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Title: Comparative study of an inclined solar panel basin solar still in passive and active mode

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Keywords: Inclined solar panel basin solar still; passive and active mode; yield and thermal effectiveness improvement, PV exergy, overall thermal effectiveness

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Abstract: The aim of the present study is to compare the performance of the Inclined Solar Panel Basin (ISPB) still integrated with (active mode) and without (passive mode) Flat Plat Collector (FPC). The maximum yield of 4.3 and 7.9 kg/day is produced from the passive and active mode respectively. The daily thermal and exergy effectiveness of the passive mode is 39.82% and 2.9% and, the active mode is 46.87% and 6.6%, respectively. For the active mode the daily yield, thermal and exergy efficiencies are increased and the panel effectiveness is decreased. An active mode increases the daily fresh water production rate, thermal and exergy effectiveness up to 44.63, 24.91 and 55.68 % respectively than the passive mode.

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***Detailed Response to Reviewers**

Dear Editor-in-Chief, Subject Editor and Reviewers,
Thanks for the valuable comments providing to ensure the quality of my research article by suggesting an important points to enhance the quality of the research. Based on your comments, we the authors made necessary revisions on the manuscript to ensure high visibility quality publication maintained by **Solar Energy**.

The comments raised by the Reviewer are responded as follows: -

Reviewer #1: Comments or Suggestions:

1. Comment: Reviewer not understanding the concept of putting solar PV panel inside the water basin, because of high temperature of basin as compared to the ambient temperature, efficiency will go down.

Response - Thank you for your valued comment, from the ref no [18 & 19] (mentioned in the manuscript) we found the problem identification. Yes panel efficiency is decreasing when there is a minimum mass flow rate of water as compared to the maximum flow rate of water and also the efficiency of the PV panel at maximum flow rate is lower than the panel at open space. But the performance of the solar still (glass basin) is better as compared to the conventional solar still.

2. Experimentation is perform only for one day, it is expected to perform at least for 2-3 days to smoothen the results pattern and concrete conclusions.

Response - Thank you for your valued comment, another one day readings are included in the revised manuscript

3. Check reference number 28.

Response - Thank you for your valued comment, Reference no-28 has been changed.

4. In all the Figures, legends used are confusing, so use clear symbols instead of confusing symbols.

Response - Thank you for your valued comment, all the graphs are redrawn

5. It is also suggested to add some more research papers based on performance enhancement of solar still using nanomaterials, storage systems, etc.

Response - Thank you for your valued comment, research article related to nanofluids Ref [31-38] and energy storage Ref [39-43] has been included in the updated manuscript

Reviewer #2:

Manuscript Number: SE-D-18-00321

Title: Comparative study of an inclined solar panel basin solar still in passive and active mode

This paper handles performance (productivity, efficiency) comparison of the inclined solar still of basin type with the flat plate collector and solar panel. Experimental results in passive and active mode of the solar still are interesting. I have some comments which I want the authors to work on before publishing it in the Solar energy journal.

1- The measurements were in just two days (one for passive still and the other for active still). There were no variables for the study. There is a possibility of errors in the measurements (the measurements in one day). Therefore, we need to deepen the study; the effect of mass flow rate must be considered.

Response - Thank you for your valued comment, Already we have communicated the effect of mass flow rate of water in passive (**4.68**, 7.56 and 10.08 kg/hr) and active mode (1.8, 3.2 and **4.7** kg/hr) to journal. In this manuscript two similar mass flow rate of water (**4.7** kg/hr) is considered for the comparative analysis.

2- In Section 2, (A constant mass flow rate of 0.0013 kg/s of input feed water is kept for both passive and active mode) this manually by using control valve and cylindrical storage tank made up of plastic with 50 liters of capacity used for make up water.

Therefore, the stability of the rate of flow is not possible in this case for the small size of the tank. you must use the correct method. The water head in feeding tank varied with time, so the flow rate varied with time.

Response - Thank you for your valued comment, a constant head level is maintained inside the feed water storage tank by float arrangement for maintaining constant flow rate of water inside the inclined basin

3- How the water is distributed inside the basin? I think there are many hot spots area over the basin. Please, added photo for the distributed pipe with dimensions.

Response - Thank you for your valued comment, Water is distributed by using the PVC pipe (1710 mm) which is holed at equal spaces for even distribution Fig. 3 Shows the water flowing arrangements in an ISPB still.

4- The daily thermal effectiveness of passive, active mode is 22.34 and 29.83. If you used the values in papers, the previous values (22.34 and 29.83) are not right.

Response - Thank you for your valued comment, it has been corrected in the abstract section

5. There are too many grammatical errors and inadequate expressions. Quality of the language in the manuscript needs to improve by a native English speaker.

Response - Thank you for your valued comment, grammar correction throughout the manuscript has been corrected

6. The detailed analysis for the experiment results is insufficient in section 3.

Response - Thank you for your valued comment, detailed analysis has been included in the section-3.

7- Please, follow the journal's guidelines.

Response - Thank you for your valued comment, As per the journal guidelines the manuscript is revised

*Highlights (for review)

Highlights

1. 44.63% higher distillate yield is obtained for an active ISPB still than the passive ISPB still.
2. 10% higher panel efficiency is obtained for the passive ISPB still than the active ISPB still.
3. The maximum daily yield, thermal and exergy efficiency of the passive ISPB still is 4.3 kg, 39.82% and 2.9%, respectively.
4. The maximum daily yield, thermal and exergy efficiency of the active ISPB still is 7.9 kg, 46.87% and 6.6%, respectively

*Marked Revised Manuscript
Click here to view linked References

Comparative study of an inclined solar panel basin solar still in passive and active mode

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Abstract:

The aim of the present study is to compare the performance of the Inclined Solar Panel Basin (ISPB) still integrated with (active mode) and without (passive mode) Flat Plat Collector (FPC). The maximum yield of 4.3 and 7.9 kg/day is produced from the passive and active mode respectively. The daily thermal and exergy effectiveness of the passive mode is 39.82% and 2.9% and, the active mode is 46.87% and 6.6%, respectively. For the active mode the daily yield, thermal and exergy efficiencies are increased and the panel effectiveness is decreased. An active mode increases the daily fresh water production rate, thermal and exergy effectiveness up to 44.63, 24.91 and 55.68 % respectively than the passive mode.

Keywords: Inclined solar panel basin solar still; passive and active mode; yield and thermal effectiveness improvement, PV exergy, overall thermal effectiveness

1. Introduction

Today's mechanized world mainly depends on the water and energy. Due to increasing population and growth of the industry, need and demand of fresh water increases.

But the water resource remains the same and it may deplete in close to future. Due to over usage of electrical energy, conventional energy sources also in the critical position and also it will be exhausted in future. To overcome energy and water issues, substitute resource has to be initiated. Generating electrical power from the Photovoltaic (PV) panel is the best substitute as an alternative to using non-renewable sources. Water has no substitute, thus the clean water level must be increased and it should be possible adequately by changing over salty seawater into drinking water through desalination method by using solar still. By incorporating both the thoughts, PV incorporated solar still is intended to produce electrical energy and water in remote areas where annual rain fall and electrical energy shortages occurred. Depending just upon the natural water cycle is not a safe thought to get fresh water. New techniques utilizing accessible sources must be produced to get more fresh water. Actually Conventional Solar Still (CSS) gives low water production per unit area. [1-4]. Kaviti et al [5], reported that the advancement in creating various modifications of Inclined Solar Stills (ISS) must be made, so as to augment the effectiveness by keeping up the minimal water depth and utilizing wick type materials in the basin of still.

Changes in renewable energy based desalination technology are experimentally researched by various researchers in worldwide and new techniques are produced every day. One such imperative change is incorporating solar panel along with the solar still which increases the electrical and thermal effectiveness of Photovoltaic Thermal (PV/T) collector. Various researches were carried out on solar still incorporated with PV/T collector. The experimental investigation on solar still incorporated with PV panel and FPC showed that integrating the PV panel with FPC, the solar still produced the daily yield of about 6-10 kg/m^2 and increased the fresh water production rate of about 60 % than the basin type solar still [6-14]. Kabeel et al [15] introduced the novel solar still integrated with the rotating fan with vertical shaft powered by PV system. This experimental set-up produced 25% higher productivity than the CSS (Yield= 4.75 L/m^2/day). Abdallah et al [16] studied the active solar still performance by using evacuated collector integrated with PV system. Integration of the PV cells at the solar still collector surface was investigated by Yari et al [17]. This PV cells attached still produced 32% higher yield than the CSS. Al-Nimr et al [18 & 19] have designed a novel desalination with PV/T concentrated and PV cells pasted at the solar still basin. It was found that the PV cells attached with the solar still produced the fresh water yield of about 6.8 L/m^2/day. Ali Riahi et al [20] and Praveen et al [21] researched the still performance by integrating AC heater and PV module.

Comparative analysis for single and double basin glass solar still with and without insulation was studied by Elango et al [22]. Khalifa et al [23] experimentally studied the solar still performance by varying the insulation thickness and found that the yield increases with increase in insulation thickness. Comparative investigation on single and double basin solar still with and without insulation was done by Al-Karaghouli [24 & 25]. Solar still with insulation improves the yield up to 20% than no insulation. Muthu Manokar et al [26] researched the performance of ISPB still at different insulation condition and found that the ISPB still with bottom and side wall insulation decreases the PV panel effectiveness because of higher heat gain in the PV panel. Various solar collectors integrated by still were reviewed by Sathyamurthy et al [27]. A review of different types of active solar still systems was done by Muthu Manokar et al [28]. Solar still through efficient heat exchange mechanism was examined by Kabeel et al [29]. Also, Kabeel et al [30] experimentally investigated the performance of active ISS.

Abdelal et al [31] replaced a pyramid solar still conventional absorber plate by a carbon fiber/epoxy integrated with Carbon Nano Tubes (CNT) and Grapheme Nano Plates (GNP). The fresh water productivity was enhanced up to 109, 65 and 30% for the composite plate integrated with 5 wt% CNT, 2.5 wt% CNT and 2.5 wt% GNP, respectively. Elango et al [32] enhanced the fresh water productivity from the CSS by using Aluminum Oxide (Al_2O_3), Tin Oxide (SnO_2) and Zinc Oxide (Zn O) Nano fluids (Nfs). It was reported that the CSS with Al_2O_3 Nfs, SnO_2 Nfs, Zn O Nfs and water produced the daily yield of 935, 805, 750 and 655 ml, respectively. The CSS with Al_2O_3 Nfs, SnO_2 Nfs and Zn O Nfs increases the yield up to 29.95, 18.63 and 12.67% than the CSS with water. Omara et al [33] fabricated a corrugated wick solar still integrated with mirrors and external condenser. It was found that the solar still output was enhanced up to 285.10 and 254.88% by using cuprous and Al_2O_3nano particles in the basin as compared to the CSS. Sahota et al [34 & 35] used Al_2O_3 Nano Particles to augment the yield from the passive Double Slope Solar Still (DSSS). Experiments were conducted on the solar still with 35 and 80 kg of water mass inside the basin and Nfs concentrations of 0.04, 0.08 and 0.12% respectively. It was reported that Nf at the concentrations of 0.12% enhances the productivity up to 12.2% and 8.4% for the water mass of 35 and 80 kg, respectively. Sahota et al [36] researched the N-PV/T-FPC-DSSS without and with heat exchanger with Copper oxide (CuO), $Al_2O_3$and Titanium oxide Nps. Among the tested Nps CuO is the best one for enhancing the solar still performance. Sharshir et al [37] researched the solar still performance with CuO and graphite micro-flakes; it enhances the yield up to 44.91 and 53.95%, respectively as compared to the CSS. Kabeel et al [38] coated the black Np in the CSS absorber plate which enhanced the daily yield up to 15 to 18% than the normal absorber plate.

Murugavel et al [39 & 40] used Sensible Heat Energy Storage Material (SHESM) such as bricks, quartzite rocks, stones and mild steel turnings for enhancing the OFF sun-shine hours productivity. Samuel et al [41] used a low cost thermal energy storage material (spherical ball heat storage medium) in the basin of solar still. It was reported that the solar still with and without storage material produced the productivity of 3.7 and 2.2 kg, respectively. Kabeel et al [42] introduced the higher thermal conductivity material (graphite) in the CSS to improve the productivity. It was found that the CSS with and without graphite produced the maximum daily yield of 7.7 and 4.4 L respectively. Graphite enhances the productivity up to 75 to 80% than the CSS. Sellami et al [43] used a Portland cement in two different form in the basin of solar still (i) powder cement (ii) adhered layer of cement. Experiments were conducted on solar still with varying the mass of powder cement (150,100 and 50g) and cement layer (300, 200 and 100g). It was reported that the solar still with 150g of powder cement is optimized the yield and enhanced the yield up to 51.14% than the CSS.

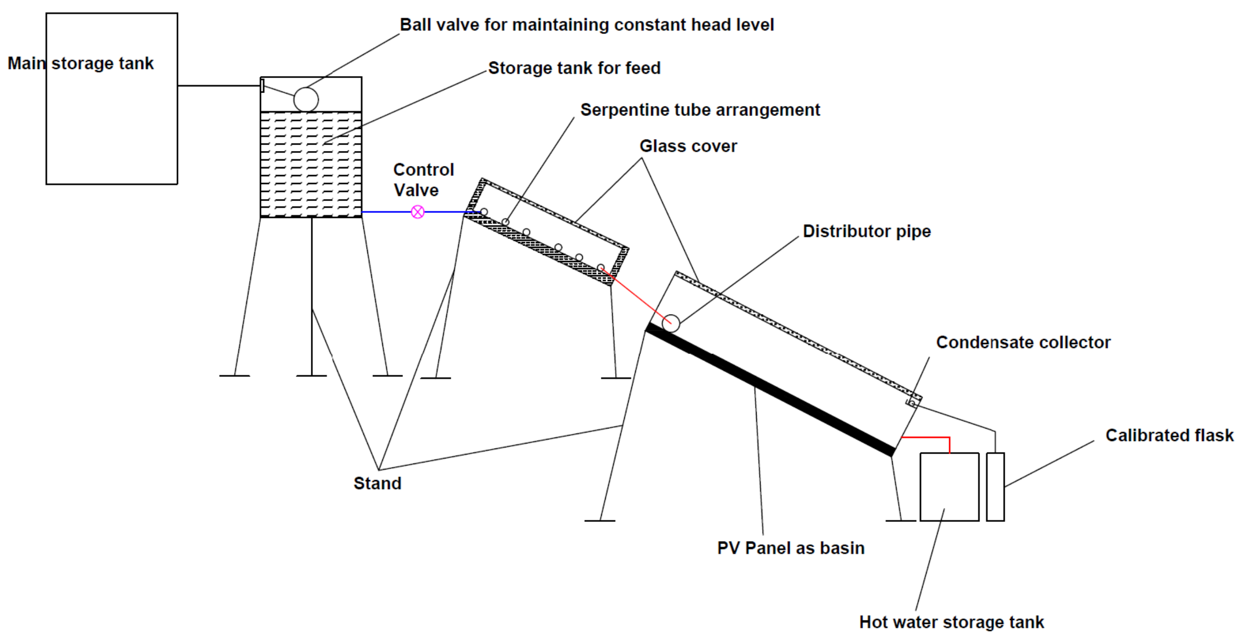
From the above literatures, it is very clear that very less experimental works were reported on the ISS in active mode (input saline water is pre-heated by using the solar collector) and hence the main aim of this research work are comparative analysis of an ISPB still in passive and active mode.

2. Design and construction of the proposed experimental arrangement:

2.1 Construction of an ISPB still in passive and active Mode

An illustrative drawing and experimental arrangement of an ISPB still in passive and active modes are shown in Fig. 1 and 2, respectively. The dimension of the solar still is 1810 mm (Length) × 920 mm (Width) × 150 mm (Height). The solar still and collector cover were fabricated using 4 mm thickness transparent glass. Cotton thread is used as a wick material to raise the evaporation rate which is fixed in the location between the successive rows and columns of the solar cells. In this setup, saline water flow arrangement is made in such a way that the water from the storage tank flows through the regulation valve, Polyvinyl Chloride inlet pipe and then to the absorber plate of the ISPB still. Saline water is fed uniformly to the basin through the regulation valve and an inlet pipe. Inlet pipe is holed at equal spaces for an even distribution. A constant head level is maintained inside the feed water storage tank by a float arrangement for maintaining constant flow rate of water inside the inclined basin. Initially a flow rate of 0.0013 kg/s of input saline water is kept for both the passive and active mode. During the operation of the ISPB still, the hot water generated from the still has been filled manually to the saline water storage tank for every one hour. The salt deposition on the PV panel was cleaned manually every 10 days with Windex. Temperature sensors are installed at the collector, absorber and exit water with the multichannel digital display device. In order to collect the condensate from the inner collector cover, a distillate collector is placed at the bottom of the glass cover. In an active mode, an FPC is integrated with the passive ISPB still.

