Experimental Performance Analysis of Multi-Parabolic Flat Plate Solar Collector

N. Dutt, R. Kumar, and K. Murugesan

Abstract In the recent couple of decades, the conventional energy sources are depleting at very fast rate and are not sufficient to meet the energy demand of the world. Renewable energy sources such as wind energy, solar energy, biomass energy scope and demand increased up to a large extent. Solar energy is pollution-free energy, freely available, and is mainly harnessed through solar collectors. In the current work, a parabolic flat plate solar collector is designed and fabricated, and experimental results are plotted at different flow rate (12, 15, 18 LPM) for the closed circulation of water. In all experimental work, maximum temperature rise of water is observed to be 5 °C. Experimental results depends on various factors as solar intensity variation with time, clouds influence between sun and collector, flow rate. Multi-parabolic flat plate solar collector results show that collector is efficient to trap and absorb the solar radiations and can be used in more efficient way in hybrid mode with ground-source heat pump.

Keywords Renewable energy · Solar energy · Parabolic solar collector · Heat transfer

1 Introduction

With the world experiencing massive energy challenges, there is still a growing need to tap into renewable energy resources. Because solar energy is pollution-free in nature, it is essential for our civilization to utilize it as a sustainable energy

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source. In November 2021, India met its goal of using non-fossil energy sources for 40% of its installed electrical producing capacity. Installed renewable energy (RE) capacity in the country is 150.05 GW, whereas nuclear energy-based installed electrical capacity is 6.78 GW [1]. Indian pressure heavy water reactors are nuclear reactors running in India to complete the energy demand of country, and research is in continuation also for the safety of nuclear reactor during loss of coolant accident [2–5]. Solar energy is the cleanest and most abundant renewable energy source accessible, and it may be used to meet a variety of energy needs, including electrical energy generation, domestic hot water generation, and building heating and cooking [6, 7]. Solar thermal collectors are very effective heat collectors that absorb sunlight. In literature, researchers have already proposed the application of solar thermal collector in different field as solar air heater with artificial roughness in which they have presented experimental/numerical results and [8–12]. Mete et al. [13] used nanofluids-based flat plate solar collector and carried out transient analysis. It is concluded that nanofluids can improve the thermal efficiency of FPSCs at lower flow rates. The parabolic trough collector is a form of solar collector that is utilized for high-temperature applications in industrial processes and electricity generation. The basic functional units of a parabolic trough collector are the reflector and the fluid carrying tube. A tracking system is required for efficient functioning in order to track the path of the sun so that incident radiation is focused along the focal line on the absorber tube or receiver tube. Because it has a larger reflector area, the efficiency of a parabolic collector is higher than that of a flat plate collector. The efficiency of a parabolic collector is also affected by the working fluid flowing inside the absorber tube. Water, antifreeze fluid containing around 40% glycol by volume, thermal oil, and air are the most common working fluids [14]. Kumar et al. [15] conducted an exergy analysis of solar parabolic collectors and concluded that the use of nanofluids and turbulence is the most effective method for increasing energetic efficiency. Madiouli et al. [16] applied the combined system having main components flat plate collector, a parabolic trough, and a packed bed for a solar still that enhanced productivity by 172% in the winter and 203% in the summer when compared to a traditional solar still. A hybrid solar collector was employed by Tian et al. [17] for whole year in sequence to evaluate and simulate annual thermal performances of the Taars solar heating plant. The solar fraction would have risen to 25.2% [18, 19]. A review of the literature shows that solar thermal energy has an impact on GSHP efficiency [20]. Ozgener and Ozgener [21] evaluated the SAGSHP with a 150-m heat exchanger and found a 68% exergy efficiency. Wang and Qi [22] worked on solar ground-coupled heat pump system and concluded that efficiency may reach over 40 and 70%. Eslami-Nejad and Bernier [23] offered an analytical model for predicting steady-state heat transfer in twin U-tube boreholes with differential mass flow rates and intake temperatures. Winter solar recharge reduces the amount of energy collected from the ground by the heat pump by 194 and 168%, respectively, for the suggested design and the solar-assisted ground-source heat pump system. Using TRANSYS software to optimize the solar-assisted ground-coupled heat pump (SAGCHP) system design, Xi et al. [24] investigated that enhancement of efficiency of 26.3% than GCHP. Kim et al. [25] discovered that the maximum coefficient of

