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INTEGRATING A VERTICAL WICK SOLAR STILL TO ENHANCE PYRAMID SOLAR STILL PRODUCTION

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ABSTRACT. Extensive research into effective water purification techniques has been prompted by the urgent worldwide dilemma of finite freshwater resources. This study looked into a novel method of solar desalination that combines a vertically positioned wick still (VWSS) with a modified pyramid still (MPSS). The research was motivated by the ever-growing water crisis caused by population increase and limited freshwater resources. The findings demonstrate that the MPSS configuration with both VWSS achieved the most significant improvements in desalination performance: The MPSS alone achieved a 20% increase in daily freshwater production (6000 ml) compared to the conventional pyramid still (PSS, 5000 ml). When combined with the downstream VWSS (total 9200 ml), the overall productivity increase of the MPSS configuration reached 84% compared to the standalone PSS. The cost of freshwater was 0.02 $/L for the PSS and 0.015 $/L for the MPSS with VWSS. The MPSS with VWSS offers significant improvements in productivity, efficiency, and cost-effectiveness compared to traditional methods.

KEYWORDS: Pyramid solar still; Vertical wick solar still; Solar desalination, Solar stills.

1. INTRODUCTION

Researchers have investigated alternative approaches, with solar distillation emerging as a promising solution. Utilizing solar energy for water purification offers a sustainable and non-traditional strategy [2–4]. Scientists worldwide have actively developed, constructed, and evaluated various solar still designs, encompassing both passive and active systems [5,6]. Their findings, meticulously documented, provide valuable knowledge for the scientific community engaged in this field. Notably, passive solar distillation, which mimics natural evaporation and condensation processes, has been extensively studied to optimize its effectiveness [7–9]. While established methods like multi-effect desalination exist [10–13], they can be complex and expensive [14,15]. Existing solar stills (SS), which rely on the fundamental principle of evaporation and condensation, offer a simpler and more cost-effective approach [16–18]. However, a review of the literature reveals limitations in their efficiency. This study proposes a novel concept to address these limitations by incorporating [mention key feature] into the SS design. This innovative approach aims to significantly enhance the efficiency of solar stills for freshwater production. Single-basin solar stills (SS) hold significant appeal due to their economic viability, operational simplicity, and environmentally friendly materials. However, their efficiency suffers from heat loss through the cover, leading to an average freshwater production of only (~3 liters) and efficiency (~30%) depending on design and location [19–22]. Many works have focused on using solar energy, whether in desalination, water heating, or in various types of industry [23-29].

This study investigates a novel solar still configuration that combines a pyramid still with a vertically positioned wick still situated behind it. The primary objective is to enhance the overall productivity of the system. The strategic placement of the wick still leverages the exiting hot water from this unit to preheat the feed water entering the pyramid still. This approach offers several advantages.

2. EXPERIMENTAL SETUP

2.1. SOLAR STILLS FABRICATION DETAILS

Fig.1 shows experimental setup and Fig. 2 provides a two-dimensional schematic depicting the complete configuration. The research introduces a modified pyramidal solar still (MPSS) resulting from design alterations to a conventional pyramidal still (PSS). To evaluate the performance of the MPSS, a comparative analysis is conducted against the PSS. Both the PSS and MPSS share a robust design constructed from 1.5 mm thick galvanized steel. They feature identical basin dimensions of 70 cm x 70 cm with a 15 cm vertical steel height. Meticulously adjusted triangular glass elements form the characteristic prismatic apex of both stills (Fig. 1). To minimize heat loss, both configurations are meticulously insulated with fiberglass. Both distillers utilize slightly thicker 3 mm transparent glass panels. Secondly, the triangular glass panels at the base of the stills are equipped with -5° angled dips to facilitate efficient channeling of condensed water droplets towards external collection bottles, as shown in Fig. 2. The dimensions of the vertical wick still (VWSS) are 70 cm in length, 10 cm in width, and 100 cm in height. The VWSS had four faces made of galvanized steel (1.5mm thickness), and the other two faces made of glass sheets (3mm thickness): one surface was the cover and the other was the front face as shown in Fig. 1.

The experiment was conducted in throughout daylight hours, spanning from 8:00 AM to 9:00 PM. During this period, various parameters were monitored and recorded on an hourly basis. These parameters included solar irradiance, air speed, water temperature within the stills, surrounding ambient temperature, glass surface temperature, and the volume of distillate produced.

Fig. 1. Experimental setup

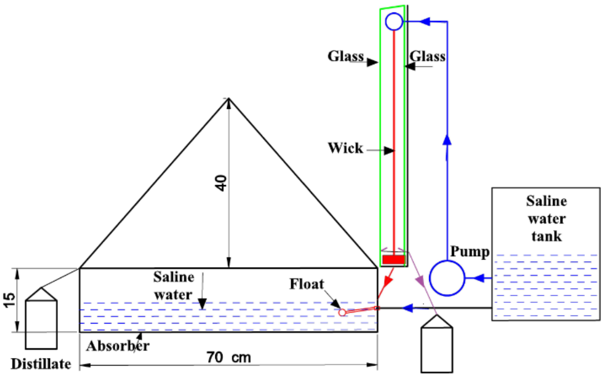

Fig. 2. Schematic diagram of the modified solar still.

