

Research Article

Experimental Investigation on the Effectiveness of Solar Still and Its Effect on Adsorption with Various Dyes

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The typical solar still with internal and exterior heat transfer was used to test the impact of mixing various colours into the basin water. This is well-known that enhancing distillation involves adding black dye to basin water. Identical design parameters create two single-slope basin-type solar stills (effective area 0.5 m²). This study conducted experiments to add black, green, blue, and red dyes to basin water during the winter for 24 hours. For more than a month, the amount of distilled water recovered per hour, with varying temperatures and solar activity (May 2021). This research aims to (i) examine the effect of various dyes with basin water on the internal and external heat transfer and performance of the system and (ii) study the effect of adding dyes into the basin water on increasing energy balance by the solar system. This is indicated by the fact that the introduction of colours into the basin water has a major impact on external and interior heat transfer. The evaporation, radiation, and heat transfer rate from liquid to glass significantly impact how well the filtration system works.

1. Introduction

When water is contaminated or mineralized, consuming water is filtered using techniques such as reverse osmosis or filtration [1]. Water extraction requires more energy, and solar energy is well developed and used everywhere [2]. Due to their low cost and lack of technical maintenance expertise, solar panels are especially suitable for underdeveloped countries and isolated rural areas [3]. Regular repairs and follow-ups are cheap, and the necessary electricity is available on site for free [4]. Water can be solar-filtered using various techniques and equipment, such as basin-style solar stills, wicks, or saltwater [5, 6]. In general, the most widely used approach is basin-type solar stills, which vary in their design, structure [7], shape [8], and production

materials [9]. On a bright, sunny day in a region with significant solar heat, these stills can produce up to 6 litres of filtered water per square metre [10].

The performance of sunken and polished nickel sun using kinetic, structural, and meteorological factors has been studied by many researchers. [11]. The primary goal is to increase the effectiveness of solar stills [12]. The black bed liner of this form of solar still collects most of the sun's radiation, some of which are conveyed into salt water, while the rest is transferred from the base of the solar still to the atmosphere [13]. The direct heating of saline water will result in higher output and a smaller loss due to the increased saline water temperature. As a result, dye development in saltwater has two benefits, resulting in a high static output H.P [14].

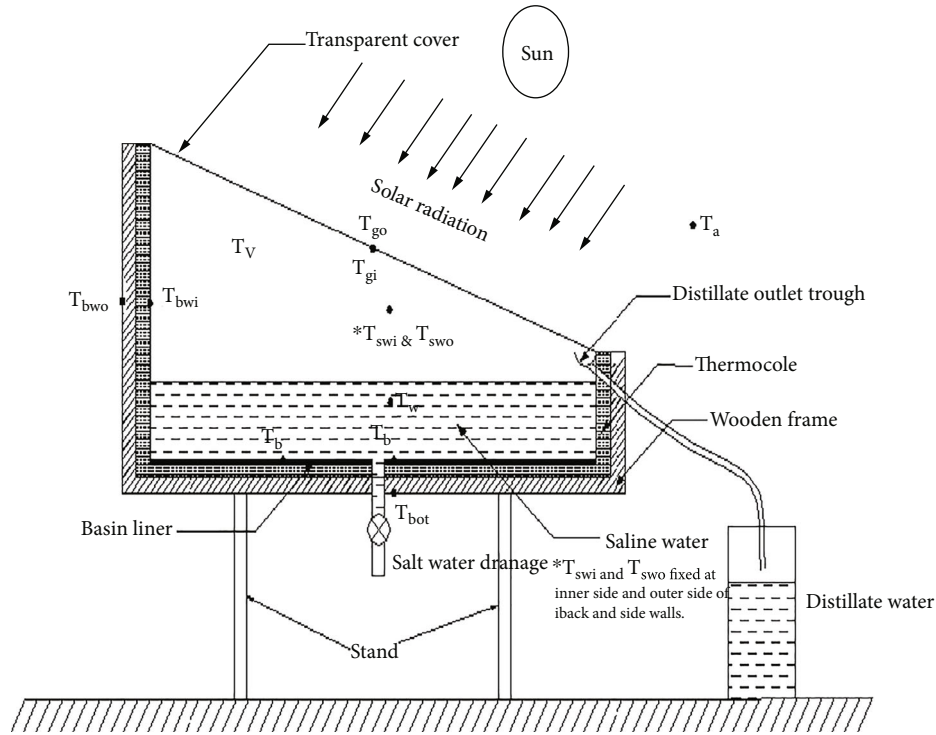


FIGURE 1: Experimental setup.



FIGURE 2: Pictorial view of experimental setup.

Sakthivel et al.'s experiments on various thicknesses of cotton fabric revealed an increase in energy and agility of 23.8% and 2.6%, respectively, over a thickness of 6 mm [15]. Garg and H.S. Deer [16] and M. S. Soda et al. [17] introducing dye into the basin water greatly increases the filtration output. Sakthivel et al. [18] suggested that 6 mm thick cotton cloth improved productivity by 28% compared to conventional solar still. Anil K Rajvanshi [19] reported that the black naphthylamine dye is the most suitable dye among all other dyes. However, Arjunan et al. [20], including vertical basins in traditional stills, enhance the efficiency of single-slope solar stills.

