Experimental investigation on the effect of water depth in conventional solar still integrated with inclined solar still

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ABSTRACT

This article primarily focuses on comparative analysis on conventional solar still (CSS), inclined solar still (ISS) and inclined solar still integrated with conventional solar still (ISS-CSS). Only a few researchers have carried out experiments on still-still integration for enhancing productivity. In the present novel system, the fresh water production rate is improved by integrating ISS with CSS. This experimental work mainly concentrates on the importance of water depth and mass flow rate of solar still. The inclined solar still is maintained at constant flow rate of about 8.33kg/hr. Experimental results showed that the maximum fresh water production from ISS-CSS, ISS, and CSS were 6.2, 5.04 and 4.24kg respectively. ISS-CSS and ISS produced 46.23\% and 18.87\% higher productivity than the CSS. Results also showed that temperature of the water is higher in the case of ISS integrated with CSS at the least amount water depth of $d_w=0.02$m. The overall improvement in yield was higher in the case of ISS integrated with CSS.

KEYWORDS

Still integration; Inclined solar still; Conventional solar still; Yield improvement

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1. Introduction

Solar still desalination is used for converting dirty water into dirt-free water and it is mainly classified into two types: Passive type solar distillation system uses only the solar energy for producing drinking water, leading to a lesser yield of fresh water. Active type solar distillation system integrating the solar still with flat plate collectors, parabolic concentrators, evacuated tube collectors, heat pipes, etc. In such a system, water to be treated is initially heated by using one of the above mentioned augmentation systems working on solar energy and then it is used in a solar still. This increases the amount of fresh water productivity. A number of experimental and theoretical studies are being carried out to augment the performance of stills [1-4]. Mahdi et al [5] fabricated a wick type solar still with a charcoal cloth as an absorber, this setup produced 53% efficiency. Matrawy et al [6] used corrugated wick material in ISS, it produced 34% higher yield than CSS. Omara et al [7] experimentally investigated the corrugated absorber wick solar still and corrugated absorber wick solar still integrated with reflectors. It was found that corrugated absorber wick solar still produced 53.36% higher yield than CSS, and corrugated absorber wick solar still integrated by reflectors produced 145.5% higher yield than CSS. The daily efficiency of corrugated absorber wick solar still was 59%. Minasian et al [8] integrated the ISS with CSS. The hot brine water leaving from ISS was feed directly into the CSS. Nagarajan et al [9] have done the theoretical and experimental analysis of ISS with baffles for enhancing the fresh water production rate. It was concluded that ISS with baffles produced 5.4 kg/m² yield, and ISS without baffles produced 3.4 kg/m² yield. ISS with baffles produced 30.23% higher yield than ISS without baffles. El-Sebaii et al [10] used baffle suspended absorber in CSS, and it was found that this technique produced 20% higher yield than CSS. Naveen Kumar et al [11] hypothetically explored the impact of incorporating a slanted solar still with triangular pyramid solar still. It was found that the greatest yield is acquired under steady water mass of 20 kg inside the basin (Y = 7.2 kg/m²). It was similarly found that the yield of clean water diminishes with increment in water mass inside the basin. Mohamed A. Eltawil et al [12] fabricated a wind turbine-FSS (wind) integration with the CSS for salt water purification. This framework comprises of the wind turbine (WT) and inclined solar water desalination (ISWD) a combined with main solar still (MSS). The evaporation and condensation occur upon both MSS and ISWD. The normal everyday effectiveness of MSS and ISWD is ranged from 67.21% to 69.59% and 57.77% to 62.01% respectively without the sun following. Y. Taamneh et al. [13-14] designed and modified a simple pyramid-shaped solar and its
performance was experimentally estimated. They found that the use of fan worked with photovoltaic solar panels becoming cost-effective and viable in enhancing the evaporation rate and hence freshwater production. Based on the performance evaluation, the daily productivity of freshwater was increased up to \( \sim 25 \) percent compared to free convection solar still. They also investigated the effect of using different basin absorber plate made of carbon fiber reinforced epoxy composites on the solar still performance. The experimental results showed that adding 2.5 wt % and 5 wt % carbon nanotubes to the carbon fiber reinforced epoxy composites caused 64% and 108.5% increase in the amount of distilled water productivity.

