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Experimental study on effect of different mass flow rate in an inclined solar panel absorber solar still integrated with spiral tube water heater

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ABSTRACT

This paper aims to analyze the performance of the inclined solar panel basin (ISPB) still integrated with a spiral tube collector (STC) at diversified mass flow rate of water (m_f). The maximum freshwater obtained at the m_f at 1.8, 3.2 and 4.7 kg/h is 8.1, 6.9 and 6.1 kg, respectively. The daily average thermal and exergy efficiency of the ISPB still integrated with the STC at the m_f at 1.8, 3.2 and 4.7 kg/h is 47.9%, 39.3% and 31.02% and 9.8%, 7.9% and 5.6%, respectively. When the m_f increases, there are a decreases in the still distillate yield, thermal and exergy efficiency.

Keywords: Active inclined solar panel basin solar still; Effect of mass flow rates; Freshwater

1. Introduction

Sustainable power source plays an important role in the movement of worldwide advancement in various routes because of its feasible nature. The developing interest for utilization of limited energy sources has expanded extensively over a time of a very long while, to the detriment of nature. This has prompted the development of a few natural issues, for example, a dangerous atmospheric change in some countries and the increasing of the demand for potable water. Solar energy-based desalination is a potential solution for the shortage of freshwater, because of the plenitude and accessibility of both salt water and sun energies (Manokar et al. 2018).

Alaudeen et al. 2018 researched a stepped tray basin sequential solar still with the inclined flat plate collector (FPC) together with a conventional basin type solar still. The experiments were conducted by the wick, the wick with coconut coir and sponge, the wick with wooden chip and pebbles, the wick with sand and wick with coal, pebbles and sponge. Results of the proposed system were compared with the CSS. It was found that an integrating the FPC with wick and sponge, wick and rock, sponge produced the maximum distilled of about 1,305 and 1,745 kg/m^2, respectively. Sharon et al. 2017 fabricated the ISS with partitioned absorber and wick absorber and conducted the experiments on the ISS at two different conditions (i) the ISS with splitting the absorber for reducing the volume of the basin water. (ii) the ISS with a black blended woolen wick. It was reported that the ISS with partitioned absorber and wick basin produced the maximum yield of about 4.475 and 4.620 L, respectively. Hansen et al. 2015 studied the ISS with innovative wick materials and wire mesh in the absorber plate. In this experiment, three different absorber plates were used (i) flat absorber plate, (ii) rectangular stepped absorber plate, (iii) weir absorber. The freshwater production was increased about 71% in the case of weir mesh absorber plate with water coral fleece than the flat absorber plate. Naveen Kumar et al. 2017, Panchal et al. 2018 and Kabeel et al. 2019 theoretically studied the performance of triangular pyramid solar still (TPSS) integrated to the ISS with baffles. Theoretical analysis has been made by varying the water mass in the TPSS (20 to 100 kg). It was submitted that the TPSS and the TPSS integrated with the ISS produced the maximum hourly productivity of 0.6 and 1.3 kg/m^2, respectively, at 20 kg of water mass. The maximum daily productivity from the TPSS and the TPSS integrated with the ISS was 3.2 and 7.2 kg/m^2, respectively, at minimum water depth. It was submitted that as increasing the water mass from 20 to 100 kg, the

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yield from the still decreases about 6%–46% at morning and increases about 46%–86% at evening. The reason for higher productivity at evening was water storage effect. Higher the water mass in the basin can store the available heat energy and produced the yield at evening and night time. The effect of insulation on the performance of the inclined solar panel basin (ISPB) still and the comparative studies of the passive and active ISPB still was studied by Manokar et al. 2018. From the literatures, it is inferred that only research was carried out an active ISS. Hence the main objective of the present study is experimental investigation on ISPB still integrated with the spiral tube collector (STC) at different mass flow rate of water.

