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Performance enhancement of single basin solar still using a composite vertical wick configuration

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ABSTRACT

Freshwater is essential for the survival of all living things in this world. Due to overpopulation and modernization, the availability of freshwater has decreased exponentially. Solar still is a simple, renewable, and sustainable energy system for producing clean water from any brackish or seawater. The main drawback of a solar still is its low productivity. The present study examines the productivity enhancement of a single basin solar still by using a composite wick material made of polyester and cotton wrapped around a vertical wood stick tested at Velammal Engineering College, Chennai, India (13.0827° N and 80.2707° E). The distillate output of the solar still with the composite wick was compared with the solar still with a single wick and a conventional solar still without any wicking material. The daily yield of the conventional solar still without any inclusion of wick material was 1,610 mL/d whereas the productivity of solar still with composite, cotton and polyester wick materials was 2,450; 2,210 and 2,080 mL/d, respectively. The modified solar still with composite wick material thus resulted in an increase of 35.35% compared to the productivity of conventional solar still. Thus it can be observed that, with the enhanced capillary performance of the composite wick material and the reduced volumetric heat capacity of the water, the yield of the solar still increases significantly.

Keywords: Solar still; Solar distillation; Water treatment; Wick material; Capillary effect; Composite wick

1. Introduction

Water scarcity is the lack of freshwater availability in a region. Due to global warming, deforestation, industrialization and overpopulation, freshwater reserves have decreased drastically [1]. Our earth has 70% water mass, but the vast portion of it is not suitable for human consumption due to the high composition of dissolved solids.

Many diseases arise due to unclean water [2]. Waterborne diseases are fatal and almost 2 million people die every year due to them [3]. The high demand for clean water led to an increased number of researches across the globe to convert the vast resources of brackish and saline water into potable water.

Various desalination technologies such as reverse osmosis, multi-effect distillation, electrodialysis, multi-stage flash distillation, and ion exchange process have been considered for the production of potable water [4]. The major drawback of all the aforementioned technologies is that they are energy intensive and indirectly consume a massive amount of fossil fuels for their operation.

Solar desalination is the process of converting saline and brackish water into potable water with the aid of solar energy alone. Solar still is a sustainable method to produce

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drinking water which is simple in construction. Solar still is a device that replicates the natural hydrological cycle in a compartment [5]. The internal energy of the impure water fed into the solar still is increased with the help of solar radiation, thus resulting in vaporization. The vapor thus formed is pure and rises due to buoyancy and as it comes in contact with the cooler side of the condensing surface, it condenses as pure water. The condensed water trickles down automatically due to the inclination angle of the cover and gets collected in a separate condensate channel. The distillate water thus produced is free from all contaminants and dissolved solids.

Even though solar still is an attractive alternative to produce clean water from impure water, the major obstacle in commercializing this sustainable product is its low productivity. The average productivity of a conventional solar still is in the range of 2–5 L/m²·d [6]. Various researchers have suggested numerous productivity enhancement techniques [7–12] to make this renewable energy system viable.

Wick material maintains uniform water depth through the capillary effect and increases productivity due to enhanced evaporating surface area. Murugan et al. [13] studied the wick-type solar still with a half barrel and corrugated absorbers. A vertical wick was added to prevent the loss of heat from the sidewalls of the basin, thus increasing the productivity by 112% and 123% for a half barrel and corrugated configuration when compared to conventional solar still. The tilted wick configuration integrated with a flat plate collector was analyzed by Negi et al. [14]. It was observed that the tilted wick solar still configuration yielded higher productivity of 3.99 kg/m² due to maximum solar absorption compared to the horizontal wick configuration, which yielded 3.216 kg/m². Essa et al. [15] studied the effect of quantum dots nanofluids on rotating wick solar stills. The modified solar still produced a maximum of 9,600 mL/m²·d.

Based on the literature survey, it is observed that solar distillers have low productivity (1.5–2.5 L/m²·d) and low thermal efficiency (~30%), which are the main bottlenecks in commercializing this sustainable technology. To obtain maximum commercialization potential, the still modifications should be simple, economical and effective so that they can be deployed in arid and remote regions.

