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Productivity Augmentation of a Solar Still with Rectangular Fins and Bamboo Cotton Wick

Mohit Bhargva[a*], Mohit Sharma[b], Avadhesh Yadav[c], Neel Kamal Batra[d], R.K. Behl[e]

[a*,b,d]*Department of Mechanical Engineering, Maharishi Markandeshwar (Deemed to be University), Mullana, India*
[c]*Department of Mechanical Engineering, National Institute of Technology Kurukshetra, India*
[e]*Department of Agriculture, Maharishi Markandeshwar (Deemed to be University), Mullana, India*

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ABSTRACT

For desalinating seawater and brackish water, a basic and inexpensive device known as a solar still is used. The limited amount of freshwater output that can be obtained from a solar still is its primary flaw, which limits its global use and applicability. The improvement of a solar still's freshwater output is the main goal of this research. Two identical single slope solar stills are created for this purpose, and one of them is changed by adding rectangular aluminium fins and a bamboo cotton wick to the still basin. This modified still is called. The other still that hasn't been altered is known as a standard still. In this experimental study, Kurukshetra, India (29.96°N, 76.87°E) weather conditions are used to evaluate both stills. At varying water depths of 1 cm, 2 cm, and 3 cm, the performance of the modified still and the conventional still are concurrently compared. According to experimentation's findings, 1 cm of water depth is where both stills' daily productivity and optimum water temperature are attained. The daily productivity of the solar still improved by about 19% when bamboo cotton wick was spread over the rectangular fins in the still basin.

1. Introduction

In India, population growth, irrigation agriculture expansion, and industrial growth are the primary causes of the recent sharp drop in groundwater levels. There is a shortage of potable water in many parts of the nation as a result of the overuse of groundwater. The easy accessibility of potable water for the public is ensured by the use of different seawater desalination techniques. For the distillation of seawater and brackish water, a solar still is a straightforward and affordable instrument. Solar energy is mainly used in the form of heat, and photovoltaics [1] [2]. Solar energy is still used in

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[*]Corresponding Author Email:bhargvam@gmail.com

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places with little access to power but plenty of solar energy. Freshwater production from a single slope solar panel ranges from 2-4 L/m^{2}day. The available literature demonstrates that using different solar system modifications still improved freshwater production. In order to improve the effective heat exchange area and still performance, solar still with various absorber configurations is used by Hansen et al. [3]. A solar still's output was increased by combining interior and external reflectors more during the winter than during the summer [4]. Jobrane et al. [5] examined a number of adapted solar still designs that used wick materials. When a wick is used in a still basin, the effective area of evaporation is increased and the rate of heat transmission is improved. Additionally, because of the slow movement of water in a wick, basin water heats up rapidly. Rotating black wick produces the greatest level of thermal efficiency. Steel wool fibers were used to boost the freshwater output by nearly 12% in the still basin [6]. When compared to a standard still basin, the use of corrugated wick absorber plates boosted water output by 132% [7]. The freshwater production was increased by 51.4% thanks to the black jute wick spread over a corrugated absorber plate [8]. Omara et al. [9] improved the output by 90% by using a double layer wick over corrugated absorber in the still basin. With the addition of 35 wick cords that were loosely suspended, mirrors, and a fan, Essa et al. [10] significantly increased the freshwater production of the solar still by 195%. Haddad et al. [11] achieved a 14.72% increase in still production during the summer by experimentally examining a single slope solar still with a vertically rotating wick. The freshwater production rises by about 51% during the winter. Experimental results showed that freshwater production is higher when a vertical wick is rotating anticlockwise than clockwise [12]. Experimental research on the horizontal wick solar still at various belt sliding velocities was conducted by Abdullah et al [13]. The output of freshwater increased by 260% in contrast to the conventional still, according to the results. The effect of utilising various wicks on the still performance was examined [14]. The water coral fleece wick produced the greatest amount of condensate, 4.28 kg/m^2. Experimental results show that using cotton wicks increases still output by 28% when compared to jute wicks [15]. With a fur fabric wick, Karthick Munisamy et al. [16] obtained a productivity of 3.63 L/m^{2}day. Murugavel et al. [17] also investigated how various wicks affected the output of stills. The experimental findings showed that cotton fabric outperformed other wick materials in terms of effectiveness. Sharon et al. [18] used a tilted jute wick in a stepped still and got a still output of 4.99 L/m^2 per day. Mahdi et al. [19] transported saline water in the still using a charcoal wick absorber that was inclined. According to the findings, effectiveness declined as salinity and flow rate rose. Sakthivel et al. [20] used a jute cloth wick fixed to the still's back wall and put in the still basin's centre. The use of jute wick increased output by 20%, according to the results. In two solar stills, the water depth was varied from 1 cm to 5 cm by Elango et al. [21], and the maximum output was achieved at 1 cm of water depth. However, in the case of stills attached to sun collectors, the lower depths result in water boiling, which reduces the still's effectiveness [22]. Experimental testing of a double slope still at different speeds of 2.5 m/s, 3.5 m/s, 5.5 m/s, and 6.9 m/s by Castillo-Téllez et al. [23] revealed that the 3.5 m/s velocity produced the greatest productivity. The majority of the current research focuses on different still design adjustments that can be made to increase freshwater output. To improve the freshwater output from the single slope solar still, various modifications were made, including the use of wick, fins, different absorber configurations, internal and external reflectors, phase change materials, and Nano-fluids in the still basin. Researchers are using various wicks, including cotton, jute, fleece, and fur, to improve the efficiency of solar stills. The primary goal of the proposed work is to increase the solar still output by covering the rectangular fins in the still basin with bamboo cotton wick. Application of bamboo cotton wick in solar still for increased productivity is not mentioned in the available books. Bamboo cotton has excellent permeability, absorbency, and capillary rise, which enable it to rapidly absorb and expel moisture. As a result, the rate of basin water uptake and evaporation is increased. To determine its value and applicability, the present study conducts an experimental investigation of the use of a bamboo cotton wick over rectangular fins in a still basin.