2. Design and construction of the ISPB still integrated with the STC

In an ISPB still integrated with the STC, the salt water from the cylindrical water storage tank is fed into a solar water heater at a constant m_f. The water flowing inside the absorber tube of solar water heater gets heated and heated water is again fed into the passive ISPB still. The schematic diagram of the ISPB still integrated with the STC is shown in Fig. 1. The photographic view of the ISPB still integrated with the STC is shown in Fig. 2. A STC solar water heater was fabricated comprising of a flat spiral tube solar collector, storage tank and control valve. The flat collector of 0.9 m (L) × 0.6 m (W) × 0.004 m (H) was fabricated with 20 mm thickness wooden box covered with 4 mm thick window glass. This water heater was mounted on supporting steel structure. 10 mm diameter and 1 mm thick copper tube in spiral shape with three winding (with 50 mm gap between successive windings) was used to circulate water in the collector. Cylindrical storage tank made up of plastic with 50 liters capacity was mounted on a steel stand.

3. Results and discussion

3.1. Hourly variations of solar irradiance, wind speed, atmospheric temperature and collector cover temperature

Variations of the solar intensity and atmosphere temperature during the study of an ISPB still integrated with the STC are shown in Figs. 3a and b. From the graph, it is clear that at the morning session solar intensity increases and reached its peak value at 1 P.M and at the evening session it is decreasing. The maximum solar intensity of 880, 870 and 900 W/m^2 and the daily average solar intensity of 699, 696 and 719 W/m^2 are noted on 1.8.2017, 4.8.2017 and 6.8.2017, respectively. The maximum atmosphere temperature of 33°C, 32°C and 35°C is noted on 1.8.2017, 4.8.2017 and 6.8.2017, respectively. During the experimental day, the daily average atmospheric temperature is between 30°C and 33°C.

Variations of wind speed and the collector cover temperature during the study of an ISPB still integrated with the STC are plotted in Figs. 4a and b. During the investigational day, the daily average wind speed is noted as 1.1, 1.8 and 2 m/s on 1.8.2017, 4.8.2017 and 6.8.2017, respectively. The maximum collector cover temperature of an ISPB still integrated with the STC is 53°C, 52°C and 47°C on 1.8.2017, 4.8.2017 and 6.8.2017, respectively. The daily average collector cover temperature of 47.1°C, 45°C and 43.2°C is measured for the wind speed of 1.1, 1.8 and 2 m/s, respectively.

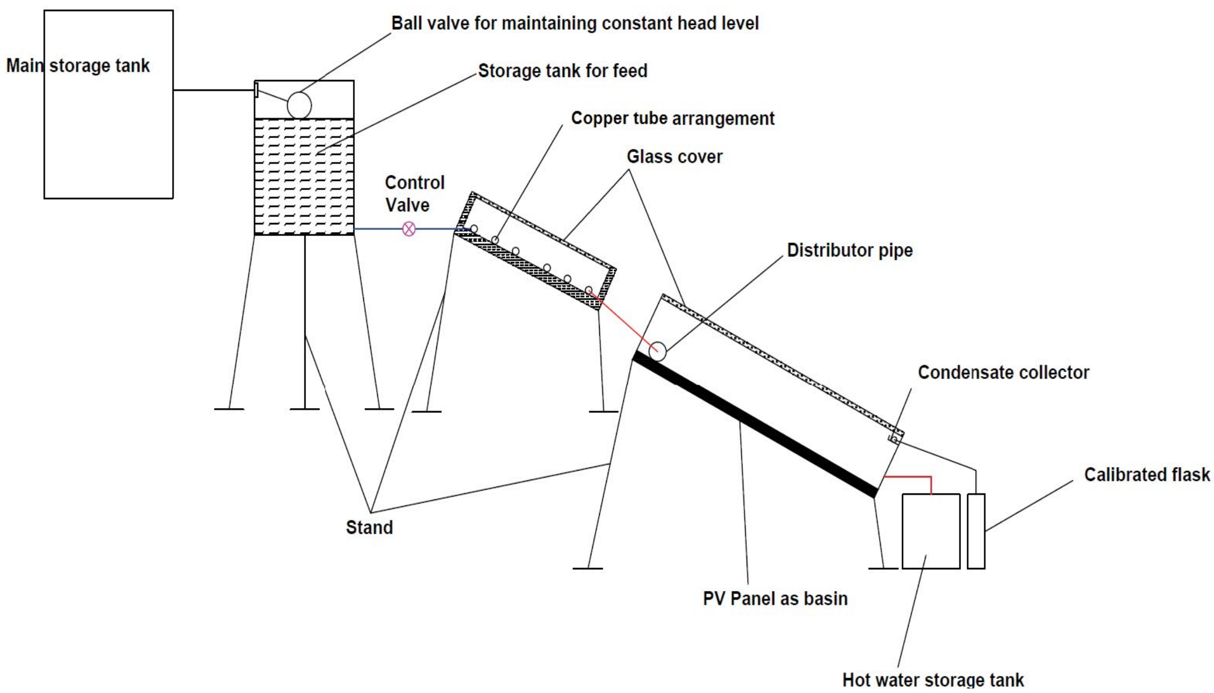

Fig. 1. Schematic diagram of the ISPB still integrated with the STC.