Based on the literature review, it is observed that the distillate output of the solar still increases with the presence of wick material, however, the effect of composite wick material on the productivity of solar still has been seldom carried out. In this context, a suitable composite wick material is chosen based on the various factors that determine the effectiveness of a wick material, such as capillarity effect, absorption, water repellence and heat transfer coefficient [16–18].

In this present investigation, the effect of wick material on the distillate output of a single basin single slope solar still is studied. The experiments were carried out by positioning the wick material perpendicular to the absorber area using a vertical stick. The distillate yield and efficiency of the solar still for individual wick materials and composite wick materials are studied and compared. The composite wick material positioned vertically resulted in higher distillate output due to higher evaporation and convective heat transfer rate.

2. Materials and methods

2.1. Experimental setup

A single basin single slope solar still of base area 0.5 m² was fabricated using galvanized iron sheets of 3 mm thickness. The galvanized iron sheet is a type of carbon steel coated with a zinc layer. The presence of zinc inhibits the formation of rust and thus enhances the life of the basin. The walls of the basin are painted black to ensure maximum solar absorption throughout the day [19]. The basin is covered at the top using a glass cover of 4 mm thickness. The glass cover is positioned at an angle of 13°, which corresponds to the latitude of the experimental location, thus ensuring maximum reception of the solar radiation. The glass cover is kept at an angle to facilitate the condensed pure water to trickle down to the collector channel with the help of gravity. The bottom and side walls of the basin are insulated using a wooden box. A hollow cylinder made of copper is fixed at the center of the basin. Polyester and cotton materials were chosen as the wick material for their water absorption and capillary rise efficiency. The wick material is wrapped around the cylinder to induce a capillary effect and increase the evaporation rate of the feed water. Fig. 1 represents the actual experimental setup.

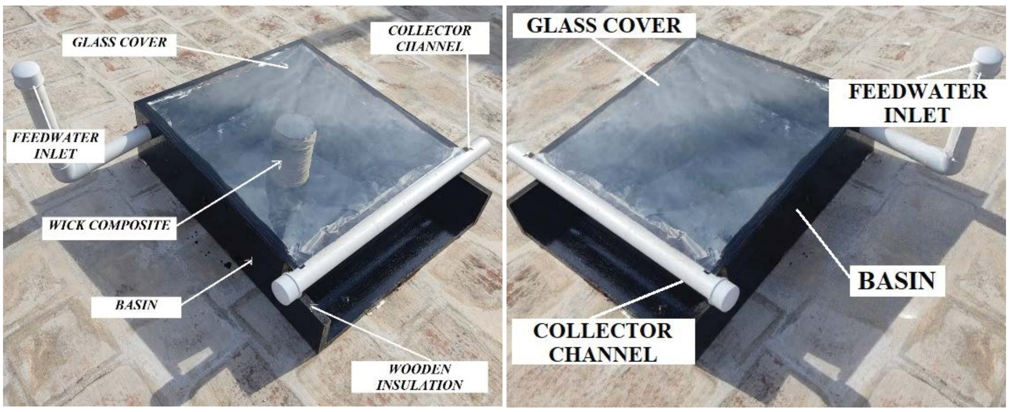

Fig. 1. Photographs of the experimental setup with and without wick material.

2.2. Experimental procedure

The experiments were carried out for a water depth of 2 cm. The still is fed with 9.8 L of tap water before the start of the investigation. The water depth was kept minimum since the productivity of a solar still has an inverse effect on the water depth [20]. The fabricated solar still was tested at Velammal Engineering College, Chennai, India (13.0827° N and 80.2707° E) for its productivity without adding wick material. The hourly distillate output was recorded from 08:00 to 18:00. The cumulative distillate output per day was also measured from 08:00 to 08:00 the subsequent day.

The experiments were carried out in the month of March 2022. The various climatic parameters that affect the productivity of solar still, such as solar radiation intensity, ambient temperature and wind velocity were measured on all experimental days to ensure that these parameters are similar so that the effect of wick material alone on the productivity of the solar still can be studied. The thermocouples were positioned at essential locations to measure the temperature of the basin, inner glass cover, feedwater and the environment. The uncertainty of all the values calculated using the various instruments is estimated using Eq. (1) [21],

$$U_x = \left[\left(\frac{dX}{dx_1}U_1\right)^2 + \left(\frac{dX}{dx_2}U_2\right)^2 + \ldots + \left(\frac{dX}{dx_1}U_n\right)^n\right]^{0.5} \tag{1}$$

The uncertainties of the various measuring instruments are illustrated in Table 1.