2. Materials and Methods

The National Institute of Technology in Kurukshetra, India, created and installed two identical single slope solar stills. Figure 1 depicts the basic layout of the experimental design. Both stills' basins are constructed from 2 mm thick galvanized iron sheet and given a matte black color. Both still basins' combined effective surface measures 0.36 m^2. Both stills have a hardwood ply board exterior body covers. Insulation made of 40mm thick glass wool fills the space between the still basin and the wooden exterior body. The side walls, front wall, and bottom absorber plate of the still bowl are all insulated. At the top of the still basin is fixed the 40 mm thick inclined clear glass cover. The glass is 30 degrees off the horizontal. Silicone gel is used to cover the space between the transparent glass's edges and the still basin. The elimination of vapor leakage from the basin and the firm fixing of glass as the upper cover of the still basin were both achieved. Bamboo cotton wick is used to cover a still bowl with rectangular-shaped aluminium fins. Figures 2 and 3 provide a schematic diagram of a solar panel's rectangular fins as well as their measurements. As seen in figure 3. (a), the bamboo cotton wick is placed over rectangular fins in the still bowl.

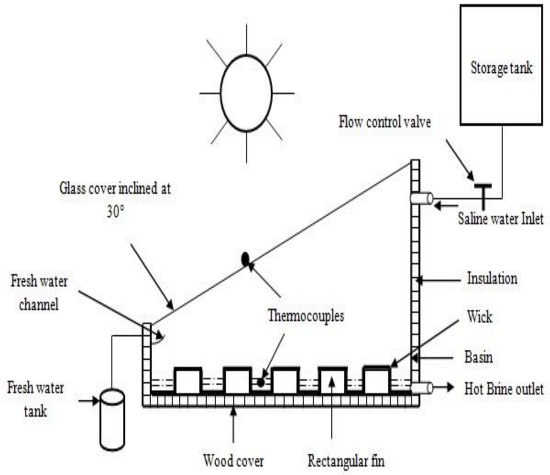

Figure 1. Schematic diagram of experimental set-up

To speed up the rate of heat absorption and heat dissipation from the candle, the bamboo cotton wick has been dyed a dark shade of black. Installation of PT-100 thermocouples allows for the measurement of temperature at various places. A thermocouple is fixed on it to detect the temperature of the outer glass cover. The rear wall of the still has two openings for seawater inlet. The outlet located at the foot of the side wall is used to collect the hot brine. Seawater is supplied to the still basin through a holding tank. The basin's water level is maintained at the intended level using a flow control valve. Figure 4.a) shows the photograph of experimental set-up and Figure 4.b) shows the photograph of distilled water and brackish water.