Shahid et al. [21] with the rapid expansion of industrial civilization came energy needs of 1.3% per year.

TABLE 1: Geometrics of the solar still.

Parameters	Dimension
Basin	0.5 m ²
Lass area	0.508 m ²
Thickness of glass	4 mm
Number of glasses	1
Slope of glass	10°

Hasanuzzaman et al. [22] reported that chemical dyes like thymol blue and orange methyl improved the still performance by about 53% and 44%, respectively. Alfred Blaszczyk et al. [23] in the study of the sustainable growth of cells dyed by black chokeberry, bomas, and leaves, cells dyed with synthetic N719 sensitivity were found to perform better with surface dyes. The literature review noted that the previous studies were focused on the effect of dyes on the distillate output. However, the role of different elements of both heat transfer coefficients on thermal performance was not explored earlier. A novel of this research work aims to investigate the impact of different dyes on internal and external heat transfer properties to identify areas for improvement.

2. Experimental Setup

In India, at the Savita School of Engineering Mechanical Engineering in Chennai and Tamil Nadu, two direct basin-type solar stills were developed and put into practice using identical design requirements. The galvanized iron

TABLE 2: Experimental uncertainty errors.

Instrument	Make and country	Model	Specification	Accuracy	Range
Thermocouple wires	—	—	K type thermocouples	$\pm 0.2^{\circ}\text{C}$	0 – 180°C
Anemometer	Kusam-meco India	KM-909	Cup type	$\pm 0.1 \text{ ms}^{-1}$	0-30 m.s^{-1}
Solarimeter	TES Instrument Taiwan	TES – 1333	Calss –A	$\pm 5 \text{ W.m}^{-2}$	0 – 2000 W.m^{-2}
Measuring jar	—	—	—	$\pm 5 \text{ ml}$	1-10 litres

sheet was 1.4 mm thick, 28 mm high, and $0.5 \times 1 \text{ m}^2$ in the area used to make a basin liner. When it hits the floor of a black-painted basin, it completely absorbs sunlight [21]. The compression surface of the stills is made of crystal with variable depth and 10^0 vertical inclinations. The following specifications are required for glass cover: (a) level of absorption heat, (b) solar energy radiation at minimum reflections, (c) transmittance at higher solar radiation, and (d) environmental heat loss by the effect of basins. Wood and silicone rubber are used to cover the glass covers. Silicone rubber is essential for improving performance because it allows for the shrinkage and relaxation of various materials. Pure water was stagnant inside the glass covers, G.I. Sheet, and the compress was then transferred to a receiving flask. A steel rule was fitted to the inner wall to monitor the water level. The side walls and bottom are insulated with a thermistor with a thickness of 25 mm and a wood with a thickness of 12.5 mm, with thermal conductivity of 0.055 W/mK and 0.015 W/mK , respectively. Figure 1 depicts the mathematical constructions of solar stills, and Figure 2 provides a visual perspective of solar stills.

The technical specifications of the system are also given in Table 1.

The glass face of the solar system is on the north side, and the solar panel runs from east to west with its elongated plane. Throughout the test every 1 hour, the amount of solar radiation, atmospheric temperature, inner surface temperature, water temperature, basin liner temperature, outer wall and lower adjacent temperature, and speed stayed distinguished. Fresh water production was gathered hourly using a calibrated flask. The daily production was calculated by adding the day and night output. The performance was evaluated separately on the day of start-up and the following day.

Type K 12 thermocouples are integrated with a digital thermometer system to monitor the temperature of the still system in different locations. During the experiment, different measurement systems were used: the solarimeter was used to calibrate the solar radiation intensity in (kW/m^2). The wind speed was calculated by a digital anemometer and steel rule fixed default to indicate the water level. Table 2 lists the device’s manufacturer, model, specifications, and error values.

3. Results and Discussions

The graphical illustrations and tables show the desalination system’s efficiency and effectiveness. Experiments were

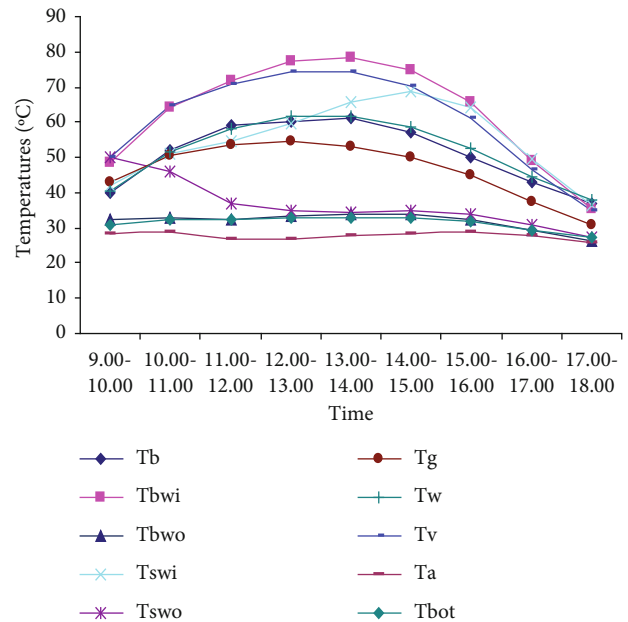


FIGURE 3: Hourly variations of various components.