3. Results and discussion

Experiments were conducted with and without the composite wick material, as mentioned in the methodology. Figs. 3–7 show the variation of solar radiation intensity, ambient temperature, inner glass cover temperature, wind velocity and water temperature on experimental days carried out with and without the wick material.

Fig. 3 depicts the hourly variation of solar radiation in W/m^2 measured using a TES 1333 Solar power meter. The intensity of solar radiation increases in the morning, reaches a peak value of 930 W/m^2 around 12:00 to 13:00 h and then decreases exponentially. Solar radiation is the only energy source for the solar still, and the still's productivity depends significantly on the intensity of solar radiation. The increase in basin water temperature depends solely on the incoming solar radiation thus influencing the still productivity. The hourly variation of distillate output usually corresponds with the distribution of solar radiation throughout the day. Since it is one of the most critical factors influencing productivity, it was ensured that the experimental investigation was carried out on days of similar solar radiation intensity.

Fig. 4 depicts the hourly variation of ambient temperature with time. The ambient temperature was measured using K-type thermocouple. It can be observed that the variation in ambient temperature corresponds to the variation in solar radiation intensity throughout the day. A peak temperature of 37°C was observed around 12:00 and 13:00. The ambient temperature decreases at high altitudes and during seasonal changes. The effect of ambient temperature on the temperature of basin water is insignificant if the basin is well insulated, whereas lower ambient temperature reduces the condensing cover temperature thus enhancing the temperature difference between the evaporation and condensing surface resulting in increased productivity. Thus, the ambient temperature inversely affects the productivity of the solar still. With the increase in ambient temperature, the temperature difference between the condensing cover and the ambient temperature increases, thus reducing the convective heat transfer rate from the condensing cover to

Table 1
Uncertainties of various instruments

Instrument	Least count	Range	Uncertainty %
Thermocouple	0.1°C	0°C–100°C	0.38
Pyranometer	1 W/m^2	0–2,500 W/m^2	3.7
Anemometer	0.1 m/s	0–32 m/s	3.7
Measuring jar	1 mL	0–1,000 mL	1.47

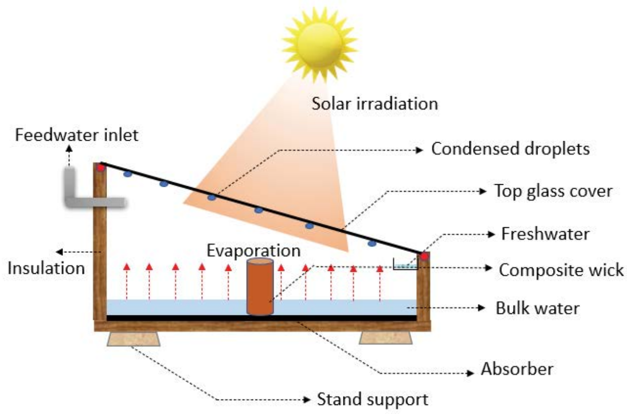

Fig. 2. Schematic diagram of the experimental setup with wick.

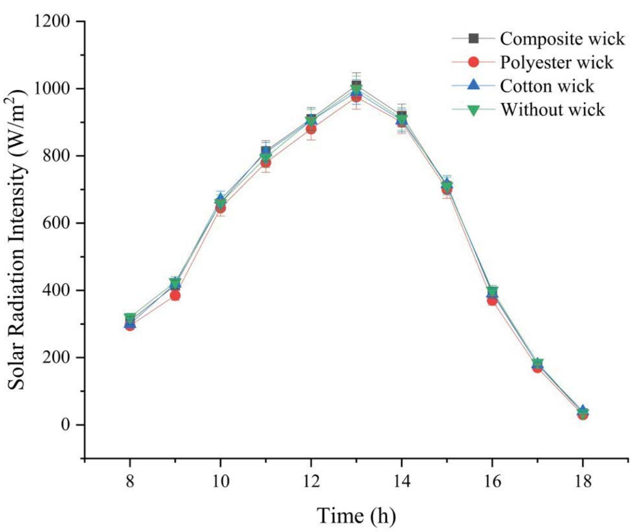

Fig. 3. Hourly variation of solar radiation.

the atmosphere. The variation of ambient temperature on both experiment days was almost similar.