The tests are carried out in January 2022 and February 2022 during the days with the most sunshine possible. The trial data is gathered between the hours of 0900 and 1700 each day. The experimental data are gathered hourly from 9AM to 5PM and include solar energy, freshwater production, basin water temperature, outer glass surface temperature, and ambient temperature.

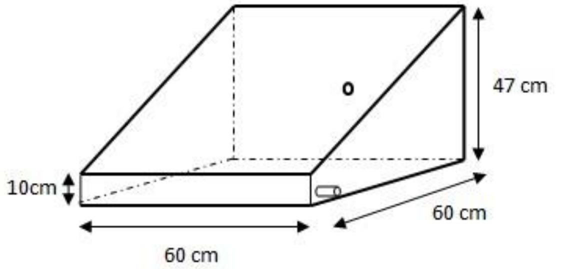

Figure 2. Schematic diagram of solar still

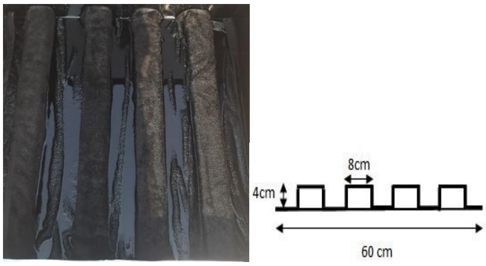

Figure 3. a) Photograph of bamboo cotton wick covered rectangular fins in the still basin; b) rectangular fin dimensions

Figure 4.a) Photograph of modified still and conventional still; b) photograph of freshwater and brackish feed water

A digital temperature indicator is connected to the PT-100 thermocouples to show measured temperature values at particular locations. A weather monitor is used to gauge the solar intensity and ambient temperature, and the results are stored in a data logger. The experimental setup is placed right next to the weather monitor. Figure 5 depicts a picture of a weather station. A cylindrical flask with a 1 L capacity is used to quantify the fresh water productivity. The table 1 provides a summary of the equipment's accuracy and percentage error during the trial. Errors in the findings of the current experiment are calculated using the methods described in Barford [24]. 3.6% is the estimated error in daily output measurement. The respective range of the instruments used for the measurement of different parameters is selected on the basis of solar still application [25].

Figure 5. Photograph of weather station

3. Results and Discussion

At three different water depths—3 cm, 2 cm, and 1 cm—the experiments are run concurrently on modified still and conventional still. The experiments are carried out in January and February 2022 during the cold. In this research, the experimental data collected on the 30 January 2022, 8 February 2022, and 18 February 2022 full sunshine days are presented. The graphical representation of the experimental data is done by using Origin software. The hourly variation of wind speed on each of the three trial days is depicted in Figure 6. On all testing days, it has been noted that the hourly wind speed values have virtually remained constant. The hourly solar intensity and ambient temperature readings for January 30, 2022 are shown in Figure 7.

Table 1. Accuracy, range and percentage errors of measuring instruments

Instrument	Accuracy	Range	Error (%)
Weather station	± 0.1 W/m^2	0-5000 W/m^2	1.5
Thermocouple	± 0.1 ˚C	0-200 ˚C	0.75
Measuring flask	± 1 ml	0-1000 ml	1

The transparent glass exterior surface and basin water of both solar stills are depicted in the above figure along with their hourly temperature values at a 3 cm water depth. The graph shows that solar energy rises in the morning, reaches its peak between noon and one o'clock, and then falls off. The highest basin water temperature in a modified still (MS) is 59.5°C, compared to 56.6°C in a conventional still (CS), as shown in figure 7. When compared to a conventional still, the existence of wick in a still basin lowers the active depth of water and raises the temperature of the water in MS. On January 30, 2022, ambient temps were recorded in the range of 11.9°C and 22.2°C. After the hours of greatest solar intensity, around 2 PM, the MS and CS basin water temperatures are observed to be at their highest. On 08-02-2022 at a depth of 2 cm, Figure 8 illustrates the temporal variation of radiation intensity, basin water temperature, and ambient temperature.

