Journal of Thermal Analysis and Calorimetry (2019) 138:3987–3995
https://doi.org/10.1007/s10973-019-08561-6

Experimental studies on inclined PV panel solar still with cover cooling and PCM

A. E. Kabeel[1] · Ravishankar Sathyamurthy[1,2] · S. A. El-Agouz[1] · A. Muthu manokar[3] · Emad M. S. El-Said[4]

Received: 4 October 2018 / Accepted: 4 July 2019 / Published online: 19 July 2019

Abstract

This work presents the experimental studies on the effect of mass stream rate of water (m_f), phase change material and cover cooling of an inclined solar panel basin solar still (ISPBSS). Experimental results revealed that cooling the entire surface of the glass cover of ISPBSS with fully opened flow of water produced the maximum distilled water. On varying m_f, the glass temperature is higher during the minimum m_f. With increased m_f from 7.35 to 13.32 and from 7.35 to 17.72 kg h^{-1}, the glass temperature is almost equivalent to the ambient temperature with fully opened flow cover cooling technique. The reduced glass temperature enhanced the rate of condensation. Similarly, the hourly instant efficiency of the ISPBSS with fully opened cover cooling is higher as compared with the similar ISPBSS without and with partially cover cooling condition. The highest hourly instantaneous efficiency of ISPBSS with partially and fully opened cover cooling is found as 85% and 88%, respectively.

Keywords Inclined solar still · PCM · Cover cooling · Solar energy

List of symbols

m_f Mass stream rate of water
M_w Mass of water
b_w Water film thickness
U_w Water film velocity
V_a Wind velocity

Abbreviations

CSS Conventional solar still
PCM Phase change material
FPC Flat plate collector
ISS Inclined solar still
ISPBSS Inclined solar panel basin solar still
PTC Parabolic trough collector

✉ A. E. Kabeel
kabeel6@hotmail.com

✉ Ravishankar Sathyamurthy
raviannauniv23@gmail.com; ravishankars05@outlook.com

[1] Mechanical Power Engineering Department, Faculty of Engineering, Tanta University, Tanta, Egypt

[2] Department of Automobile Engineering, Hindustan Institute of Technology and Science, Chennai, Tamil Nadu 603103, India

[3] Department of Mechanical Engineering, B.S. Abdur Rahman Crescent Institute of Science and Technology, Chennai, Tamil Nadu, India

[4] Mechanical Engineering Department, Faculty of Engineering, Fayoum University, Fayoum, Egypt

Introduction

For a social and economic development of health, food, energy and environment, water appears to be the main aspect. At the present hour, the available quality drinking water does not meet its demand. The shortage of freshwater resources is mainly due to physical shortage of water in the surface and groundwater resources, shortage due to developmental activities through advanced technologies and irregular supply of freshwater through various institutions. According to the report of IBRD/IDA, out of 7.2 billion population nearly one-third of people suffer from inaccessibility to potable water. According to WHO and UNICEF, 3 out of 10 people in the world lack access to safe drinking water. Desalination using renewable energy is one of the best methods to meet the freshwater requirements using low-cost energy [1–12]. So, researchers aim to maximize the use of a clean, renewable and inexpensive energy source such as solar energy, in low-capacity thermal desalination units in desalination systems [13–15].

Sathyamurthy et al. [16] analyzed a ISS with baffle plates numerically under varying the m_f and inlet water temperature. It was derived that increasing the m_f resulted in reduced water temperature due to faster movement of water in the basin and it absorbs minimum heat energy from the basin. Sarhaddi et al. [17] comparatively studied the energy and exergy of a weir cascaded solar still. From the publication, it was found that the exergy efficiency improved with the addition of phase change material (PCM), while the energy efficiency decreases. Similarly, the increase in ambient temperature leads to the decrease in the thermal and exergy efficiency. Also, the exergy efficiency of the system with PCM was lower during the morning hours, whereas the exergy efficiency was higher during the off-shine hours in the clear sunny condition.

Fathy et al. [18] improved the freshwater yield from a conventional double-slope solar still by integrating a solar parabolic trough collector (PTC) and oil heat exchanger with fins inside the basin. Results revealed that the influence of PTC and fin-type heat exchanger improved the water temperature by 50% as compared to solar still without integration. Similarly, increasing the water depth in the basin resulted in lower yield. Furthermore, continuous tracking mechanism of a PTC improved the freshwater yield to a maximum of 1.8 kg h^{-1} which is 11.11% higher as compared to solar PTC with the non-tracking mechanism. The daily yield was improved two times than the conventional double-slope solar still with fixed PTC, while the solar still with tracking PTC was improved by 2.5 times. An accumulated yield of 10.93 and 8.53 kg m^{-2} was observed in the case of least water depth on solar still with and without tracking mechanism, respectively. On the economic analysis, this type of tracking mechanism requires higher initial investment and it produced only a marginal increase in the freshwater yield as compared to solar still with fixed PTC.