The hourly variation of glass cover temperature throughout the day is presented in Fig. 5. The glass cover temperature also closely correlates with the solar radiation intensity throughout the day. K-type thermocouples were used to measure the inner glass cover temperature. With an increase in solar radiation intensity, the evaporation and condensation rate increase, thus raising the temperature of the condensing cover. With the increase in ambient temperature, the convective heat transfer rate between the cover and the atmosphere also reduces, thus increasing its temperature. The ambient temperature variation of the still with wick material is slightly higher than the glass cover of the still without wick due to enhanced evaporation and condensation rate in the former configuration.

The hourly variation of water temperature is depicted in Fig. 6. The water in the basin receives its thermal input through solar radiation falling on it and also through the walls of the basin through convection. Insulation of the basin is important to ensure that the heat energy from the basin is transferred to the feedwater and not lost to the surrounding through convection. The material of the basin also plays a major role in the basin water temperature. During off-sunshine hours, the reduction in ambient temperature reduces the basin temperature thus lowering the water temperature. The water temperature rises in the forenoon, reaches a peak value of around 66°C at 13:00 and decreases gradually till sunset. The water temperature of the still without and with a wick is almost the same, even though there is a slight reduction in water temperature in the still with wick material which can be a result of the shadow formed due to the presence of the vertical wick cylinder.

Fig. 7 presents the variation of wind velocity throughout the day for both the configuration of solar still. Wind

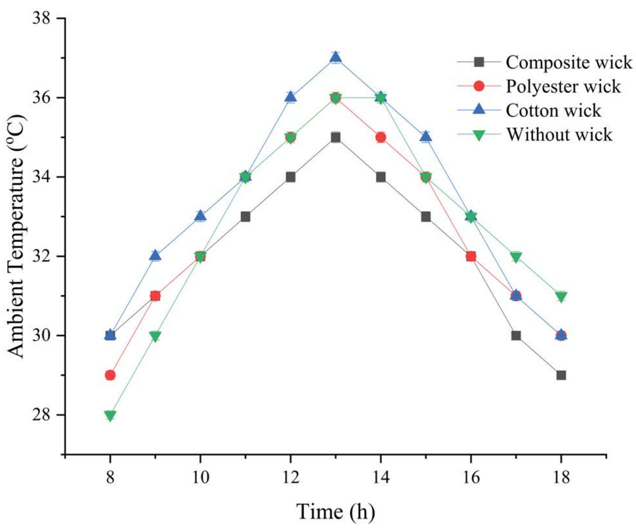

Fig. 4. Hourly variation of ambient temperature.

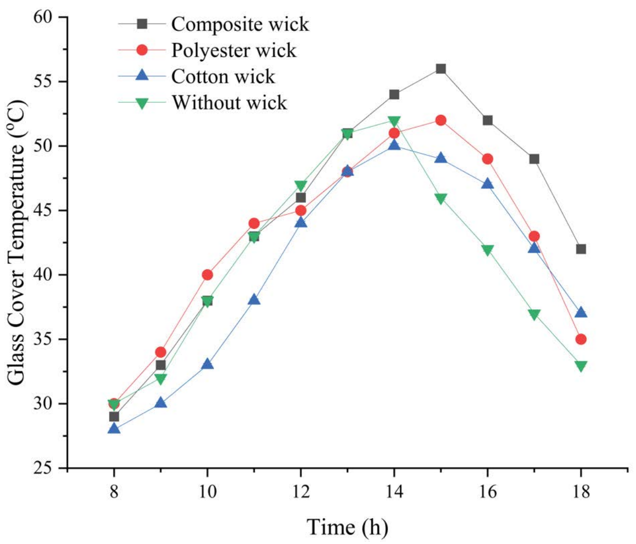

Fig. 5. Hourly variation of glass cover temperature.

