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Experimental analysis of solar still integrated with novel wiper on inner glass surface

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ABSTRACT

The conventional solar still (CSS) yield is constrained by various environmental and design parameters. One of the key operational factors that determines the still performance is the value of solar radiation reaching the basin water surface. In the present work, an attempt to improve value of solar radiation reaching the basin surface and a solution to avoid the distillate loss from glass cover to the basin is presented. In this article, A wiper integrated solar still (WISS) is developed by means of implementing an internal glass wiper that can also collect the wiped distillate yield effectively. Here, the WISS performance characteristics is evaluated experimentally and the results are compared with CSS performance. The results are in good agreement with the thermal model developed with MATLAB 2015 for CSS. Clearing the glass of the foggy condensate ensured an additional 91 W/m^2 (maximum) of incident radiation reaching the basin. An hourly collection of 56 mL (maximum) wiped yield is obtained in addition to the hourly distillate yield for the WISS system. The maximum total yield improvement of 22.1% is obtained for the WISS for a total yield value of 2,575 mL/d for a pair of consecutive days, while the maximum total yield improvement across all the days against the CSS system is found to be 33.7% for a total yield value of 2,567 mL. The maximum improvement in instantaneous thermal efficiency is found to be 19.1% corresponding to an efficiency value of 46.7% for the WISS system over 39.2% for the CSS system. The total hourly yield for the WISS is found to deviate by 9.9% while the deviation for the CSS is 19.6% from the expected values obtained from thermal model. The WISS system also ensured zero loss of distillate to the basin from inner glass surface hence this provides a scope for development flat glass solar stills. The optimum frequency of wiper operation needs further improvement along with assessment of suitable material for effective wiping.

Keywords: Glass surface wiper; Distillate loss to basin; Wiper integrated solar still; Conventional solar still

1. Introduction

Minimising the glass temperature and maximizing the basin water temperature is the main motive for solar still development [1]. The solar still performance is mainly affected either by the environmental or design parameters. Since the researchers can only control the later, a quest to improve the solar still yield by improving the still design continues to present new horizons every day. While a suitable geographic location like a coastal area with ample wind and sunshine is said to be ideal for solar still performance

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[2], a solar still design that intercepts and absorbs maximum solar radiation with maximum top heat loss can be regarded as 'the best' from design point of view.

There have been continuous efforts to improve the solar still performance by ways and means permitted by the latest technology available. Among the most recent approaches towards accurate prediction of a solar still Elaziz et al. [3] have presented an artificial neural network (ANN) model with ensemble random vector functional link (EnsRVFL) for performance prediction of active solar still with nanoparticles and have obtained 94% higher peak increment in productivity compared to conventional solar still. Essa et al. [4] experimented with a solar still integrated with a rotating wick belt and quantum dots Nano fluid to achieve significant improvement in distillate yield and thermal efficiency. In another novel improvement in solar stills, Essa et al. [5] have studied a vertical solar still with rotating discs for surface tension reduction and radiation absorption improvement in solar still basin.

For any given solar distillation unit, the highest possible rate of evaporation and condensation has to be achieved simultaneously by all means possible in order to best utilise the available solar radiation. The rate of evaporation can be significantly improved by increasing the basin water temperature by various means and reflectors are one of the simplest methods to achieve this. By implementing a reflector along with a sliding wick belt, Abdullah et al. [6] have enhanced the productivity by 300% when compared to a conventional solar still. Tanaka and Nakatake [7] have worked at improving a tilted wick solar still by utilising a flat plate reflector and have achieved a 9% higher average daily yield. Batineh and Abbas [8] have analysed a solar still integrated with internal reflectors and fins and have achieved tremendous increment in both productivity and efficiency of distillation. Wang et al. [9] have studied a passive vertical multiple effect diffusion solar still directly heated by a parabolic concentrator and have obtained a daily maximum yield of 5.3 kg/m^2. Shmroukh and Ookawara [10] have evaluated a transparent acrylic stepped solar still with internal and external reflectors with copper fins in the basin and have found the configuration to be best suitable for harsh climatic conditions. Solar devices have tremendous potential for remote locations and can provide access to a clean technology for cooking [11] and clean drinking water [1] to the people.

Glass cover cooling is one of the simplest yet effective means of improving rate of condensation and hence affects the still yield significantly. Elmaadawy et al. [12] have integrated direct glass cooling by water in combination with three different thermal storage techniques. A related glass cooling technique has been attempted by Abu-Arabi et al. [13] where solar collectors are coupled with solar still augmented with Phase change materials. In a recent review by Omara et al. [14] various solar still glass cooling techniques have been illustrated. It has been reported that water film over glass is an effective means of cooling and still performance improvement. Though an ill designed system may adversely affect performance. Water film-based cooling has been reported to increase the solar still yield by 20% as per Hijleh and Mousa [15] in another research by Hijleh [16] an improvement in solar still yield by 6% by means of water film cooling has been reported. Also, the effect of wind speed is said to have no effect on the film cooled glass in this case. El-Samadony et al. [17] have studied theoretically in detail the film thickness of water over the glass for cooling purpose and obtained a daily yield of 5.58 kg/m^2/d. In another recent research work Jathar et al. [18] have studied glass cover cooling in addition to nanoparticles mixed in the basin and have reported a maximum of 51.28% gain in productivity for 0.2% concentration of MgO. Dimri et al. [19] have numerically studied the effect of glass temperature on solar still yield and have concluded the crucial role of inner glass temperature on solar still yield. In another research work, Tiwari et al. [20] have presented analytical expressions for temperature of various solar still components and have also studied the effect of condensing cover inclination along with packing factor and mass flow rate on hourly yield. Bhargava et al. [21] have presented the effect of shading and glass cooling on evacuated tube augmented solar still and have found an increase in yield by 16.4% for half shade and cooling. Shoeibi et al. [22] have compared a thermoelectric cooler assisted water cooled solar still with an air cooled solar still and have obtained 81% higher yield for water cooled system. Shoeibi et al. [23] have also hailed glass cooling over external condenser and thermoelectric cooling as the largest contributor in improving the rate of condensation at the cover. In another investigation by Tiwari et al. [24] for annual performance analysis of different inclination, the cover angles value of 15° is found to be most suitable for summer season however the smaller angles of inclination result in higher distillate loss to the basin.

Though outer glass surface cooling for solar stills ensures a quicker droplet formation from the condensate and higher distillate yield, the same comes at a cost of precious cooling water being lost to the ambient. Also, the glass surface cooling or cleaning is at the outer surface and hence the translucent nature of glass due to condensate still poses a hindrance to the solar radiation reaching the basin. One of the methods to maximise the solar radiation reaching the basin is by means of concentrating the radiation from the bottom of the basin [25]. Such configuration is regarded as an inverted absorber solar still (IABS). It is an improvement over conventional solar still (CSS) that improves the value of solar radiation reaching the basin by allowing the radiation through the top as well as bottom of the still and hence doubling the distilled water output [26].