performance (COP) of HSG-CHPS can approach 2.81. Girard et al. [26] investigated that COP of SGSHP and GSHP comes in range of 4.3–5.8 for different locations. Sun et al. [27] presented and investigated an unique SAGSHP system that utilizes heat cascading. The results of the field test reveal that the day-averaged indoor temperature can fulfill the Chinese norm (not falling below 16 °C). Naranjo-Mendoza et al. [28] conducted experimental work on SAGSHP and concluded that system is able to fulfill the requirement of building heating in winter. Weeratunge et al. [29] minimized the operational cost of a solar-assisted ground-source heat pump system by 7.8%. Ji et al. [30] performed numerical simulation on TRNSYS software and proposed optimal solar collector area of the SAGSHP system. Kegel et al. [31] used vacuum tube solar thermal collector (STC) so that bore size can be reduced. Wang et al. [32] used the TRNSYS simulation framework to model a solar heating system with ground-source heat pumps and evaluated the energy performance based on a winter season operation plan. The heat pump COP is enhanced, and the whole system COP can reach 8.17. In the present work, a multi-parabolic profile flat plate solar collector has been design and fabricated to investigate the transient heat transfer properties at various water flow rates.

2   Experimental Setup

Multi-parabolic flat plate solar collector (MPFPSC) is designed and fabricated keeping objective of heat transfer through solar radiations to water flowing inside the closed pipe. In the present paper, preliminary results are presented. For designing collector, two wooden boxes are used in which four parabolic solar collectors are placed, two in each box. These collectors were made up of aluminum sheet of having 0.95 reflectivity. Curvature is provided to focus the solar radiations on the pipe carrying water. The solar collectors were covered with the transparent glass sheet so that the solar radiation is trapped inside the wooded box based on greenhouse effect. In this experiment, it is tried to combine the both effects, reflection of solar radiations through aluminum sheets, and to focus the solar radiations concentrically to the pipe carrying water. Another is, direct heating of the pipe kept inside the glass covered wooden box. Apart from it, it is kept watch on the solar radiation coming to earth with the help of solar intensity meter. Solar intensity varies of many factor, like in the noon, sun it at the top of the solar collector, and with time, there is relative motion between sun and solar collector; hence, intensity of sun for solar collector varies with time. Another factor is the cloud presence in the sky. Sometimes, cloud may come between solar collector and sun and will move away with time. Cloud intensity is also an important factor, which effects the solar intensity on the solar collector. Experiments were performed to do the performance analysis of the solar collector. Transient data are recorded with the help of the data logger. A total number of six thermocouples measure the temperature during experiments. Two thermocouples were applied for the measurement of temperature of water. Four thermocouples installed inside the wooden box, between glass sheet and curved aluminum plates.
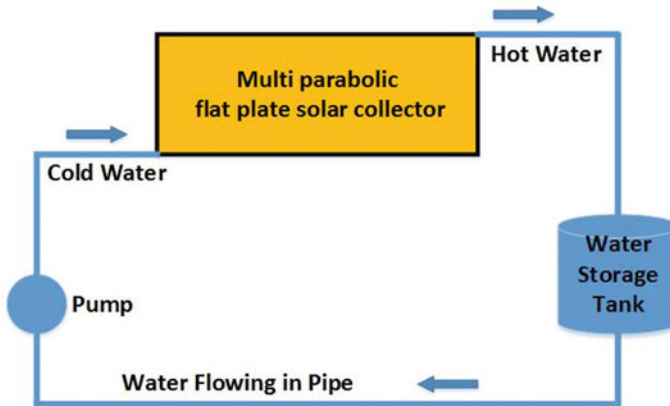
Fig. 1 Layout of the experimental setup

A rotameter was used to measure the flow rate of water. A 1-inch pipe (inner diameter) was used for the flow of water. Different water flow rate is maintained during the experiment each day. During experiment, solar intensity was varying due to the influence of clouds in the sky. Before starting the experiment, a tank was filled with water up to the desired level. Initially, water temperature was measured. J-type thermocouples were used for the experiment. Figure 1 shows water flows in the closed loop. There are four main components in the experimental setup are MPFPSC, pump, water storage tank, and pipelines to carry the water in the closed loop.