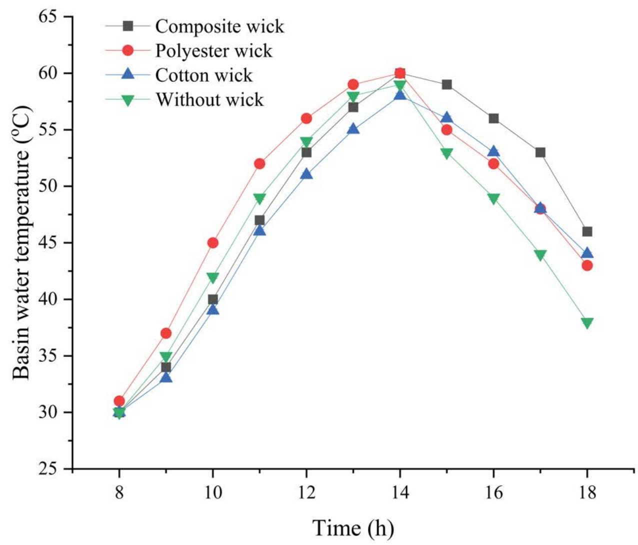

Fig. 6. Hourly variation in water temperature.

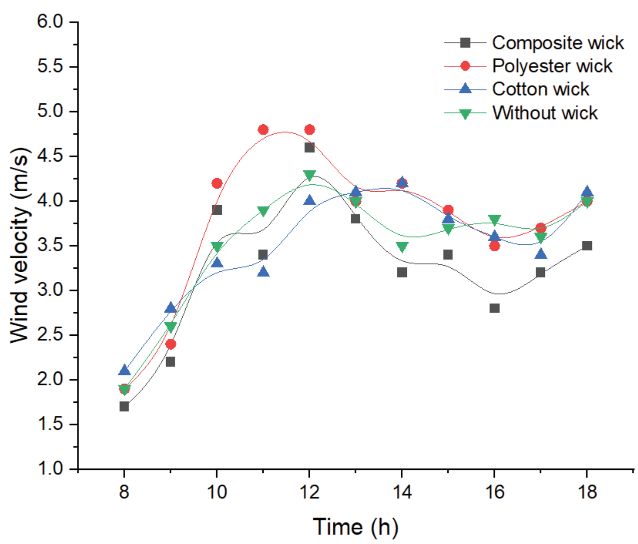

Fig. 7. Hourly variation of wind velocity.

velocity is one of the critical parameters that influence the productivity of solar still. The wind velocity flowing over the basin does not have any significant effect on the productivity since the basin is insulated, whereas the wind velocity at the glass cover affects the productivity of the solar still. With increased wind velocity, the convective heat transfer rate between the glass cover and the environment increases, thus reducing the condensing cover temperature. The increase in temperature difference between the water surface and glass cover thus significantly increases the solar still productivity. Wind velocity is not directed by any external force in this research work. The velocity of the wind that flows naturally is measured and recorded using an anemometer.

Fig. 8 depicts the effect of wick on the hourly productivity of a single basin single slope solar still. It can be observed that the hourly productivity of the solar still increases in the presence of the wick material. The variation in productivity corresponds to the variation in solar radiation intensity irrespective of the wick material. The capillary effect aids in absorbing the water and spreading it across to increase the feedwater's evaporating surface area. The incoming solar radiation is absorbed by the wick materials, thus raising the temperature of the water present and resulting in enhanced evaporation. The capillary effect and low thermal capacity of the wick materials aid in increasing the surface temperature of the wick and thus enhancing the evaporation rate. The composite wick material consisting of polyester and cotton addresses the issue of dry spots arising from a single wick material thus increasing the productivity.

Fig. 9 depicts the daily production of potable water from solar still with and without wick material. It can be seen that the average productivity of the solar still using composite wick material is 35.35% higher than the productivity of the still without wick material. The presence of wick material enhances the evaporation rate of the feedwater, thus resulting in increased distillate output. The capillary action of the wick material aids in the interception of maximum solar radiation due to increased evaporating surface area resulting in increased yield. The daily yield of the solar still with composite wick material is 17.7% and 10.85% higher than the solar still with polyester and