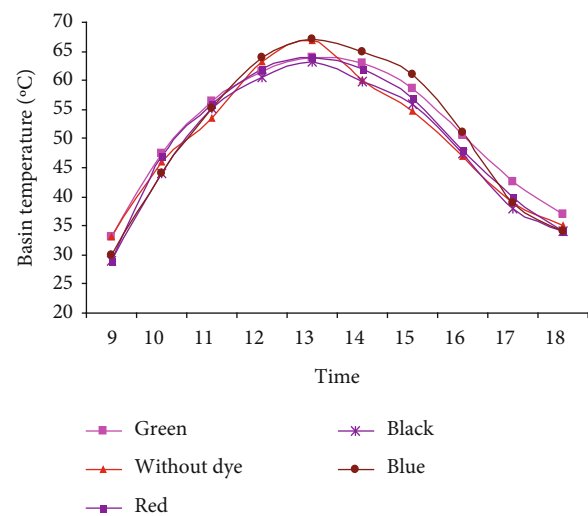


FIGURE 4: Adsorption test for basin liner temperature without dye temperature with various dyes.

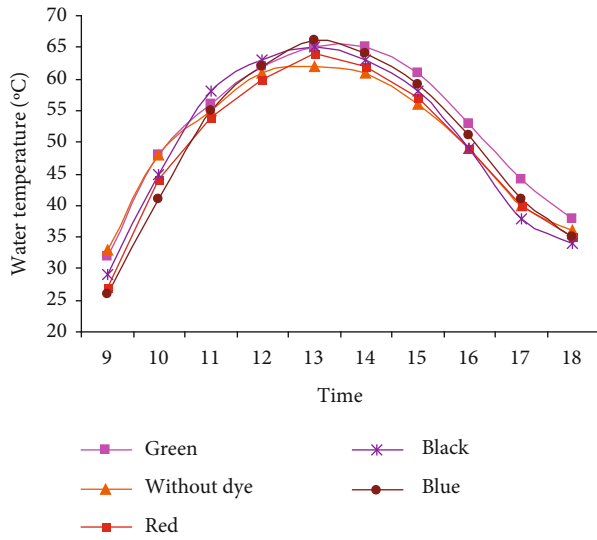


FIGURE 5: Adsorption test of water with various temperatures.

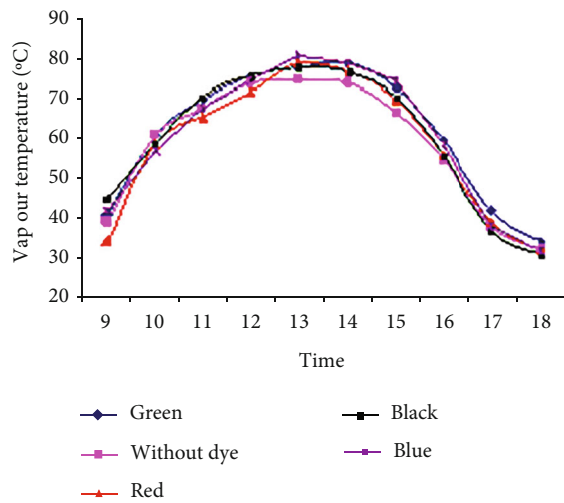


FIGURE 6: Hourly variations of vapour dye colours.

performed every day from 9:00 to 18:00. Various factors were frequently considered during the examinations, including basin water temperature, periodic glass enclosure, interior walls (back and side walls), and lower side wall. The solar insolation in hourly variation, wind speed, atmospheric temperature, and relative humidity for the conventional solar distillation was noticed that the solar insolation increases from about 200 W/m^2 (morning 9.00 hrs) to 950 W/m^2 for 13.00 hrs. Also, when solar insolation is 17.00 hours, it decreases from 950 W/m^2 to 200 W/m^2 . It was observed that the ambient temperature ranged between 30°C and about 41°C during the experimental observations, the atmospheric wind velocity varied from 1 m/s to 4.2 m/s , and the relative humidity was found to be more than 75% throughout the year. Experimental tests were conducted for several days under these conditions. Comparison of results can be reasonably conducted under the same environmental conditions to obtain comparable results.