Fig. 2. Photographic view of the ISPB still integrated with the STC.

3.2. *Effect of mass flow rate on basin and water temperature of an ISPB still integrated with the STC*

Variations of the basin temperature for an ISPB still integrated with the STC under different m_f are plotted in Fig. 5a. Basin temperature increases with increasing of solar intensity and reached its peak value at 2 P.M and after that its value reduced. The maximum basin temperature of 72°C, 69°C and 65°C is obtained for the m_f at 1.8, 3.2 and 4.7 kg/h, respectively. The daily average basin temperature of an ISPB still integrated with the STC at the m_f at 1.8, 3.2 and 4.7 kg/h is 62.1°C, 59.1°C and 55.2°C, respectively. When the m_f increases from 1.8 to 3.2 kg/h and from 1.8 to 4.7 kg/h there are a decreasing of basin temperature of about 4.8% and 11.1%, respectively. An increasing m_f resulted in, higher volume of flowing saline water in an ISPB still basin which results in the lower basin temperature.

Variations of water temperature for an ISPB still integrated with the STC under the different m_f are plotted in Fig. 5b. Water temperature is directly proportional to the basin temperature and it reached the peak value at 2 P.M after that it gets reduced. The maximum water temperature of an ISPB still integrated with the STC at the m_f at 1.8, 3.2 and 4.7 kg/h is 76°C, 73°C and 70°C, respectively. The daily average water temperature of 65.7°C, 63°C and 60.7°C is obtained for the m_f at 1.8, 3.2 and 4.7 kg/h, respectively. The daily average water temperature is reduced up to 4.1% and 7.6% when the m_f increases from 1.8 to 3.2 kg/h and from 1.8 to 4.7 kg/h, respectively. An ISPB still integrated with the STC operates at minimum m_f increases the contact time between the saline water and spiral tube absorber which results in higher water temperature and hence higher productivity. When the m_f increased, the volume of flowing water in the absorber plate increased which reduces the contact time between the saline water and absorber plate and hence produced less productivity.

3.3. *Effect of mass flow rate on accumulated yield, thermal and exergy efficiency of an ISPB still integrated with the STC*

Variations of EHTC for an ISPB still integrated with the STC at different m_f are shown in Fig. 6a. The maximum EHTC of 94.03, 83.47 and 73.36 W/m^2 K is obtained for an ISPB still integrated with the STC operates under the m_f at 1.8, 3.2 and 4.7 kg/h, respectively. The daily average EHTC for an ISPB still integrated with the STC under the m_f at 1.8, 3.2 and 4.7 kg/h is 64.43, 57.37 and 50.98 W/m^2 K, respectively. There is a 10.97% and 20.88% decreases in daily average EHTC when the m_f increases from 1.8 to 3.2 kg/h and from 1.8 to 4.7 kg/h, respectively. An increasing m_f decreased the saline water temperature and also the EHTC.