2.2. MEASURING TOOLS

To ensure accurate performance evaluation, both solar stills were outfitted with essential measurement sensors. A pyranometer (accuracy ±1 W/m^2 & range 0 – 5000 W/m^2), strategically positioned horizontally on the ground test location, monitored solar irradiance. Continuous and precise temperature data acquisition was achieved using a network of thermocouple sensors (accuracy ±0.5 °C & range -50 – 160 °C) interfaced with an Arduino Mega controller. Airspeed was captured by an anemometer (accuracy ±0.1 m/s & range 0.1 – 30 m/s). Finally, the volume of produced distillate was meticulously measured using graduated flasks (accuracy ±1 mL & range 0 – 2000 mL).

3. RESULTS AND DISCUSSION

Based on the equations from Ref. [30], the amount of productivity improvement is evaluated by:

$$\mathit{Productivity}\ \text{improvement, \%} = \frac{\mathit{MPSS\ productivity} - \mathit{PSS\ productivity}}{\mathit{PSS\ productivity}} \times 100$$

3.1. PERFORMANCE OF PSS AND MPSS WITH VWSS

Fig. 3 presents the changes in irradiance and temperatures for the ambient, basin liner, water, and glass cover (glazing) in both stills (PSS and MPSS). The data suggests that the feed water temperature in the PSS fluctuates around the ambient air temperature due to its direct exposure to external weather conditions. This is evident from the figure, where the PSS feed water temperature sometimes slightly exceeds the air temperature and sometimes nearly matches it. In contrast, the MPSS benefits from a dual feed water source. The primary source is preheated water coming from the VWSS. This preheated water contributes to a significantly higher feed water temperature in the MPSS compared to the PSS, ranging from approximately 0.5 to 6.5 °C above ambient temperature. The elevated feed water temperature translates to a consistently higher water temperature within the MPSS compared to the PSS. This difference ranges from 0 to 2.5 °C. For example, at 1:00 PM, the MPSS water temperature reaches 70 °C, while the PSS water temperature is only 67.5 °C. Consequently, the increased water temperature in the MPSS leads to a higher rate of evaporation compared to the PSS. This phenomenon is reflected in the consistently higher glass temperature observed in the MPSS throughout the day. At 1:00 PM, the MPSS glass temperature is 56 °C, while the PSS glass temperature is 54 °C. The passage additionally mentions that the solar radiation intensity at noon was 1150 W/m^2 and the air temperature was 42 °C.

The data confirms that the tilted glass design of the MPSS allows it to consistently capture a higher solar radiation intensity compared to the VWSS. For instance, at noon, the MPSS received a radiation intensity of 1150 W/m^2, whereas the VWSS only received 550 W/m^2. This translates to an average daily radiation intensity of 667 W/m^2 for the MPSS and 293 W/m^2 for the VWSS. In simpler terms, the VWSS receives less than half the solar radiation captured by the MPSS. Consequently, the temperature of the wick in the VWSS remains lower than the water temperature within the MPSS. At 13:00, the MPSS water temperature reached 70 °C, while the wick temperature was only 65 °C. It's important to note that the feed water for the VWSS is at approximately ambient temperature, whereas the MPSS benefits from preheated feed water. A similar trend is observed with the glass temperatures. The MPSS glass consistently exhibits a higher temperature throughout the day compared to the VWSS. At 13:00, the MPSS glass temperature was 56 °C, while the VWSS glass temperature was only 45 °C. This can be attributed to the condensation process in the VWSS occurring on both the front and back windshields. However, the back windshield receives minimal solar radiation due to being shaded by the wick, resulting in a lower temperature. Additionally, the vertical orientation of the VWSS glass causes condensed water droplets to slide down quickly due to gravity, further limiting heat retention.

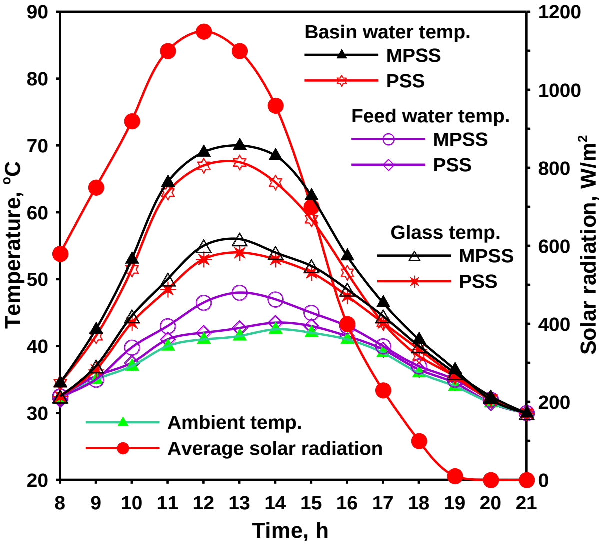

Fig. 3. Radiance and temperatures of ambient, glass and water for tested distillers.