(A) INCLINED PV BASIN SOLAR STILL UNDER ACTIVE MODE



(B) INCLINED PV BASIN SOLAR STILL UNDER PASSIVE MODE

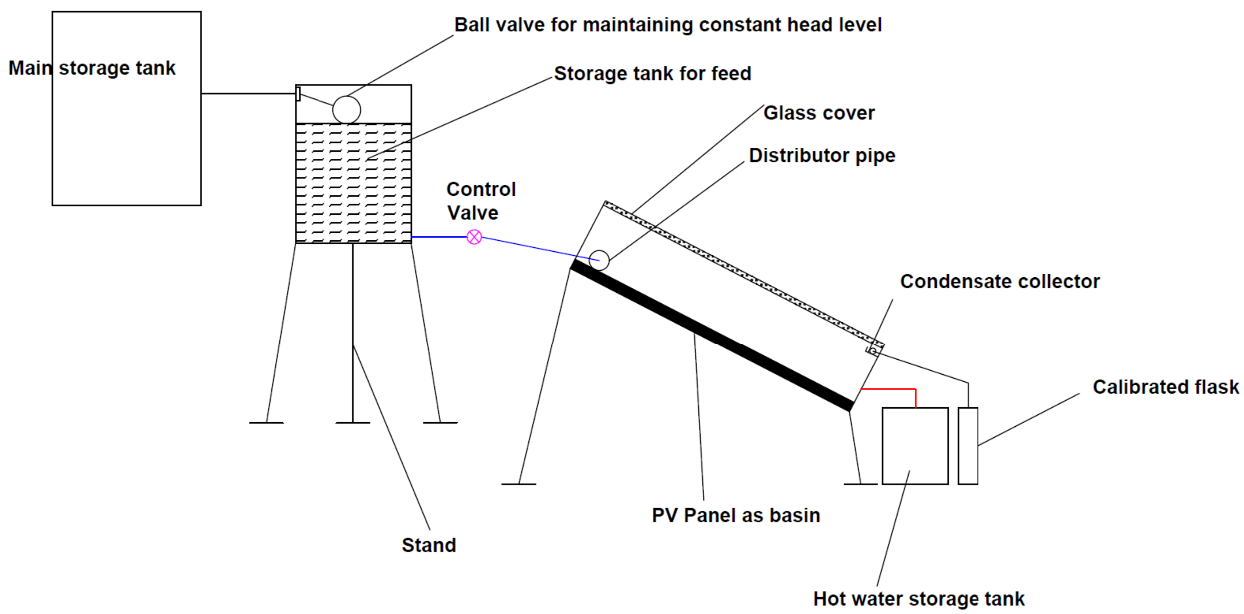


Fig. 1 Schematic drawings of (a) ISPB still in active mode and (b) ISPB still in passive mode

Fig. 2 Experimental arrangement of passive and active ISPB still

Fig. 3 Water flowing arrangements within the ISPB still.

2.2 Description of the FPC solar water heater

An FPC solar water heater was fabricated comprising of a flat solar collector, storage tank, and control valve. The flat collector of 0.9 m (L) x 0.6 m (W) x 0.004 m (H) was fabricated by using a 20 mm thickness wooden box covered with 4 mm thick window glass. This water heater was mounted on the supporting steel structure constructed of 10 mm diameter and 1 mm thickness copper tube in a flat shape with three winding (with 50 mm gap between windings) were used to circulate the water in an FPC collector. Cylindrical storage tank made up of plastic with 50 liters of capacity was mounted on a steel stand. The measuring jar and stopwatch were used to determine the mass flow rate of inlet saline water.

The entire set-up was faced south direction with the inclination angle equal to the latitude of Chennai (13° N) to receive the maximum solar intensity.

The accuracy and error limits of the various measuring instruments were listed in Table 1. Solar power meter (TES 1333), cup anemometer (AM4836), and digital multimeter were used to measure the solar intensity, wind velocity and voltage, current produced from the PV panel. The cost analysis for the passive and active ISBP still is listed in Table 2.

Experiments were carried out for the ISPB still in passive and active mode during the month of March-2017 to May-2017. The average solar intensity was calculated throughout the testing period. Two similar atmospheric condition days 24-4-2017 (average solar intensity 830 W/m^2) and 9-5-2017 (average solar intensity 815 W/m^2) are considered for the comparative analysis.

Table. 1 Accuracy, range and error limits for various measuring instruments

Sl. no	. Instruments	Accuracy	Range	% error
1	Thermocouple	±1°C	0–100°C	0.5%
2	Solar power meter	±1 W/m^2	0–2500 W/m^2	2.5 %
3	Anemometer	±0.1 m/s	0–15 m/s	10%
4	Measuring jar	±10 m L	0–1000 m L	10%
5	Multimeter	±1 V ±0.1 A	0-1000 V 0-10 A	0.5% 10%

Table. 2 Cost Analysis for passive and active ISBP still

S.No	Materials	Unit Cost(Rs)	Total Cost(Rs)
	Passive ISBP still		
1	Absorber (PV panel)	Rs 100/ Watt	Rs 15,000
2	Collector cover and side cover	Rs 1,600	Rs 1,600
3	Distillate strip	Rs 100	Rs 100
	ISPB still	(A)	Rs 16,700
4	Storage tank and stand	Rs 500	Rs 500
5	Control valve	Rs 150	Rs 150
6	Fabrication cost	Rs 250/hr	Rs 500
	Accessories and Fabrication cost	(B)	Rs 1150
	Total cost	(A+B)	Rs 17,850 /-
	Active ISBP still		
1	Passive ISBP still	(A+B)	Rs 17,850 /-
2	Copper material	Rs 700	Rs 700
3	FPC glass collector	Rs 300	Rs 300
4	Wooden box	Rs 600	Rs 600

5	FPC water heater	(C)	Rs 1600
6	Control valve	Rs 150/ 1 piece	Rs 150
7	Fabrication cost	Rs 250/h	Rs 750
	Accessories and Fabrication cost	(D)	Rs 900
	Total Cost	(A+B+C+D)	Rs 20,350

3. Results and discussion

3.1 Hourly variations of different parameters in passive and active ISPB still.

The variations of solar irradiance, glass, basin, ambient, and saline water temperatures for the passive ISPB still are plotted in Fig. 4. It was found that the daily average solar intensity is 830 W/m^2 in 24.4.2017 and 783 W/m^2 in 28.4.2017. The highest hourly solar intensity is 1010 and 980 W/m^2 in 24.4.2017 and 28.4.2017, respectively. The daily average wind velocity is 1.5 m/s in 24.4.2017 and 1.9 m/s in 28.4.2017. It is observed that, the maximum ambient temperatures of 41 ° C was reached at 1 P.M and average ambient temperatures is 37 ° C in 24.4.2017. Temperatures of glass, basin, and saline water increased with increases in solar radiation and it reached its maximum value at 1 P.M, after that the value decreased. The highest temperatures of glass, basin, and the saline water were found to be 53, 68 and 65° C, respectively in 24.4.2017.

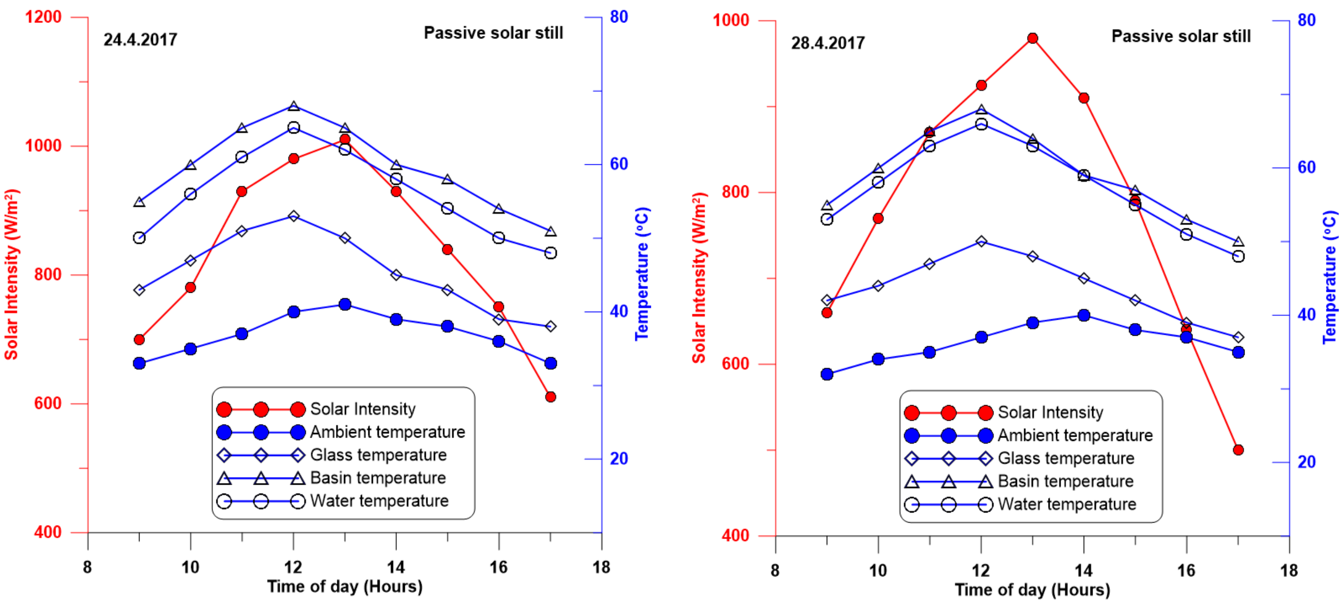


Fig. 4 Hourly variations of different parameters in passive ISPB still for two test days

The variations of solar irradiance, ambient temperature and the temperatures of glass, basin, and saline water for the active ISPB still are plotted in Fig. 5. It was found that the daily average solar intensity is 799 and 815 W/m^2 in 3.5.2017 and 9.5.2017, respectively. The highest hourly solar intensity is 995 and 990 W/m^2 in 3.5.2017 and 9.5.2017, respectively. The average wind velocity during the operation of the active mode was 2 and 2.2 m/s in 3.5.2017 and 9.5.2017, respectively. The maximum ambient temperature (40° C) reached at 1 P.M and the average ambient temperature was 36.7° C in 3.5.2017. The glass, basin and saline water temperatures increased with increase in solar intensity in the morning and reached maximum at 1 P.M, after that the values decreased. The highest glass, basin and water temperatures were found to be 54, 75 and 70° C, respectively in 9.5.2017. For the active ISPB still, the daily average water and basin temperatures increased up to 9.3 and 5.1%, respectively as compared to the passive ISPB still due to the effect of integrating an FPC to the passive ISPB still.

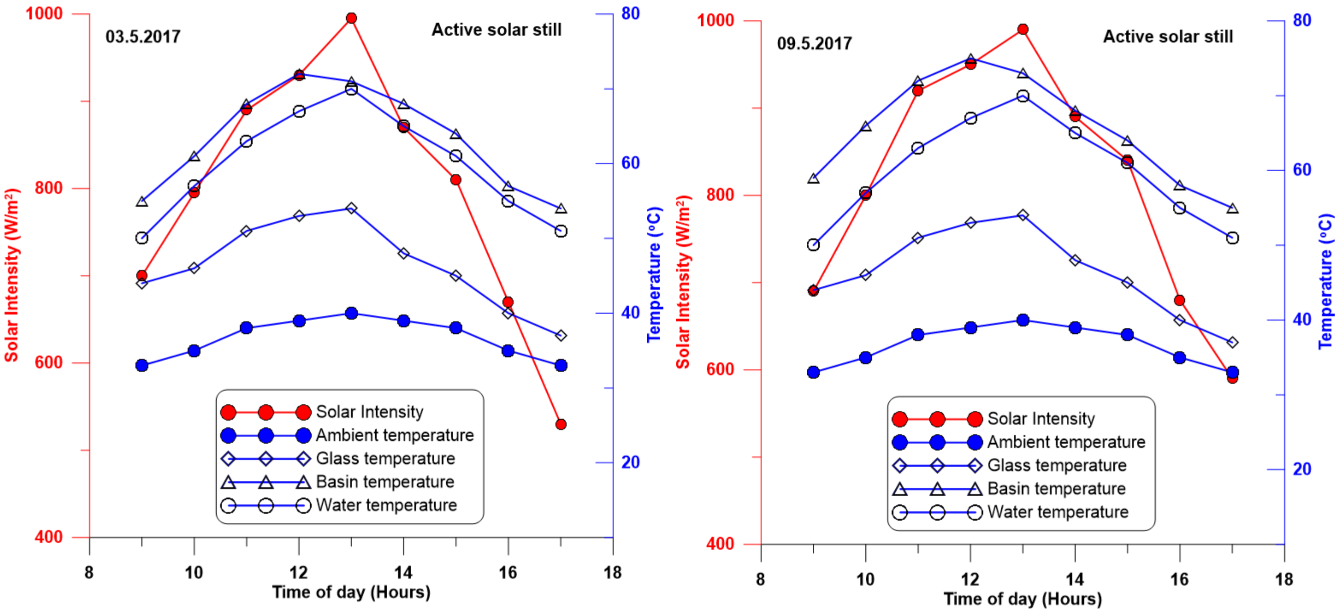


Fig. 5 Hourly variations of different parameters in active ISPB still for two test days

3.2 Hourly variations of Evaporative Heat Transfer Coefficient (EHTC) and still productivity for passive and active ISPB still

Fig. 6 depicts the variation of EHTC and productivity of the passive and active ISPB still. It is noted that the EHTC for the active mode is higher than the passive mode. The maximum EHTC of 67 and 90 W/m^{2}K is obtained for the passive and active mode in 24.4.2017 and 9.5.2017, respectively. Also, the average EHTC for the active mode is about 25% higher than the passive mode. The deviation observed to increases in EHTC is because of the incorporation of the FPC to the ISPB still.

EHTC from water to collector cover is given by,

$$h_{e,w-g} = 16.273X10^{-3}xh_{c,w-g}\left[\frac{P_w - P_{gi}}{T_w - T_{gi}}\right]$$

Convective heat transfer coefficient from water to collector cover is given by,

$$h_{c,w-g} = 0.884\left[\left(T_w - T_{gi}\right) + \frac{\left(P_w - P_{gi}\right)\left(T_w + 273\right)}{\left(268.9X10^{-3} - P_w\right)}\right]$$

Partial vapour pressure at water temperature is given by,

$$P_w = exp\left(25.317 - \left(\frac{5144}{273 + T_w}\right)\right)$$

Partial vapour pressure at inner surface of collector cover is given by,

$$P_{gi} = exp\left(25.317 - \left(\frac{5144}{273 + T_{gi}}\right)\right)$$

The maximum hourly yield of the ISPB still is higher when the still is integrated with the FPC. The maximum hourly productivity of 0.7 and 1.4 kg/h was obtained for passive and active mode at 12 P.M in 24.4.2017 and 9.5.2017, respectively. It was found that the maximum daily yield produced from the passive and active mode is 4.38 and 7.91 kg respectively. In the case of active mode, the still productivity is increased up to 44.63 % than the passive mode. The increase in yield is because of the integration of the FPC with the ISPB still. FPC with the ISBP still increaseds the saline water temperature up to 75 ° C. The evaporation rate of the active ISPB still was higher than the passive ISPB still due to higher inlet water temperature and hence the active ISPB still produced the higher yield.