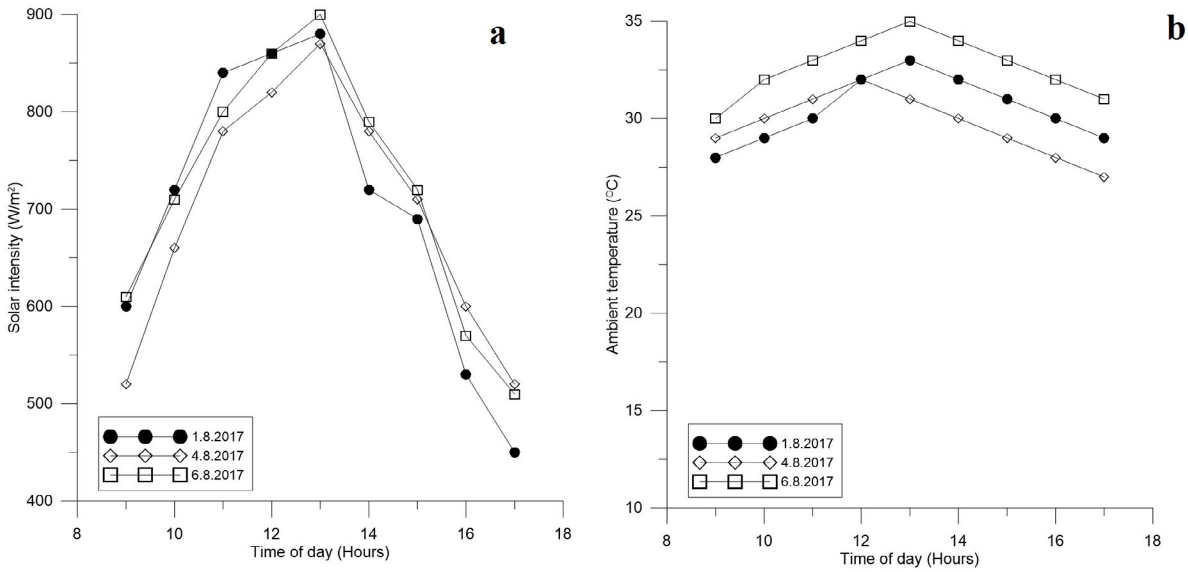

Fig. 3. (a) Diurnal variation of solar intensity, (b) atmospheric temperature.

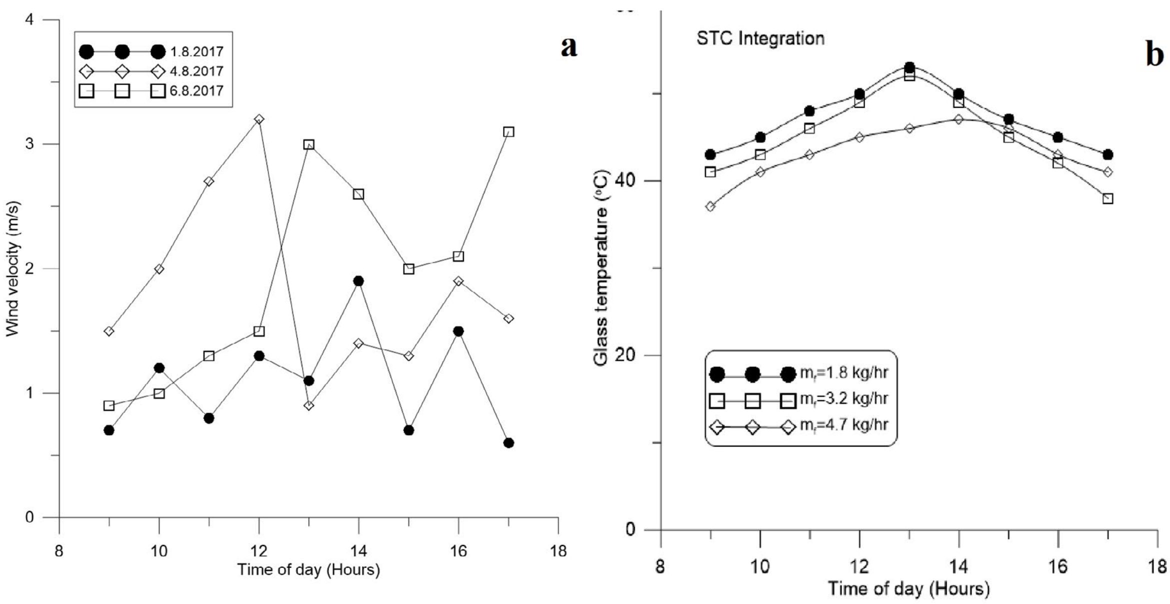

Fig. 4. (a) Diurnal variations of wind speed, (b) collector cover temperature.