Figure 2 depicts the process of installation of experimental setup. Initially, inclined wooden blocks are installed at the roof of the building. After the successful installation of wooden blocks, parabolic collector was placed inside the wooden box, two in each box. Hence, total four parabolic collectors are placed in two-wooded box having surface area of 8 m^2.

After successful installation of the wooden box and parabolic collector, water pipe lines are installed at the focal length of the parabolic flat plate collector. Four pipelines were installed along the focal length of the parabolic collector. Figure 3 depicts the pipelines installed along the length of the parabolic collector. In final stage, experimental setup was covered with the help of transparent glass cover so that solar radiations of shorter wavelength can enter easily inside the collector and produce heating inside it. Water flow direction was kept from bottom to top on inclined experimental setup. All pipes were arranged in parallel and were connected to each other, having one inlet and one outlet.

Water was circulated with the help of pump of 0.5 HP at different flow rate. Initially, water was collected inside the tank as shown in Fig. 4. To control the water flow rate, an open/close valve was used, and to measure the water flow rate, a rotameter of 20 LPM rotameter was used. Flexible pipes were used for the connections of the experimental accessories.
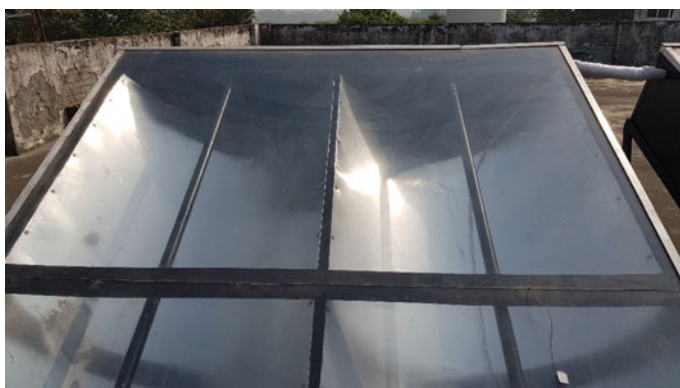
Fig. 2 Installation of the experimental setup

Fig. 3 Installed pipelines for water flow

Fig. 4 Components of experimental setup

3   Results and Discussion

Performance of solar collector depends upon various factors as intensity of solar radiation, flow rate, specific heat, thermal conductivity, absorptivity, reflectivity of the glass cover, emissivity of the reflecting sheet, wind velocity, ambient temperature, and overall losses by solar collector. In experiment, results are plotted for the different flow rate of water. Other parameter in experiments was solar intensity variation with time and due to clouds in sky, was under control of nature and cannot be controlled manually. Results are plotted for the realistic natural conditions. Objective of the experiment is to get the details of effective rise in temperature of water due to solar collector. This experiment was performed in the month of November. This experimental setup can be integrated in hybrid mode with ground-source heat pump and can be utilized for space heating in winter season. Figure 5 shows the results of inlet and outlet temperature of water with time. Time is plotted on the *X*-axis is the real-daytime data of date November 19, 2020. First experiment was performed at 12 LPM water flow rate. Experiment was started at 11:55 a.m., and reading was recorded by the data logger at an interval of 1 s. To measure the solar intensity, solar intensity meter was used, and readings were recorded manually at an interval of 5 min as shown in Fig. 6. The reason of increase in temperature of water is due to absorption of heat accumulated inside the collector. Flow of water was kept in the closed loop. It has been observed that with the passage of time, the difference in inlet temperature and outlet temperature decreases with time. Reason of decrease in temperature of water at inlet and outlet temperature is explained here. As every time in each cycle, water extracting the available heat from the collector and is coming to near the collector temperature to maintain the heat balance. It is observed from graph (Fig. 5) that, temperature of water at inlet and outlet following the parabolic trend. Main reason to follow parabolic temperature trend is due to the variation of solar radiation intensity for collector due to presence and absence of clouds in between solar collector and orientation of the earth with respect to sun with time. Figure 6 shows the solar intensity variation with time from start of the experiment. It is known that solar intensity would be maximum at 12:00 noon because at that time sun would be at the top of the head. However, in graph is observed that solar intensity is low initially and then increases, fluctuates, and slowly decreases with time. The maximum and minimum intensity of solar radiation during experiment observed is 786 and 57 W/m^2, which is a big variation and reason for such trend is already explain above. However, very fast fluctuations of the solar radiation would not influence the effectiveness of multi-parabolic flat plat solar collector temperature at the same rate because it takes time for water to extract the heat flowing inside the pipe. Hence, it can be seen the Fig. 5 that water in and out temperature does not fluctuate so fast. In and out temperature difference of water with time is shown in Fig. 7. It is concluded that MPFPSC is effective to raise the temperature of the water circulating in the closed loop. As this experiment, there is no heat exchanger to extract the heat of the hot water coming from the solar collector; hence, temperature difference between inlet water and outlet water decreases with time, whether solar intensity low or high.