Since concentrating the radiation on to the basin results in higher condensing glass temperatures, a flow of water over the glass can further improve the distilled water yield [27]. For an IABS system, the solar radiation reaching the basin is unaffected by the condensation at the cover since the radiation is permitted through the bottom of the basin while the condensation occurs at the top cover of the still. A significant improvement in IABS performance can be achieved by means of a triple effect IABS system where a 30% higher yield is obtained compared to CSS still [28]. Despite some salient features, IABS systems are quick to lose the thermal energy gained in the day through bottom in absence of bottom insulation [29] and hence are limited to operation during sunshine hours only.

For a conventional solar still, vapours formed during the humidification process inside the cavity, are bound to rise and condense at the top glass cover. The condensed droplets do not trickle down the glass cover unless having attained enough mass to overcome the inertial and adhesive forces with the glass. Change in the optical characteristics of the glass and condensate droplets together, results into loss of solar radiation from the surface due to reflection in excess of 10% as depicted here in the presented work. Here, a difference of 91 W/m^2 (maximum) of incident radiation was found between that at the glass upper surface and basin water surface. This translates into a considerable loss of the otherwise usable radiation and hence the distillate yield. The main objective of the present work is to maximise the value of solar radiation reaching the basin by operating an inner glass surface wiper in order to maintain the optical clarity of the glass cover while minimising the loss of distilled water to the basin by channelizing the wiped condensate into the main distillate collection channel.

2. Fabrication of experimental setup

2.1. Construction details

A single slope solar still with unit basin area is fabricated with white PVC boards as outer structure since they are weather-proof and can withstand high temperature values in summer. They are easy to work upon and are sturdy enough to replace ply boards for this purpose the basin and inner side walls are constructed out of GI sheet. The basin and side walls are painted matt black for maximum absorption of the incident solar radiation. The glass cover chosen for the cover is 3.5 mm thick float glass placed at an angle 23°, that is, equivalent to the approximate latitude of Raipur, Chhattisgarh India. The still cavity is made leak proof by means of silicone as sealant. The glass cover is placed in specially made slots in all the four walls of the still and is sealed with silicone to the walls. The conventional still (CSS) is placed facing south atop the department of Mechanical Engineering, NIT Raipur for experimental analysis. The wiper integrated solar still (WISS) is an upgrade over the conventional still (CSS) that is achieved by integrating a wiper with wiped condensate collection mechanism into the solar still cavity of the CSS.

Fig. 1a shows the schematic representation of the proposed solar still with unit area of the basin integrated with the novel glass wiper (WISS) while Fig. 1b contains the physical description of the glass wiper and the wiping process along with distillate collection process. The photographic image of the conventional solar still (CSS) without wiping operation is shown in Fig. 2a while Fig. 2b represents the photographic image of the proposed WISS system after wiper operation. The physical dimensions and other material details for the fabricated solar still is provided in Table 1. As presented in Fig. 1, the wiper is placed horizontally along the plane parallel to the glass surface and on C-shaped aluminium rails that are fixed on to the trapezoidal walls of the still. Placed right adjacent to the wiper, is a C-shaped flow channel to collect the condensate during wiping action. This condensate is passed on to the yet another channel embedded below the rails and drains the same to the main condensate collection channel. The distillate is finally collected and is sum of the conventional yield and the yield obtained by the wiping action.

The wipers are operated by a rope and pulley system powered by a 5 W, 5 rpm synchronous motor that reverses its rotation direction when restarted. In this way the motor is responsible for the upward and downward motion of the wiper. In the present work, the wiper is operated once every hour for a duration required by the wiper to complete one ascend and descend cycle. Since the performance parameters of the present solar still are evaluated for every 1 h, the wiper too is operated after duration of 1 h for the present work. The frequency of the wiper operation may be optimised in future for further improvement in the distillate yield value. The motor power input is negligibly small; hence the same is neglected in the mathematical modelling for efficiency calculations. The condensate collection and wiping action is primarily achieved during the descent of the wiper since the downward trickling is the natural tendency of the droplets to flow to the distillate collection channel. The wiper after completing its action, returns to the top position for its dwell period and is held there by a timer arrangement added to motor circuit. During peak yield hours, the glass surface right behind the wiper is occupied by the condensate gathered immediately after the wiping, therefore the wiping and condensate collection is also carried out during the ascending motion of the wiper.

The CSS operation without the proposed wiper system is presented in Fig. 2a. The otherwise transparent glass cover can be visibly said to have turned translucent due to the condensate formation on the glass. Thus, the reduction in solar radiation intensity reaching the basin was found to be 91 W/m^2 (max). The earlier literature has discussed in great depths regarding glass top surface cleaning and cooling techniques, but work pertaining to glass inner surface wiping is yet to be reported. A glass wiping system with the arrangement as shown in Figs. 1a and b, has been designed to collect and connect the wiped distillate yield to the main collection channel along with the wiping action. The material chosen for wiping action here is an L shaped Styrofoam of appropriate dimensions so as to minimise its projection on the basin. The wiper dwells at the top position of the still so as to avoid any interference to the radiation. Fig. 2b shows the proposed WISS system after the wiping operation during the wiper's descend. The improvement in glass clarity is clearly visible and the radiation loss due to otherwise translucent glass is compensated.

As shown in Fig. 3, the distillate after trickling down from the front end during descend (facing downwards) is transferred to the side collection channel. The side channel as discussed earlier, acts as a tributary and transfers the distillate during the wiping action to the main distillate channel at the bottom of the still. During the peak hours in the afternoon the glass is occupied by the condensate immediately after the wiping. The ascending motion of the wiper causes the distillate to trickle through the passage provided across the foam as shown in Fig. 1b Hence the proposed system ensures zero loss of distillate to the basin.

2.2. Instrumentation for experiments

The instruments used in experimentation as presented in Figs. 4a–c are solar watt meter and turbine type anemometer,