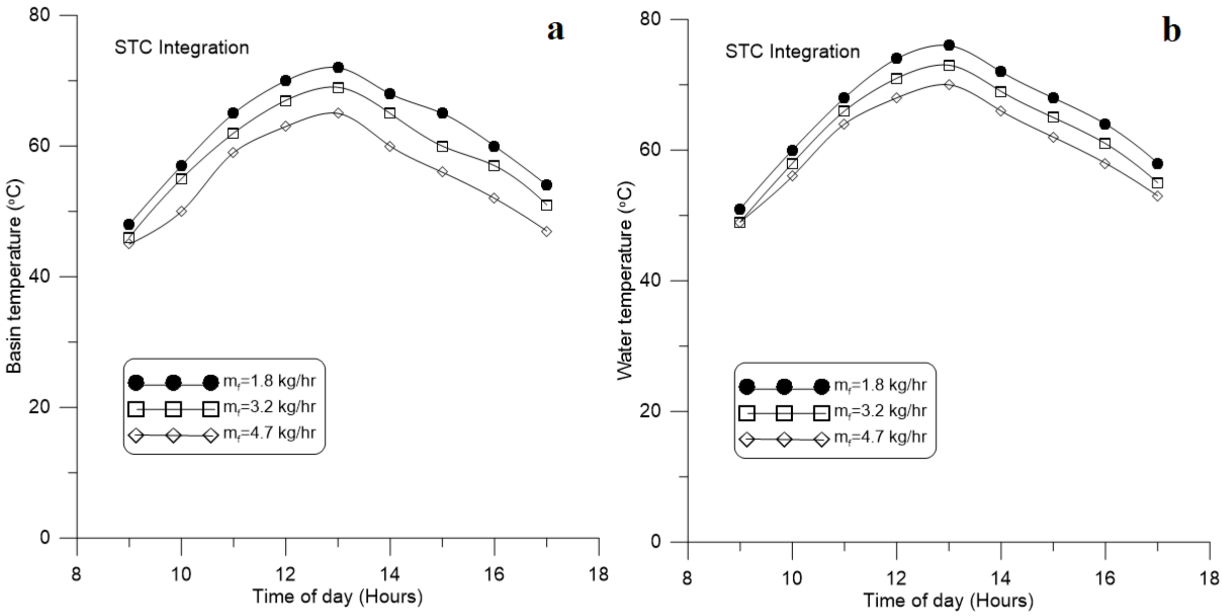

Fig. 5. Hourly variations of (a) basin temperature and (b) water temperature for an ISPB still integrated with the STC.

The EHTC from water to collector cover is given by Manokar et al. 2018:

$$h_{e,w-g} = 16.273 \times 10^{-3} \text{x} h_{c,w-g} \left[\frac{P_w - P_{gi}}{T_w - T_{gi}} \right] \quad (1)$$

The convective heat transfer coefficient from water to collector cover is given by Manokar et al. 2018:

$$h_{e,w-g} = 0.884 \left[\left(T_w - T_{gi} \right) + \frac{\left(P_w - P_{gi} \right)\left(T_w + 273 \right)}{\left(268.9 \times 10^{-3} - P_w \right)} \right] \quad (2)$$

Partial vapour pressure at water temperature is given by Manokar et al. 2018:

$$P_w = \exp\left(25.317 - \left(\frac{5{,}144}{273 + T_w} \right) \right) \quad (3)$$

Partial vapour pressure at inner surface of collector cover is given by Manokar et al. 2018:

$$P_{gi} = \exp\left(25.317 - \left(\frac{5{,}144}{273 + T_{gi}} \right) \right) \quad (4)$$