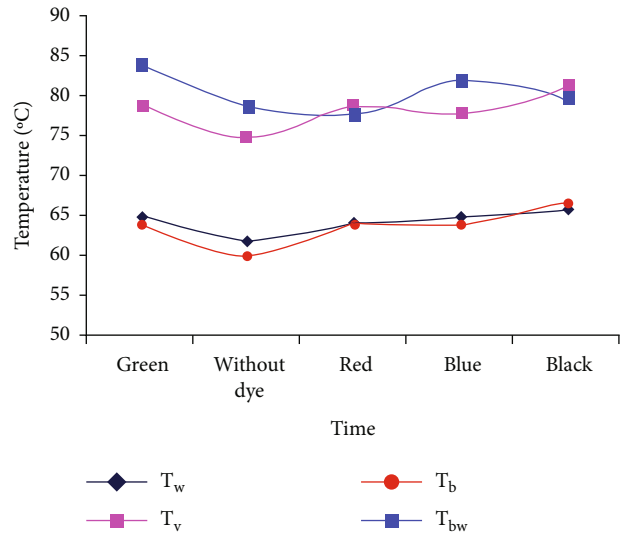


FIGURE 7: Maximum temperature with different component variations.

Figure 3 illustrates the hourly fluctuations of solar stills, glass, steam, and basin temperature with 10 mm of water but without adding dye. The various component's temperatures can rise steadily until they reach their highest value at noon.

Figure 3 compares the daily fluctuations of the sun's liquid, glass, condenser, and basin temperature with 10 mm of water without adding dye. As can be seen, the temperature of many elements rises steadily until they reach their higher value at noon. It should not lose more energy than the sun has. The steam condenses on the glass because its temperature is significantly lower than the steams. The still's back wall will start reaching the maximum temperature from 11:00 am onwards. During this time (9:00 am to 10:00 am), the glass absorbs more energy and the performance is worse as the glass temperature is higher than the steam temperature. Also observed was the collected water applied with various dyes, as shown in Figure 3.

Due to the constant contact between the two forming the heat balance, the basin temperature approaches the water temperature in almost all cases (except black dye).

Figures 4 and 5 give the adsorption test results for basin liner temperature and water temperature of various dyes, respectively. Figure 4 shows the adsorption test of basin liner temperature; it can be understood that the temperature of the basin liner with the black dye added water was lower than other watercolours. This may be why the lack of radiation transmissivity through the black-coloured water. The water temperature of various coloured water was analyzed, and the results are in Figure 5. In the early morning, it became clear that the temperature of the black water was higher than the other colours. However, at noon, the green-coloured water temperature was higher than the other coloured waters.

We find that the temperature of the basin water is generally higher than the temperature of the basin liner for the black liquid. The presence of black dye in the water will

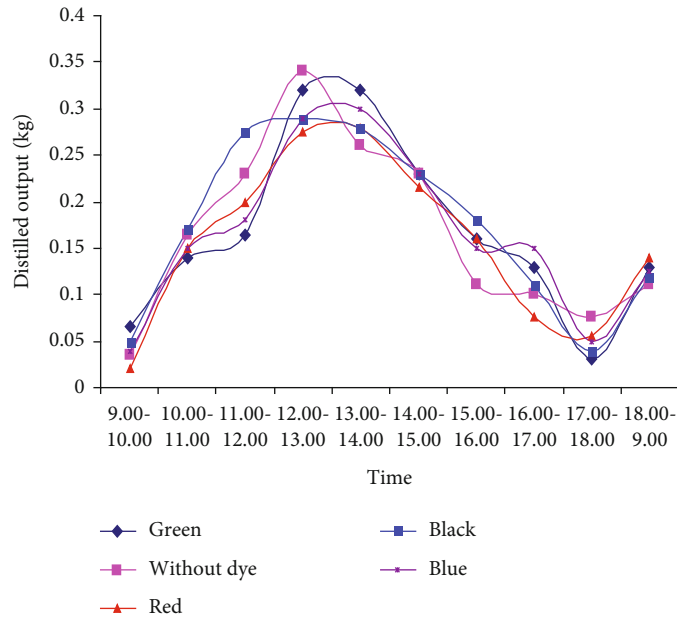


FIGURE 8: Distilled output by hourly basis variations.

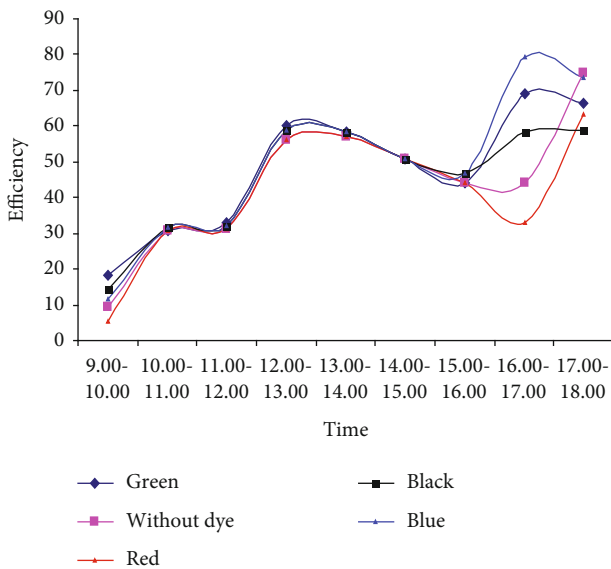


FIGURE 9: Hourly variations efficiency.