Muftah et al. [19] theoretically analyzed a modified stepped solar still with fins, and internal and external reflectors. In addition to the above modification, an additional condenser is placed in such a way that the vapor formed was condensed in a separate chamber. In this arrangement, the environmental parameters were not influenced for condensation. Results revealed that water and glass temperatures of the modified solar still were improved as compared to solar still without modification. Similarly, the influencing parameter for enhanced condensation is the water–glass temperature difference which was almost similar to the solar still with and without modifications during the sunshine hours, whereas during the off-shine hours the water–glass temperature difference is higher for solar still with modification. On the other hand, the freshwater yield was improved from their proposed technique from 6.9 to 8.9 kg m^{-2}.

Shanmugam et al. [20] comparatively analyzed the conventional solar still (CSS) with a cotton wick, fins, jute cloth, PCM and nanoparticles for improving the yield. Results showed that the influence of fins and cotton wick with PCM and nanoparticle produced a maximum yield of 9.36 kg m^{-2} which is two times higher than the CSS with a cotton wick, PCM and nanoparticles as absorbing medium. The maximum instantaneous efficiency of the CSS with PCM and nanoparticle during summer and winter was found to be 59.14 and 27.13%, respectively.

Pal et al. [21] experimentally analyzed a double-slope solar still with multi-wick arrangement. Results showed that there was a significant improvement in the productivity from the multi-wick solar still from the modified solar still and found as 11.94%, while the depth of water decreased from 2 to 1 cm during winter condition. Similarly, the freshwater yield was improved to about 9% with the use of black cotton wick while comparing it with jute cloth material. The first literature which shows the single- and double-basin ISS was given by Aybar et al. [22], and El-Agouz et al. [23] theoretically studied the performance of an ISS by recycling the hot water to the ISS basin using the water pump. The performance of both stills was analyzed by varying mass of water (M_w), water film thickness (b_w), velocity (U_w) and wind velocity (V_a) In the first analysis, b_w was varying from 0.25 to 3 mm and $M_w = 30$ kg, $U_w = 0.01$ m s^{-1} and $V_a = 4$ m s^{-1} were kept constant. It was found that still production and efficiency were higher in model 2 (ISS with closed loop) than those of model 1 (ISS with open loop) as of higher temperature difference between water and glass. In the second analysis, U_w changes from 0.01 to 0.05 m s^{-1} and $M_w = 30$ kg, $b_w = 1$ mm and $V_a = 4$ m s^{-1} were kept constant. It was found that the increases in m_f resulted in a quicker flow of water in the ISS basin; hence, it has less time to utilize the heat from the ISS basin.

Alaudeen et al. [24] fixed stepped tray inside a CSS with inclined flat plate collector (FPC) and energy storage materials for augmenting the yield of freshwater. It was found that integrating the FPC with wick and sponge, wick and rock, and sponge produced the maximum yield of about 1305 and 1745 kg m^{-2}, respectively. The first literature report on SSS with glass cover cooling methods has been given by El-Samadony et al. [25, 26]. The higher temperature difference between the water and glass produced the maximum solar still efficiency. It was recommended that the yield increases up to 2.87% by the water flowing into the basin. The performance of the SSS with copper tray basin was published by Abujazar et al. [27, 28]. This solar still have 55.6% higher evaporation area than the CSS. The thermodynamic analysis and water quality analysis of the CSS with heat exchanger and coarse aggregate were experimentally analyzed by Dhivagar and

Sundararaj [29]. Results revealed that the exergy and energy efficiency of modified solar still is higher as compared to that of the CSS. The results on water quality analysis revealed that the pH value of potable water produced during the trials was in the range of 6.5 to 7.2 and it is within the drinking water standards.

Sakthivel and Arjunan [30] carried out a thermodynamic analysis on the effect of cotton wick energy material on the CSS. Energy and exergy efficiency of the CSS revealed that the optimum thickness of cotton wick material was found at 6 mm, whereas [31] performed experiments on the CSS with hollow fin filled with wax material on varying water depth. Experimental results revealed that the potable water produced from modified solar still with phase change material was increased to about 94% and the potable water produced from the CSS with fins was increased by 64% than the CSS without fins.

From the literature, it is identified that there are only a few works related to the simultaneous production of power and yield from the ISPBSS. In the present study, the effect of cover cooling and the effect of m_f in the PV panel surface and effect of PCM heat energy storage were experimentally studied on the performance for simultaneous production of power and distillate yield. Furthermore, the effect of cover cooling on thermal efficiency of ISPBSS is explained in detail.

Experimental

Figure 1 shows the schematic and experimental photograph of an ISPBSS with cover cooling arrangement. The experimental setup consists of 1.6 m^2 area of inclined PV panel with side walls at a height of 0.15 m. Glass cover with a thickness of 4 mm is used for the present study with a transmissivity of 0.92. Over the glass cover, piping arrangements were provided to cool the entire glass surface over a length of 2 m. Holes are provided in the piping of glass cover at frequent intervals to ensure that the entire glass cover is cooled. The feed water to cool the glass cover is made through gravity-free flow to extract the heat energy stored in the glass cover, where the constant feed of cooling water to cover is maintained by providing a float arrangement provided in the separate storage tank. To ensure the constant free flow arrangement of water inside the inclined basin, ball and float arrangement is provided in the storage tank and the constant head level is maintained. The free flow arrangement inside the basin is made similar to the arrangements made for cover cooling. To augment the freshwater yield from the modified solar still, additional arrangement by adding PCM at the bottom of the basin is made to ensure that the heat is utilized during the off-shine hours. A constant mass of 10 kg is used at the bottom of the PV panel to extract the heat from the PV panel to reach the melting point of PCM material. Simultaneously, the power production from the PV panel is improved by varying the m_f inside the inclined surface. To reduce the fouling effect, the panel is frequently cleaned with water to ensure that the power production from the ISPBSS is not affected by the deposition of salt over the clear glass surface. The entire experiments were conducted during summer in the month of May 2018 for the climatic condition of Chennai, India, in the rooftop of Department of Mechanical Engineering, SA Engineering College.