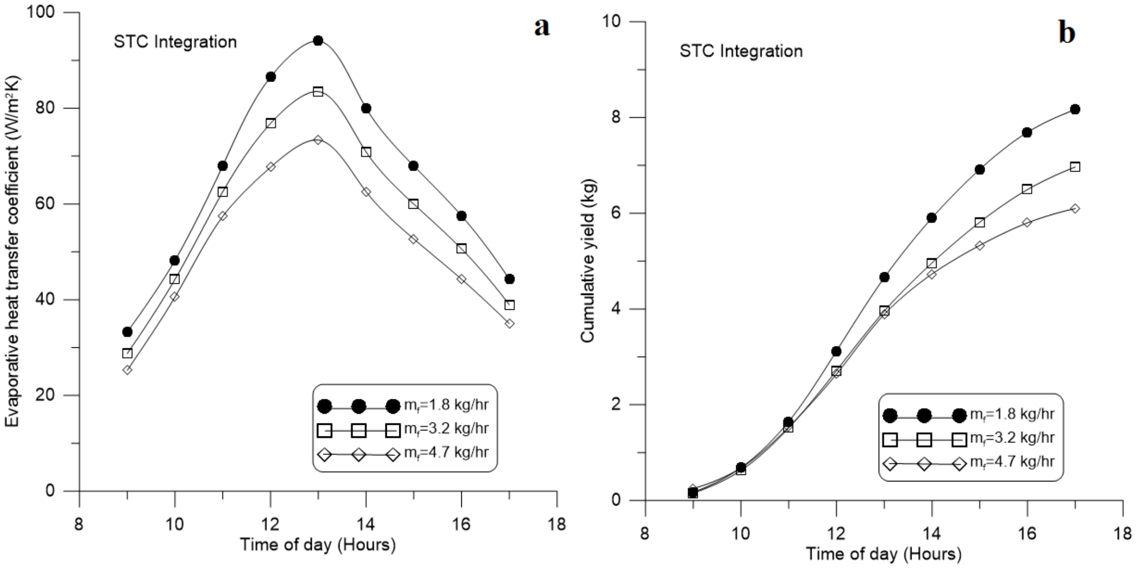

Fig. 6. Hourly variations of (a) EHTC and (b) accumulated yield from an ISPB still integrated with the STC.

Variations of cumulative yield from an ISPB still integrated with the STC at different m_f are shown in Fig. 6b. The maximum daily productivity from an ISPB still integrated with the STC is maximum at minimum m_f. The daily yield from an ISPB still integrated with the STC at m_f at 1.8, 3.2 and 4.7 kg/h is 8.1, 6.9 and 6.1 kg, respectively. The amount of fresh water production mainly depends on the water temperature. It can be seen that water temperature of an ISPB still integrated with the STC increased by maintaining the minimum m_f. It is found that the daily fresh water production rate decreases up to 14.68% and 25.3% when the m_f increases from 1.8 to 3.2 kg/h and from 1.8 to 4.7 kg/h, respectively.

Variations of thermal efficiency of the ISPB still integrated with the STC at different m_f are shown in Fig. 7a. The maximum thermal efficiency of the ISPB still integrated with the STC at m_f of 1.8, 3.2 and 4.7 kg/h is 68.3%, 61% and 54.3%, respectively. It is found that 47.9%, 39.3% and 31.02% daily average thermal efficiency for the ISPB still integrated with the STC at the m_f at 1.8, 3.2 and 4.7 kg/h, respectively. The thermal efficiency of an ISPB still integrated with the STC is decreased when the m_f is increased. There are a 17.9% and 35.2% decreases in daily average thermal efficiency of an ISPB still integrated with the STC when the m_f increases from 1.8 to 3.2 kg/h and from 1.8 to 4.7 kg/h, respectively.

Thermal effectiveness of the ISPB still integrated with STC is given by [13,14]:

$$\eta_{A.\mathrm{th}} = \frac{m_{\mathrm{ew}} h_{\mathrm{fg}}}{\left[A_c \times I_c(t) + A_s \times I_s(t)\right] \times 3{,}600} \times 100 \qquad (5)$$

Variations of exergy efficiency of the ISPB still integrated with the STC under different m_f are shown in Fig. 7b. The maximum hourly exergy efficiency of an ISPB still integrated with the STC is 15.5%, 12.5% and 10.2% at m_f at 1.8, 3.2 and 4.7 kg/h, respectively. The daily average exergy efficiency of 9.8%, 7.9% and 51.6% is obtained for the m_f at 1.8, 3.2 and 4.7 kg/h, respectively. Increasing the m_f results in decreasing the exergy efficiency of an ISPB still integrated with the STC. When the m_f increases from 1.8 to 3.2 kg/h and from 1.8 to 4.7 kg/h, the exergy efficiency of an ISPB still integrated with the STC decreases up to 19.3% and 43.7%, respectively.