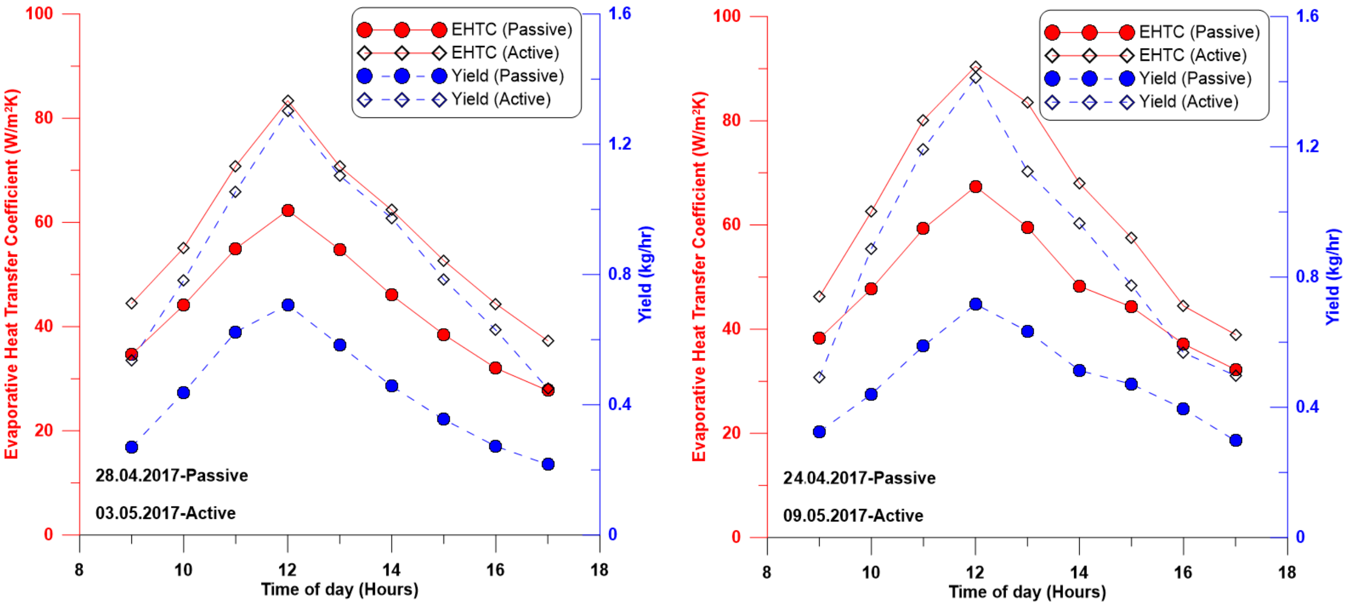


Fig. 6 Hourly variations of EHTC and Yield for the passive and active ISPB still

3.3 Hourly variations of exergy and thermal effectiveness for passive and active ISPB still

The variations of the exergy and thermal effectiveness of the passive and active modes are plotted in Fig 7. It was found that the exergy effectiveness of the active mode is higher than the passive mode due to the variation in input between passive (exergy input to a solar still) and active modes (summation of exergy inputs of solar still and an FPC). The maximum exergy effectiveness of 4.89% and 11.08% is obtained for the passive and active modes in 24.4.2017 and 9.5.2017, respectively. The maximum daily average exergy effectiveness of the passive and active mode is found to be 2.9 and 6.6% in 24.4.2017 and 9.5.2017, respectively. The active ISPB still produced 55.68% higher exergy effectiveness as compared to the passive ISPB still. The exergy effectiveness of the passive ISPB still is estimated as,

Exergy effectiveness of the passive ISPB still is given by,

$$\eta_{p.e} = \frac{e_{p.out}}{e_{p.in}}$$

Passive exergy output of the ISPB still is given by,

$$e_{p.out} = \left(m_d x h_{fg}\right)\left(1 - \left[\frac{T_a + 273}{T_w + 273}\right]\right)$$

Passive exergy input of the ISPB still is given by,

$$e_{p.in} = (A x I_t)\left[1 + \left(\frac{1}{3}\left[\frac{T_a + 273}{6000}\right]^4 - \frac{4}{3}\left[\frac{T_a + 273}{6000}\right]\right)\right]$$

Exergy effectiveness of the active ISPB still is given by,

$$\eta_{a.e} = \frac{e_{a.out}}{e_{p.in} + e_{fpc.in}}$$

Active exergy output of the ISPB is given by,

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

Active exergy input of the ISPB still is given by,

$$e_{a.in} = e_{p.in} + e_{fpc.in}$$

Exergy input to the FPC is given by,

$$e_{fpc.in} = Q_u\left[1 - \frac{T_a + 273}{T_w + 273}\right]$$

Useful heat gained by the FPC collector is given by,

$$Q_u = (IxA_p) - q$$

Heat lost from the FPC collector is given by,

$$q = UA(T_b - T_a)$$

From the experimental results, it was found that the thermal effectiveness of the active mode is better than the passive mode. The maximum thermal effectiveness of the passive and active mode is 50.94% and 66.49%, respectively. The maximum daily average thermal effectiveness of the passive and active ISPB still is 39.82% and 46.87% in 24.4.2017 and 9.5.2017, respectively. The thermal effectiveness of the active ISPB still is 15.05% higher than the passive ISPB still. The reason for the higher thermal effectiveness of the active ISPB still is due to the integration of the FPC with the ISPB still resulting in larger solar energy receiving surface which in turn increased the evaporation rate, yield and thermal effectiveness of the proposed system.

Thermal effectiveness of passive ISPB still is given by,

$$\eta_{p.th} = \frac{m_{ew} * h_{fg}}{I_S(t) * A_s * 3600} \times 100\%$$

Thermal effectiveness of the active ISPB still is given by,

$$\eta_{A.th} = \frac{m_{ew} h_{fg}}{[A_c \times I_c(t) + A_s \times I_s(t)] \times 3600} \times 100$$

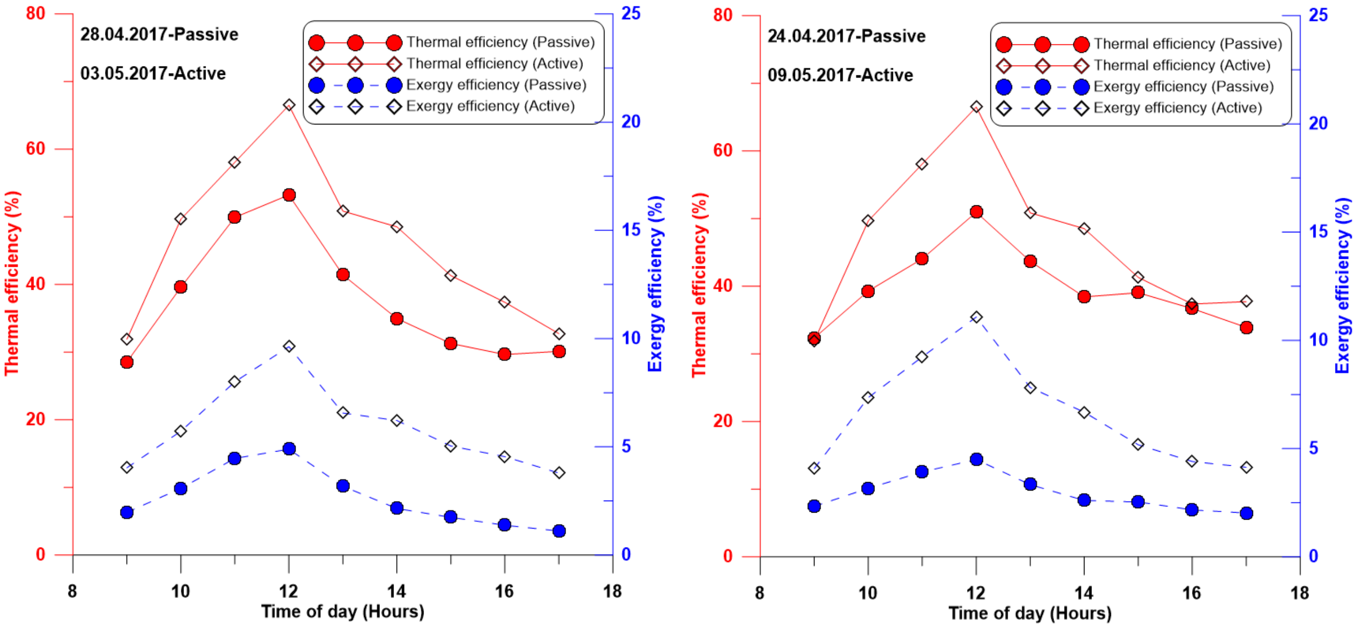


Fig. 7 Hourly variation of the thermal and exergy effectiveness of the passive and active ISPB still.

3.4 Hourly variations of PV panel power production and effectiveness for passive and active mode

Figs. 8 and 9 show the variations of power productions, panel effectiveness, voltage and current from the passive and active mode, respectively. The maximum current generated from the passive mode is 2.3 amps (I(t)= 1010 W/m^2, panel temperature=55 ^{o} C) and 2.1 amps (I(t)= 980 W/m^2, panel temperature=53 ^{o} C) in 24.4.2017 and 28.4.2017, respectively. Similarly, the maximum current generated from the active mode is 2 amps I(t)= 995 W/m^2, panel temperature=58 ^{o} C) and 2.1 amps I(t)= 990 W/m^2, panel temperature=56 ^{o} C) in 3.5.2017, 9.5.2017, respectively. On comparing the data obtained in 24.4.2017 and 9.5.2017, the main reasons for the decrease in current in the active mode over the passive mode are due to increase in PV panel temperature by 5.17% and decrease in solar intensity approximately by1.98 %.

The electrical power generated from the solar panel increased in the morning and reached its maximum value of 92 (24.4.2017) and 82 (28.4.2017) W for the passive mode and 76 (3.5.2017) and 82 (9.5.2017) W for the active mode, at 12 P.M and it decreased in the sunset period. The maximum daily average power generation from the passive and active ISPB still is 70 (24.4.2017) and 58 (9.5.2017) W respectively. From the experimental investigation, it is observed that the panel power production capacity mainly depends on the solar intensity and the PV panel temperature. The electrical power generated by the active mode is 17.14% less than that of the passive mode because of the higher heat gain of the basin.

Electrical effectiveness of the PV panel is given by,

$$\eta_{pv\,electrical} = \frac{FF * V * I}{I_s(t) * A_s} \times 100\%$$

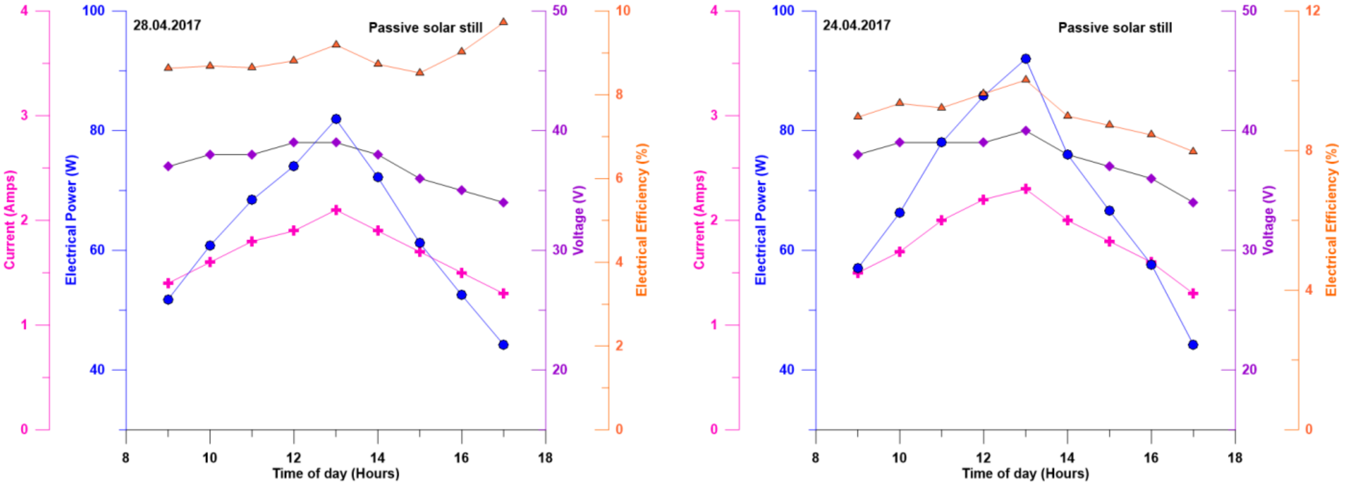


Fig. 8 Variations of power productions and panel effectiveness for the passive mode

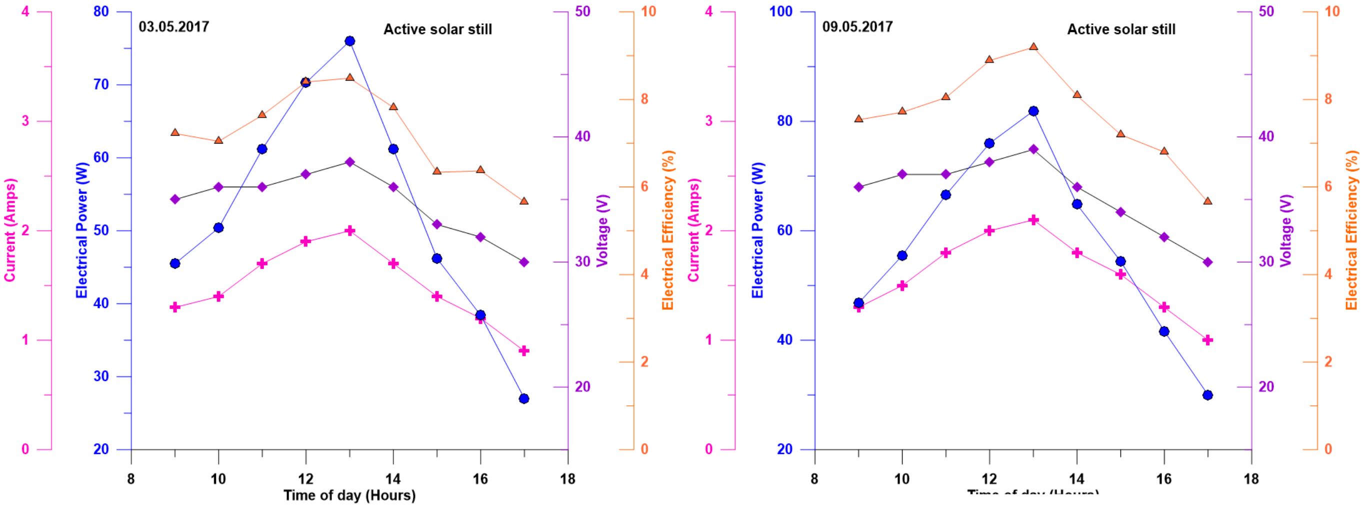


Fig. 9 Variations of power productions and panel effectiveness for the active mode

From Figs. 8 and 9 it is clear that by integrating the FPC with the ISPB still, the panel effectiveness is decreased because of the increase in panel and water temperatures. The maximum hourly PV efficiencies for the passive mode is 10.02% in 24.4.2017, 9.19% in 28.4.2017 and the active mode is 8.49% in 3.5.2017, 9.19% in 9.5.2017, at 12 P.M and the daily average panel effectiveness for the passive and active mode was found to be 9.03% (24.4.2017), 8.59% (28.4.2017) and 7.22% (3.5.2017), 7.68% (9.5.2017), respectively. The daily panel effectiveness of the active mode is 15-16% less than the passive mode. The panel effectiveness is reduced due to increases in panel temperature and the condensed water on the collector cover creates the partial shading effect.

3.5 Variations of panel and ambient temperatures, PV panel electrical, thermal and exergy effectiveness for passive and active mode.

Thermal effectiveness of the PV panel is obtained by,

$$\eta_{pv\,thermal} = \frac{FF * V_{oc} * I_{sc}}{0.38\, I_s(t) * A_s} \times 100\%$$

The constant 0.38 is the electric power production effectiveness for a conventional power plant. It converts the electrical energy produced from the PV panel to equivalent thermal energy. PV thermal effectiveness for both passive and active mode has the similar trend like PV electrical effectiveness and it reached its peak value of 26.63% (24.4.2017), 24.44% (28.4.2017) and 22.33% (3.5.2017), 24.19% (9.5.2017) respectively at 1 P.M. The daily average thermal effectiveness of PV panel for the passive mode is 24.02% and 22.82% in the date of (24.4.2017) and 28.4.2017, respectively. Similarly, for the active mode is 19% and 20.21% in 3.5.2017 and 9.5.2017, respectively.