The power output from the PV panel is estimated using a calibrated voltmeter and ammeter. The solar intensity and wind velocity were measured using solarimeter (TES1333R) and wind anemometer (AM4836) with data logging facility. The other parameters such as panel, outlet water and glass temperatures were measured using RTD-PT100 a sensor, while the distillate collected is measured using a calibrated flask.

Results and discussion

The major phenomenon of the condensation process of solar desalination unit is the ambient condition and glass cover temperature. There is also a greater possibility of vapor to leak through the condensate pipe at higher temperature of glass as the continuous evaporation leads to reaching the saturation temperature. Figures 2–4 show the diurnal variations in the glass temperature of ISPBSS with two different modes of cover cooling technique employed under three different m_f inside the ISPBSS. It can be observed that the temperature of glass for a constant m_f inside the inclined basin is higher to about 27% as compared to the increased flow rate of 13.35 kg h^{-1} under fully closed condition (without cooling glass cover). This is mainly due to the increase in vapor temperature accumulated in the chamber of ISPBSS. Similarly, glass temperature decreases with partially opened condition and fully opened condition. The extraction of heat energy through the glass surface decreases the temperature of glass, thus increasing the temperature difference between water and glass for enhanced condensation. The maximum cover temperature for ISPBSS without cover cooling is found as 77.7, 66.1 and 60.0 °C for 7.35, 13.35 and 17.72 kg h^{-1} of m_f inside the inclined surface, respectively. For the ISPBSS with cover cooling under fully opened condition, the cover temperatures are found to be 31.0, 29.3 and 29.0 °C for the same m_f. The cover temperature under partially opened condition was increased by 35.56, 34.57 and 28.87% for 7.35, 13.35 and 17.72 kg h^{-1}, respectively.

The variations in the average glass cover temperature of ISPBSS with and without cooling medium are given in