Y. Taamneh et al. [15] investigated the effect of natural Jordanian zeolite (NJ zeolite) as a thermal energy storage material on the thermal efficiency of solar still. It was found that the solar still performance was enhanced by 43% when using NJ zeolite. The authors believe that lots of work can be performed to improve the solar still efficiency. Therefore, in this study, the effect of integrating ISS with CSS, ISS, and CSS have been experimentally tested and investigated.

2. Experimental Methodology

2.1 Inclined Solar Still

An inclined solar still consists of a black painted basin inside which four baffles are placed at an equal distance of about 0.13 m. The still is made of mild steel material, where the area of the basin is 0.65 m \( \times \) 0.65 m. The height of the still is 0.15 m. The top of the solar still is enclosed by a glass cover having 4 mm thickness. The side walls as well as bottom of the basin are covered by an insulation material to prevent convective heat losses. The entire solar still is kept in a north-south direction at a 30° inclination.

The brackish water from the storage tank is fed into the basin of solar still at a constant flow rate of about 8.33 kg/hr. The flow rate of water is controlled by a flow control valve. The feed water continuously flows to the still basin, thus the outlet water temperature increases by absorbing the solar radiation from the absorber of the still. The presence of baffles increases the time contact of water within the solar still, thus the water temperature increases. As the heat from the basin is rejected to feed water, the evaporation takes place. Since the glass cover is kept inclined, the condensed water droplets flow down the still and are collected on the distillate collector. Fig. 1 shows the photographic view of an inclined solar still with baffles.
2.2 Conventional Solar Still

The conventional solar still is completely made of glass material. The basin is made of reflector glasses for complete absorption of solar radiation within the solar still. The top of solar still is enclosed by a glass cover of about 4mm thickness. The still is kept towards north-south direction at an inclination of 13°. The entire still is insulated by the wood material to prevent heat losses. The brackish water from the storage tank is fed into the basin at different depths such as 0.02m, 0.04m, and 0.06m. Effect of water depth on the yield of fresh water is experimentally analyzed. Fig. 2 shows the photographic view of conventional solar still.

2.3 Inclined solar still integrated with conventional solar still

In this type of integration, the fed water storage tank is connected in series with CSS and ISS. The outlet of inclined still is connected to the inlet of CSS through a flexible hose. The hot water from the outlet of ISS is utilized by CSS for improving its productivity of fresh water. Fig. 3 shows the photographic view of an ISS integrated with CSS.

3 Measuring system

The solar intensity is measured using solar power meter TES 1333R with the range of (0-2500 W/m²) and accuracy of (±1W/m²). A cup type anemometer is used for measuring wind velocity of air with the range of (0-45 m/s) and accuracy of (±0.1m/s). K-type thermocouples with the range of (0 to 100°C) and accuracy of (±1°C) are attached to 12 nodal temperature indicator for measuring temperatures at various points. The depth of water in the ISS and CSS are measured using a calibrated scale with the accuracy of (±0.1cm). A calibrated beaker with the range of (0-1000mL) and accuracy of (±10mL) is used for measuring fresh water. The flow rate of feed water in an inclined solar still is measured using mass conservation principle.

4 Results and Discussion

4.1 Inclined solar still with baffles

Fig. 4 (a) and (b) shows the variation of glass and water temperature on different experimental days at a constant flow rate of water inside the ISS with baffles. It is observed that the water temperature is increased due to increase in solar intensity that is crucial for evaporation from the surface layer of the basin. While observing the variation in water
temperature, the peak average temperature is found to be 48.5°C. It can be observed that the water temperature on (10/4/16) is the lowest throughout the day due to the lower solar intensity and ambient temperature. The temperature of the glass is reduced with increased wind velocity for enhanced condensation. While observing the variation in glass temperature, the peak average temperature is found to be 43.4°C for a wind velocity of 1.1 m/s. The mean temperature variation between water and glass with peak intensity is found to be 5±0.2°C.

**Fig. 5 (a) and (b)** shows the difference between the theoretical and the experimental yield from ISS with baffles on different experimental ambient conditions at constant flow rate of water inside the basin. It can be observed that due to the variation of wind velocity, ambient temperature, and solar intensity curves, the yield varies as the heat taken away from the cover is lower. It is clear that the wind velocity over the cover plays a significant role in fresh water production from the solar still. With the placement of baffles at frequent interval the evaporative heat transfer coefficient is increased by 10% than Dunkles [citation missing] prediction from the same condition and water mass flow rate. The peak evaportative heat transfer coefficient during summer and winter is found to be 66 and 45 W/m²K. The deviations among experimental over theoretical values are found to be within the range (±7%). The maximum yield from the solar still with baffles is found to be 0.75 and 0.42 kg with the average solar intensity of 589 and 465 W/m², respectively.