Fig. 10 shows the variations of solar panel temperature, ambient temperature, PV panel electrical, thermal and exergy effectiveness for the passive mode. It can be seen that at 9 A.M the value of solar intensity, PV panel temperature and exergy effectiveness started from 700 W/m^2, 41 °C and 16.07% in 24.4.2017 and 660 W/m^2, 40 °C and 17.98% in 28.4.2017, respectively. With the increase in time, the solar intensity and PV panel temperature increased linearly and reached its peak value at 1 P.M and the exergy effectiveness decreased linearly and reached its lower value at 1 P.M. After 1 P.M the solar intensity, panel temperature decreased and the exergy effectiveness increased. At 5 P.M the maximal exergy effectiveness was about 20.94% and 27.16% obtained in 24.4.2017 and 28.4.2017, respectively.

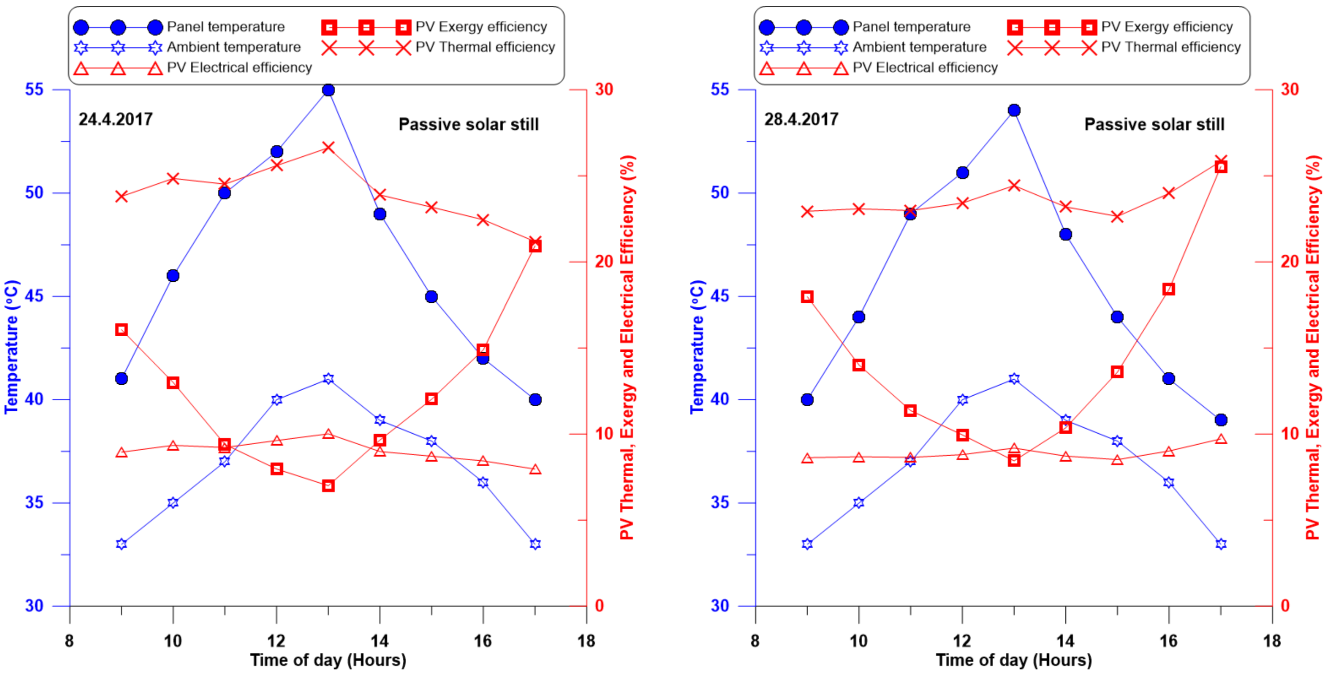


Fig. 10 Variations of panel and ambient temperatures, PV panel electrical, thermal and exergy effectiveness for the passive mode

Hourly variations of atmosphere temperature, panel temperature, PV panel electrical, thermal and exergy effectiveness for the active mode is shown in Fig. 11. The value of the solar radiation, PV panel temperature and exergy effectiveness started with 700 W/m^2, 44 °C and 27.96% in 3.5.2017 and 690 W/m^2, 45 °C and 18.07% in 9.5.2017, respectively. Except exergy effectiveness all the other parameters increased steadily and reached its peak value at 1 P.M after that the values decreased slightly. After 1 P.M the exergy effectiveness of the PV panel increased and reached its maximum value of 27.96% and 24.51% at 5 P.M in 3.5.2017 and 9.5.2017, respectively.

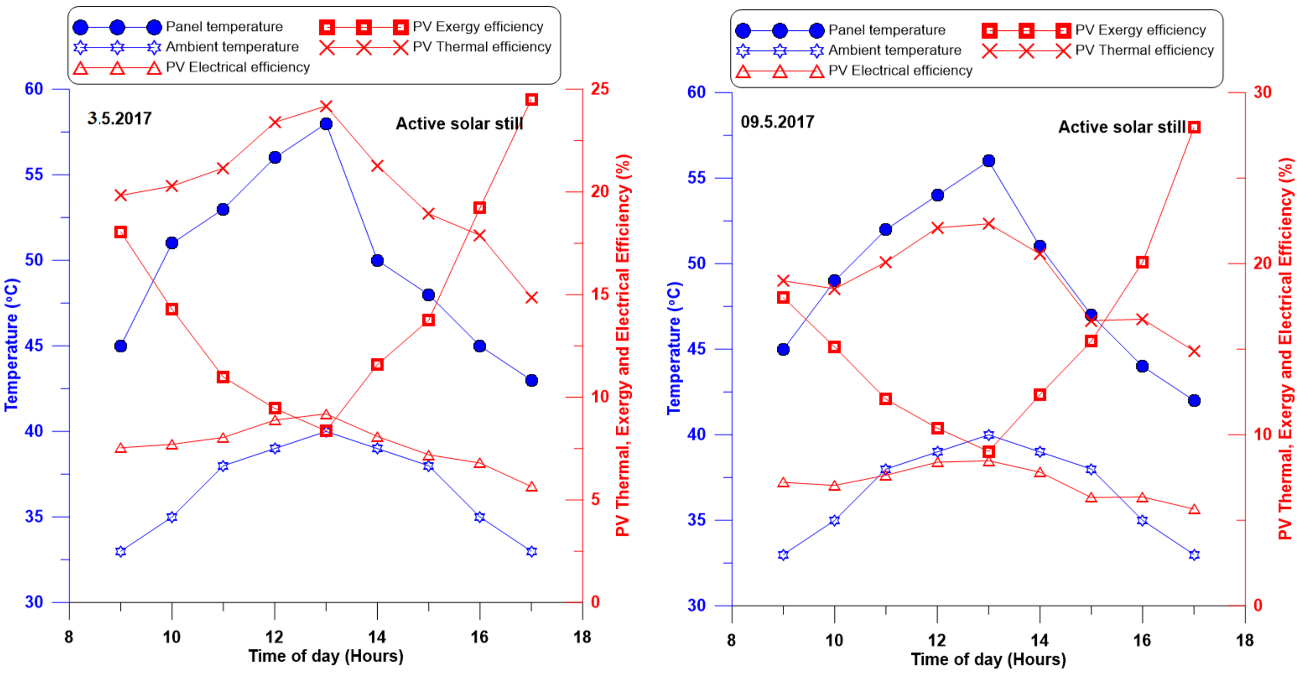


Fig. 11 Variations of panel and ambient temperatures, PV panel electrical, thermal and exergy effectiveness for the active mode

It is concluded that the exergy effectiveness of the PV panel is higher at lower values of solar intensity, ambient temperature and PV panel temperature. The daily average PV panel exergy effectiveness of the passive mode is 12.3 in 24.4.2017 and 14.76 in 28.4.2017 and the active mode is 15.6% in 3.5.2017, 14.5% in 9.5.2017.

Exergy effectiveness of the PV panel is obtained by,

$$\eta_{pv\,exergy} = \frac{FF * V_{oc} * I_{sc} - VI}{0.933\, I_s\,(t) * A_s} \times 100\%$$

3.6 Hourly variations of the overall thermal and exergy effectiveness of an ISPB still for passive and active mode

Fig. 12 shows the hourly variations of the overall thermal and exergy effectiveness of the passive and active modes. The daily average thermal effectiveness of the passive mode is 63.84 and 60.45% in 24.4.2017 and 28.4.2017, respectively. Similarly the active mode is 65.87% and 67.08% in 3.5.2017 and 9.5.2017, respectively. The daily average exergy effectiveness of the passive mode is 15.28 and 17.42% in 24.4.2017 and 28.4.2017, respectively. Similarly the active mode is 21.56% and 21.13% in 3.5.2017 and 9.5.2017, respectively. The overall thermal effectiveness of the passive ISPB still is higher during the OFF-shine hours. The active ISPB still produced only 5.9% higher daily overall thermal effectiveness than the passive ISPB still because of the collector surface area of the active mode is higher than the passive mode.

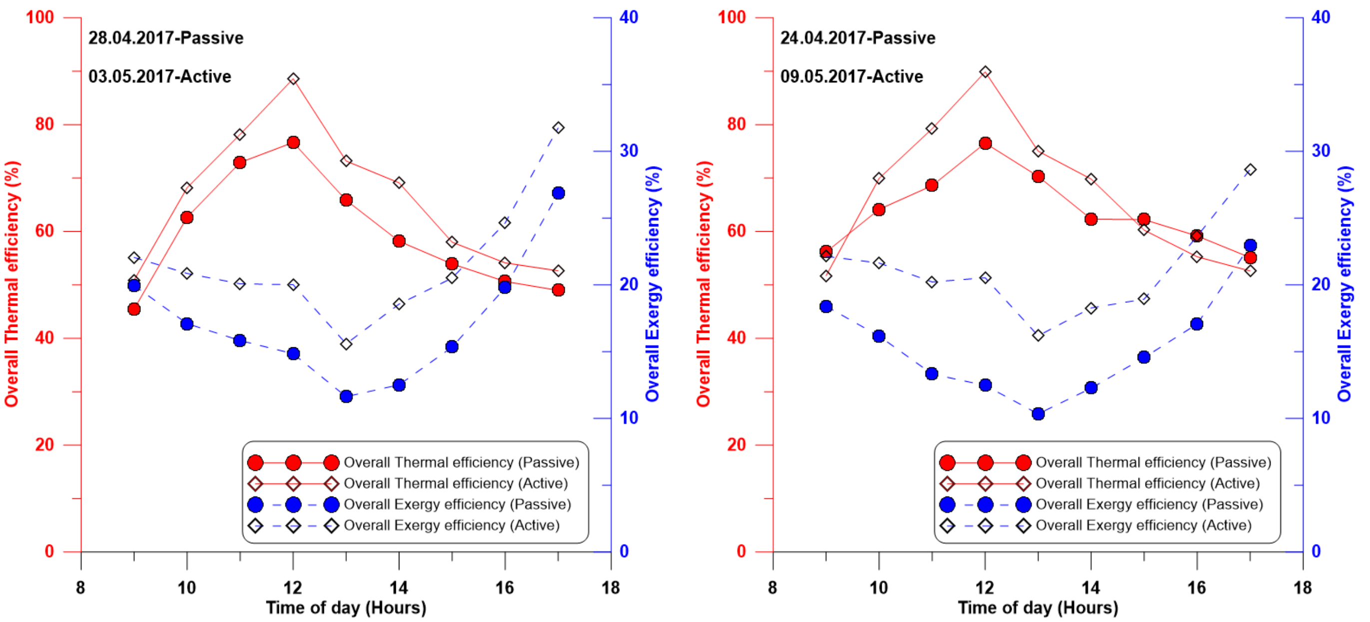


Fig. 12 Hourly variations of the overall thermal and exergy effectiveness of the passive and active ISPB still

Overall thermal effectiveness of the passive ISPB still is given by,

$$\eta_{overallP.thermal} = \frac{m_{ew} * h_{fg}}{I_S(t) * A_s * 3600} \times 100\% + \frac{FF * V_{oc} * I_{sc} - VI}{0.933\ I_s(t) * A_s} \times 100\%$$

Overall thermal effectiveness of the active ISPB still is given by,

$$\eta_{overallA.thermal} = \frac{m_{ew} h_{fg}}{[A_c \times I_c(t) + A_s \times I_s(t)] \times 3600} \times 100 + \frac{FF * V_{oc} * I_{sc} - VI}{0.933\ I_s(t) * A_s} \times 100\%$$

Overall exergy effectiveness of the passive ISPB still is given by,

$$\eta_{overallPexergy} = \frac{(m_d * h_{fg})\left(1 - \left[\frac{T_a + 273}{T_w + 273}\right]\right)}{(A_s * I_t)\left[1 + \left(\frac{1}{3}\left[\frac{T_a + 273}{6000}\right]^4 - \frac{4}{3}\left[\frac{T_a + 273}{6000}\right]\right)\right]} + \frac{FF * V_{oc} * I_{sc} - VI}{0.933\, I_s(t) * A_s} \times 100\%$$

Overall exergy effectiveness of the active ISPB still is given by,

$$\eta_{overallAexergy} = \frac{(m_d * h_{fg})\left(1 - \left[\frac{T_a + 273}{T_w + 273}\right]\right)}{(A_s * I_t)\left[1 + \left(\frac{1}{3}\left[\frac{T_a + 273}{6000}\right]^4 - \frac{4}{3}\left[\frac{T_a + 273}{6000}\right]\right)\right] + Q_u\left[1 - \frac{T_a + 273}{T_w + 273}\right]} + \frac{FF * V_{oc} * I_{sc} - VI}{0.933\, I_s(t) * A_s} \times 100\%$$

The daily productivity, thermal and exergy efficiency of the passive and active ISPB still, as well as the % rise are shown in Table. 3. As shown in Table 3, the daily productivity ranges between 3.9 to 4.3 kg/m^2 and 7.6 to 7.9 kg/m^2 for the passive and active mode, respectively. For the active mode the daily productivity is improved by 45.6 and 48.7%.

Table 3. Percentage rise in productivity, thermal and exergy efficiency of the active ISPB still over the passive ISPB still

S.no	Productivity (kg)			Thermal efficiency (%)			Exergy efficiency (%)		
	passive	active	% rise	passive	active	% rise	passive	active	% rise
1	4.3	7.9	45.6	39.82	46.87	15	2.9	6.6	56
2	3.9	7.6	48.7	38	45.7	16.8	2.6	5.9	56

3.7 Comparison of productivity of different PV/T solar still

The comparison of yield of different hybrid PV/T solar still is summarized in Table 4. The yield is higher in the case of solar still integrated with an electrical heater [16]. Hybrid PV/T solar still integrated with an FPC produced the maximum yield of about 6-10 kg/m^2. The passive ISPB still produced yield of about 4.4 kg and the active ISPB still produced the maximum daily fresh water of about 7.9 kg. For the active mode the fresh water yield is increased up to 44.37% than the passive mode.

Table. 4 Comparison of productivity of different PV/T solar still

S.No	Author name	Experimental work done	Yield (kg/m^2)
1	Kumar et al [6]	Hybrid (PV/T) active solar still.	6 - 10

2	Dev et al [7]	solar still with an FPC incorporated with the PV module	7.223
3	Kumar et al [8]	Active solar still (hybrid PV/T)	7.22
4	Gaur et al [9]	most effective use of number of collectors for integrated PV/T hybrid active solar still	7.9
5	Eltawil [11]	solar still utilizing PV, FPC and air heater	6-10
6	Saeedi et al [12]	Active solar still (PV/T)	8.37
7	Singh et al [14]	Active solar still (two hybrid PVT collectors)	6 - 10
8	Abdallah et al [16]	solar still incorporated with Super Heat Conduction Metal Vacuum Tube	12 L/m^2
9	Yari et al [17]	Integration of solar still and PV module	4.77
10	Al-Nimr et al [19]	PV cells fixed at the solar still basin and incorporated with finned condenser at outer surface	6.8
12	Ali-Riahi et al [20]	Solar still incorporated with AC-heater and PV module	5.7
13	Praveen Kumar et al [21]	PV/T active solar still with effective heating	8.542 L
14	Muthu Manokar et al [26]	Integrating PV panel in an inclined solar still-Passive mode	4.4 kg
15	Muthu Manokar et al **(present study)**	Solar panel basin solar still integrated with an FPC-Active mode (present study)	7.9 kg

CONCLUSIONS

In this study, the performance of an Inclined Solar Panel Basin (ISPB) still integrated with (active mode) and without (passive mode) Flat Plate Collector (FPC) has been compared experimentally under Indian climatic conditions.