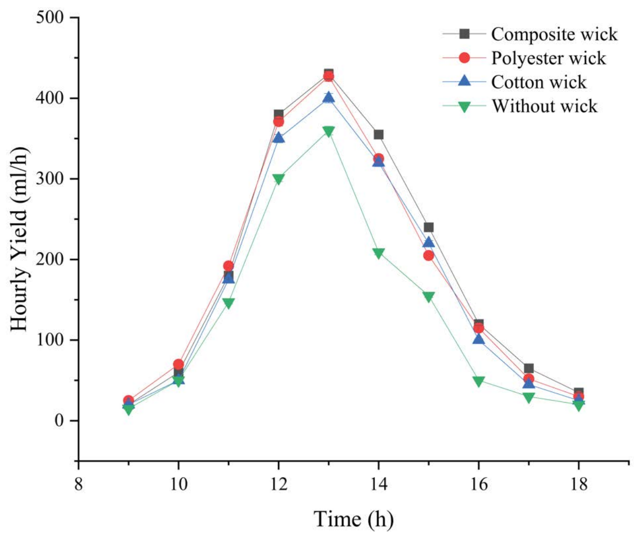

Fig. 8. Comparison of the hourly yield of the solar still with and without composite wick material.

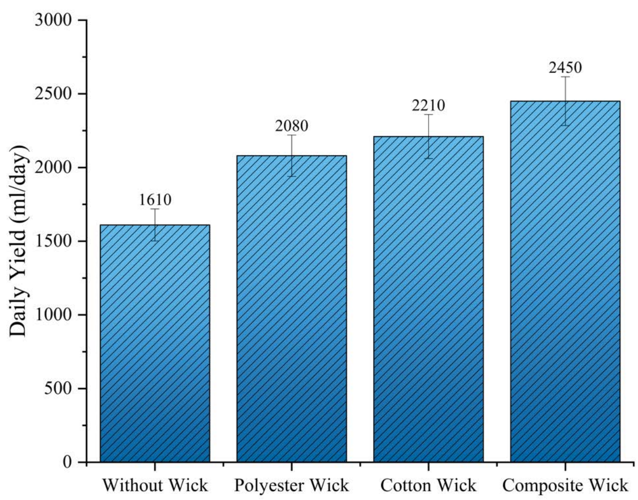

Fig. 9. Comparison of the daily yield of solar still with and without wick material.

Table 2
Comparison of productivity of various configurations of wick solar still

Authors	Base area (m^2)	Wick configuration	Productivity (L/d)
Negi et al. [14]	1.0	Horizontal wick with FPC	3.21
		Titled wick (30°) with FPC	3.99
Essa et al. [15]	1.0	Rotating wick	8.20
Omara et al. [22]	1.0	Vertical rotating wick	4.35
Suneesh et al. [23]	1.5	Tilted basin fully covered	3.36
Jobrane et al. [24]	1.0	Titled basin partially covered	3.64
Ghandourah et al. [25]	1.0	Tilted wick novel solar still	4.03
		Wick material coated with nanoparticles	5.39
Present work	0.5	Vertical composite wick	2.45
		Vertical cotton wick	2.21
		Vertical polyester wick	2.08

cotton wick material, respectively. The composite wick material with different pore sizes facilitates both high narrow siphoning and fluid return. It balances the capillary pressure generation and liquid permeability to enhance the capillary effect and the evaporation rate resulting in higher yield than homogenous wicks.

A comparison between the present work and previous literature focusing on the yield augmentation of a solar still using wick material is presented in Table 2.

4. Conclusions

In the present work, the effect of a composite wick material made of polyester and cotton material on the productivity of single basin single slope solar still is analyzed. The wick material is placed in a vertical cylindrical configuration to absorb maximum radiation. The vertical configuration of the composite wick material is compared with the results of previous researchers in different configurations, as depicted in Table 2. The vertical wick material has improved productivity over horizontal wick configuration and is cost-effective compared to rotation and sliding wick configurations. The key findings are deduced as follows:

- The presence of wick material enhances the hourly distillate output of the solar still. The productivity of the solar still is in correspondence with the solar radiation intensity throughout the day. Peak productivity was observed at 13:00 in all the configurations, with a maximum distillate output of 430 mL in the composite wick solar still and 360 mL in the conventional solar still.
- The daily productivity of the solar still increases with the presence of wick material. The daily yield of the solar still with composite, polyester and cotton wick materials are 2,450; 2,080 and 2,210 mL/d, respectively. Whereas, it is 1,610 mL/d for the conventional solar still without wick material. An effective increase of 35.35% was observed in productivity due to the presence of composite wick material.

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