the solar still, and the condensate is collected as the distilled water output. This process is repeated in a double- or multiple-effect solar still, so that the heat of condensation is used to drive a subsequent evaporation process. The use of multiple effects tends to improve performance but comes at a cost. The use of active components, such as pumps and fans, is another way to improve performance, but it comes with costs and complexity.
Numerous studies have been conducted to investigate the factors influencing the freshwater output of solar desalination.
Omara et al. installed internal mirrors inside the stepped solar still to increase the evaporation of the solar still and gained a 75% increase in

distiller productivity [18].

Kabeel et al. tested the efficiency of a nanofluid and external condenser solar desalination system. The results showed that using nanofluid and a condenser increased the productivity of solar stills by 53.2% and 116%, respectively [19].

The productivity of conventional solar still (CSS) coupled with flat plate collector (FPC) increased about 60% [20] . Furthermore, the long – term testing of impact of coupling the FPC with CSS concluded that increasing water level can improve water production and reported that the efficiency increases due to the heat storage effect.[21]

The performance of conventional single slope solar stills is tested experimentally, as well as the impact of integrating a flat plate collector (FPC) and a parabolic trough collector (PTC) supported by a packaged glass ball layer (PLGB), which acts as a thermal storage medium to the systems. The incident solar energy from the PTC-FPC is collected in a still basin by two separate loops of finned pipes acting as heat exchangers. When compared to conventional solar, FPC-PTC-PLGB solar increased productivity by 172% in winter and 203% in summer. The efficiency of the solar still with FPC-PTC-PLGB is 16.24% in winter and 21.83% in summer [22].

1.1. Scope and originality of this work

In this work, we present for the first time, a new concept of free water production by using Solar Still with built-in parabolic trough collector (PTC).

Based on the literature and author's knowledge , the following points will be examined.

- Design and Installing a suitable by dimensions parabolic trough collector
- Using the built-in parabolic trough collector as a fixed position heat source for increasing the temperature of absorbing plat , saline water and vapor zone in the CSS to increase evaporation.
- Test the effect of the built-in parabolic trough collector as a heat storage after the sunset .
- Under various conditions, assess the productivity and performance of the CSS with the built-in PTC.

This novel concept for improving the thermal properties of the CSS, which has never been tested before, is expected to have a significant impact on evaporation.

2. METHODOLOGY

The approach used in this study to achieve the results is described here.

A. *Experimental setup*

In the current study, a parabolic trough collector (PTC) was integrated with CSS and used as a fixed position heat source to raise the temperature of the absorbing plat, saline water, and vapor zone in the CSS to improve evaporation and increasing freshwater productivity in a single slope solar still.

B. *Experimental procedures and productivity enhancement mechanism*

A single basin solar still combined with PTC, as depicted in Figure 1, was tested from 9:00 AM to 4:00 PM in the month of February in SABRATHA, LIBYA.

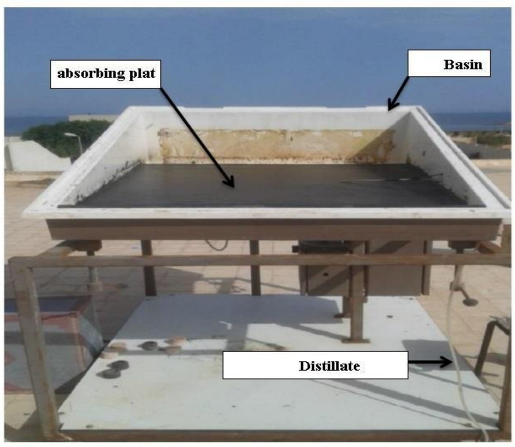

Fig. 1: (a) conventional single basin solar still (CSS),

Fig. 1: (b) a single basin solar still integrated with PTC.