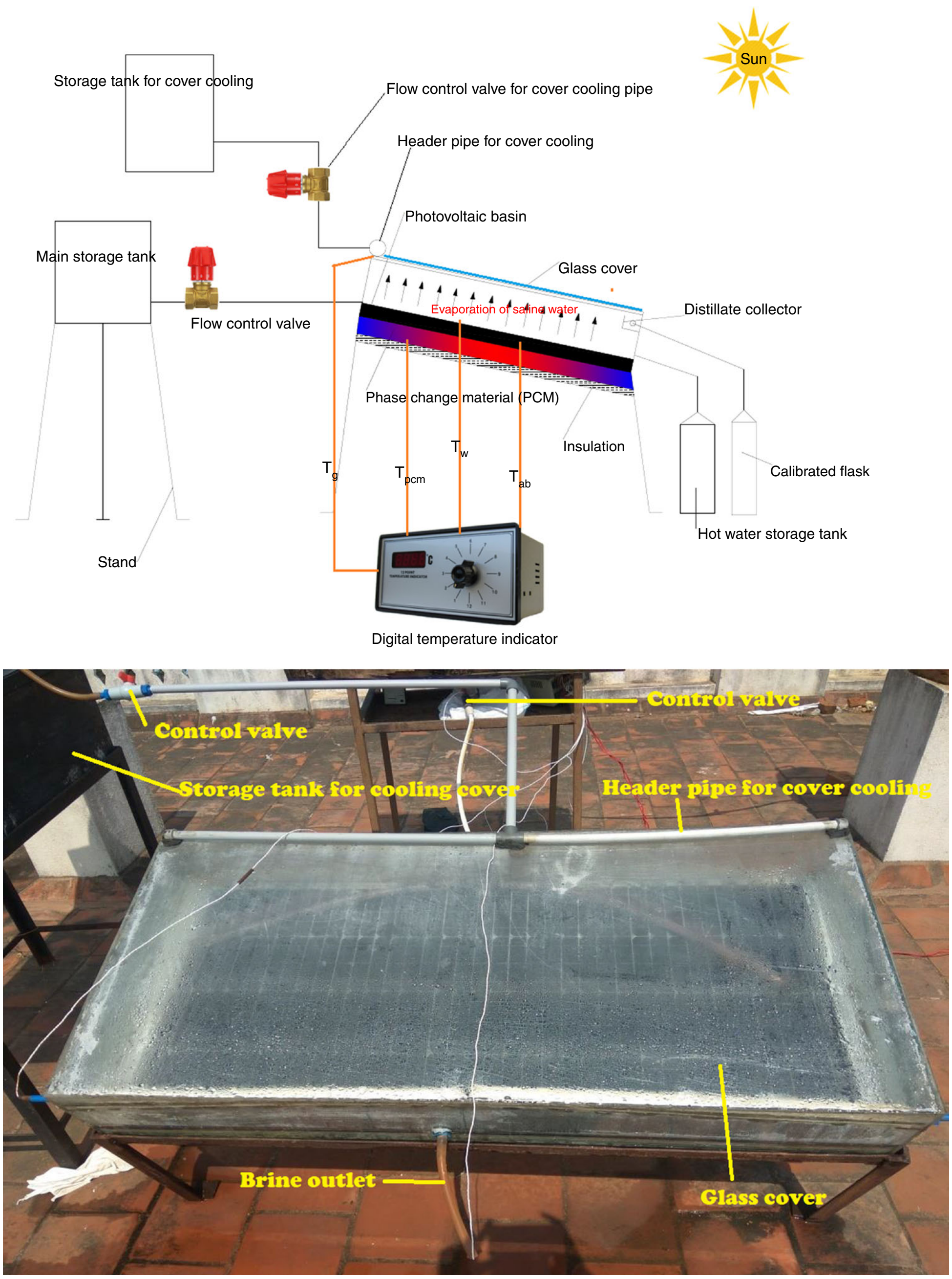

Fig. 1 Schematic and photograph of the experimental setup with cover cooling and PCM

Table 1. It can be observed that the glass cover temperature of the ISPBSS decreases with the increase in m_f inside the basin of the inclined surface. This increase is due to the effect of an increase in the vapor temperature inside the closed chamber. Subsequently, the increase in the m_f inside the basin reduces the temperature of cover with respect to partially closed and fully closed conditions as compared to the ISPBSS without any cover cooling arrangements. The average reduction in the temperature of glass for maximum m_f is found to be 28.87 and 49.9% for partially opened and fully opened conditions with respect to the ISPBSS without cover cooling. The cooling of the glass cover is enhanced by 35.56 and 53.97% for partially and fully opened conditions, respectively, at a minimum m_f between the parallel plates.

Figures 5 and 6 show the variations in the instantaneous hourly thermal efficiency of the ISPBSS with PCM operated with cover cooling under partially and fully opened

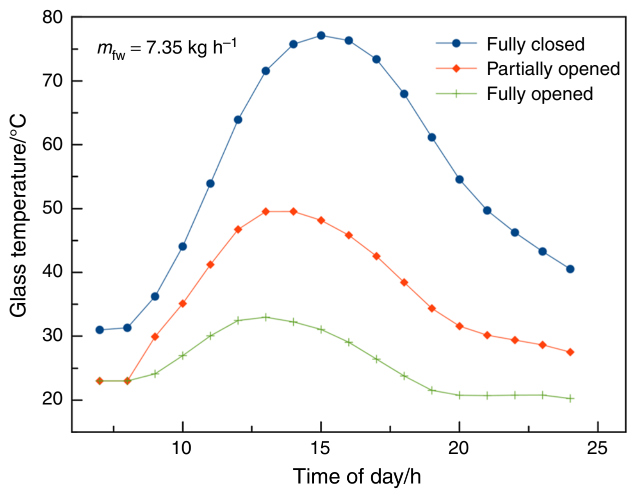

Fig. 2 Diurnal variations in glass temperature for three different modes of operation for cover cooling at a constant in the PV absorber surface ($m_{f,w}$ = 7.35 kg h^{-1})

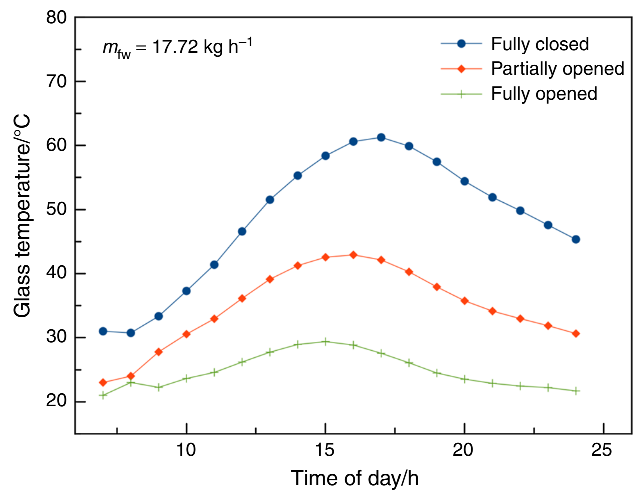

Fig. 4 Diurnal variations in glass temperature for three different modes of operation for cover cooling at a constant m_f in the PV absorber surface ($m_{f,w}$ = 17.35 kg h^{-1})

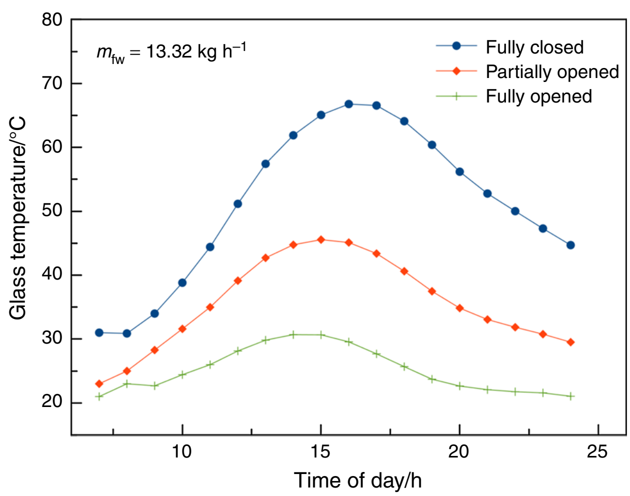

Fig. 3 Diurnal variations in glass temperature for three different modes of operation for cover cooling at a constant m_f in the PV absorber surface ($m_{f,w}$ = 13.35 kg h^{-1})