The exergy efficiency of an ISPB still integrated with the STC is given by Manokar et al. 2018:

$$\eta_{a.e} = \frac{e_{a.\mathrm{out}}}{e_{p.\mathrm{in}} + e_{\mathrm{fpc}.i}} \qquad (6)$$

An active exergy output of an ISPB is given by Manokar et al. 2018:

$$e_{a.\mathrm{out}} = \left(m_d \mathrm{x} \mathrm{h}_{\mathrm{fg}}\right)\left(1 - \left[\frac{T_a + 273}{T_w + 273}\right]\right) \qquad (7)$$

An active exergy input of an ISPB still is given by Manokar et al. 2018:

$$e_{a.\mathrm{in}} = e_{p.\mathrm{in}} + e_{\mathrm{fpc.in}} \qquad (8)$$

An exergy input to the STC is given by Manokar et al. 2018:

$$e_{\mathrm{fpc.in}} = Q_u\left[1 - \frac{T_a + 273}{T_W + 273}\right] \qquad (9)$$

Useful heat gained by the STC is given by Manokar et al. 2018:

$$Q_u = \left(1 \times A_p\right) - q \qquad (10)$$

Heat lost from the STC is given by [14]:

$$q = \mathrm{UA}\left(T_b - T_a\right) \qquad (11)$$

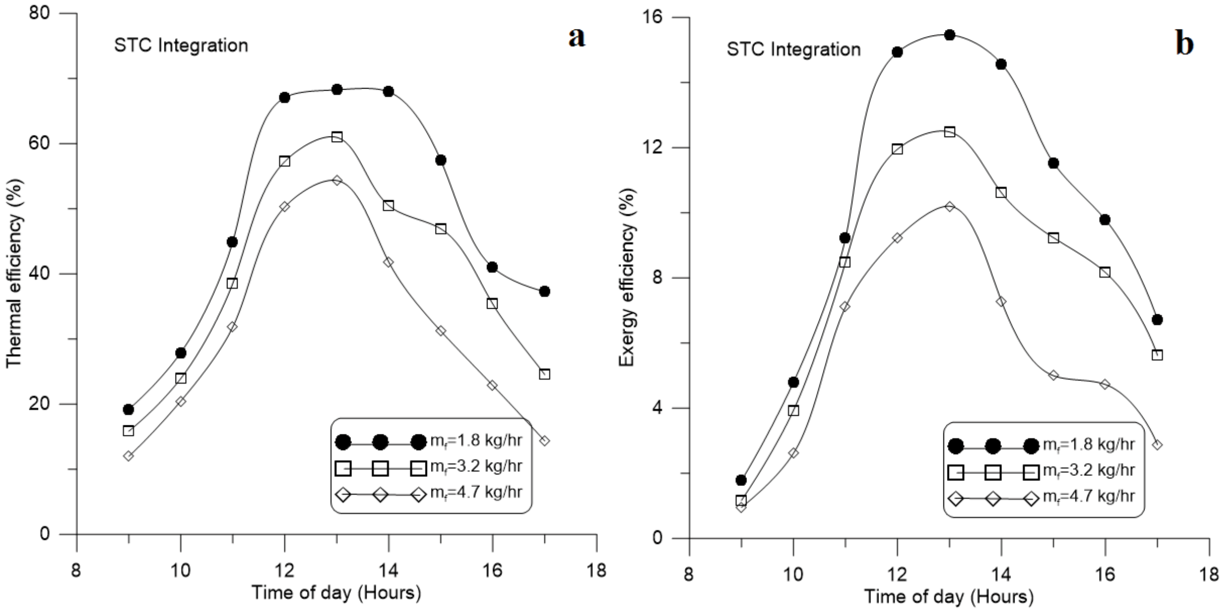

Fig. 7. Hourly variations of (a) thermal efficiency and (b) exergy efficiency of the ISPB still integrated with the STC.

4. Conclusions

The effect of varying different m_f in an ISPB still integrated with the STC was experimentally studied. The results inferred that an increasing m_f reduces the performance of an ISPB still. When the mass flow rate of ISPB still is varied from 1.8 to 3.2 kg/h, the daily productivity, thermal and exergy efficiency of the system decreases about 14.68%, 17.9% and 19.3 %, respectively. Further the mass flow rate of ISPB still is varied to 4.7 kg/h, the daily productivity, thermal and exergy efficiency of the system decrease to about 25.3%, 35.2% and 43.7%, respectively.