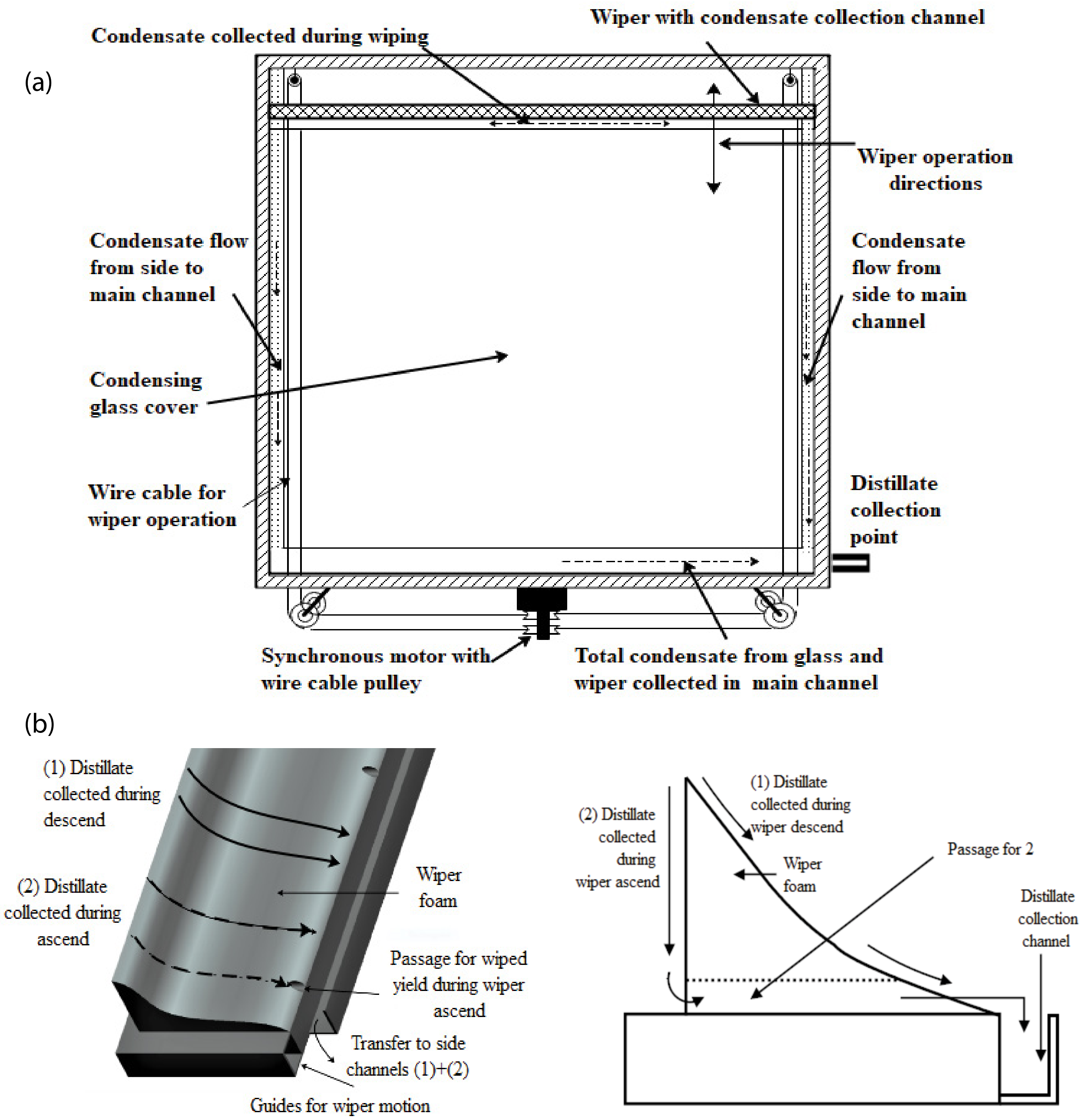


Fig. 1. (a) Schematic diagram of wiper integrated solar still (WISS) (top view). (b) Glass wiper physical description and wiping process.

PT 100 2 wire type RTD and weighing machine for measuring distillate output respectively.

3. Principle of working and motivation

The CSS system works on the basic principle of humidification and dehumidification. Promoting either or both of these processes by means of improvisations and modifications, leads to distillate yield enhancement. The heat transfer process along with their respective direction is illustrated in Fig. 5. The network of thermal resistances as faced by the solar radiation before the same is utilised for distillation is described here. The proposed work presented here intends to implement an inner glass surface wiper in the solar still cavity to periodically wipe the glass inner surface and hence eliminate the loss of distillate to the basin.

Apart from improving the optical transmissivity of the glass that is marred by fogging due to condensation of vapours. In the present system, wiping action is accomplished in such a manner that no condensate is lost to the basin and is carefully collected along with the distillate yield. The wiper operation though, restarts the condensation

Fig. 2. (a) CSS without wiping action and (b) WISS after wiping inner glass surface.

Table 1
Material details for experimental setup fabrication

Criteria	Values, type
Outer structure construction material	PVC board, 17 mm thick
Basin material	GI Sheet
Glass thickness and type	3.5 mm float glass
Basin absorber surface finish	Matt black
Insulation	Polyurethane sheet, 41 mm thick
Mass of water in the basin	25 kg
Glass cover inclination angle with horizontal	23°

process again from mist stage at the inner surface of the glass but the gain in distillate yield obtained due to additional solar radiation reaching the basin and the avoidance of distillate loss to the basin proves the worth of this system. The present study deals with hourly operation of the wiper only and hence allows the condensate to grow for sufficient duration at the glass surface. During the peak hour (beyond afternoon) operation of the still, the effect of wiping is found to be negligible on the condensation process. For the non-peak hours or starting of the day, the slower rate of evaporation and condensation demand for higher radiation into the basin to speed up the rate of evaporation. In either case, the wiper can be found to be useful in improving the productivity. Hence the present work intends to deal with the following issues in the conventional solar still setup.

- Improving the value of solar radiation reaching the still basin by clearing the condensate from the inner glass surface by means of a proposed motorised glass wiper that is operated once in 1 h.
- Elimination of dropping distillate loss to the basin from inner surface of the glass.
- Minimise the difference between theoretically predicted (that has been predicted for clear glass) and actual yield, since while predicting theoretical yield, the glass has been assumed a clear glass throughout the process in thermal modelling of solar stills.

4. Pre experimental findings and observations

It has been observed while carrying out experiments that the accumulation of water droplets on inner surface of glass cover reduces the value of radiation reaching the basin surface. Also, the loss of precious distillate directly to the basin, from the inner glass surface in the form of heavy water droplets is yet another challenge. In order to proceed with the experimental analysis, a couple of pre-experimental activities have been carried out to determine the value of parameters that are crucial for the evaluation of performance of the proposed WISS system. The aim of the first activity is to determine the value of maximum condensate that can be collected from the glass surface at any given instance. The second activity is aimed at determining the exact value of the solar radiation reaching the basin in the presence of condensate on the inner surface of the glass.

4.1. Determination of condensate mass available at glass surface at any instance

The activity has been carried out to determine mass of condensate accumulated at the inner glass surface that becomes partially opaque to the incident radiation that is reaching to the basin at any instance. This has been found by raising the glass at top and manually wiping using an absorbing cloth till it appears completely clear.

A cotton cloth with known mass is used for wiping the glass completely until no droplets are visible on the surface. The cloth is once again weighed for evaluating the distillate mass wiped. The difference in mass is found to be 90 mL. This is the maximum mass that can be collected by the wiper with 100% efficiency. This is done during peak