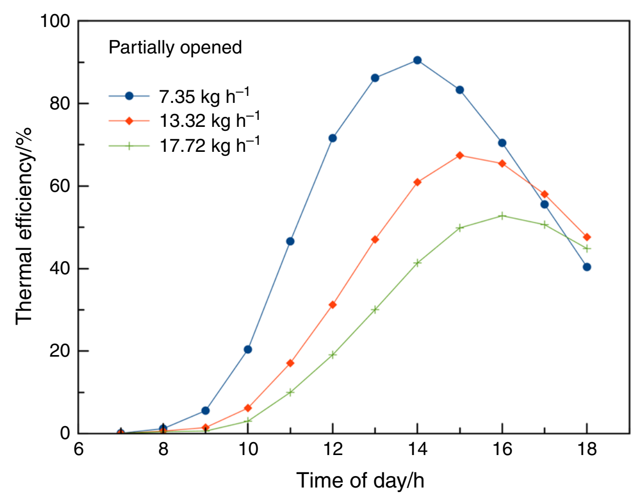

Fig. 5 Variations in hourly instantaneous thermal efficiency of ISPBSS under varying m_f (partially opened condition)

Table 1 Variations in the daily average temperature of glass cover in the ISPBSS with and without cover cooling

Different m_f	Daily average temperature of glass/°C			Decrease in cover temperature/%		
	Fully closed	Partially opened	Fully opened	Fully closed	Partially opened	Fully opened
7.35/kg h^{-1}	55.4	35.7	25.5	Ref	35.56	53.97
13.32/kg h^{-1}	51.2	33.5	25.2		34.57	50.78
17.72/kg h^{-1}	48.5	34.5	24.3		28.87	49.90

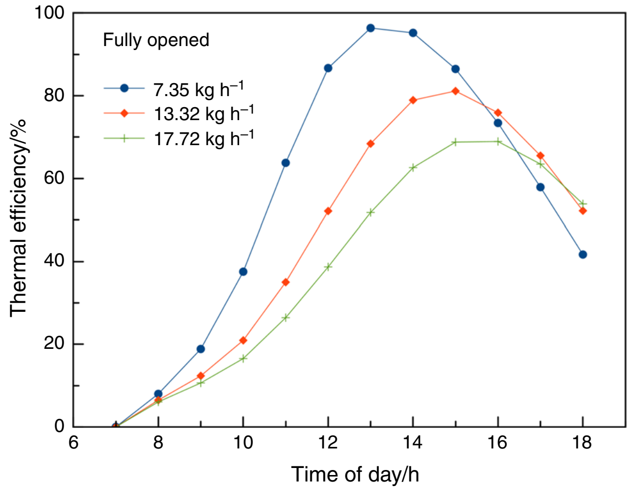

Fig. 6 Variations in hourly instantaneous thermal efficiency of ISPBSS under varying m_f (fully opened condition)

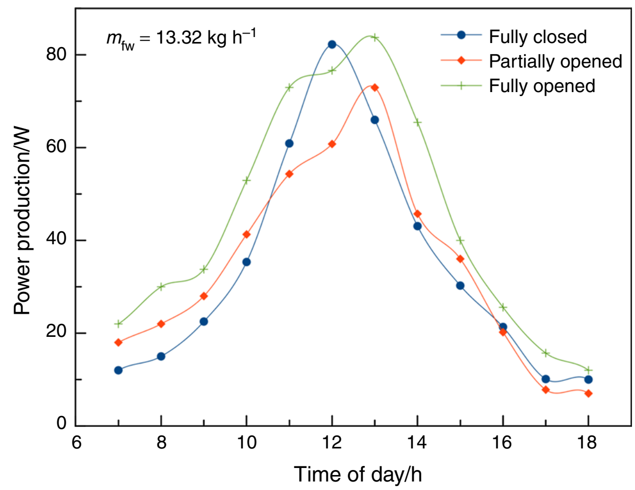

Fig. 8 Variations on power production under different cases and m_f at 13.32 kg h^{-1}

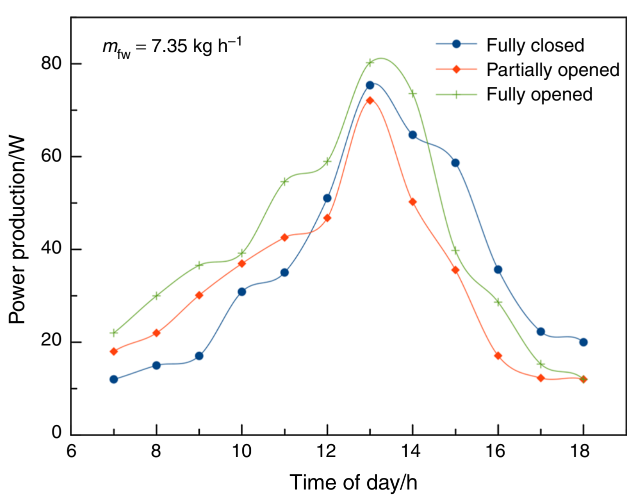

Fig. 7 Variations on power production under different cases and m_f at 7.35 kg h^{-1}