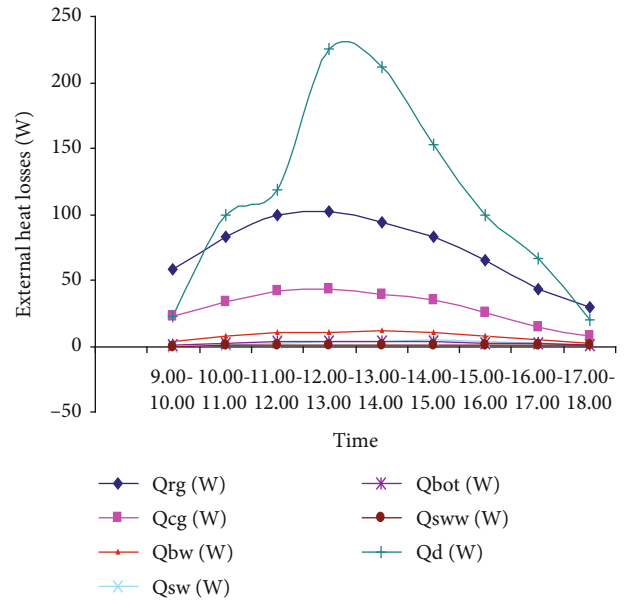


FIGURE 10: Hourly variations of individual external heat transfer without dye.

absorb more energy than the colourless water; this may cause the water temperature to be higher than the basin liner. It is understood that during the maximum period, the vapour temperature of black-coloured water is higher than that other coloured waters. However, in colourless water, the vapour temperature is recorded as low. Increased basin water temperature may lead to an increase in vapour temperature (this may be illustrated in Figure 3). Figure 6 illustrates the hourly variations of vapour temperature.

Using various coloured water, Figure 7 displays the highest water temperature, capacitance, container liner, and inner wall. All cases have high and constant interior wall temperatures. In water bodies, the maximum temperature

of the wall thickness surface is reached at 84°C. The vapour and basin liner temperatures may depend on water temperature; hence, these temperatures will vary with water temperature.

The observation indicates that the maximum 79°C and minimum 75°C vapour temperature is highlighted in green-coloured and colourless water (without dye). The observation also shows that the higher and lower water temperature verified in black-coloured and colourless water was 66°C and 62°C, respectively.

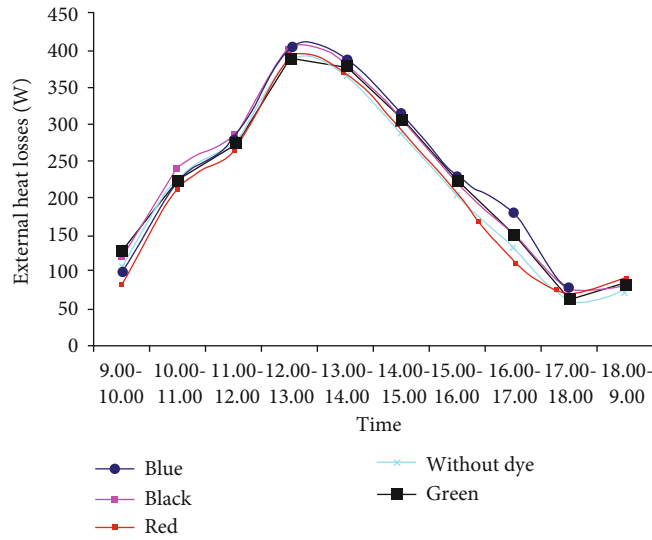


FIGURE 11: Hourly variations of total external heat loss.

From morning to evening, the production rate increases. Daily variations in the efficiency of sunlight are shown in Figure 8. It indicates that in the morning, from 9:00 am to 12:00 noon, the black dye mixed with water gives more yield than the others. During this period, the black-coloured water temperature was also higher than the other coloured water temperatures; due to these property changes, the absorptivity of solar radiation was considerably high. Between 12:00 noon and 1:00 pm, colourless water gives more yield than the others because of its maximum radiation transmissivity through the water. So, its yield increases with basin liner as well as water temperature. In the late afternoon, green- and blue-coloured waters yield more than the others. Also, from Figure 8, it is understood that between 18:00 and 9:00 o'clock (next day), the efficiency is high in the red-coloured water and low in black-coloured and colourless waters. The experimental result shows the extreme productivity of 1.745 kg (3.49 kg/m²-day) for 24 hours (09:00–09:00 the next day) was obtained from black-coloured water.

Evaluating solar still performance is thought to become the most crucial step in ensuring the greatest static efficiency. According to Figure 9, black water is more efficient than some between 10:00 and 14:00. It is also clear that between two hours between 15:00 and 18:00, almost all the coloured waters enjoy a brief performance.