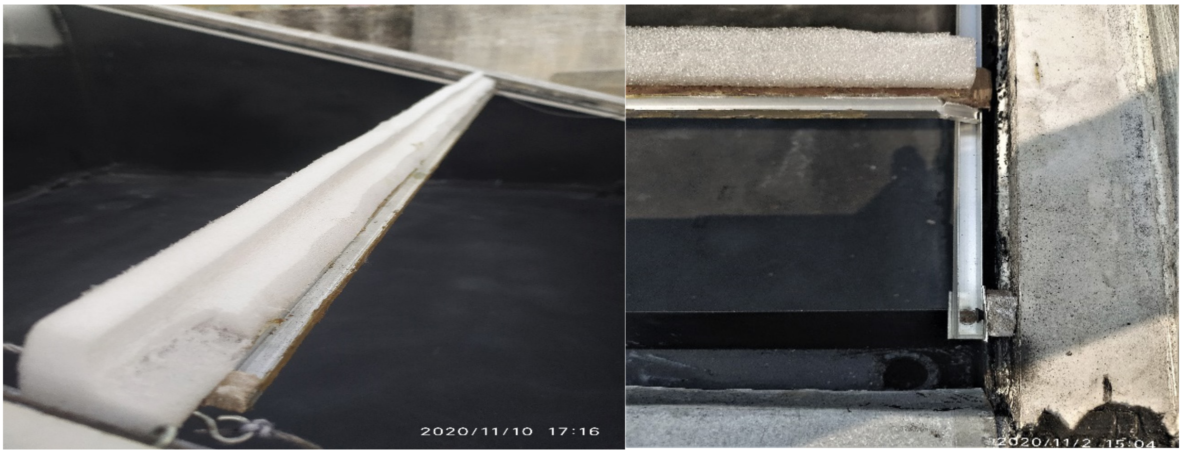
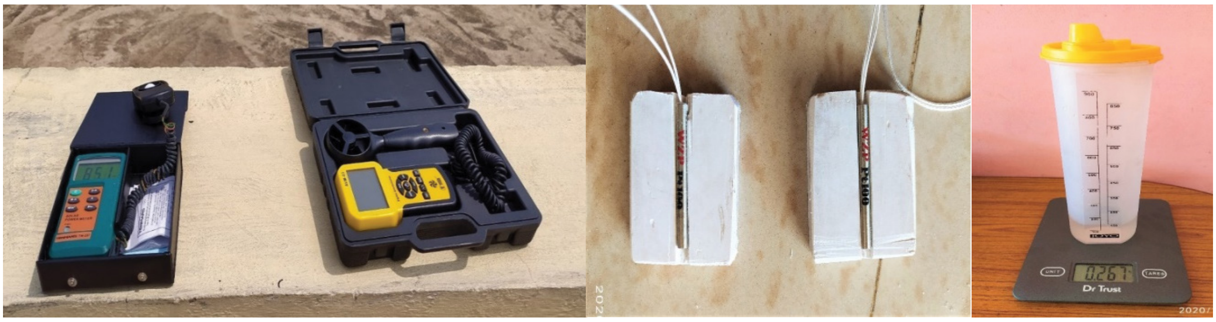


Fig. 3. Photograph of the wiper and distillate flow channel.



(a) (b) (c)

Fig. 4. Measuring instruments and sensors for experiments.

condensation hours between 1,100 to 1,600 h. The mass of condensate available at any instance at the glass for an area of 1.08 m^2, is approximately determined to be 90 mL.

4.2. Effect of condensate on incident radiation reaching the basin

For this activity, the solar watt meter is placed at 4 different parts of the solar still on November 2, 2020 at two different hours. The first attempt is in the morning at 1,100 h and the second attempt is at 1,600 h. The positions and values read out by the solar watt meter are listed in Table 2. An opening for placement of watt meter sensor is provided in the side wall of the still.

5. Experimentation method and procedure

The method and procedure adopted while carrying out the experimentation is presented below and the flow diagram indicating a layout of the proposed strategy adopted is presented in Fig. 6.

- The conventional solar still (CSS) of unit basin area is fabricated and installed at National Institute of Technology Raipur Chhattisgarh India (21.2514° N, 81.6296° E).
- The solar still is modified by integrating a novel inner glass surface wiper inside the cavity and hence the wiper integrated solar still (WISS) is developed.
- The experiments are conducted on the CSS and WISS on alternate days for the month of November for the duration 03/11/2020 to 08/11/2020.
- The day is assumed to start at 800 h and end by 1,600 h, depending upon the available sunshine and distillate output yield obtained.
- The performance characteristics of CSS in terms of temperature difference between glass cover and basin, hourly distillate yield and instantaneous thermal efficiency is evaluated for 3 d each.
- The experiment is repeated on alternate 3 d for parameters as discussed in step e for the WISS with hourly wiper operation.
- The wiper is operated before the distillate yield is collected from the side distillate collection point of the still. Hence the hourly distillate collected on 4, 6 and 8 November is sum of the conventional yield and wiped distillate and is considered as yield from WISS system.
- The parameters as mentioned in step e are compared for both the cases and the results are plotted.
- The experimental results for both CSS and WISS are compared with the results from the mathematical model developed for CSS system and the deviation from the expected hourly yield values obtained from mathematical model is calculated.

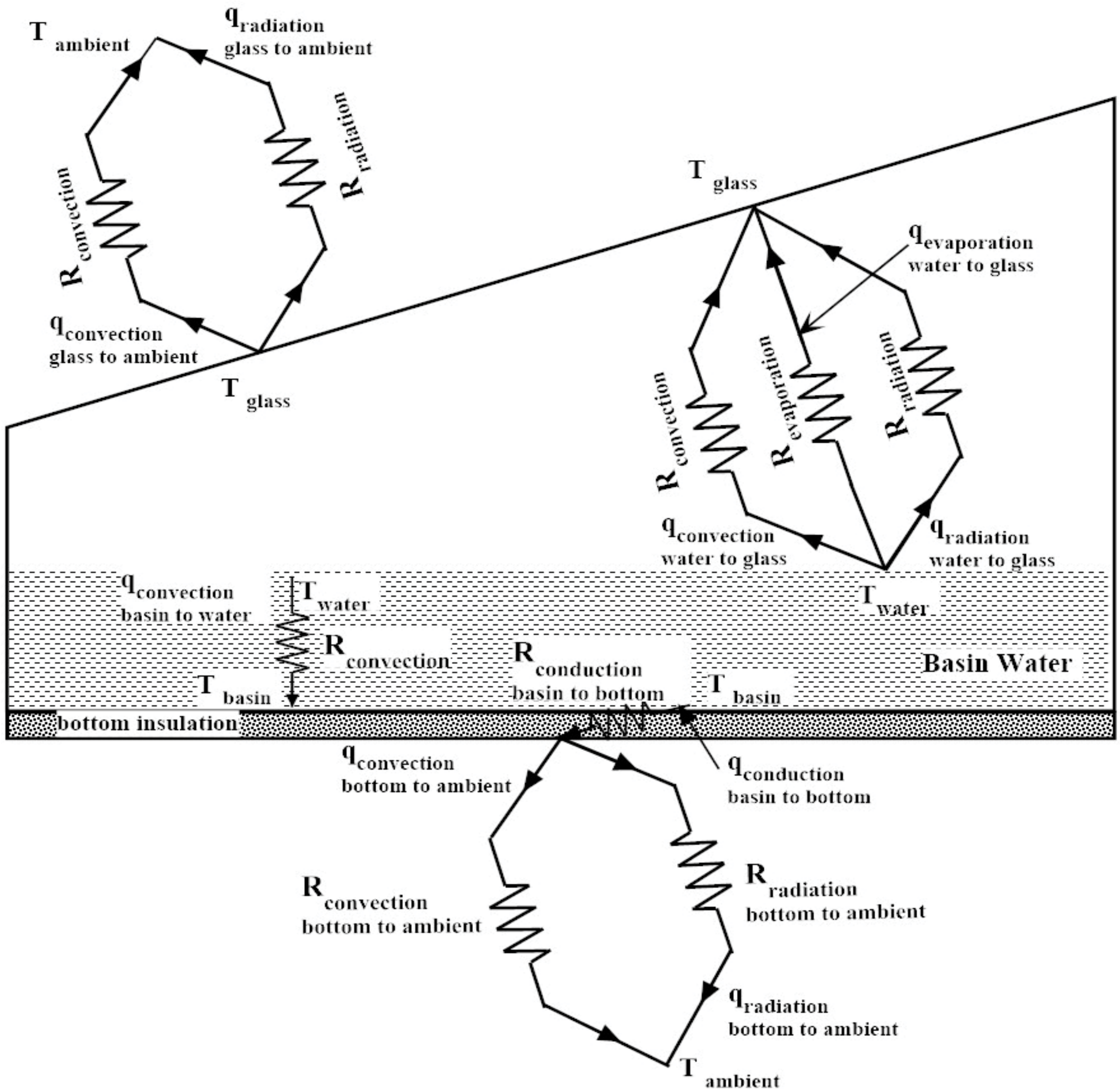


Fig. 5. Thermal resistance and heat transfer processes in a solar still.