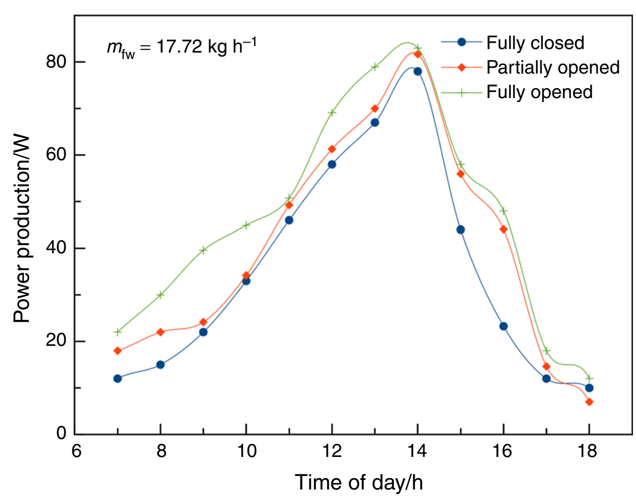

Fig. 9 Variations on power production under different cases and m_f at 17.72 kg h^{-1}

conditions. It can be seen that the hourly thermal efficiency of the modified solar still is maximum to about 90.3% and 97% for partially and fully opened conditions, respectively, at minimum m_f inside the inclined surface. This is mainly due to the rejection of larger amount of heat by the vapor accumulated between the parallel plates (PV panel and glass cover) to the flowing water over the exterior inclined glass surface. With the increase in m_f, the efficiency is found to be decreasing as the interaction of water with solar intensity is minimum for a reduction in thermal efficiency and yield. Similarly, the values of thermal efficiency are higher in the case of fully opened condition for all the cases as compared to the partially opened condition.

The thermal efficiency of the ISPBSS is estimated using [32],

$$\eta_{th} = \frac{m_{e,w-g} \times h_{fg}}{I(t) \times A_w \times 3600} \times 100 \quad (1)$$

Figures 7–9 show the hourly variation in power production of ISPBSS under different m_f. It can be observed that the effect of cover cooling on the glass surface of ISPBSS increases the rate of power production from the panel as the vapor is condensed at the faster rate in the inner cover surface. The maximum power production from the PV panel for 7.35, 13.32 and 17.72 kg h^{-1} was found to be 80, 82 and 83 W, respectively, at 1 PM (13:00 h) with fully opened flow of water over the cover surface. Figure 9 shows that at higher m_f with continuous flow of water over the cover surface is lower as compared to

Table 2 Variation in yield and improvement in freshwater from the ISPBSS with and without cover cooling

m_f inside the inclined basin	Yield/kg			Improvement in yield/%	
	Without cover cooling	With cover cooling (partially opened)	With cover cooling (fully opened)	With cover cooling (partially opened)	With cover cooling (fully opened)
7.35/kg h^{-1}	10.4	12.29	14.17	18.17	36.25
13.32/kg h^{-1}	8.32	10.05	12.92	20.79	55.29
17.72/kg h^{-1}	6.94	8.46	11.8	21.90	70.03

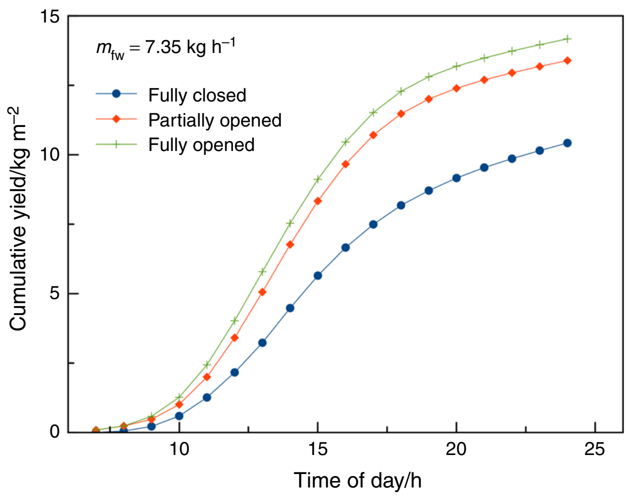

Fig. 10 Variations on cumulative yield under different cases and constant m_f at 7.35 kg h^{-1}

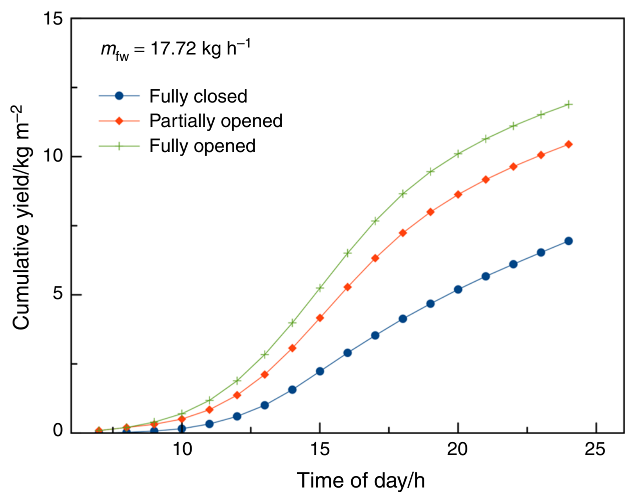

Fig. 12 Variations on cumulative yield under different cases and constant m_f at 17.72 kg h^{-1}