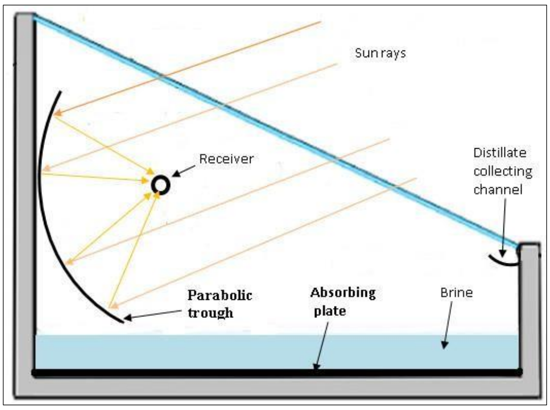

Fig.2 Experimental set-up (a) Experimental platform and (b) Schematic representation of the experimental set-up.

The experimental setup, as shown in Fig. 1, consists of a solar still and a Parabolic trough solar collector. The two specified components are united in one structure

The used Cussons' P7130 single-slop solar still consists of a basin, absorber plate, glass cover, and temperature gauge sensors. The traditional single-slop solar still is seen in Figure (1). The thermal glass cover has dimensions (148 cm x 108.5 cm) and a thickness of 6mm and is mounted at an angle of 14° to ensure the flow of condensate on its lower surface to the assembly channel. The solar still is thermally insulated from the bottom and sides to avoid heat losses. The basin base has a 1.3 m2 heat absorption plate that retains thermal solar energy required for evaporation; the basin is linked to a network of pipelines that deliver water to the solar still: The solar still's absorbing plate is coated black, allowing it to absorb more solar light. In addition, the 0.33 m^2 parabolic trough solar collector has a reflective surface and an aluminum tube receiver. The studies were carried out over a period of five days

C. Characteristics of PTC

Table 1: The ptc characteristics used in the study.

Characteristics	*Symbol*	*Value*
Aperture width (m)	AW	0,303
Aperture Area (m^2)	Aa	0,33
Collector height (m)	H	0.0574
Collector length (m)	L	1
Focal length (m)	FL	0.1
Geometrical concentration ratio	C	6.57
Parabola curve length (m)	S	0.33
Receiver Area (m^2)	Arec	0.0502
Receiver inner diameter (m)	Di	0.0145
Receiver outer diameter(m)	Do	0.016
Rim angle (°)	φr	74.26
Rim radius (m)	rr	0.157

C. *Calculated technical parameters*.

The most essential dimensionless technical element of it is the efficiency of the solar still (η). The efficiency of a solar still determined by (1) [23].

$$\eta = \frac{\dot{m}_{PFW}\, h_{fg\,water}}{A_{receiver}\, G} \qquad (1)$$

Where $\dot{}$***PFW*** is the mass of fresh water produced and ***G*** is the received solar radiation. *hfg*, water also represents the needed heat of vaporization for changing the phase of water from liquid to gas. *hfg*, is function of water temperature (T_W) by the following relationship

$$h_{fg} = \begin{pmatrix} 2501.9 - 2.40706\,T_w + 1.192217 \times 10^{-3} T_w^2 \\ -1.5863 \times 10^{-5} T_w^3 \end{pmatrix} \qquad (2)$$

The performance of the energy balance equations on various components has been predicted in the DSSSanalysis, and the steady state analysis of solar still is described by the instantaneous heat balance equation onbasin water [24].A.

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$$I\tau\alpha = q_e + q_r + q_c + q_k + C_w \frac{dT_w}{dt} \quad (3)$$

Where :

q_e - Evaporative heat loss from the water to the glass cover W/m^2

q_r - Radiative heat loss from the water to the glass cover W/m2

q_c- Convective heat loss from the water to the glass cover W/m2

q_k -The conductive heat loss from water basin W/m2

$\frac{dTw}{dt}$ - The rate of change in basin temperature over time.

Furthermore, Areceiver in Eq. (1) represents the region that receives solar radiation. Areceiver only comes from the solar still in passive mode. However, when calculating the efficiency of the modified solar still, the area of the preheating collector should also be considered.

3. RESULTS AND DISCUSSION

The results of the research are presented in this part, along with a discussion of them. The hourly profiles of important performance metrics for the five explored modes are then plotted and analyzed in this section , and the five different modes are compared together from the perspectives of daily freshwater production and daily efficiency. The hourly basis values of solar radiation, ambient temperature, water temperature , freshwater output and efficiency of the solar still for five different experiments are reported in next figures.