- The parameters like solar radiation, instantaneous thermal efficiency, hourly yield, and ambient temperature are plotted for 800 to 1,600 h since the radiation received beyond 1,600 h is negligible for the experimental setup site.

6. Assumptions

The following assumptions were made for the experimental analysis

- The Solar watt meter displays the total incident radiation that is inclusive of diffused and reflected radiation available at the glass surface and the basin. Hence the same is considered here as the Incident radiation.
- The heat capacity of basin material, bottom insulation and glass are neglected.
- The entire basin water and the glass surface is assumed to be at the same temperature.
- The inertial losses in turbine type anemometer used is neglected and the instantaneous wind velocity at the glass surface is considered to be the final value of wind velocity.

7. Results and discussion

7.1. Solar radiation variation

Fig. 7 shows the variation of solar radiation for the days from 3 to 8 November 2020. The intensity variation across the six consecutive days of experimentation is found to be similar. The highest radiation values for the days under consideration is 749 W/m^2 at 1,200 h on November 8. The values of radiation, wind velocity, ambient and component temperatures are noted for every hour between 800

Table 2
Solar radiation values at various points in CSS

Attempt 1, 1,100 h		Attempt 2, 1,600 h	
Sensor position	Radiation value (W/m^2)	Sensor position	Radiation value (W/m^2)
Centre, above the glass	720	Centre, above the glass	348
Centre, below the glass	632	Centre, below the glass	261
Centre, above water surface	630	Centre, above water surface	256
Centre, above water surface, after wiping	709	Centre, above water surface, after wiping	344

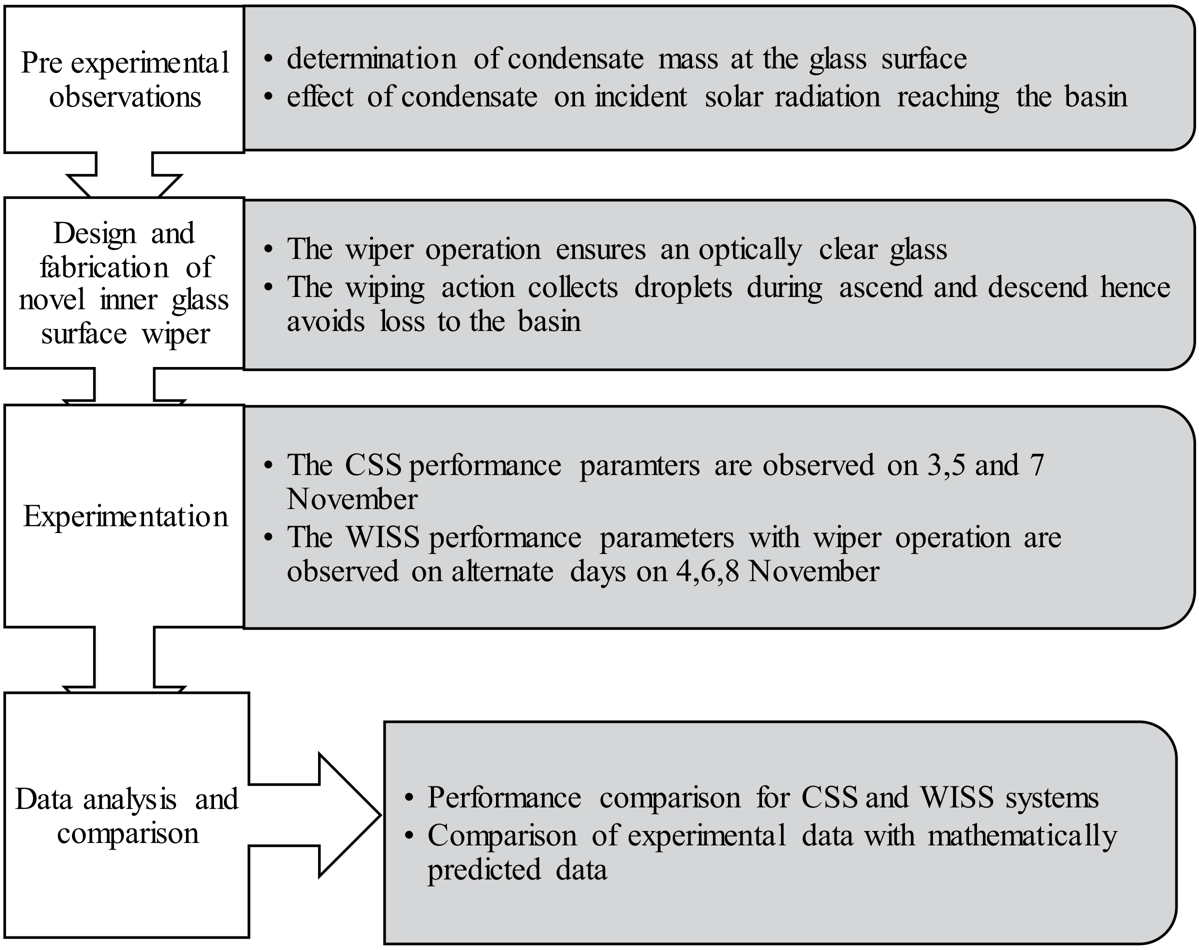


Fig. 6. Flow diagram indicating approach adopted for the analysis.

and 1,600 h atop Department of Mechanical Engineering, National Institute of Technology Raipur, and Chhattisgarh India. The solar intensity measurement is performed every hour by placing the watt meter sensor over a fixed point on the glass surface.

7.2. Ambient temperature variation

Fig. 8 depicts the variation of ambient temperature across the 6 d of experimentation. The general trend for ambient air temperature is observed to be similar for all the days of experimental observations. The peak ambient temperature among all the days is found to occur at 1,500 h on November 4 with a temperature value of 33.3°C while the lowest temperature for the period under consideration is 21.1°C at 800 h on November 8. The maximum temperature for all the days under consideration is found to occur between 1,400 to 1,600 h where the peak temperature value for November 5, 6 and 8 is recorded at 1,400 h.

7.3. Hourly yield variation

Fig. 9 represents the hourly yield variation along the day for all the 6 d under consideration between 800 to 1,600 h.