Abbreviations

CSS — Conventional solar still
EHTC — Evaporative heat transfer coefficient
ISPB — Inclined solar panel basin
m_f — Mass flow rate of water

Nomenclature

A — Area, m^2
h — Heat transfer coefficient, W/m^2K
I(*t*) — Solar intensity, W/m^2
L — Latent heat of vaporization, kJ/kg K
M — Hourly productivity from solar still, $kg/m^2 h$
P — Partial vapour pressure, N/m^2
T — Temperature, °C
H — Efficiency, %

Subscript

a — Ambient
c — Convective
d — Daily
e — Evaporative
g — Glass
gi — Inner glass
pv — Photovoltaic
s — Surface area of condensing cover
w — Water

References

Manokar, A.M., Murugavel, K.K. and Esakkimuthu, G., 2014. Different parameters affecting the rate of evaporation and condensation on passive solar still–A review. Renewable and Sustainable Energy Reviews, 38, pp. 309–322.

Manokar, A.M., Winston, D.P., Kabeel, A.E., El-Agouz, S.A., Sathyamurthy, R., Arunkumar, T., Madhu, B. and Ahsan, A., 2018. Integrated PV/T solar still-A mini-review. Desalination, 435, pp. 259–267.

Sathyamurthy, R. and Arunkumar, T., 2018. Different parameter and technique affecting the rate of evaporation on active solar still-a review. Heat and Mass Transfer, 54(3), pp. 593–630.

Manokar, A.M., Vimala, M., Winston, D.P., Ramesh, R., Sathyamurthy, R., Nagarajan, P.K. and Bharathwaaj, R., Different parameters affecting the condensation rate on an active solar still—A review. Environmental Progress & Sustainable Energy.

Kabeel, A.E., Manokar, A.M., Sathyamurthy, R., Winston, D.P., El-Agouz, S.A. and Chamkha, A.J., 2019. A review on different design modifications employed in inclined solar still for enhancing the productivity. Journal of Solar Energy Engineering, 141(3), p. 031007.

Alaudeen, A., Johnson, K., Ganasundar, P., Abuthahir, A.S. and Srithar, K., 2014. Study on stepped type basin in a solar still. Journal of King Saud University-Engineering Sciences, 26(2), pp. 176–183.

Sharon, H., Reddy, K.S., Krithika, D. and Philip, L., 2017. Experimental performance investigation of tilted solar still with basin and wick for distillate quality and enviro-economic aspects. Desalination, 410, pp. 30–54.

Hansen, R.S., Narayanan, C.S. and Murugavel, K.K., 2015. Performance analysis on inclined solar still with different new wick materials and wire mesh. Desalination, 358, pp. 1–8.

Naveen Kumar, P., Harris Samuel, D.G., Nagarajan, P.K. and Sathyamurthy, R., 2017. Theoretical analysis of a triangular pyramid solar still integrated to an inclined solar still with baffles. International Journal of Ambient Energy, 38(7), pp. 694–700.

Naveen Kumar, P., Manokar, A.M., Madhu, B., Kabeel, A.E., Arunkumar, T., Panchal, H. and Sathyamurthy, R., 2017. Experimental investigation on the effect of water mass in triangular pyramid solar still integrated to inclined solar still. Groundwater for Sustainable Development, 5, pp. 229–234.

Panchal, H., Taamneh, Y., Sathyamurthy, R., Kabeel, A.E., El-Agouz, S.A., Naveen Kumar, P., Manokar, A.M., Arunkumar, T., Mageshbabu, D. and Bharathwaaj, R., 2018. Economic and exergy investigation of triangular pyramid solar still integrated to inclined solar still with baffles. International Journal of Ambient Energy, pp. 1–6.

Kabeel, A.E., Taamneh, Y., Sathyamurthy, R., Naveen Kumar, P., Manokar, A.M. and Arunkumar, T., 2019. Experimental study on conventional solar still integrated with inclined solar still under different water depth. Heat Transfer—Asian Research, 48(1), pp. 100–114.

Manokar, A.M., Winston, D.P., Kabeel, A.E. and Sathyamurthy, R., 2018. Sustainable fresh water and power production by integrating PV panel in inclined solar still. Journal of Cleaner Production, 172, pp. 2711–2719.

Manokar, A.M., Winston, D.P., Mondol, J.D., Sathyamurthy, R., Kabeel, A.E. and Panchal, H., 2018. Comparative study of an inclined solar panel basin solar still in passive and active mode. Solar Energy, 169, pp. 206–216.