Figure 8 shows the air temperature inside and outside the collector which varies with time due to variation in solar intensity.

Two other experiments were also performed at different flow rate of water. Each experiment was performed on the separate day. Graphical results are summarized here from Figs. 9, 10, 11, 12, 13, 14, 15 and 16. It is concluded that variation of flow rate has marginally effects the final results.
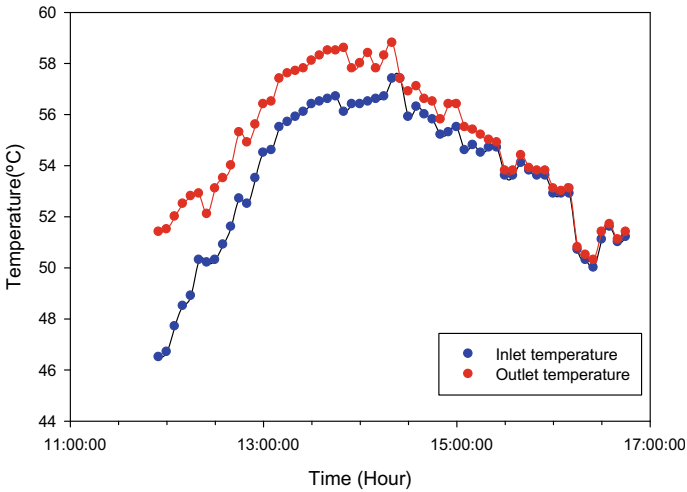
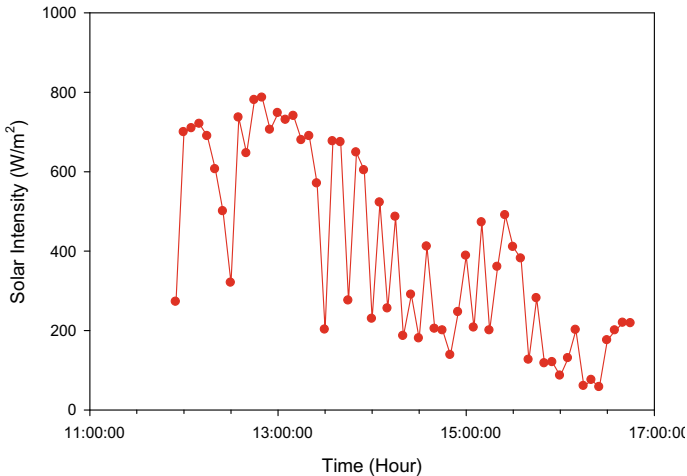