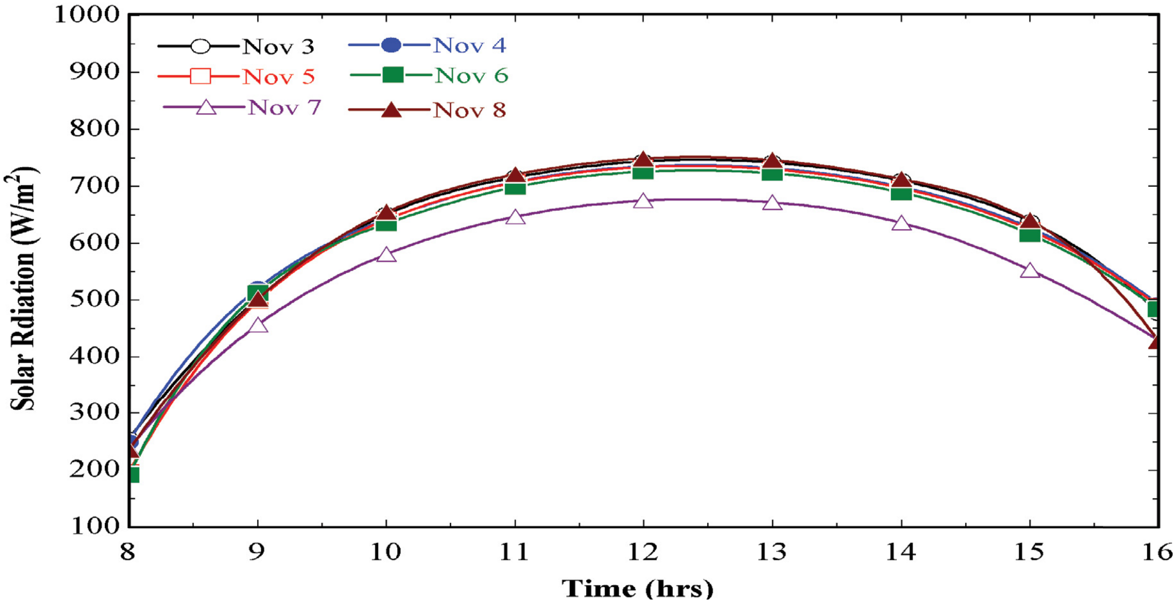


Fig. 7. Incident solar radiation vs. time for 3, 4, 5, 6, 7 and 8 November.

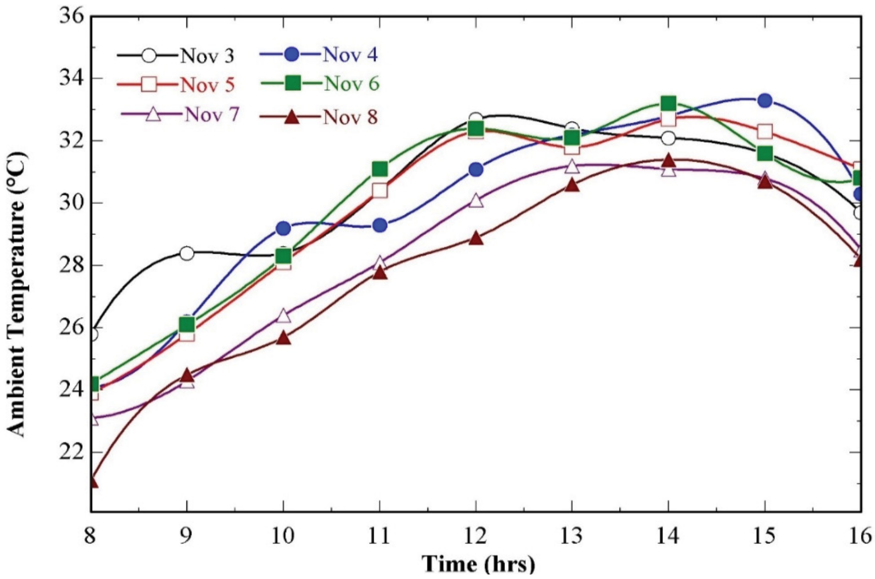


Fig. 8. Ambient temperature vs. time for 3, 4, 5, 6, 7 and 8 November.

The hourly yield for the proposed WISS system is found to be higher than the conventional system throughout the day for all the three set of days considered for experimentation. The peak performance point in terms of hourly yield is found to occur at 1,400 h for both systems on all the days. The maximum hourly yield for the proposed WISS system is found to be 511 mL on November 4 at 1,400 h while for the same duration the maximum yield for the conventional system is found to be 461 mL on the previous day, this is an increment of 10.8% over the CSS. The maximum hourly yield gain at 1,400 h for the proposed WISS system is 21.9% for November 4 against the minimum hourly yield of 419 mL for the CSS system at 1,400 h on November 7.

The daily total yield for proposed WISS system on November 4, 6 and 8 is found to be 20.2%, 21.4% and 22.1% higher than the CSS system. The improved value of the yield can be attributed to the improved $\Delta T_{w\text{-}g}$ that is difference between basin water and glass temperature due to improved transparency of the glass cover as a result of wiping. The gain in hourly yield, apart from conventional distillate collection by dripping, is during wiper ascend and descend.

7.4. Instantaneous thermal efficiency variation

The experimental analysis presented here has been compared with the results of mathematical modelling of

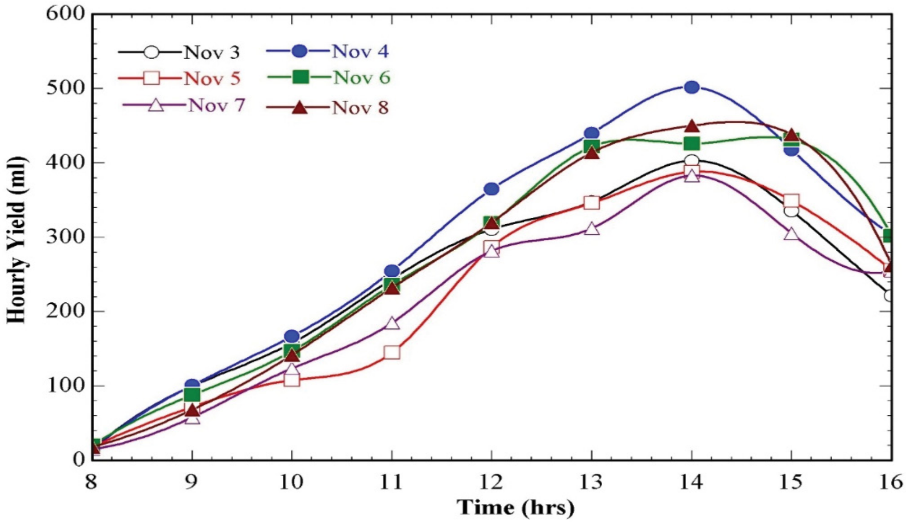


Fig. 9. Hourly yield variation vs. time for 3, 4, 5, 6, 7 and 8 November.

the conventional single slope solar still in MATLAB 2015. The mathematical model developed by Mishra et al. [30] is considered here for comparison of performance of the CSS and WISS systems presented here. The instantaneous thermal efficiency variation is calculated by Eqs. (1)–(3) as given by Mishra et al. [30].