From the experimental study the following conclusions have arrived:-

1. The amount of fresh water production from the active mode is 44.63% higher than that of the passive mode.
2. The electrical and thermal effectiveness of the PV panel in the passive mode is 15.02 and 15.87% and higher than the active mode.
3. The maximum daily yield, thermal and exergy effectiveness of the passive ISPB still is 4.38 kg, 39.82% and 2.9%, respectively.
4. The maximum daily yield, thermal and exergy effectiveness of the active ISPB still is 7.9 kg, 46.87%, and 6.6%, respectively.
5. The daily overall thermal effectiveness of about 63.84 and 67.08% and daily overall exergy effectiveness of about 15.28 and 21.13% is obtained for the passive and active ISPB still, respectively.

6. The overall performance of the active ISPB still is better than the passive ISPB still. The daily thermal and exergy effectiveness of the active ISPB still is 15.05% and 55.68% higher than the passive ISPB still.

Nomenclature

A - Area (m^2)
Exinput - Exergy input of an ISPB Still (W/m^2)
Exoutput - Exergy output of an ISPB Still (W/m^2)
h- Heat transfer coefficient (W/m^2K)
I – Current (A)
I (t) – Solar intensity (W/m^2)
ISPB -Inclined Solar Panel basin
EHTC -Evaporative Heat Transfer Coefficient
CNT -Carbon Nano Tubes
GNP -Grapheme Nano Plates
L_{fg} – Latent heat of Vaporization (kJ/kg K)
m_{ew} - Hourly productivity from an ISPB Still (kg/m^2 h)
P- Power production
PV- Photovoltaic
PV/T – Photovoltaic Thermal
T – Temperature (^{o} C)
V – Voltage (V)
$\eta_{overall, exe}$ - Overall exergy effectiveness (%)
η_{pv} - PV panel effectiveness (%)
Al_2O_3 -Aluminum oxide
SnO_2 -Tin oxide
Zn O -Zinc Oxide

Subscript

a- Ambient
d- Daily
e- Evaporation
g- Glass
s- Sun
w- Water

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Comparative study of an inclined solar panel basin solar still in passive and active mode

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Abstract:

The aim of the present study is to compare the performance of the Inclined Solar Panel Basin (ISPB) still integrated with (active mode) and without (passive mode) Flat Plat Collector (FPC). The maximum yield of 4.3 and 7.9 kg/day is produced from the passive and active mode respectively. The daily thermal and exergy effectiveness of the passive mode is 39.82% and 2.9% and, the active mode is 46.87% and 6.6%, respectively. For the active mode the daily yield, thermal and exergy efficiencies are increased and the panel effectiveness is decreased. An active mode increases the daily fresh water production rate, thermal and exergy effectiveness up to 44.63, 24.91 and 55.68 % respectively than the passive mode.

Keywords: Inclined solar panel basin solar still; passive and active mode; yield and thermal effectiveness improvement, PV exergy, overall thermal effectiveness

1. Introduction

Today's mechanized world mainly depends on the water and energy. Due to increasing population and growth of the industry, need and demand of fresh water increases.

But the water resource remains the same and it may deplete in close to future. Due to over usage of electrical energy, conventional energy sources also in the critical position and also it will be exhausted in future. To overcome energy and water issues, substitute resource has to be initiated. Generating electrical power from the Photovoltaic (PV) panel is the best substitute as an alternative to using non-renewable sources. Water has no substitute, thus the clean water level must be increased and it should be possible adequately by changing over salty seawater into drinking water through desalination method by using solar still. By incorporating both the thoughts, PV incorporated solar still is intended to produce electrical energy and water in remote areas where annual rain fall and electrical energy shortages occurred. Depending just upon the natural water cycle is not a safe thought to get fresh water. New techniques utilizing accessible sources must be produced to get more fresh water. Actually Conventional Solar Still (CSS) gives low water production per unit area. [1-4]. Kaviti et al [5], reported that the advancement in creating various modifications of Inclined Solar Stills (ISS) must be made, so as to augment the effectiveness by keeping up the minimal water depth and utilizing wick type materials in the basin of still.

Changes in renewable energy based desalination technology are experimentally researched by various researchers in worldwide and new techniques are produced every day. One such imperative change is incorporating solar panel along with the solar still which increases the electrical and thermal effectiveness of Photovoltaic Thermal (PV/T) collector. Various researches were carried out on solar still incorporated with PV/T collector. The experimental investigation on solar still incorporated with PV panel and FPC showed that integrating the PV panel with FPC, the solar still produced the daily yield of about 6-10 kg/m^2 and increased the fresh water production rate of about 60 % than the basin type solar still [6-14]. Kabeel et al [15] introduced the novel solar still integrated with the rotating fan with vertical shaft powered by PV system. This experimental set-up produced 25% higher productivity than the CSS (Yield= 4.75 L/m^2/day). Abdallah et al [16] studied the active solar still performance by using evacuated collector integrated with PV system. Integration of the PV cells at the solar still collector surface was investigated by Yari et al [17]. This PV cells attached still produced 32% higher yield than the CSS. Al-Nimr et al [18 & 19] have designed a novel desalination with PV/T concentrated and PV cells pasted at the solar still basin. It was found that the PV cells attached with the solar still produced the fresh water yield of about 6.8 L/m^2/day. Ali Riahi et al [20] and Praveen et al [21] researched the still performance by integrating AC heater and PV module.

Comparative analysis for single and double basin glass solar still with and without insulation was studied by Elango et al [22]. Khalifa et al [23] experimentally studied the solar still performance by varying the insulation thickness and found that the yield increases with increase in insulation thickness. Comparative investigation on single and double basin solar still with and without insulation was done by Al-Karaghouli [24 & 25]. Solar still with insulation improves the yield up to 20% than no insulation. Muthu Manokar et al [26] researched the performance of ISPB still at different insulation condition and found that the ISPB still with bottom and side wall insulation decreases the PV panel effectiveness because of higher heat gain in the PV panel. Various solar collectors integrated by still were reviewed by Sathyamurthy et al [27]. A review of different types of active solar still systems was done by Muthu Manokar et al [28]. Solar still through efficient heat exchange mechanism was examined by Kabeel et al [29]. Also, Kabeel et al [30] experimentally investigated the performance of active ISS.

Abdelal et al [31] replaced a pyramid solar still conventional absorber plate by a carbon fiber/epoxy integrated with Carbon Nano Tubes (CNT) and Grapheme Nano Plates (GNP). The fresh water productivity was enhanced up to 109, 65 and 30% for the composite plate integrated with 5 wt% CNT, 2.5 wt% CNT and 2.5 wt% GNP, respectively. Elango et al [32] enhanced the fresh water productivity from the CSS by using Aluminum Oxide (Al_2O_3), Tin Oxide (SnO_2) and Zinc Oxide (Zn O) Nano fluids (Nfs). It was reported that the CSS with Al_2O_3 Nfs, SnO_2 Nfs, Zn O Nfs and water produced the daily yield of 935, 805, 750 and 655 ml, respectively. The CSS with Al_2O_3 Nfs, SnO_2 Nfs and Zn O Nfs increases the yield up to 29.95, 18.63 and 12.67% than the CSS with water. Omara et al [33] fabricated a corrugated wick solar still integrated with mirrors and external condenser. It was found that the solar still output was enhanced up to 285.10 and 254.88% by using cuprous and Al_2O_3nano particles in the basin as compared to the CSS. Sahota et al [34 & 35] used Al_2O_3 Nano Particles to augment the yield from the passive Double Slope Solar Still (DSSS). Experiments were conducted on the solar still with 35 and 80 kg of water mass inside the basin and Nfs concentrations of 0.04, 0.08 and 0.12% respectively. It was reported that Nf at the concentrations of 0.12% enhances the productivity up to 12.2% and 8.4% for the water mass of 35 and 80 kg, respectively. Sahota et al [36] researched the N-PV/T-FPC-DSSS without and with heat exchanger with Copper oxide (CuO), $Al_2O_3$and Titanium oxide Nps. Among the tested Nps CuO is the best one for enhancing the solar still performance. Sharshir et al [37] researched the solar still performance with CuO and graphite micro-flakes; it enhances the yield up to 44.91 and 53.95%, respectively as compared to the CSS. Kabeel et al [38] coated the black Np in the CSS absorber plate which enhanced the daily yield up to 15 to 18% than the normal absorber plate.

Murugavel et al [39 & 40] used Sensible Heat Energy Storage Material (SHESM) such as bricks, quartzite rocks, stones and mild steel turnings for enhancing the OFF sun-shine hours productivity. Samuel et al [41] used a low cost thermal energy storage material (spherical ball heat storage medium) in the basin of solar still. It was reported that the solar still with and without storage material produced the productivity of 3.7 and 2.2 kg, respectively. Kabeel et al [42] introduced the higher thermal conductivity material (graphite) in the CSS to improve the productivity. It was found that the CSS with and without graphite produced the maximum daily yield of 7.7 and 4.4 L respectively. Graphite enhances the productivity up to 75 to 80% than the CSS. Sellami et al [43] used a Portland cement in two different form in the basin of solar still (i) powder cement (ii) adhered layer of cement. Experiments were conducted on solar still with varying the mass of powder cement (150,100 and 50g) and cement layer (300, 200 and 100g). It was reported that the solar still with 150g of powder cement is optimized the yield and enhanced the yield up to 51.14% than the CSS.

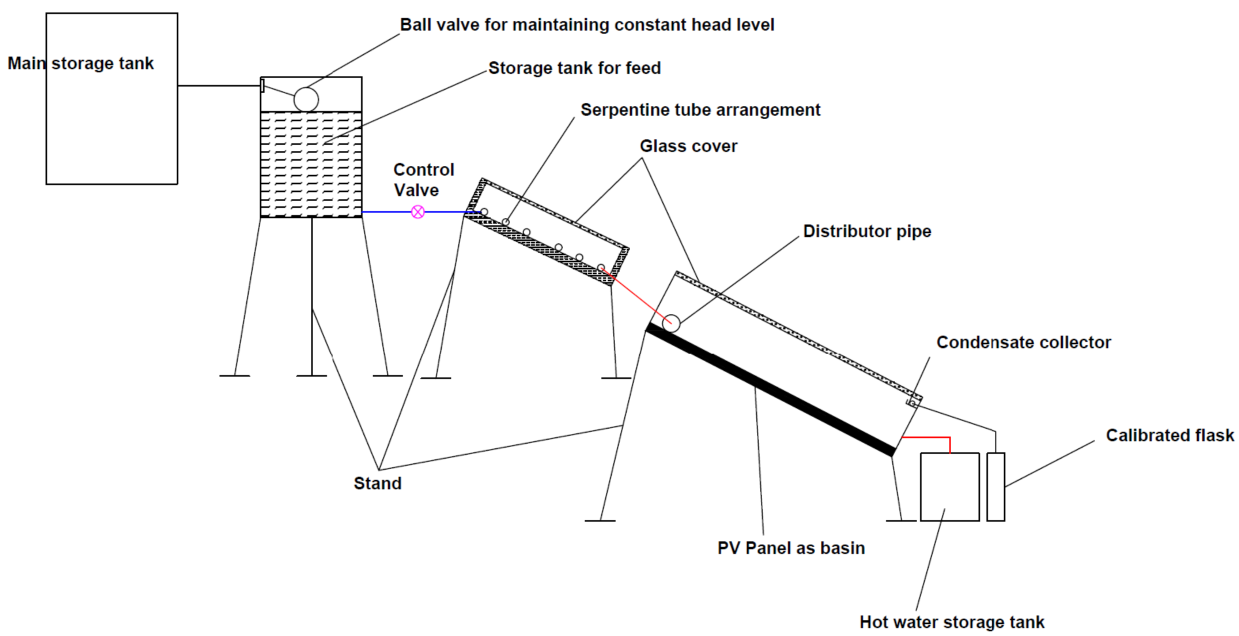
From the above literatures, it is very clear that very less experimental works were reported on the ISS in active mode (input saline water is pre-heated by using the solar collector) and hence the main aim of this research work are comparative analysis of an ISPB still in passive and active mode.

2. Design and construction of the proposed experimental arrangement:

2.1 Construction of an ISPB still in passive and active Mode

An illustrative drawing and experimental arrangement of an ISPB still in passive and active modes are shown in Fig. 1 and 2, respectively. The dimension of the solar still is 1810 mm (Length) × 920 mm (Width) × 150 mm (Height). The solar still and collector cover were fabricated using 4 mm thickness transparent glass. Cotton thread is used as a wick material to raise the evaporation rate which is fixed in the location between the successive rows and columns of the solar cells. In this setup, saline water flow arrangement is made in such a way that the water from the storage tank flows through the regulation valve, Polyvinyl Chloride inlet pipe and then to the absorber plate of the ISPB still. Saline water is fed uniformly to the basin through the regulation valve and an inlet pipe. Inlet pipe is holed at equal spaces for an even distribution. A constant head level is maintained inside the feed water storage tank by a float arrangement for maintaining constant flow rate of water inside the inclined basin. Initially a flow rate of 0.0013 kg/s of input saline water is kept for both the passive and active mode. During the operation of the ISPB still, the hot water generated from the still has been filled manually to the saline water storage tank for every one hour. The salt deposition on the PV panel was cleaned manually every 10 days with Windex. Temperature sensors are installed at the collector, absorber and exit water with the multichannel digital display device. In order to collect the condensate from the inner collector cover, a distillate collector is placed at the bottom of the glass cover. In an active mode, an FPC is integrated with the passive ISPB still.

(A) INCLINED PV BASIN SOLAR STILL UNDER ACTIVE MODE



(B) INCLINED PV BASIN SOLAR STILL UNDER PASSIVE MODE

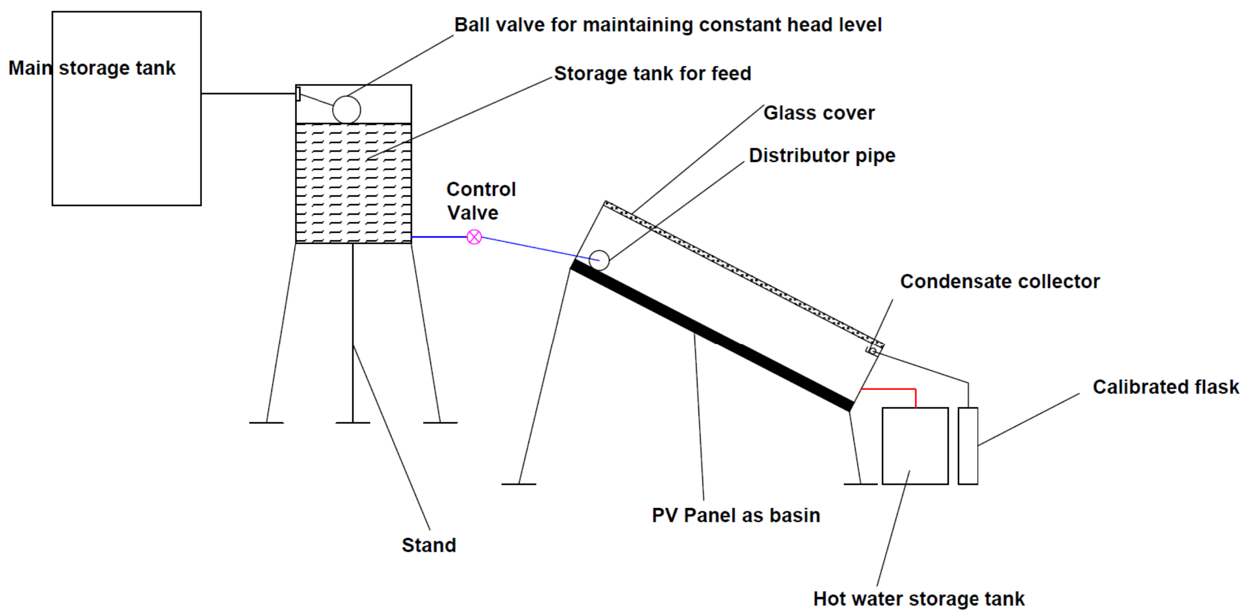


Fig. 1 Schematic drawings of (a) ISPB still in active mode and (b) ISPB still in passive mode

Fig. 2 Experimental arrangement of passive and active ISPB still

Fig. 3 Water flowing arrangements within the ISPB still.