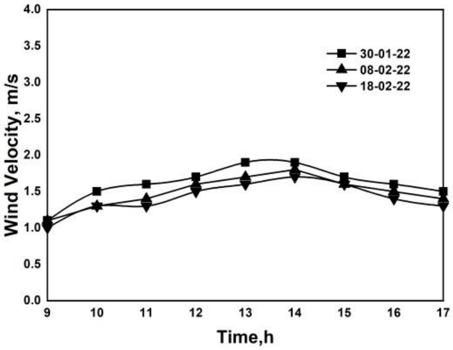

Figure 6. Hourly variation of wind speed on all testing days

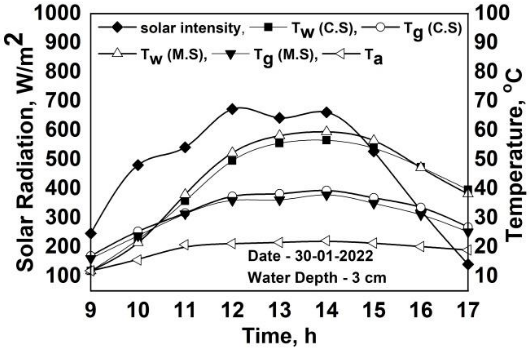

Figure 7. Hourly variation of all parameters at 3cm water depth

On February 18, 2022, at a depth of 1 cm, Figure 8 depicts the time variation of radiation intensity, basin water temperature, and ambient temperature. The MS and CS both record maximum water temperatures of 65°C and 61.7°C, respectively. Due to a faster heat exchange rate at shallower water depths, the optimum water temperature in both MS and CS is reached at 1 PM at a depth of 1 cm.

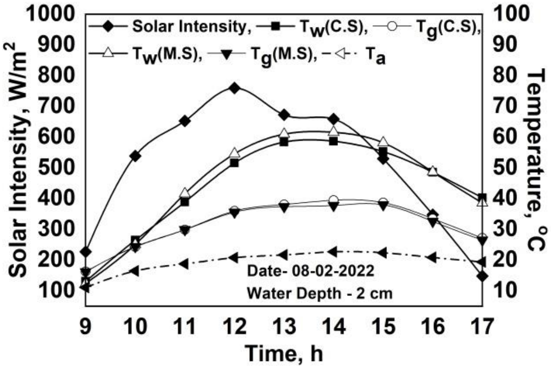

Figure 8. Hourly variation of all parameters at 2cm water depth

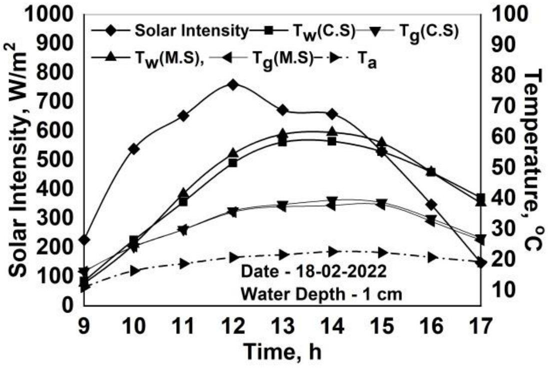

Figure 9. Hourly variation of all parameters at 1cm water depth

The hourly variation of the sun's intensity, the surrounding temperature, the water temperature in the basin, and the temperature of the transparent glass at a depth of 1 cm are all shown in Figure 9. In the MS and CS basins, the maximum water temperatures were 61.6°C and 58.7°C, respectively, at 2PM. Figure 10 displays the hourly freshwater production from MS and CS at all ocean depths. Both stills produce more freshwater as the water level gets shallower. This is because less water evaporates rapidly at lower water depths, which increases evaporation rate. The MS at 1 cm of water depth at 2 PM achieves the highest hourly freshwater productivity of 179 ml. Additionally, it has been found that at all water depths, MS has a greater hourly productivity than CS. This is as a result of the rectangular fins and bamboo cotton wick increasing the exposed heat transmission area. Additionally, the bamboo cotton wick's slow movement of water accelerates evaporation and increases freshwater production. The total productivity variation of both stills at all water depths is shown in Figure 11. The MS at 1 cm water depth yields the greatest cumulative productivity of 859 ml (2.43 L/m^{2}d). The daily productivity of the still increases by 22% when bamboo cotton wick is used over rectangular fins in contrast to a CS.