The rate of heat consumption in evaporation and hourly yield can be obtained from:

$$\dot{q}_{\text{ew}} = h_{\text{ew}}\left(T_w - T_g\right) \quad (1)$$

$$m_{\text{ew}} = \frac{h_{\text{ew}}\left(T_w - T_g\right)}{l} \times 3{,}600\ \text{kg/m}^2\text{h} \quad (2)$$

Further, the instantaneous thermal efficiency for conventional solar still (when, $\dot{Q}_u = 0$) can be obtained as follows:

$$\eta_{i,\text{conventional}} = \frac{\dot{q}_{\text{ew}}}{I(t)} \quad (3)$$

The instantaneous thermal efficiency of the proposed WISS system against CSS systems is illustrated in Fig. 10. The duration for which the efficiency values are calculated is 800 to 1,600 h. The radiation value after this period is considerably lower while the distillate yield is on the rise and hence the value of efficiency for the hours beyond 1,600 is impractical. The efficiency trend for both the conventional and proposed system are observed to follow the same trend. Both the systems are found to peak their corresponding instantaneous thermal efficiency at 1,500 h. The efficiency trend is observed to decline gradually after 1,500 h following Eq. (3), since there is a decline in incident radiation after 1,500 h on all the days and a much steeper decline in corresponding mass of evaporated water as evident from Figs. 7 and 10, respectively.

The peak instantaneous thermal efficiency of the CSS system is 42.3%, 40.2% and 39.2% while that of the proposed system is 46.7%, 45.5% and 45.5% for November 3, 5 and 7 and November 4, 6 and 8 respectively. This clearly indicates a maximum efficiency gain of 19.1% at peak efficiency hour of 1,500 h corresponding to 46.7% and 39.2% for November 4 and November 7 respectively for the proposed WISS system over the CSS system. The minimum efficiency gain at 1,500 h is found to be 7.5% for the November 3 and November 6, 8 respectively. Hence it can be concluded that the proposed WISS system is at least 7.5% more efficient than the conventional system for the peak yield hour and at best 19.1% better than the conventional system in utilising the incident solar radiation for distillation. While all the physical and environmental parameters for both the systems is similar, the lead in hourly yield and instantaneous thermal efficiency can be attributed to the proposed glass wiper system.

8. Performance comparison for WISS system for peak performance day

The proposed WISS system here is an improvement over the CSS system. This modification is done without any physical or parametric changes made to the basic structure or operation of the existing CSS, hence the thermal model developed by Mishra et al. [30] is fairly applicable for the performance comparison of the proposed system.

A comparison of the performance in terms of hourly yield for proposed WISS system is presented against the corresponding results from the mathematical model obtained through MATLAB 2015 program. Here, since the mathematical models in previous literature and one developed by Mishra et al. [30] have an inherent limitation of assuming the glass to be clear throughout the distillation process, the theoretical values of the hourly yield are found to differ from the experimental yield by a larger margin when compared to that of the CSS system. The hourly and total yield (experimental) of the days with wiper operation are plotted as Yield$_{\text{th}}$ assuming that the system had no wiper on that particular day. It is found that the experimental results so obtained are remarkably close to the theoretical result expected for a conventional system for the same day.

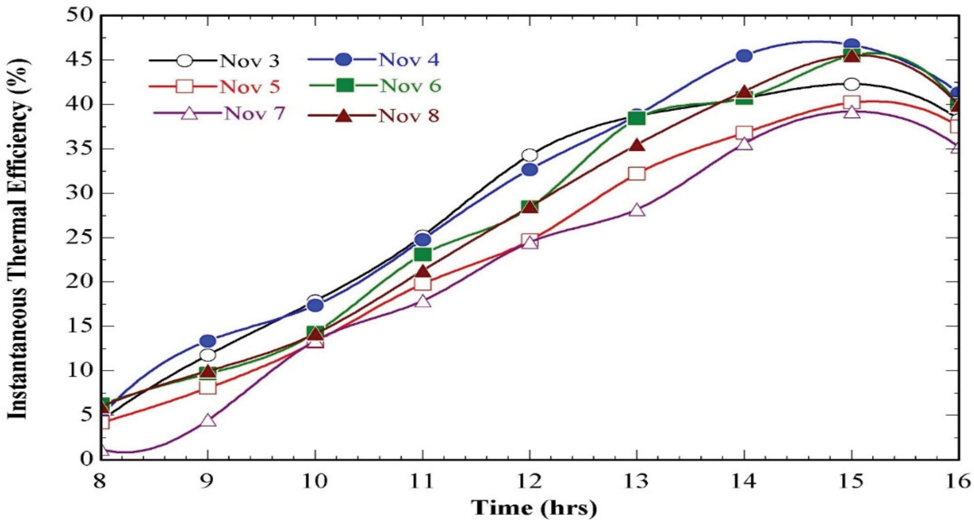


Fig. 10. Instantaneous thermal efficiency vs. time for 3, 4, 5, 6, 7 and 8 November.

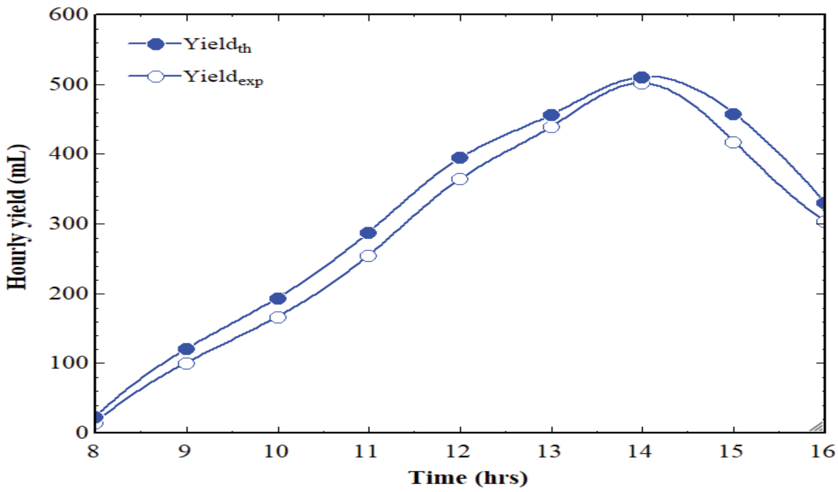


Fig. 11. Comparison of hourly yield (experimental and theoretical) for November 4.

8.1. Comparison of theoretical hourly yield with experimental hourly yield

Among all the 6 d, the proposed WISS system on November 4, with 2567 mL of total yield is found to be the highest total hourly yield obtained experimentally. The theoretical yield predicted by the mathematical model for the same day is found to 7.5% higher with 2777 mL of total predicted yield. Since November 4 is found to be the day with highest predicted and experimental yield values, Fig. 11 presents the comparison between the hourly yield Yield$_{th}$ and Yield$_{exp}$ for the day corresponding to WISS operation along with the difference between the theoretically predicted experimentally obtained yield values. The maximum difference between the predicted and experimental hourly yield for November 4 is obtained at 800 h when the predicted yield is found to be 34.9% higher than the experimental yield while the two curves are found to be closest at 1400 h with a mere difference of 1.8%. The maximum difference between the predicted and experimental yield for all other days is also found to occur at 800 h (Appendix1) while the minimum difference for other set of days is obtained at different hours between 1,200 to 1,600 h.