A. *The Solar intensity*

Figure 3 shows the variations in solar radiation measured during the test period. Measured radiation is conducted from 10:00 to 4:00 p.m. At 10 a.m., the solar intensity is low, and with time, the intensity begins to rise until it reaches its peak around 13:30 p.m. The intensity decreases at the end of the day.

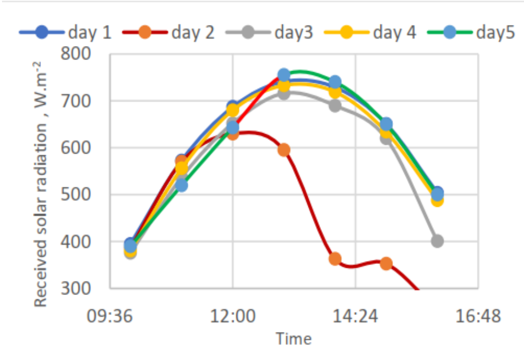

Fig. 3. Hourly profiles for received solar radiation.

B. *Ambient Temperature*

As shown in Figure 4 the ambient temperature ranged from 17 °C to 21 °C in the morning, peaking at around 30 °C at 14:00 on practically all days. In the afternoon, the temperature drops to around 19 °C

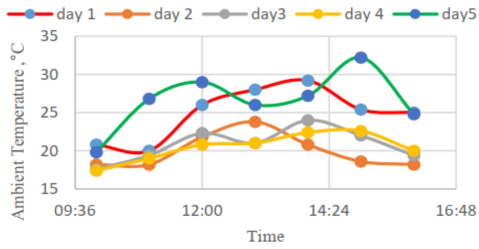

Fig. 4. Hourly profiles for ambient temperature

C. *Brine Temperature in the basin*

Fig. 5 show the recorded data for water temperature in the five different scenarios. The graph in Fig. 4 reveals that the temperature of the water in the basin increases from 10:00 to 15:00 and then drops, but the rate of decrease is slower than the rate of increase. This happens because the temperature of the water in the basin depends on both the amount of solar radiation it receives and the ambient temperature. When the irradiance and ambient temperature are higher, the water in the basin gets hotter. Since the ambient temperature is greater in the afternoon than in the morning, as shown in the Figure4 , the water temperature is highest at 15:00 when the maximum values are recorded.

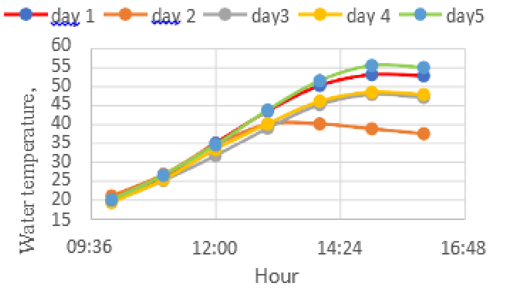

Fig. 5. Hourly profiles for ambient temperature

D. Hourly productivity

Fig. 6 display the hourly profiles of the system's fresh output for the five situations that were studied as the primary technical parameters of a solar still. Fig. 6illustrates the significance of utilizing the PTC. Basically, fresh water productivity is pretty weak when radiation levels are low, especially in the morning hours from 10 to 12 .But as the water temperature and solar energy increase, and the sun hits the PTC in the solar still at around 1pm, the productivity rate starts to climb rabidly.

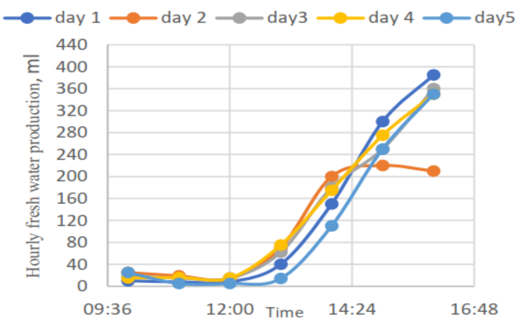

Fig 6: Hourly profiles for fresh water production

E. The daily Cumulative productivity

Figure 7 depicts the total water productivity of solar still with PTC.As seen in the graph, the cumulative amount of distillate for the five analyzed cases behaves similarly to the hourly productivity for all cases. According to table 2, the overall water productivity of the modified solar still was 921 ml per day from 10:00 to 16:00 and 2451 ml per day for 24 hours. Table 2 displays the hourly productivity, productivity throughout the night, and overall production per day.During the night, productivity ranged from 850 ml to 1650 ml, and overall productivity ranged from 1608 ml to 2451 ml.