It may be why the ambient temperature is less (winter). This causes the glass surface to abruptly cool, enhancing the temperature change between the aqueous and glass and causing more absorption. The maximum efficiency obtained in the black-coloured water is 49.36% among all other coloured and colourless waters. It is 10% higher than the colourless water and 19% higher than the red-coloured water.

Figure 10 shows the hourly variation of various external heat transfers involving the solar still for a 10 mm water level without dye. From 9:00 to 13:00, the convection and radia-

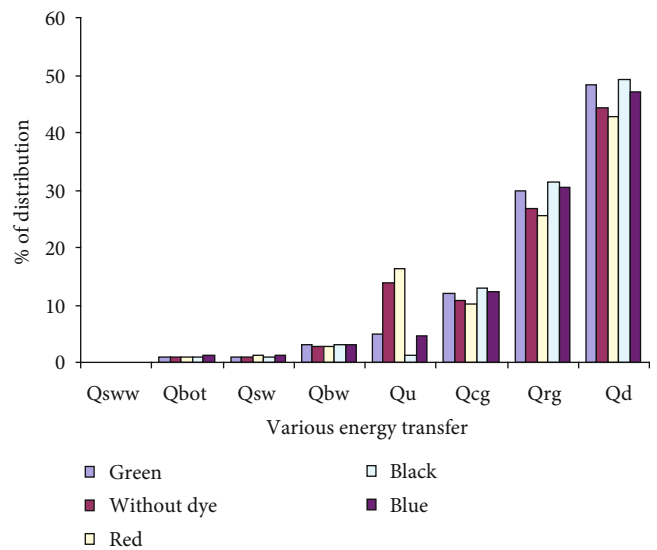


FIGURE 12: Percentage of energy heat losses distribution for various components.

tion heat losses from the windows to the environment are high, and then they decrease in the early morning. Due to high solar intensity and more condensation, the temperature of the glass increases during this period; this will lead to the temperature gradient between glass and ambient; this may be the reason for increasing the temperature transition from glass to the atmosphere. In the morning, the outer wall surface temperatures are higher than the inner wall surfaces. Due to this temperature difference, the heat enters from outer to inner surfaces through the wall materials in the morning. This heat transfer introduces negative values in Figure 10 between 9:00 and 11:00 o'clock. The results show

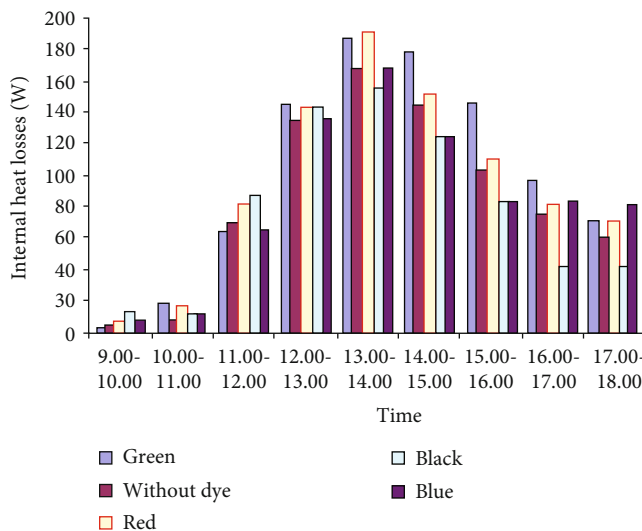


FIGURE 13: Hourly variations of total internal heat losses.

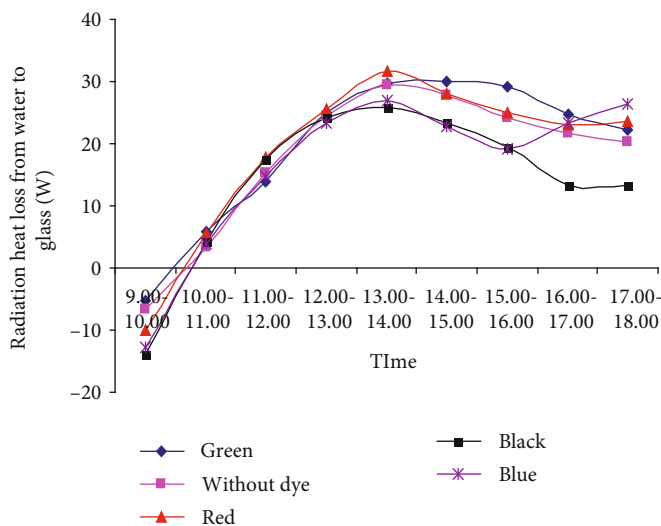


FIGURE 14: Hourly variations of water to a glass of heat loss radiation.

that for the entire day, only 2.48 W of heat transfer through the water contact surface to the atmosphere occurred. Compared to other losses, it is significantly smaller. The higher energy usage was obtained 1155.04 W for converting fresh water.