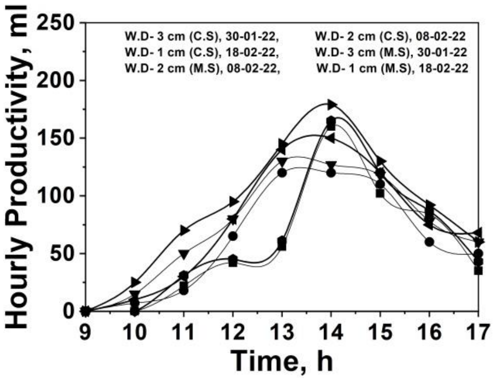

Figure 10. Hourly freshwater output for both stills

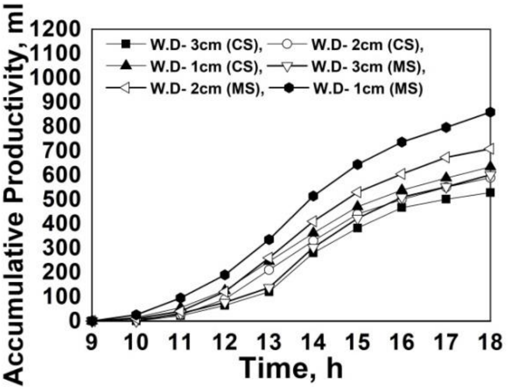

Figure 11. Accumulated freshwater output for both stills

The daily efficiency (η_d) is represented by the following formulae:

$$\eta_d = \sum m_a h_{fg} / \sum I_t A_b \qquad (1)$$

The maximum daily efficiency of both stills is obtained at a water depth of 1cm. The calculations for maximum daily efficiency show the values of 35.2% and 31.5% for the MS and CS respectively.

4. Validation

Several research studies pertaining to solar still and its productivity enhancement have been performed in the past few decades. The freshwater output in the range of 3.2 l/m^2-4.8 l/m^2 is obtained when pin fins covered with wick were used in the still basin [26]. A maximum freshwater output of 4.5 l/m^2 per day was obtained when square fins were used in still basin [27]. Annual experimental performance of solar still with fins in still basin showed maximum and minimum freshwater output of 6.8 l/m^2 per day and 2.3 l/m^2 per day in the months of April and December respectively [28].

5. Limitations and future scope of the study

The main limitation of the present study is the low freshwater output obtained from the still. But, if multiple numbers of solar stills are operated simultaneously then the freshwater output could be increased rapidly. Some of the future scope of the present study is as follows:

1. The solar still can be integrated with solar concentrators to enhance the evaporation rate of basin water.
2. The phase change materials and sensible heat storage materials can be used to enable the freshwater output at night time.
3. The use of nanoparticles in the still basin can increase the heat transfer rate of the basin water.
4. The application of external condenser can increase the condensation rate of vapours in still basin.

6. Conclusions

The purpose of the current research is to increase freshwater productivity by modifying a single slope solar still with rectangular fins and bamboo cotton wick. At 3 cm, 2 cm, and 1 centimetre of water depth, the performance of MS and CS are contrasted. Bamboo cotton wick contributed to the improvement of freshwater output and thermal efficiency of the single slope solar still because of its excellent moisture absorption and fast drying properties. Following are a few conclusions drawn from the current study:

1. The exposed heat transfer area and basin water evaporation rate were boosted by the use of rectangular aluminium fins.
2. In the instance of MS and CS, the highest basin water temperatures are attained at 2:00 PM at depths of 3 cm and 2 cm, and at 1:00 PM at 1 cm.
3. For the MS, a water depth of 1 cm results in a maximal water temperature of 65 °C.
4. In the instance of MS at a 1 cm water depth, the maximum daily freshwater output and thermal efficiency of 2.43 l/m2day and 35.2% are attained.
5. When compared to CS, MS has an overall productivity and thermal efficiency that are greater by 19% and 3.5%, respectively.

Nomenclature

A_b	Area of still basin (m^2)
I_t	Solar intensity at given time interval (s)
h_{fg}	Latent heat (J/Kg)
m_a	Amount of freshwater produced (ml)
η_d	Daily efficiency (%)

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