### 4.2 Conventional solar still with integration

ISS is integrated with CSS for increasing the water temperature of CSS. Fig. 6 shows the variation in temperature of the glass, water and basin of a solar still, solar intensity and ambient temperature of ISS-CSS at two different constant water depth, 0.02m, and 0.04m. It can be observed that the variation in temperature of water, basin, and glass is gradually increasing with increase in the solar intensity. The variation in temperature of the water is mainly due to the integration of solar stills. It is also observed that the variation in solar intensity and ambient temperature are within the limit of ±7.7%. The maximum temperature recorded is found to be 56 and 53°C with a maximum solar intensity of 998 and 994 W/m² respectively. Similarly, the variation in the yield and evaporative heat transfer coefficient of integrated solar still is plotted in **Fig. 7**. It is observed that the evaporative heat transfer coefficient is higher in both cases of integration. The maximum evaporative heat transfer
coefficient observed to be 69 and 68.4 W/m²K for 0.02 and 0.04 m water depth, respectively, while the maximum yield is observed to be 1 and 0.97 kg/m².

Table 2 compares the yield of all the solar stills with different water depths (0.02m, 0.04m, and 0.06m). The maximum productivity values obtained for ISS-CSS, CSS, and ISS at 0.02m water depth and flow rate of water at 8.33 kg/hr are 6.2, 4.24, and 5.04 kg/m² respectively. From the experiments, it was observed that the productivity of ISS-CSS produced a higher yield than ISS and CSS. At stand-alone operation, ISS with baffles produced more productivity than CSS.

5. Conclusion

The following conclusions are drawn from the experimental studies.

- Experiments are carried out for three solar still namely, conventional solar still, inclined solar still and inclined solar still integrated with conventional solar still.
- The productivity of solar still is strongly influenced by various parameters such as solar intensity, basin area, depth of water. Also, the productivity of fresh water increases when the depth of water is reduced.
- To preheat the feed water, inclined solar still is used as a solar energy collector thereby the productivity of solar stills are enhanced.
- The maximum productivity obtained from conventional solar still integrated with an inclined solar still is 6.2 kg/m².
- Inclined solar still integrated with conventional solar still produced 46.23% higher productivity than the conventional solar still.
- Inclined solar still produced 18.87% higher productivity than the conventional solar still.

Abbreviations

CSS Conventional Solar Still
ISS Inclined Solar Still
ISS-CSS Inclined Solar Still Integrated With Conventional Solar Still

References


Fig. 1 photograph of an inclined solar still with baffles
Fig. 2 Photographic view of conventional solar still
Fig. 3 Photographic view of an inclined solar still integrated with conventional solar still
Fig. 4 Hourly variation of (a) glass and (b) water temperature of inclined solar still with baffles.
Fig. 5 Hourly variation of evaporative heat transfer coefficient and yield from inclined solar still with baffles (a) summer and (b) winter
Fig. 6 Hourly variation of solar intensity and temperature from conventional solar still with integration
Fig. 7 Variation of evaporative heat transfer coefficient and yield from conventional solar still with integration
Table. 1. Accuracy, range, and errors for measuring instruments

<table>
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<th>Instrument</th>
<th>Accuracy</th>
<th>Range</th>
<th>Error (%)</th>
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<td>Thermocouple</td>
<td>±1°C</td>
<td>0-100°C</td>
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<tr>
<td>Solar power meter</td>
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<td>0-2500 W/m²</td>
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<tr>
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<td>0-45 m/s</td>
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<tr>
<td>Beaker</td>
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Table. 2 Variation in yield from different solar still

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of solar still</th>
<th>Depth of water/ Flow rate of water</th>
<th>Yield (kg/m²)</th>
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<td>CSS</td>
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<td></td>
<td></td>
<td>0.04 m</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.06 m</td>
<td>2.8</td>
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<td>2</td>
<td>ISS</td>
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<td>5.04</td>
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<td>3</td>
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<td>6.2</td>
</tr>
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<td></td>
<td></td>
<td>0.04 m</td>
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<td></td>
<td></td>
<td>0.06 m</td>
<td>3.98</td>
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