Fig. 5 Inlet outlet water temperature variation at 12 LPM

Fig. 6 Solar intensity variation for 12 LPM case
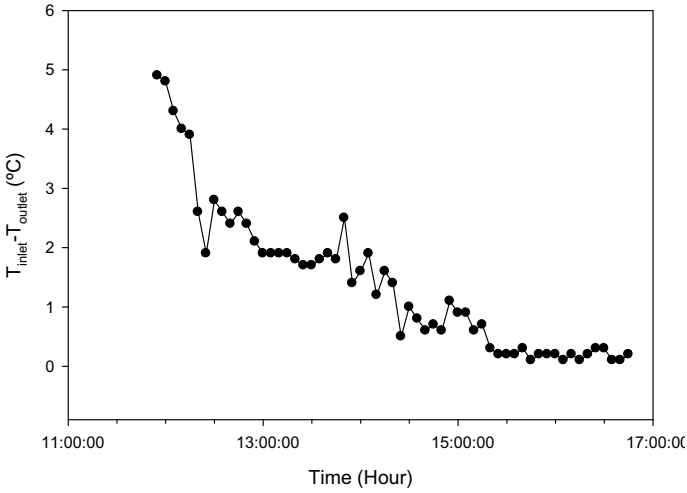
Fig. 7 Temperature difference at inlet and outlet for 12 LPM case
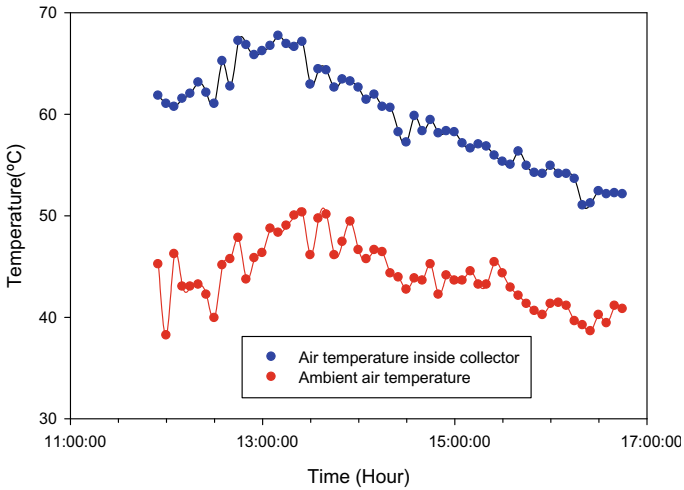
Fig. 8 Air temperature inside and outside the collector for 12 LPM case

4 Conclusion

Solar-assisted MPFPSC is an important alternate technology for utilization of renewable energy for space heating applications. In this study, an attempt has been made to study the performance of MPFPSC at different flow rates (12 LPM, 15 LPM, 18 LPM). Experimental results show the maximum temperature difference of water at inlet and outlet of collector is 5 °C, which decreases with the time. Experimental
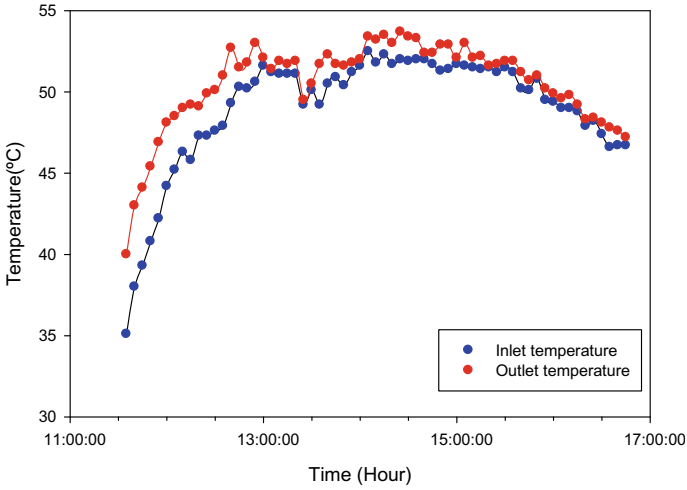
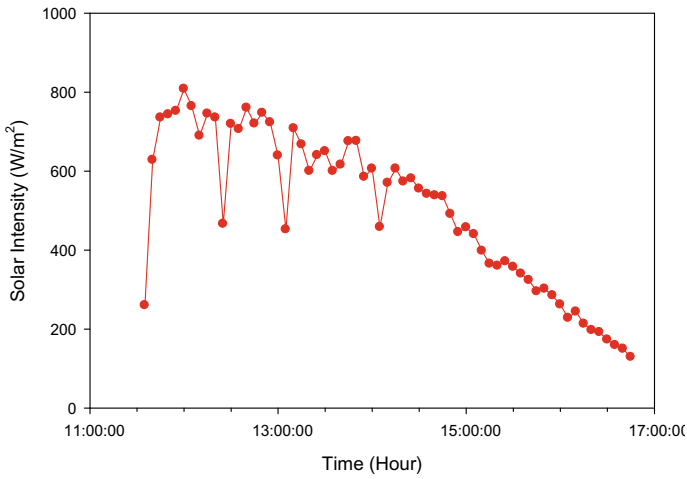**Fig. 9** Inlet outlet water temperature variation at 15 LPM