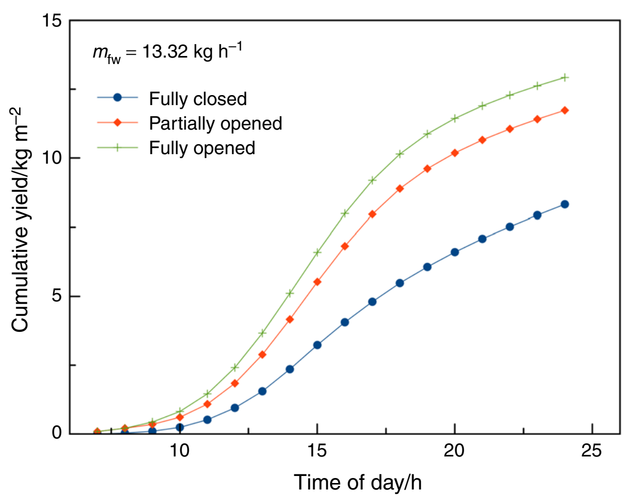

Fig. 11 Variations on cumulative yield under different cases and constant m_f at 13.32 kg h^{-1}

without flow and with partially opened as it is due to the accumulation of water vapor evaporating at slower rate. This phenomenon is majorly due to effect of the decreasing retention time of water with solar intensity. Similarly, there is an increase in the power production during off-shine hours as the vapor evaporated from the surface is completely converted into freshwater with heat extraction by the flowing water.

The variations in the yield of freshwater from the ISPBSS with and without cover cooling are shown in Table 2 and Figs. 10–12. It can be observed that the freshwater yield is increased to about 18.17 and 36.25% for the constant m_f in the PV absorber surface ($m_{f,w}$ = 7.35 kg h^{-1}) for partially and fully opened conditions, respectively, for cover cooling over the glass surface as compared to the ISPBSS without modifications. Similarly, an increased m_f resulted in the decreases in the freshwater yield. This is because the retention time of water inside the basin is lower due to the gravity-free flow to the lower end of the inclined surface. While analyzing the yield at lower m_f in the PV absorber surface, the yield is higher as compared to other two m_f. With the interaction of water on the outside glass surface, the maximum amount of heat rejected by the vapor is gained, and thus, the temperature of the glass surface is reduced. During the partially opened condition, the flow of water is reduced to half the value as compared to fully opened condition, and hence, the reduction in cover temperature depends on the ambient parameters such as the temperature of water flowing over the cover surface, ambient temperature and wind velocity. To ensure that the flow rate is not varied, a float arrangement is kept in the storage tank.

Conclusions

Experimental studies on the ISPBSS with PCM were conducted under the Chennai climatic conditions. For enhanced performance and improved yield, partially and fully opened cover cooling methods were employed, and the performance of the ISPBSS and improvement in power production and freshwater yield were analyzed. Experimental studies revealed that the ISPBSS performance and PV power production depend on the panel surface, cover and water temperature. Increasing the m_f reduced the yield of freshwater produced by 50%, whereas there is an increase in the PV power generation. In all the cases of the effect of cover cooling by fully opened method, the PV power generation is improved by 10% as compared to the ISPBSS without cover cooling arrangement. Similarly, the total freshwater yields under minimum m_f in the PV surface with partially and fully opened cover cooling were found to be 12.29 and 14.17 kg m^{-2}, respectively. The yield of freshwater is improved by 18.17 and 36.25% for partially and fully opened cover cooling arrangements, respectively, under least m_f.