2.2 Description of the FPC solar water heater

An FPC solar water heater was fabricated comprising of a flat solar collector, storage tank, and control valve. The flat collector of 0.9 m (L) x 0.6 m (W) x 0.004 m (H) was fabricated by using a 20 mm thickness wooden box covered with 4 mm thick window glass. This water heater was mounted on the supporting steel structure constructed of 10 mm diameter and 1 mm thickness copper tube in a flat shape with three winding (with 50 mm gap between windings) were used to circulate the water in an FPC collector. Cylindrical storage tank made up of plastic with 50 liters of capacity was mounted on a steel stand. The measuring jar and stopwatch were used to determine the mass flow rate of inlet saline water.

The entire set-up was faced south direction with the inclination angle equal to the latitude of Chennai (13° N) to receive the maximum solar intensity.

The accuracy and error limits of the various measuring instruments were listed in Table 1. Solar power meter (TES 1333), cup anemometer (AM4836), and digital multimeter were used to measure the solar intensity, wind velocity and voltage, current produced from the PV panel. The cost analysis for the passive and active ISBP still is listed in Table 2.

Experiments were carried out for the ISPB still in passive and active mode during the month of March-2017 to May-2017. The average solar intensity was calculated throughout the testing period. Two similar atmospheric condition days 24-4-2017 (average solar intensity 830 W/m^2) and 9-5-2017 (average solar intensity 815 W/m^2) are considered for the comparative analysis.

Table. 1 Accuracy, range and error limits for various measuring instruments

Sl. no	. Instruments	Accuracy	Range	% error
1	Thermocouple	±1°C	0–100°C	0.5%
2	Solar power meter	±1 W/m^2	0–2500 W/m^2	2.5 %
3	Anemometer	±0.1 m/s	0–15 m/s	10%
4	Measuring jar	±10 m L	0–1000 m L	10%
5	Multimeter	±1 V ±0.1 A	0-1000 V 0-10 A	0.5% 10%

Table. 2 Cost Analysis for passive and active ISBP still

S.No	Materials	Unit Cost(Rs)	Total Cost(Rs)
	Passive ISBP still		
1	Absorber (PV panel)	Rs 100/ Watt	Rs 15,000
2	Collector cover and side cover	Rs 1,600	Rs 1,600
3	Distillate strip	Rs 100	Rs 100
	ISPB still	(A)	Rs 16,700
4	Storage tank and stand	Rs 500	Rs 500
5	Control valve	Rs 150	Rs 150
6	Fabrication cost	Rs 250/hr	Rs 500
	Accessories and Fabrication cost	(B)	Rs 1150
	Total cost	(A+B)	Rs 17,850 /-
	Active ISBP still		
1	Passive ISBP still	(A+B)	Rs 17,850 /-
2	Copper material	Rs 700	Rs 700
3	FPC glass collector	Rs 300	Rs 300
4	Wooden box	Rs 600	Rs 600

5	FPC water heater	(C)	Rs 1600
6	Control valve	Rs 150/ 1 piece	Rs 150
7	Fabrication cost	Rs 250/h	Rs 750
	Accessories and Fabrication cost	(D)	Rs 900
	Total Cost	(A+B+C+D)	Rs 20,350

3. Results and discussion

3.1 Hourly variations of different parameters in passive and active ISPB still.

The variations of solar irradiance, glass, basin, ambient, and saline water temperatures for the passive ISPB still are plotted in Fig. 4. It was found that the daily average solar intensity is 830 W/m^2 in 24.4.2017 and 783 W/m^2 in 28.4.2017. The highest hourly solar intensity is 1010 and 980 W/m^2 in 24.4.2017 and 28.4.2017, respectively. The daily average wind velocity is 1.5 m/s in 24.4.2017 and 1.9 m/s in 28.4.2017. It is observed that, the maximum ambient temperatures of 41 ° C was reached at 1 P.M and average ambient temperatures is 37 ° C in 24.4.2017. Temperatures of glass, basin, and saline water increased with increases in solar radiation and it reached its maximum value at 1 P.M, after that the value decreased. The highest temperatures of glass, basin, and the saline water were found to be 53, 68 and 65° C, respectively in 24.4.2017.

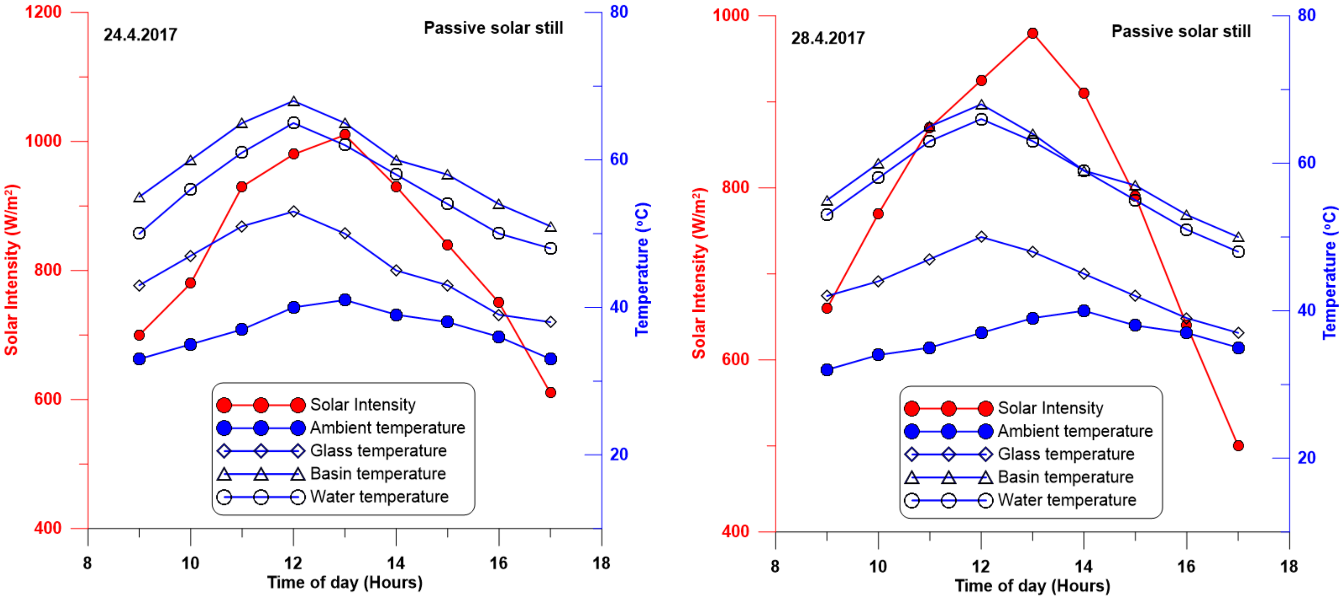


Fig. 4 Hourly variations of different parameters in passive ISPB still for two test days

The variations of solar irradiance, ambient temperature and the temperatures of glass, basin, and saline water for the active ISPB still are plotted in Fig. 5. It was found that the daily average solar intensity is 799 and 815 W/m^2 in 3.5.2017 and 9.5.2017, respectively. The highest hourly solar intensity is 995 and 990 W/m^2 in 3.5.2017 and 9.5.2017, respectively. The average wind velocity during the operation of the active mode was 2 and 2.2 m/s in 3.5.2017 and 9.5.2017, respectively. The maximum ambient temperature (40° C) reached at 1 P.M and the average ambient temperature was 36.7° C in 3.5.2017. The glass, basin and saline water temperatures increased with increase in solar intensity in the morning and reached maximum at 1 P.M, after that the values decreased. The highest glass, basin and water temperatures were found to be 54, 75 and 70° C, respectively in 9.5.2017. For the active ISPB still, the daily average water and basin temperatures increased up to 9.3 and 5.1%, respectively as compared to the passive ISPB still due to the effect of integrating an FPC to the passive ISPB still.

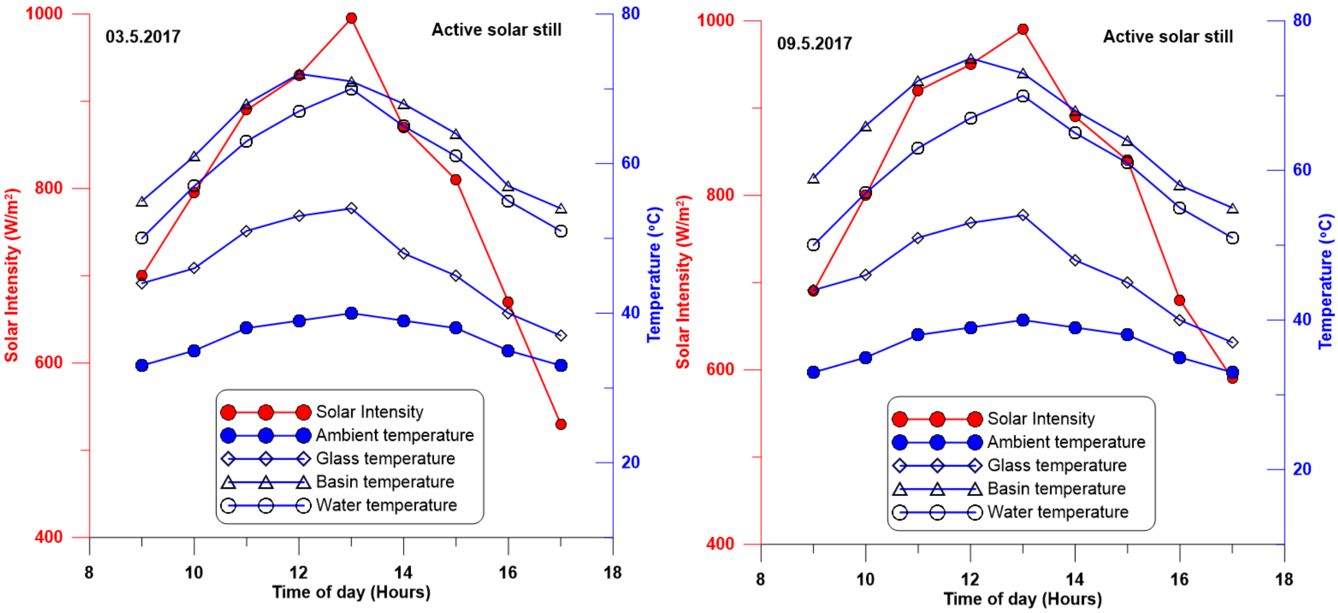


Fig. 5 Hourly variations of different parameters in active ISPB still for two test days

3.2 Hourly variations of Evaporative Heat Transfer Coefficient (EHTC) and still productivity for passive and active ISPB still

Fig. 6 depicts the variation of EHTC and productivity of the passive and active ISPB still. It is noted that the EHTC for the active mode is higher than the passive mode. The maximum EHTC of 67 and 90 W/m^{2}K is obtained for the passive and active mode in 24.4.2017 and 9.5.2017, respectively. Also, the average EHTC for the active mode is about 25% higher than the passive mode. The deviation observed to increases in EHTC is because of the incorporation of the FPC to the ISPB still.

EHTC from water to collector cover is given by,

$$h_{e,w-g} = 16.273X10^{-3}xh_{c,w-g}\left[\frac{P_w - P_{gi}}{T_w - T_{gi}}\right]$$

Convective heat transfer coefficient from water to collector cover is given by,

$$h_{c,w-g} = 0.884\left[\left(T_w - T_{gi}\right) + \frac{\left(P_w - P_{gi}\right)\left(T_w + 273\right)}{\left(268.9X10^{-3} - P_w\right)}\right]$$

Partial vapour pressure at water temperature is given by,

$$P_w = exp\left(25.317 - \left(\frac{5144}{273 + T_w}\right)\right)$$

Partial vapour pressure at inner surface of collector cover is given by,

$$P_{gi} = exp\left(25.317 - \left(\frac{5144}{273 + T_{gi}}\right)\right)$$

The maximum hourly yield of the ISPB still is higher when the still is integrated with the FPC. The maximum hourly productivity of 0.7 and 1.4 kg/h was obtained for passive and active mode at 12 P.M in 24.4.2017 and 9.5.2017, respectively. It was found that the maximum daily yield produced from the passive and active mode is 4.38 and 7.91 kg respectively. In the case of active mode, the still productivity is increased up to 44.63 % than the passive mode. The increase in yield is because of the integration of the FPC with the ISPB still. FPC with the ISBP still increaseds the saline water temperature up to 75 ° C. The evaporation rate of the active ISPB still was higher than the passive ISPB still due to higher inlet water temperature and hence the active ISPB still produced the higher yield.

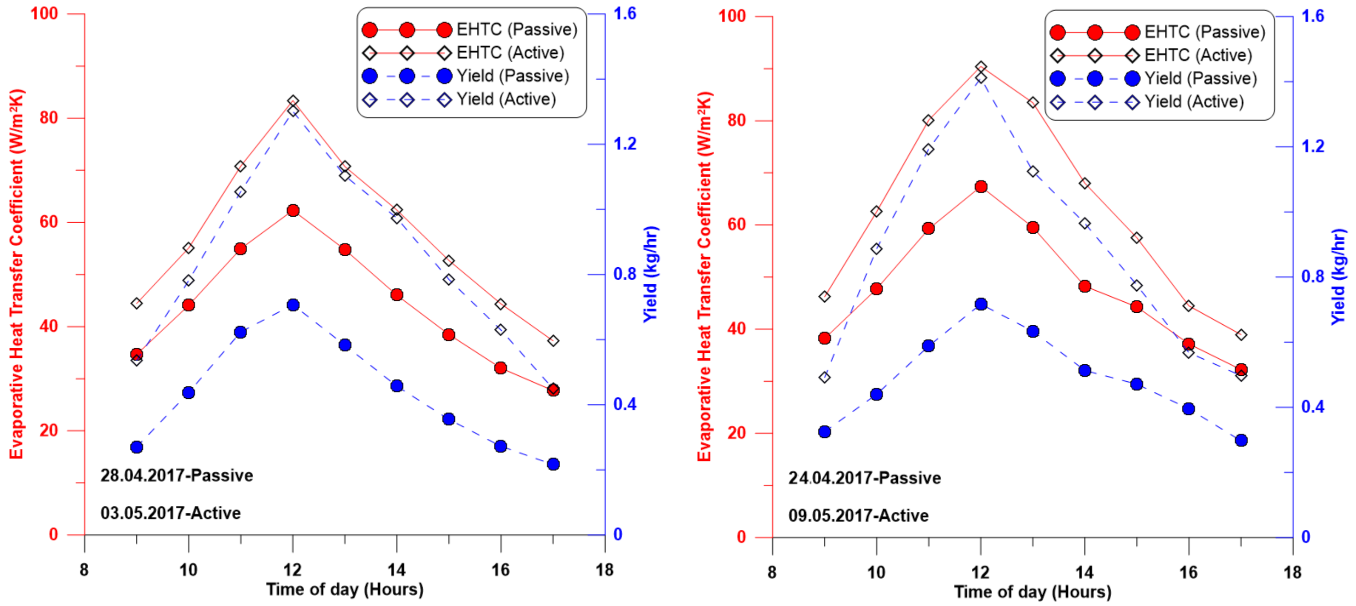


Fig. 6 Hourly variations of EHTC and Yield for the passive and active ISPB still

3.3 Hourly variations of exergy and thermal effectiveness for passive and active ISPB still

The variations of the exergy and thermal effectiveness of the passive and active modes are plotted in Fig 7. It was found that the exergy effectiveness of the active mode is higher than the passive mode due to the variation in input between passive (exergy input to a solar still) and active modes (summation of exergy inputs of solar still and an FPC). The maximum exergy effectiveness of 4.89% and 11.08% is obtained for the passive and active modes in 24.4.2017 and 9.5.2017, respectively. The maximum daily average exergy effectiveness of the passive and active mode is found to be 2.9 and 6.6% in 24.4.2017 and 9.5.2017, respectively. The active ISPB still produced 55.68% higher exergy effectiveness as compared to the passive ISPB still. The exergy effectiveness of the passive ISPB still is estimated as,