Figure 11 shows hourly variations of total external heat losses for different coloured waters. It indicates that the external heat losses are more in black-coloured water from 9:00 am to 1:00 pm than in others, and furthermore, it decreases gradually in the evening hours. The blue-coloured water experiences more external heat losses and its value was 2274.88 W throughout the day, whereas in the red-coloured water, the losses are less and are equal to 2102.57 W.

It is clear from the table that, around 9:00 am, the convection and radiation heat transfer from glass to the envi-

ronment are greater (almost 50%). - 1:00 pm in black-coloured water, due to the high temperature of the glass, vapour, and water. Considering Figure 8, it is clear that the external losses will also influence the distillate output.

Figure 12 indicates the percentage of the energy distribution of various energy transfers for different coloured water. In addition to any energy transfer, consumption and energy balance are not calculated for losses due to steam leakage from valves, connections, energy stored in water, etc. All the energy transfers from the still are very close value for all coloured water, except unaccountable losses. Unaccountable losses are more in the red-coloured and colourless waters; this may be why its lower productivity.

Internal heat transfer is another important factor in influencing solar productivity.

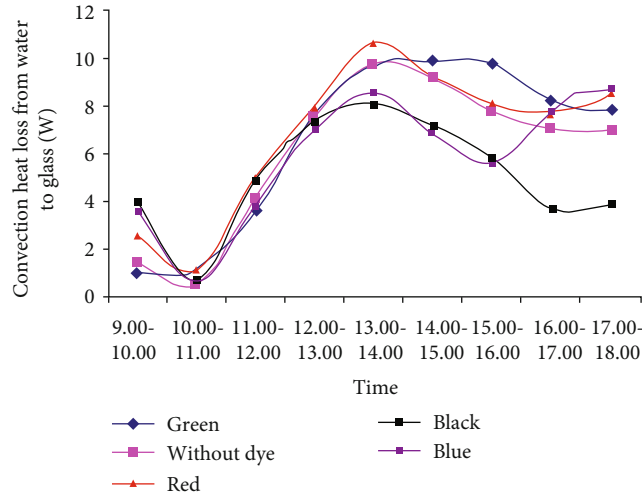


FIGURE 15: Hourly water to the glass variations of convection.

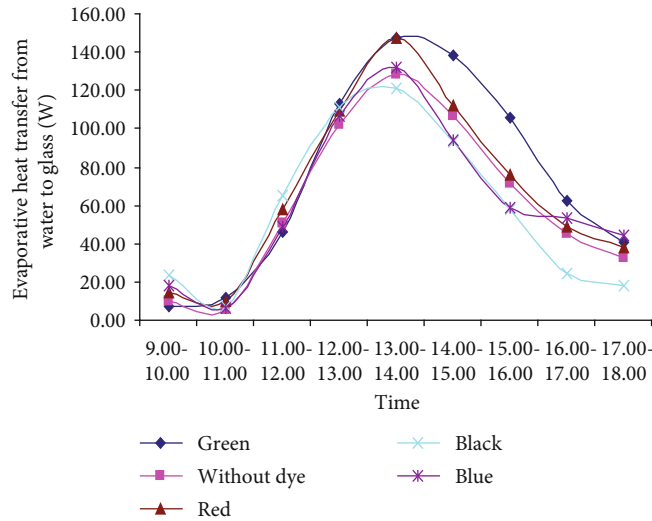


FIGURE 16: Evaporative heat loss from water to glass Hourly variations.

The following governing equations of internal heat transfer are water to glass radiation heat loss (Q_{rw})

$$Q_{rw} = \varepsilon_{\text{eff}} \sigma A_w (T_w^4 - T_g^4), \quad (1)$$

water to glass convective heat loss (Q_{cw})

$$Q_{cw} = h_{cw} A_w (T_w - T_g), \quad (2)$$

water to glass evaporative heat loss (Q_{ew})

$$Q_{ew} = h_{ew} A_w (T_w - T_g). \quad (3)$$

Figure 13 shows the hourly variations of internal heat transfer for different coloured water. We can see from the

picture. The output of 8 and 13 is inversely related to the internal heat transfer. In the early process on morning (9:00 o'clock-11:00 o'clock), internal heat transfer is very less; this may be the reason for decreasing productivity during that period. Similarly, the productivity is also high if internal heat transfer is high.

Figures 14–16 depict the hourly variations in heat exchange through the liquid to glass via irradiation, convection, and absorption for various water colours. Figure 14 indicates that the radiative heat transfer is negative from 9:00 am to 11:00 am. Figures 15 and 16 demonstrate that radiative and evaporation heat transport decreases from 9:00 am to 11:00 am. After 11:00 am, these heat transfers gradually increase to the maximum value in the afternoon (13:00–14:00 pm) and then decrease in the late afternoon. Figure 17 shows the hourly variations of convection transfer