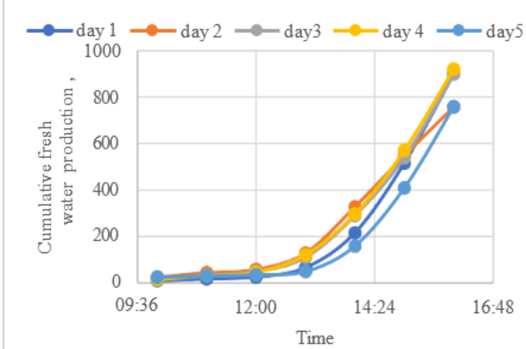

Fig 7: The hourly Cumulative productivity profiles.

Table 2. The values of the cumulative fresh water production for five different tested cases of css with ptc ; in ml.

hour	Day1	Day2	Day3	Day4	Day5
10	10	25	18	15	25
11	8	19	15	16	5
12	8	14	15	15	5
13	40	70	62	75	14
14	150	200	180	175	110
15	300	220	250	275	250
16	385	210	360	350	350
10	1550	850	1200	1275	1650
Total	2451	1608	2100	2196	2409

F. Efficiency of modified Solar Still

Figure 8 illustrates the experiment period's instantaneous thermal efficiency. It is observed that the efficiency of the modified solar still depends mostly on productivity, which is dependent on solar radiation, PTC, and radiation surfaces. In general, when radiation levels are low, efficiency is quite weak, especially in morning hours of 10:00 to 12:00. However, as water temperature and solar energy increase, and the sun rays hits the PTC in the Solar Still around 1 p.m., efficiency starts to rise rapidly. The greatest efficiency value attained is 44.9 %.

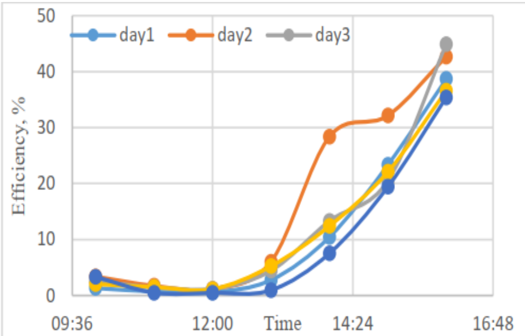

Fig. 8: The efficiency of the modified solar still on hourly basis for different days.

4. CONCLUSIONS

The productivity and efficiency of improved solar still uses PTC are investigated experimentally in this study. The performance is expressed in terms of maximum productivity and efficiency achieved during the experiment period. According to the obtained results, the following conclusions can be drawn:

5. **The maximum productivity of a modified and PTC at hourly is 385 ml.**
6. **The maximum cumulative productivity per hour is 921 ml for the seven-hour work period**
7. **The highest overall productivity is 2451 ml. The maximum efficiency per hour of the modified despite PTC is 44.9 %.**

To provide a comprehensive analysis, we compared the outcomes of our research with earlier investigations. It is important to note that no previous study has examined solar stills with built-in PTCs, therefore our comparison is with PTC-coupled stills and stills coupled with flat plate collectors (FPC).
Table 3 presents a comparison between our research findings and prior studies on solar stills utilizing a parabolic trough collector (PTC) and flat plate collectors (FPC).
. This study focuses on comparing distillate production and thermal efficiency data with previously reported findings. Despite variations in climatic conditions such as solar intensity, ambient temperature, and wind speed, the overall results remain comparable.
Our results demonstrate superior performance compared to previous studies due to the integration of the PTC within the solar still, resulting in higher temperatures and increased water evaporation.

Table 3: comparison of the study and different research work.

references	Thermal efficiency	Average Yield
Madiouli et al.[25]	21.83% in summer	250
Fathy et al.[26]	36.87% with tracked PTC	96.3
PATİL M et al.[27]	42.76%	125
Ramachandra et al., [28]	6.82% with FPC	112.25
Badran et al., [29]	22.26%	95.83

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