8.2. Comparison of experimental total yield vs theoretical total yield

The experimental and theoretical total yield for the operating hours from 800 to 1,600 h for both CSS and WISS across all the 6 d of experimentation is presented in Fig. 12. It can be inferred from the histogram that the days when the wiper integrated system is tested, the yield is found to be higher for all the three pair of days. The highest total yield as obtained experimentally for a WISS system on November 4 is 2,567 mL that is 8.2% smaller than the theoretically expected yield of 2,777 mL. For other set of days, the difference between the theoretically expected

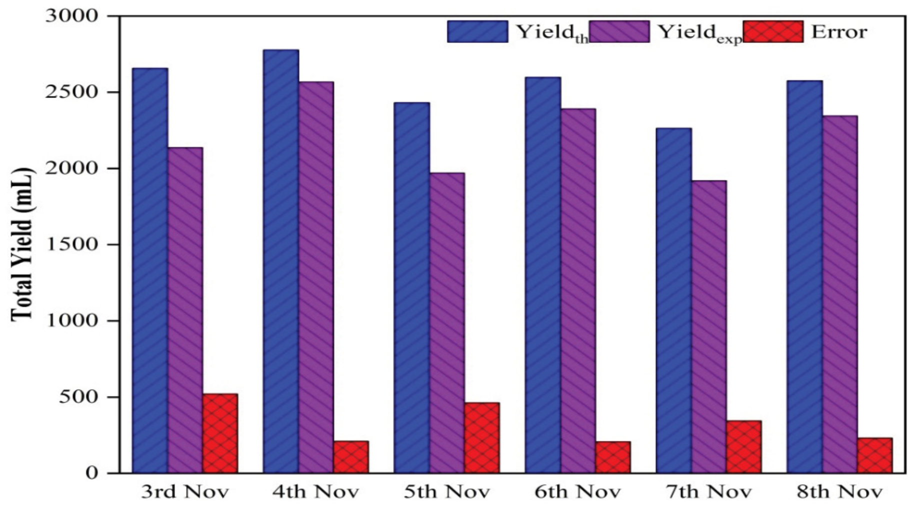


Fig. 12. Total yield variation (experimental and theoretical).

and experimentally obtained total yield values are 8.7% and 9.9% for November 6 and 8 respectively.

For the days with CSS system operation, the difference between theoretically expected and experimentally obtained total yield values is 19.6%, 19.0% and 15.6% for November 3,5 and 7 respectively. This clearly shows that that a wiper integrated single slope solar still system can compensate for the effect of condensate accumulation on the glass cover inner surface of the solar still and hence ensure an improved value of incident solar radiation reaching the basin.

The hourly yield variation for all the 6 d is given in Appendix 1.

9. Conclusions

- The maximum total yield considered for the duration of 800 to 1,600 h determined experimentally for the WISS is found to be 2,567 mL on November 4 while the highest total yield for the conventional system is found to be 1,919 mL on November 7. This concludes that the proposed system at best, gives a 33.7% higher yield than the conventional system.
- The experimental hourly total yield obtained for the WISS system is found to be in good agreement with the theoretical total yield obtained from mathematical modelling, with a maximum deviation of 9.9% from the theoretical value while for the CSS system, the deviation is found to be 19.6% maximum from the expected theoretical outcome. This further strengthens the claim that a solar still with proposed glass wiper can deliver hourly distilled water yield closer to the expected value.
- The total yield for proposed WISS system on 4, 6 and 8 November is found to be 20.2%, 21.4% and 22.1% higher than the CSS system for November 3, 5 and 7.
- The maximum instantaneous thermal efficiency of the proposed WISS system is found to be at maximum 19.1% higher than the conventional system for the peak yield hour of 1,500 h.
- The proposed system may be a possible solution for distillate loss to the basin due to smaller values of glass cover inclination and can be an integral part of all the solar still types with flat glass cover.
- The proposed solar still with novel wiper for inner surface of glass condensing cover is found to be a simple and effective way to deal with translucent glass cover caused due to fogging hence enables an additional 10% of incident solar radiation reaching the basin thus improving the distillate yield without affecting the normal still operation.

10. Future scope

The present work may be continued for further improvements in daily yield for the conventional single slope solar stills by incorporating different materials for wiping action. The work may also be tested for solar stills with small glass cover inclination. The wiper operation may be further optimised for summer peak conditions since the wiper may prove to be more effective during higher vapour generation and condensation rates achieved during summer. The proposed system may allow smaller values of glass inclination without loss of distillate and hence a considerably smaller system warm up time.

Symbols

m_{ew}	—	Mass of evaporated water, g
$\Delta T_{w\text{-}g}$	—	Temperature difference between basin water and inner glass surface, °C
l	—	Latent heat of vaporisation of water, kJ/kg
h_{ew}	—	Evaporative heat transfer coefficient, W/m^{2}K
$I(t)$	—	Incident solar radiation over the glass at the time t, W/m^2
$\dot{q}_{ew}$	—	Evaporative heat transfer rate, W
η_i	—	Instantaneous thermal efficiency, %
$\dot{q}$	—	Rate of heat transfer, W
R	—	Thermal resistance, m^{2}K/W
Yield$_{exp}$	—	Experimental distillate water yield obtained, mL

$Yield_{th}$	—	Theoretical distillate water yield obtained, mL
Nov	—	Month of November

Abbreviations

CSS	—	Conventional solar still
WISS	—	Wiper integrated solar still
GI	—	Galvanised iron
NIT	—	National Institute of Technology
RTD	—	Resistance Temperature Detector
PT	—	Platinum

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Appendix 1

	Experimental and theoretical hourly yield in mL											
Time	$Yield_{exp}$ (Nov 3)	$Yield_{th}$ (Nov 3)	$Yield_{exp}$ (Nov 4)	$Yield_{th}$ (Nov 4)	$Yield_{exp}$ (Nov 5)	$Yield_{th}$ (Nov 5)	$Yield_{exp}$ (Nov 6)	$Yield_{th}$ (Nov 6)	$Yield_{exp}$ (Nov 7)	$Yield_{th}$ (Nov 7)	$Yield_{exp}$ (Nov 8)	$Yield_{th}$ (Nov 8)
8	14	22	15	23	18	31	20	28	15	24	18	28
9	100	145	101	121	72	94	88	103	58	94	68	95
10	158	232	167	194	108	158	147	160	124	159	142	168
11	244	342	255	288	145	218	236	268	185	224	232	259
12	311	401	365	395	287	325	319	337	282	317	320	357
13	348	445	440	457	346	425	422	461	312	365	414	445
14	403	460	502	511	388	451	426	461	383	419	450	481
15	336	362	418	458	349	426	431	462	305	362	438	462
16	222	248	304	330	256	303	302	318	255	301	262	280
	2,136	2,656	2,567	2,777	1,969	2,431	2,391	2,598	1,919	2,263	2,344	2,575