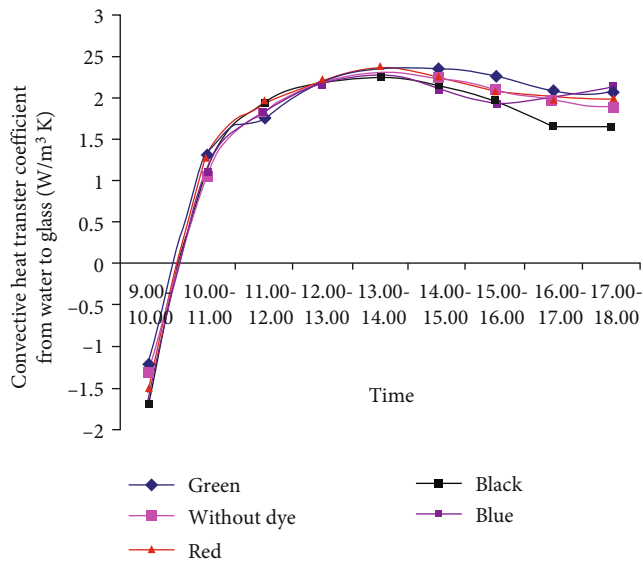


FIGURE 17: Hourly variations of convection transfer coefficient from water to glass.

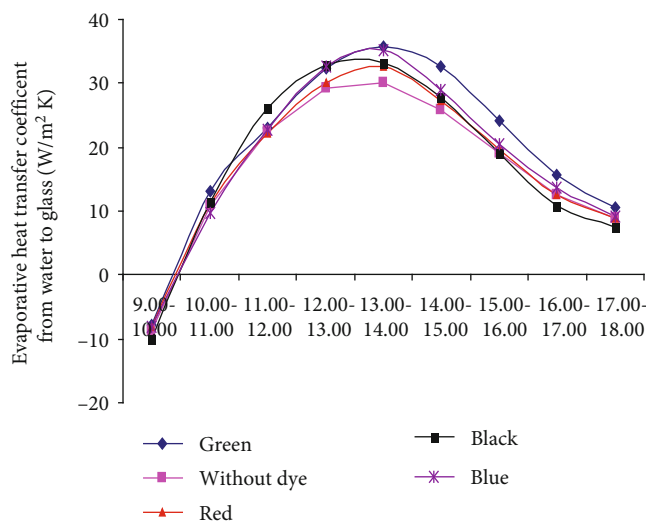


FIGURE 18: Water to glass evaporative heat transfer coefficient hourly changes.

coefficient from water to glass. Figure 18 exposes the water to glass evaporative heat transfer coefficient hourly changes. At this point, all of this indicates that the ambient temperature of the glass is higher than the water temperature; it may result in heat flowing from glass to the water through convection and radiation. This may be one of the reasons for lower productivity during this period.

4. Conclusion

The following findings result from a thorough experimental investigation into how different dyes affected the local and global heat transfer coefficients in basic solar still.

- (i) The black water in the basin liner has a lower temperature than other colours (green, blue, red, and colourless water). In the early morning, black water has a higher temperature than other coloured water
- (ii) The black-coloured water gives more yield than the others from 9:00 am to 12:00 noon; between 12:00 noon and 1:00 pm, the colourless water gives more yield than the others do; in the late afternoon, green- and blue-coloured waters give more yield than the others do. Between 6:00 pm and 9:00 am (next day), the productivity was high in the red-coloured water and low in black-coloured and colourless waters
- (iii) The maximum productivity of 1.745 kg (3.49 kg/m²-day) for 24 hours (9:00 o'clock – 09:00 o'clock) was obtained from black-coloured water
- (iv) The maximum efficiency obtained in the black-coloured water is 49.36% among all other coloured and colourless waters. It is 10% higher than the colourless water and 19% higher than the red-coloured water
- (v) The maximum energy utilization is 1155.04 W for transforming fresh water from salient water. The minimum amount of energy losses from the water contact surface to the ambient environment equal to 2.48 W
- (vi) The external heat losses are more in black-coloured water from 9:00 am to 1:00 pm than in others, and it decreases gradually in the evening hours. The blue-coloured water experiences more external heat losses and its value is 2274.88 W throughout the day, whereas in the red-coloured water, losses are less and are equal to 2102.57 W
- (vii) Internal heat transfer is another important factor in influencing solar productivity. When internal heat transfer is low, productivity is also low
- (viii) Heat enters from glass to the water through convection and radiation from 9:00 am to 11:00 am due to the higher glass temperature than the water temperature, leading to lower productivity

Nomenclature

- A_w : Area of basin water (m²)
- h_{cw} : Convective heat transfer coefficients from water to glass (W/m²K)
- h_{ew} : Evaporative heat transfer coefficients from water to glass (W/m²K)
- σ : Stefan Boltzman constant (W/m²K⁴)
- Q_{cw} : Convection heat transfer from water to glass (W)
- Q_{ew} : Evaporative heat transfer from water to glass (W)
- Q_{rw} : Radiation heat transfer from water to glass (W)
- T_a : Ambient temperature (°C)
- T_g : Glass temperature (°C)

T_w : Water temperature ($^{\circ}\text{C}$).

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

No conflicts of interest exist, according to the authors, with the publishing of this paper.

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