Fig. 10 Solar intensity variation for 15 LPM case

results depend and vary on various factors as solar intensity variation with time, cloud presence between sun and solar collector, which reduces the intensity of solar radiation, flow rate of water. Study shows that MPFPSC results are effective and can be used in hybrid mode with ground-source heat pump for space heating in winter season.
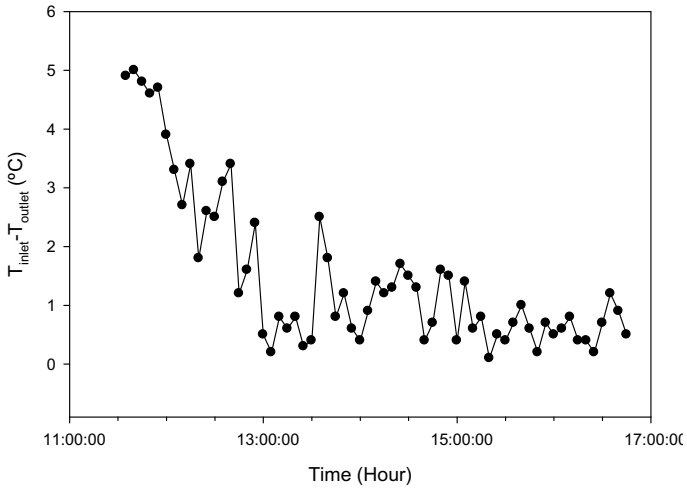
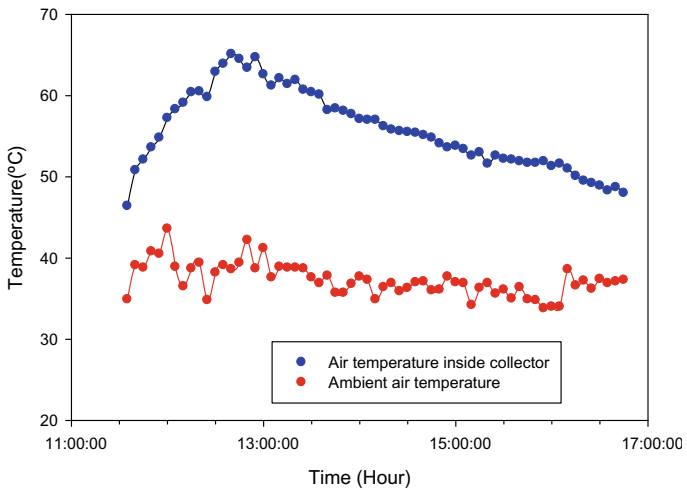**Fig. 11** Temperature difference at inlet and outlet for 15 LPM case

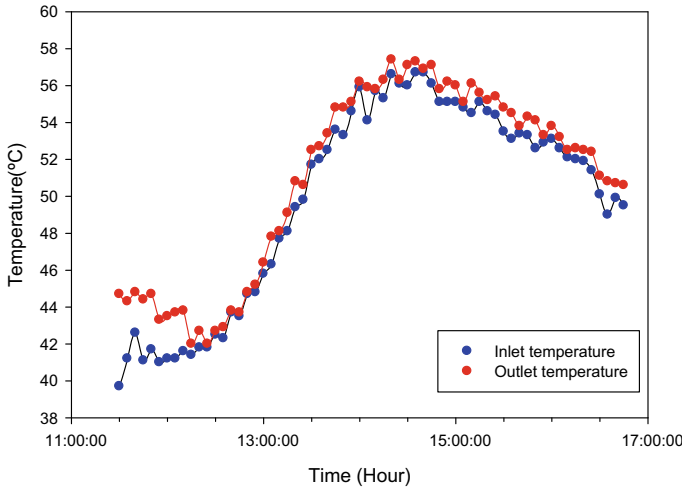**Fig. 12** Air temperature inside and outside the collector for 15 LPM case