Exergy effectiveness of the passive ISPB still is given by,

$$\eta_{p.e} = \frac{e_{p.out}}{e_{p.in}}$$

Passive exergy output of the ISPB still is given by,

$$e_{p.out} = \left(m_d x h_{fg}\right)\left(1 - \left[\frac{T_a + 273}{T_w + 273}\right]\right)$$

Passive exergy input of the ISPB still is given by,

$$e_{p.in} = (A x I_t)\left[1 + \left(\frac{1}{3}\left[\frac{T_a + 273}{6000}\right]^4 - \frac{4}{3}\left[\frac{T_a + 273}{6000}\right]\right)\right]$$

Exergy effectiveness of the active ISPB still is given by,

$$\eta_{a.e} = \frac{e_{a.out}}{e_{p.in} + e_{fpc.in}}$$

Active exergy output of the ISPB is given by,

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

Active exergy input of the ISPB still is given by,

$$e_{a.in} = e_{p.in} + e_{fpc.in}$$

Exergy input to the FPC is given by,

$$e_{fpc.in} = Q_u\left[1 - \frac{T_a + 273}{T_w + 273}\right]$$

Useful heat gained by the FPC collector is given by,

$$Q_u = (IxA_p) - q$$

Heat lost from the FPC collector is given by,

$$q = UA(T_b - T_a)$$

From the experimental results, it was found that the thermal effectiveness of the active mode is better than the passive mode. The maximum thermal effectiveness of the passive and active mode is 50.94% and 66.49%, respectively. The maximum daily average thermal effectiveness of the passive and active ISPB still is 39.82% and 46.87% in 24.4.2017 and 9.5.2017, respectively. The thermal effectiveness of the active ISPB still is 15.05% higher than the passive ISPB still. The reason for the higher thermal effectiveness of the active ISPB still is due to the integration of the FPC with the ISPB still resulting in larger solar energy receiving surface which in turn increased the evaporation rate, yield and thermal effectiveness of the proposed system.

Thermal effectiveness of passive ISPB still is given by,

$$\eta_{p.th} = \frac{m_{ew} * h_{fg}}{I_S(t) * A_s * 3600} \times 100\%$$

Thermal effectiveness of the active ISPB still is given by,

$$\eta_{A.th} = \frac{m_{ew} h_{fg}}{[A_c \times I_c(t) + A_s \times I_s(t)] \times 3600} \times 100$$

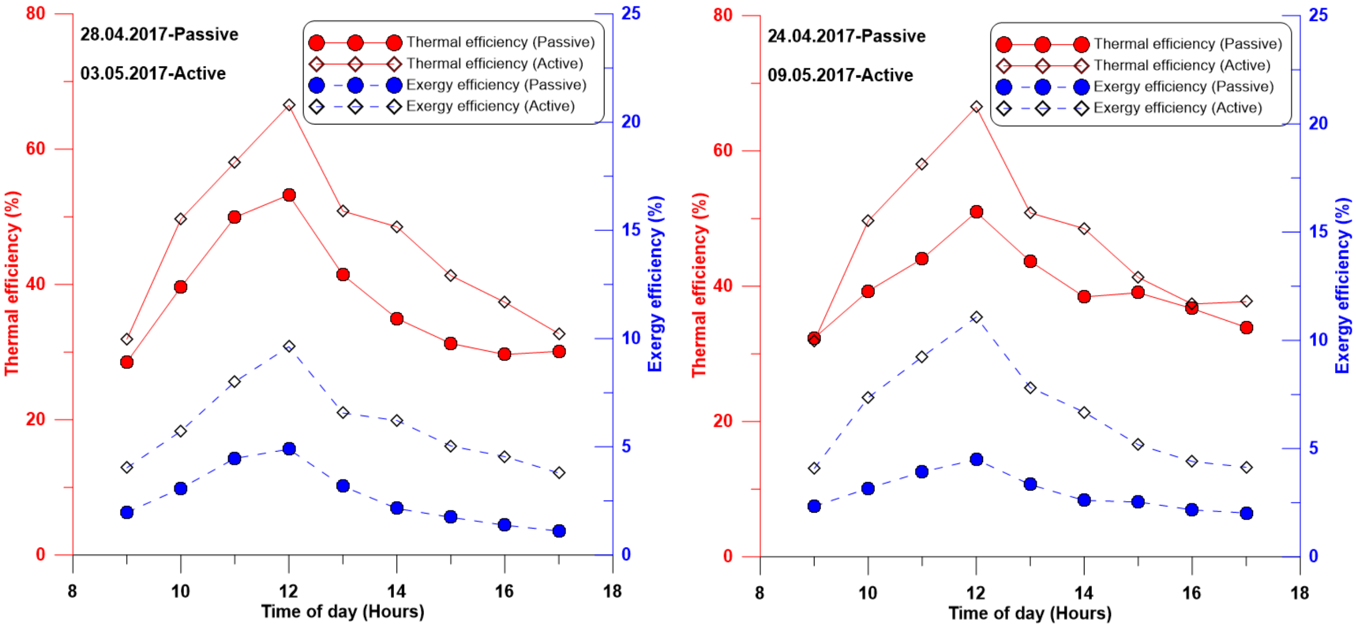


Fig. 7 Hourly variation of the thermal and exergy effectiveness of the passive and active ISPB still.

3.4 Hourly variations of PV panel power production and effectiveness for passive and active mode

Figs. 8 and 9 show the variations of power productions, panel effectiveness, voltage and current from the passive and active mode, respectively. The maximum current generated from the passive mode is 2.3 amps (I(t)= 1010 W/m^2, panel temperature=55 ^{o} C) and 2.1 amps (I(t)= 980 W/m^2, panel temperature=53 ^{o} C) in 24.4.2017 and 28.4.2017, respectively. Similarly, the maximum current generated from the active mode is 2 amps I(t)= 995 W/m^2, panel temperature=58 ^{o} C) and 2.1 amps I(t)= 990 W/m^2, panel temperature=56 ^{o} C) in 3.5.2017, 9.5.2017, respectively. On comparing the data obtained in 24.4.2017 and 9.5.2017, the main reasons for the decrease in current in the active mode over the passive mode are due to increase in PV panel temperature by 5.17% and decrease in solar intensity approximately by1.98 %.

The electrical power generated from the solar panel increased in the morning and reached its maximum value of 92 (24.4.2017) and 82 (28.4.2017) W for the passive mode and 76 (3.5.2017) and 82 (9.5.2017) W for the active mode, at 12 P.M and it decreased in the sunset period. The maximum daily average power generation from the passive and active ISPB still is 70 (24.4.2017) and 58 (9.5.2017) W respectively. From the experimental investigation, it is observed that the panel power production capacity mainly depends on the solar intensity and the PV panel temperature. The electrical power generated by the active mode is 17.14% less than that of the passive mode because of the higher heat gain of the basin.

Electrical effectiveness of the PV panel is given by,

$$\eta_{pv\,electrical} = \frac{FF * V * I}{I_s(t) * A_s} \times 100\%$$

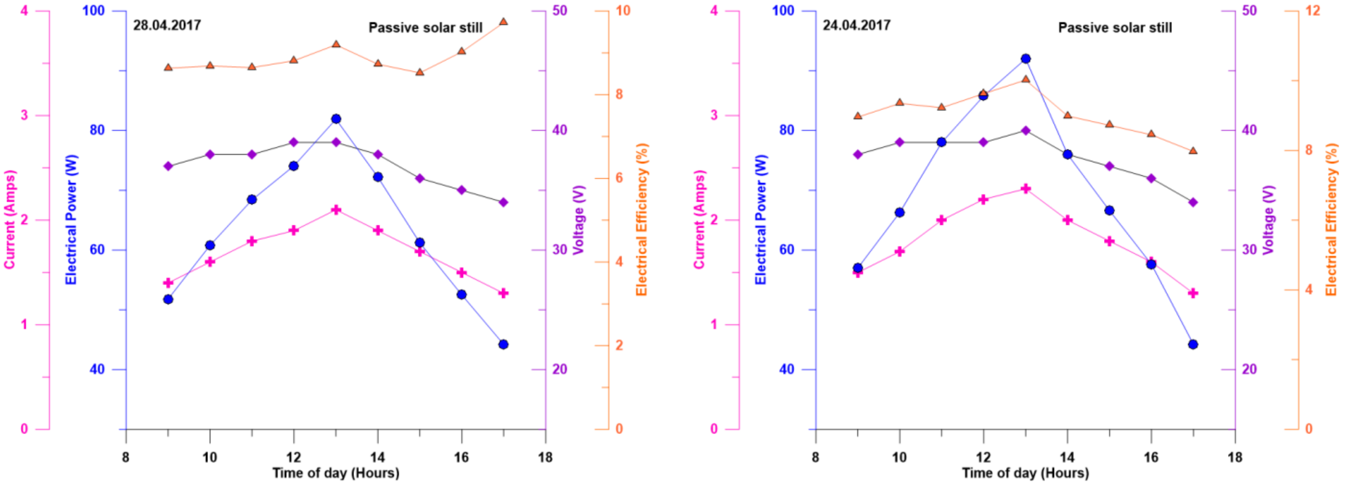


Fig. 8 Variations of power productions and panel effectiveness for the passive mode

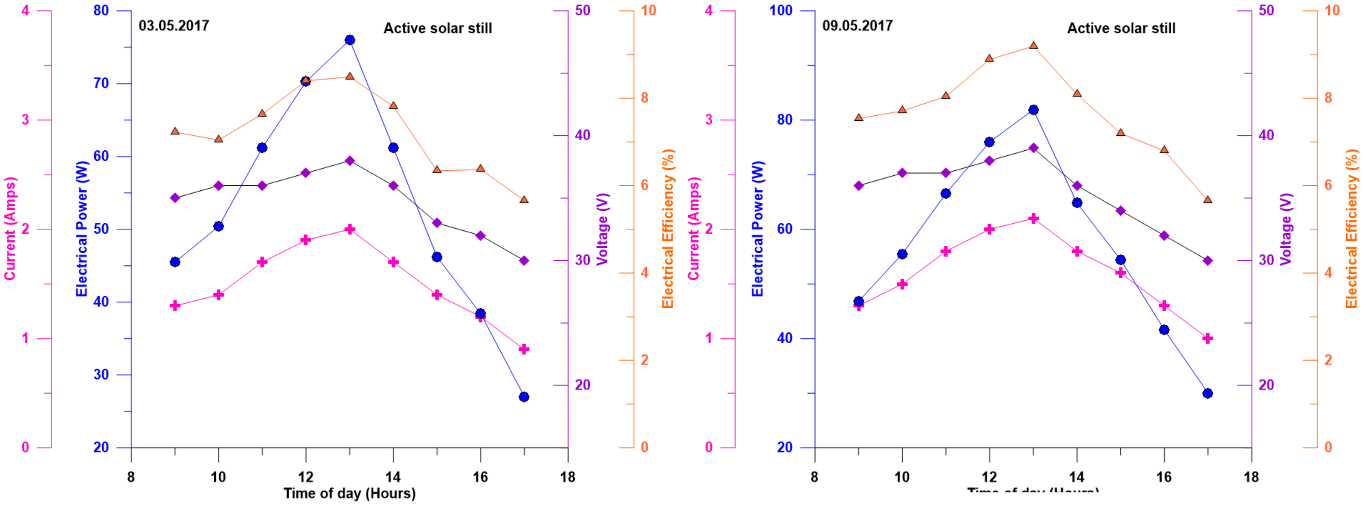


Fig. 9 Variations of power productions and panel effectiveness for the active mode

From Figs. 8 and 9 it is clear that by integrating the FPC with the ISPB still, the panel effectiveness is decreased because of the increase in panel and water temperatures. The maximum hourly PV efficiencies for the passive mode is 10.02% in 24.4.2017, 9.19% in 28.4.2017 and the active mode is 8.49% in 3.5.2017, 9.19% in 9.5.2017, at 12 P.M and the daily average panel effectiveness for the passive and active mode was found to be 9.03% (24.4.2017), 8.59% (28.4.2017) and 7.22% (3.5.2017), 7.68% (9.5.2017), respectively. The daily panel effectiveness of the active mode is 15-16% less than the passive mode. The panel effectiveness is reduced due to increases in panel temperature and the condensed water on the collector cover creates the partial shading effect.

3.5 Variations of panel and ambient temperatures, PV panel electrical, thermal and exergy effectiveness for passive and active mode.

Thermal effectiveness of the PV panel is obtained by,

$$\eta_{pv\,thermal} = \frac{FF * V_{oc} * I_{sc}}{0.38\, I_s\,(t) * A_s} \times 100\%$$

The constant 0.38 is the electric power production effectiveness for a conventional power plant. It converts the electrical energy produced from the PV panel to equivalent thermal energy. PV thermal effectiveness for both passive and active mode has the similar trend like PV electrical effectiveness and it reached its peak value of 26.63% (24.4.2017), 24.44% (28.4.2017) and 22.33% (3.5.2017), 24.19% (9.5.2017) respectively at 1 P.M. The daily average thermal effectiveness of PV panel for the passive mode is 24.02% and 22.82% in the date of (24.4.2017) and 28.4.2017, respectively. Similarly, for the active mode is 19% and 20.21% in 3.5.2017 and 9.5.2017, respectively.

Fig. 10 shows the variations of solar panel temperature, ambient temperature, PV panel electrical, thermal and exergy effectiveness for the passive mode. It can be seen that at 9 A.M the value of solar intensity, PV panel temperature and exergy effectiveness started from 700 W/m^2, 41 °C and 16.07% in 24.4.2017 and 660 W/m^2, 40 °C and 17.98% in 28.4.2017, respectively. With the increase in time, the solar intensity and PV panel temperature increased linearly and reached its peak value at 1 P.M and the exergy effectiveness decreased linearly and reached its lower value at 1 P.M. After 1 P.M the solar intensity, panel temperature decreased and the exergy effectiveness increased. At 5 P.M the maximal exergy effectiveness was about 20.94% and 27.16% obtained in 24.4.2017 and 28.4.2017, respectively.