References

1. Sathyamurthy R, El-Agouz SA, Nagarajan PK, Subramani J, Arunkumar T, Mageshbabu D, Madhu B, Bharathwaaj R, Prakash N. A review of integrating solar collectors to solar still. Renew Sustain Energy Rev. 2017;77:1069–97.
2. Praveen kumar B, Prince Winston D, Pounraj P, Muthu Manokar A, Sathyamurthy R, Kabeel AE. Experimental investigation on hybrid PV/T active solar still with effective heating and cover cooling method. Desalination. 2018;435:140–51.
3. Sathyamurthy R, Harris Samuel DG, Nagarajan PK, El-Agouz SA. Review of different solar still for augmenting fresh water yield. J Environ Sci Technol. 2015;8(6):244–65.
4. Harris Samuel DG, Nagarajan PK, Arunkumar T, Kannan E, Sathyamurthy R. Enhancing the solar still yield by increasing the surface area of water—a review. Environ Prog Sustain Energy. 2015. https://doi.org/10.1002/ep.12280.
5. Manokar AM, Prince Winston D, Kabeel AE, El-Agouz SA, Sathyamurthy R, Arunkumar T, Madhu B, Ahsan A. Integrated PV/T solar still-a mini-review. Desalination. 2018;435:259–67.
6. Nagarajan PK, et al. Analysis of an inclined solar still with baffles for improving the yield of fresh water. Process Saf Environ Protect. 2017;105:326–37.
7. Sathyamurthy R, et al. Experimental investigation on a semi-circular trough-absorber solar still with baffles for fresh water production. Energy Convers Manag. 2015;97:235–42.
8. Kabeel AE, Arunkumar T, Denkenberger DC, Sathyamurthy R. Performance enhancement of solar still through efficient heat exchange mechanism—a review. Appl Therm Eng. 2017;114:815–36.
9. Pounraj P, Prince Winston D, Kabeel AE, Praveen Kumar B, Muthu Manokar A, Sathyamurthy R, Cynthia Christabel S. Experimental investigation on Peltier based hybrid PV/T active solar still for enhancing the overall performance. Energy Convers Manag. 2018;168:371–81.
10. Manokar AM, Prince Winston D, Kabeel AE, Sathyamurthy R. Sustainable fresh water and power production by integrating PV panel in inclined solar still. J Clean Prod. 2018;172:2711–9.
11. Manokar AM, et al. Comparative study of an inclined solar panel basin solar still in passive and active mode. Sol Energy. 2018;169:206–16.
12. Arunkumar T, Denkenberger D, Velraj R, Sathyamurthy R, Tanaka H, Vinothkumar K. Experimental study on a parabolic concentrator assisted solar desalting system. Energy Convers Manag. 2015;105:665–74.
13. Kabeel AE, Abdelgaied M, El-Said EMS. Study of a solar-driven membrane distillation system: evaporative cooling effect on performance enhancement. Renew Energy. 2017;106:192–200.
14. Kabeel AE, El-Said EMS. Technological aspects of advancement in low-capacity solar thermal desalination units. Int J Sustain Energy. 2013;32(5):315–32.
15. Kabeel AE, El-Said EMS. Development strategies and solar thermal energy utilization for water desalination systems in remote regions: a review. Desalination Water Treat. 2014;52(22–24):4053–70.
16. Sathyamurthy R, Harris Samuel DG, Nagarajan PK. Theoretical analysis of inclined solar still with baffle plates for improving the fresh water yield. Process Saf Environ Protect. 2016;101:93–107.
17. Sarhaddi F, Tabrizi FF, Zoori HA, Mousavi SAHS. Comparative study of two weir type cascade solar stills with and without PCM storage using energy and exergy analysis. Energy Convers Manag. 2017;133:97–109.
18. Fathy M, Hassan H, Salem Ahmed M. Experimental study on the effect of coupling parabolic trough collector with double slope solar still on its performance. Sol Energy. 2018;163:54–61.
19. Muftah AF, Sopian K, Alghoul MA. Performance of basin type stepped solar still enhanced with superior design concepts. Desalination. 2018;435:198–209.
20. Shanmugan S, Palani S, Janarthanan B. Productivity enhancement of solar still by PCM and Nanoparticles miscellaneous basin absorbing materials. Desalination. 2018;433:186–98.
21. Pal P, Yadav P, Dev R, Singh D. Performance analysis of modified basin type double slope multi-wick solar still. Desalination. 2017;422:68–82.
22. Aybar HŞ, Irani F, Arslan M. Performance analysis of single and double basin-inclined solar water distillation systems with and without black-fleece wick. Desalination Water Treat. 2016;57(37):17167–81.
23. El-Agouz SA, El-Samadony YAF, Kabeel AE. Performance evaluation of a continuous flow inclined solar still desalination system. Energy Convers Manag. 2015;101:606–15.
24. Alaudeen A, Johnson K, Ganasundar P, Syed Abuthahir A, Srithar K. Study on stepped type basin in a solar still. J King Saud Univ Eng Sci. 2014;26(2):176–83.
25. El-Samadony YAF, Kabeel AE. Theoretical estimation of the optimum glass cover water film cooling parameters combinations of a stepped solar still. Energy. 2014;68:744–50.
26. El-Samadony YAF, El-Maghlany WM, Kabeel AE. Influence of glass cover inclination angle on radiation heat transfer rate within stepped solar still. Desalination. 2016;384:68–77.

27. Abujazar MSS, Fatihah S, Kabeel AE. Seawater desalination using inclined stepped solar still with copper trays in a wet tropical climate. Desalination. 2017;423:141–8.
28. Abujazar MSS, et al. Productivity modelling of a developed inclined stepped solar still system based on actual performance and using a cascaded forward neural network model. J Clean Prod. 2018;170:147–59.
29. Dhivagar R, Sundararaj S. Thermodynamic and water analysis on augmentation of a solar still with copper tube heat exchanger in coarse aggregate. J Therm Anal Calorim. 2019;136(1):89–99.
30. Sakthivel TG, Arjunan TV. Thermodynamic performance comparison of single slope solar stills with and without cotton cloth energy storage medium. J Therm Anal Calorim. 2019;137(1):351–360
31. Kumar TS, Jegadheeswaran S, Chandramohan P. Performance investigation on fin type solar still with paraffin wax as energy storage media. J Therm Anal Calorim. 2018;136(1):101–12.
32. Elshamy SM, El-Said EMS. Comparative study based on thermal, exergetic and economic analyses of a tubular solar still with semi-circular corrugated absorber. J Clean Prod. 2018;195:328–39.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.