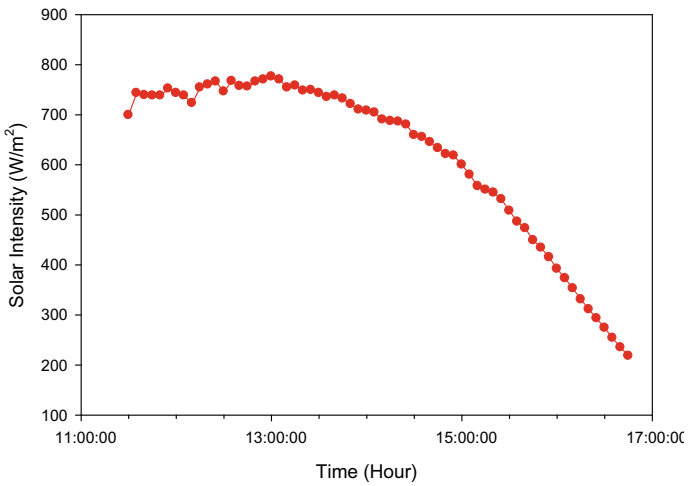**Fig. 13** Inlet outlet water temperature variation at 18 LPM
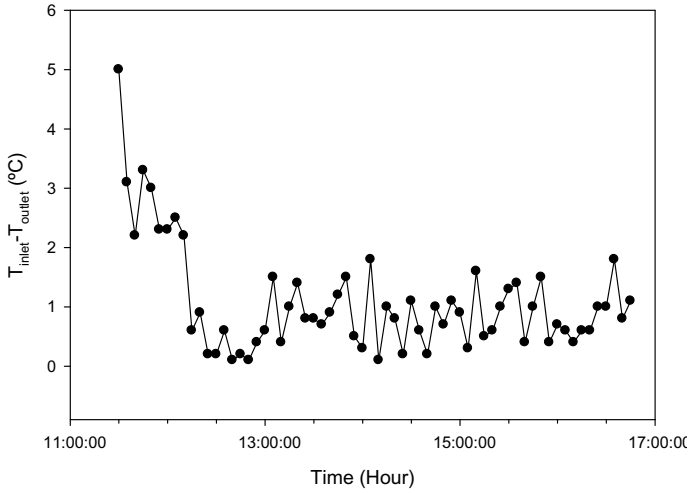
Fig. 14 Solar intensity variation for 18 LPM case

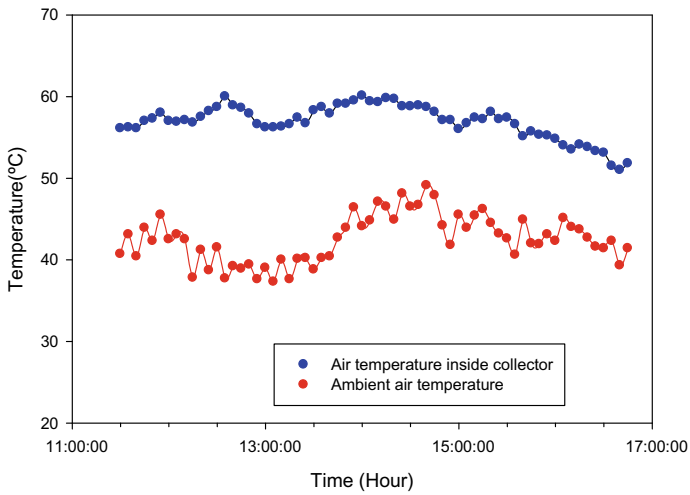**Fig. 15** Temperature difference at inlet and outlet for 18 LPM case

Fig. 16 Air temperature inside and outside the collector for 18 LPM case

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