Fig. 4 show cases the instantaneous and accumulated yields for MPSS, PSS, and VWSS and combined MPSS and VWSS together. The superior performance of the MPSS is evident from its consistently higher productivity compared to both the PSS and the VWSS. At 13:00, the hourly productivity reached 800 ml, 935 ml, and 530 ml for the PSS, MPSS, and VWSS, respectively. This translates to a total production of 5000 ml, 6000 ml, and 3200 ml for PSS, MPSS, and VWSS, respectively. In conclusion, the MPSS demonstrates a 20% increase in productivity compared to the PSS. When considering the combined productivity of the VWSS and the downstream PSS (9200 ml), the overall productivity increase achieved by the MPSS configuration reaches 84% compared to the standalone PSS.

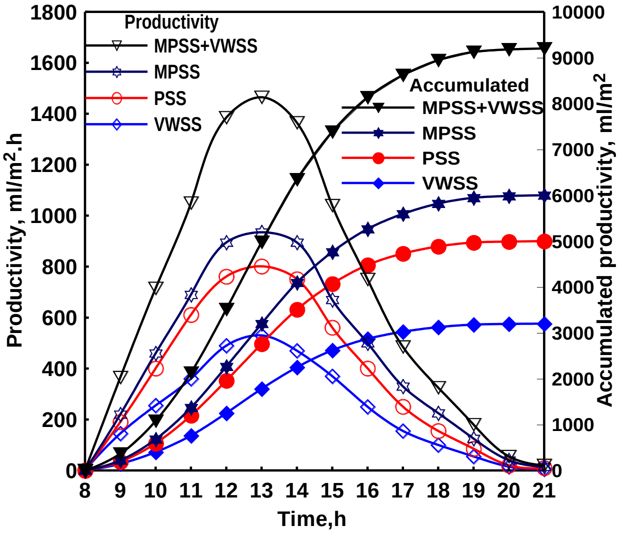

Fig. 4. The hourly and accumulated production for PSS, MPSS, and VWSS and combined MPSS and VWSS together.

4. ECONOMIC ANALYSES OF SSs

By using the information provided in Tables 1, 2, the calculations are used to determine the costs associated with tested SSs. The specific formulas used for these calculations are presented in Table 3. The cost of fresh water is 0.02 $/L for the pyramid SS and 0.015 $/L for the modified pyramid SS with VWSS

Table 1. Fixed costs of solar stills components.

Item	**Cost of pyramid SS ($)**	**Cost of modified pyramid SS ($)**
Iron sheet	20	20
Ducts and fittings	30	35
Glass cover	15	30
Insulation	15	15
Paint	5	5
Pump	-	10
Production	25	40
Total fixed cost (F)	**110**	**155**

Table 2. Relations for cost analysis according to Ref. [72].

No.	**Formula**	**Description**
1.	$CRF = \frac{i\,(1+i)^n}{(1+i)^n - 1}$	Capital recovery factor
2.	$FAC = F\,(CRF)$	Fixed annual cost
3.	$SFF = \frac{i}{(1+i)^n - 1}$	Sinking fund factor
4.	$S = 0.2\,F$	Salvage value
5.	$ASV = \mathrm{S\ (SFF)}$	Annual salvage value
6.	$AMC = 0.15\ \mathrm{(FAC)}$	Annual maintenance costs
7.	$TAC = \mathrm{FAC + AMC - ASV}$	Total annual cost
8.	$CPL = TAC/M$	Cost of distilled water

Table 3. Assumptions used in the economic analysis.

No.	**Variable**	**Mean**	**Quantity**
1.	n	System lifetime	20
2.	i,%	Interest rate	15
3.	N, Day	Working days of year	340
4.	F,$	System fixed cost (see Table 1)	155 for MPSS 110 for PSS
5.	M, L/m^2.year	Average yearly productivity	2370 for MPSS 1292 for PSS
6.	CPL, $/L	Cost of distilled water	0.015 for MPSS 0.02 PSS

5. CONCLUSION

This study explored a novel solar desalination system combining a modified pyramid still (MPSS) with a vertically positioned wick still (VWSS). The MPSS alone achieved a 20% increase in daily freshwater production (6000 ml) compared to the conventional pyramid still (PSS, 5000 ml). When combined with the downstream VWSS (total 9200 ml), the overall productivity increase of the MPSS configuration reached 84% compared to the standalone PSS. The cost of freshwater was 0.02 $/L for the PSS and 0.015 $/L for the MPSS with VWSS. In conclusion, this study demonstrates that the MPSS with integrated VWSS offers a promising and cost-effective solution for enhanced solar desalination performance

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