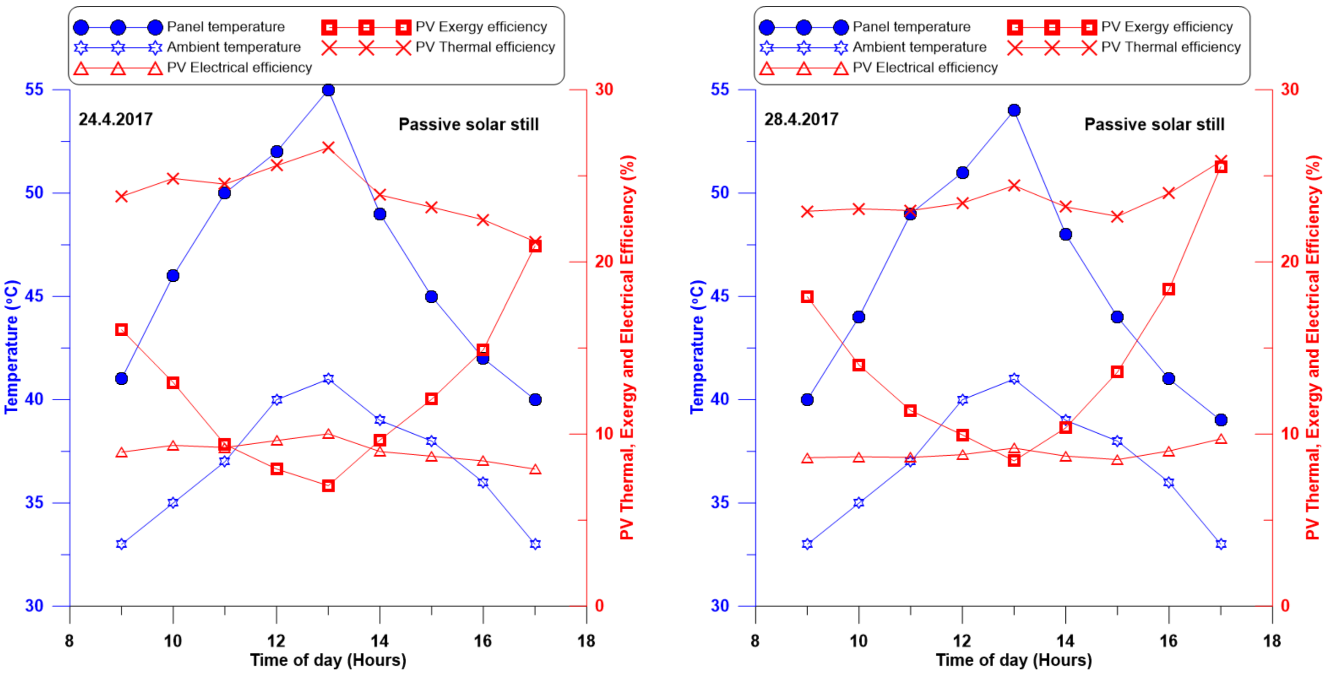


Fig. 10 Variations of panel and ambient temperatures, PV panel electrical, thermal and exergy effectiveness for the passive mode

Hourly variations of atmosphere temperature, panel temperature, PV panel electrical, thermal and exergy effectiveness for the active mode is shown in Fig. 11. The value of the solar radiation, PV panel temperature and exergy effectiveness started with 700 W/m^2, 44 °C and 27.96% in 3.5.2017 and 690 W/m^2, 45 °C and 18.07% in 9.5.2017, respectively. Except exergy effectiveness all the other parameters increased steadily and reached its peak value at 1 P.M after that the values decreased slightly. After 1 P.M the exergy effectiveness of the PV panel increased and reached its maximum value of 27.96% and 24.51% at 5 P.M in 3.5.2017 and 9.5.2017, respectively.

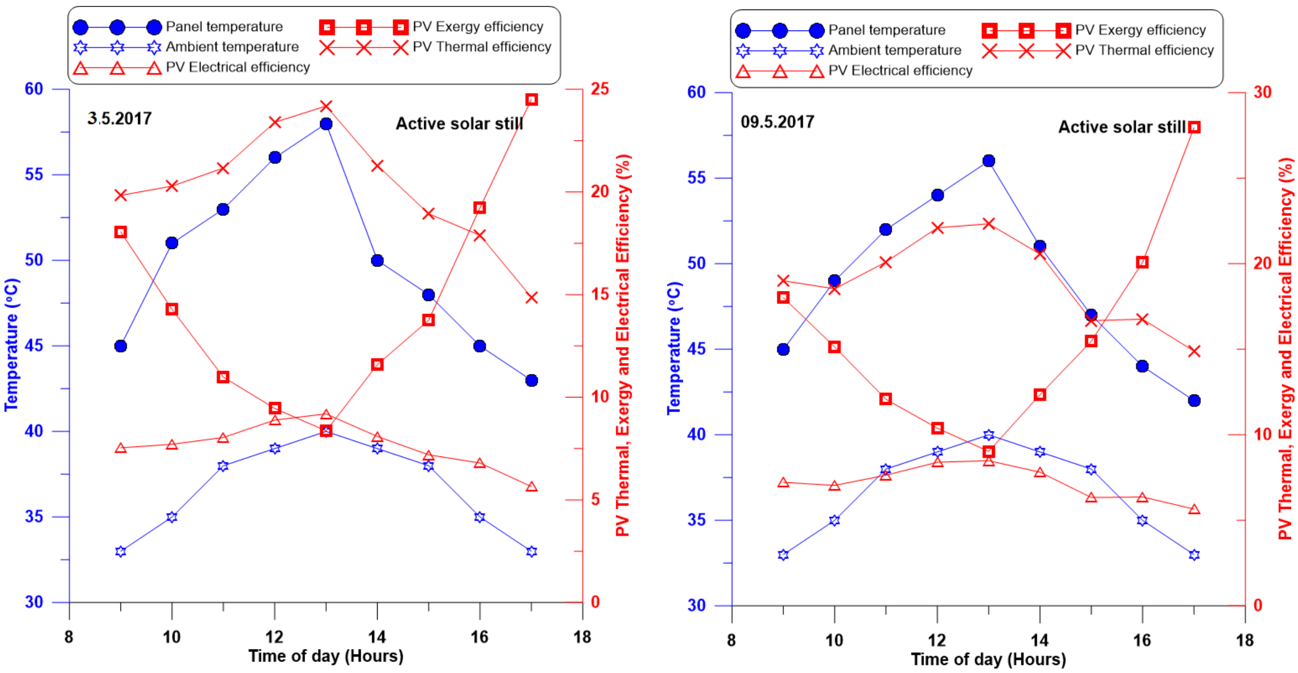


Fig. 11 Variations of panel and ambient temperatures, PV panel electrical, thermal and exergy effectiveness for the active mode

It is concluded that the exergy effectiveness of the PV panel is higher at lower values of solar intensity, ambient temperature and PV panel temperature. The daily average PV panel exergy effectiveness of the passive mode is 12.3 in 24.4.2017 and 14.76 in 28.4.2017 and the active mode is 15.6% in 3.5.2017, 14.5% in 9.5.2017.

Exergy effectiveness of the PV panel is obtained by,

$$\eta_{pv\,exergy} = \frac{FF * V_{oc} * I_{sc} - VI}{0.933\, I_s\,(t) * A_s} \times 100\%$$

3.6 Hourly variations of the overall thermal and exergy effectiveness of an ISPB still for passive and active mode

Fig. 12 shows the hourly variations of the overall thermal and exergy effectiveness of the passive and active modes. The daily average thermal effectiveness of the passive mode is 63.84 and 60.45% in 24.4.2017 and 28.4.2017, respectively. Similarly the active mode is 65.87% and 67.08% in 3.5.2017 and 9.5.2017, respectively. The daily average exergy effectiveness of the passive mode is 15.28 and 17.42% in 24.4.2017 and 28.4.2017, respectively. Similarly the active mode is 21.56% and 21.13% in 3.5.2017 and 9.5.2017, respectively. The overall thermal effectiveness of the passive ISPB still is higher during the OFF-shine hours. The active ISPB still produced only 5.9% higher daily overall thermal effectiveness than the passive ISPB still because of the collector surface area of the active mode is higher than the passive mode.

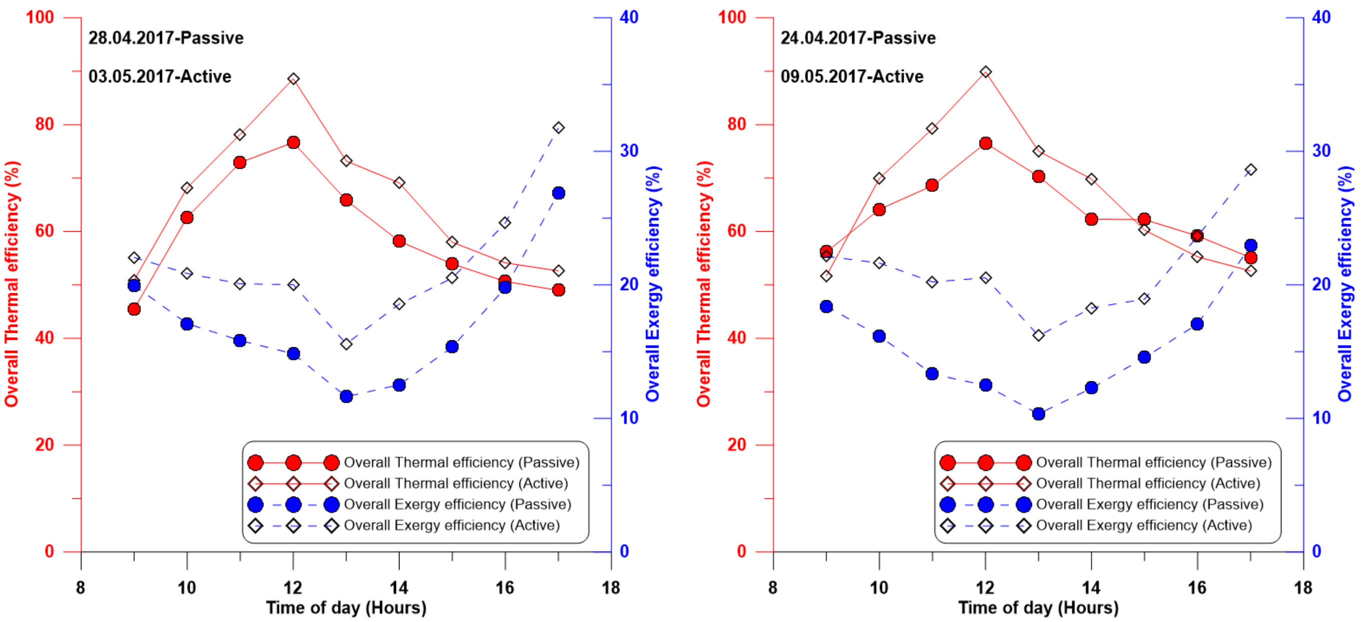


Fig. 12 Hourly variations of the overall thermal and exergy effectiveness of the passive and active ISPB still

Overall thermal effectiveness of the passive ISPB still is given by,

$$\eta_{overallP.thermal} = \frac{m_{ew} * h_{fg}}{I_S(t) * A_s * 3600} \times 100\% + \frac{FF * V_{oc} * I_{sc} - VI}{0.933\, I_s(t) * A_s} \times 100\%$$

Overall thermal effectiveness of the active ISPB still is given by,

$$\eta_{overallA.thermal} = \frac{m_{ew} h_{fg}}{[A_c \times I_c(t) + A_s \times I_s(t)] \times 3600} \times 100 + \frac{FF * V_{oc} * I_{sc} - VI}{0.933\, I_s(t) * A_s} \times 100\%$$

Overall exergy effectiveness of the passive ISPB still is given by,

$$\eta_{overallPexergy} = \frac{(m_d * h_{fg})\left(1-\left[\frac{T_a+273}{T_w+273}\right]\right)}{(A_s * I_t)\left[1+\left(\frac{1}{3}\left[\frac{T_a+273}{6000}\right]^4-\frac{4}{3}\left[\frac{T_a+273}{6000}\right]\right)\right]} + \frac{FF * V_{oc} * I_{sc} - VI}{0.933\, I_s(t) * A_s} \times 100\%$$

Overall exergy effectiveness of the active ISPB still is given by,

$$\eta_{overallAexergy} = \frac{(m_d * h_{fg})\left(1-\left[\frac{T_a+273}{T_w+273}\right]\right)}{(A_s * I_t)\left[1+\left(\frac{1}{3}\left[\frac{T_a+273}{6000}\right]^4-\frac{4}{3}\left[\frac{T_a+273}{6000}\right]\right)\right] + Q_u\left[1-\frac{T_a+273}{T_w+273}\right]} + \frac{FF * V_{oc} * I_{sc} - VI}{0.933\, I_s(t) * A_s} \times 100\%$$

The daily productivity, thermal and exergy efficiency of the passive and active ISPB still, as well as the % rise are shown in Table. 3. As shown in Table 3, the daily productivity ranges between 3.9 to 4.3 kg/m^2 and 7.6 to 7.9 kg/m^2 for the passive and active mode, respectively. For the active mode the daily productivity is improved by 45.6 and 48.7%.

Table 3. Percentage rise in productivity, thermal and exergy efficiency of the active ISPB still over the passive ISPB still

S.no	Productivity (kg)			Thermal efficiency (%)			Exergy efficiency (%)		
	passive	active	% rise	passive	active	% rise	passive	active	% rise
1	4.3	7.9	45.6	39.82	46.87	15	2.9	6.6	56
2	3.9	7.6	48.7	38	45.7	16.8	2.6	5.9	56

3.7 Comparison of productivity of different PV/T solar still

The comparison of yield of different hybrid PV/T solar still is summarized in Table 4. The yield is higher in the case of solar still integrated with an electrical heater [16]. Hybrid PV/T solar still integrated with an FPC produced the maximum yield of about 6-10 kg/m^2. The passive ISPB still produced yield of about 4.4 kg and the active ISPB still produced the maximum daily fresh water of about 7.9 kg. For the active mode the fresh water yield is increased up to 44.37% than the passive mode.

Table. 4 Comparison of productivity of different PV/T solar still

S.No	Author name	Experimental work done	Yield (kg/m^2)
1	Kumar et al [6]	Hybrid (PV/T) active solar still.	6 - 10

2	Dev et al [7]	solar still with an FPC incorporated with the PV module	7.223
3	Kumar et al [8]	Active solar still (hybrid PV/T)	7.22
4	Gaur et al [9]	most effective use of number of collectors for integrated PV/T hybrid active solar still	7.9
5	Eltawil [11]	solar still utilizing PV, FPC and air heater	6-10
6	Saeedi et al [12]	Active solar still (PV/T)	8.37
7	Singh et al [14]	Active solar still (two hybrid PVT collectors)	6 - 10
8	Abdallah et al [16]	solar still incorporated with Super Heat Conduction Metal Vacuum Tube	12 L/m^2
9	Yari et al [17]	Integration of solar still and PV module	4.77
10	Al-Nimr et al [19]	PV cells fixed at the solar still basin and incorporated with finned condenser at outer surface	6.8
12	Ali-Riahi et al [20]	Solar still incorporated with AC-heater and PV module	5.7
13	Praveen Kumar et al [21]	PV/T active solar still with effective heating	8.542 L
14	Muthu Manokar et al [26]	Integrating PV panel in an inclined solar still-Passive mode	4.4 kg
15	Muthu Manokar et al **(present study)**	Solar panel basin solar still integrated with an FPC-Active mode (present study)	7.9 kg

CONCLUSIONS

In this study, the performance of an Inclined Solar Panel Basin (ISPB) still integrated with (active mode) and without (passive mode) Flat Plate Collector (FPC) has been compared experimentally under Indian climatic conditions.

From the experimental study the following conclusions have arrived:-

1. The amount of fresh water production from the active mode is 44.63% higher than that of the passive mode.
2. The electrical and thermal effectiveness of the PV panel in the passive mode is 15.02 and 15.87% and higher than the active mode.
3. The maximum daily yield, thermal and exergy effectiveness of the passive ISPB still is 4.38 kg, 39.82% and 2.9%, respectively.
4. The maximum daily yield, thermal and exergy effectiveness of the active ISPB still is 7.9 kg, 46.87%, and 6.6%, respectively.
5. The daily overall thermal effectiveness of about 63.84 and 67.08% and daily overall exergy effectiveness of about 15.28 and 21.13% is obtained for the passive and active ISPB still, respectively.

6. The overall performance of the active ISPB still is better than the passive ISPB still. The daily thermal and exergy effectiveness of the active ISPB still is 15.05% and 55.68% higher than the passive ISPB still.

Nomenclature

A - Area (m^2)
Exinput - Exergy input of an ISPB Still (W/m^2)
Exoutput - Exergy output of an ISPB Still (W/m^2)
h- Heat transfer coefficient (W/m^2K)
I – Current (A)
I (t) – Solar intensity (W/m^2)
ISPB -Inclined Solar Panel basin
EHTC -Evaporative Heat Transfer Coefficient
CNT -Carbon Nano Tubes
GNP -Grapheme Nano Plates
L_{fg} – Latent heat of Vaporization (kJ/kg K)
m_{ew} - Hourly productivity from an ISPB Still (kg/m^2 h)
P- Power production
PV- Photovoltaic
PV/T – Photovoltaic Thermal
T – Temperature (^{o} C)
V – Voltage (V)
$\eta_{overall, exe}$ - Overall exergy effectiveness (%)
η_{pv} - PV panel effectiveness (%)
Al_2O_3 -Aluminum oxide
SnO_2 -Tin oxide
Zn O -Zinc Oxide

Subscript

a- Ambient
d- Daily
e- Evaporation
g- Glass
s- Sun
w- Water

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