Experimental investigation of hot water assisted solar air collector

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Abstract – A solar flat plate collector is a device that converts the solar radiation energy from the sun into heat energy. A solar flat plate collector was designed and fabricated. The solar air collector has an absorbing plate of 1m × 0.06m area made up of galvanized iron. Outer frame of collector is fabricated with plywood. It is painted black using metal paint in order to increase its heat absorbing capacity. In order to increase the heating efficiency of the collector a serpentine coil of copper pipe is welded to the bottom of the absorber plate through which hot water is passed. Efficiency of solar flat plate collector was increased by 15.58% using this method.

Keywords: hot water, heat gain, solar collector, heat source, thermal efficiency

1. Introduction

Solar energy is one of the most promising non-conventional energy sources that can be collected for various uses by solar collectors. A solar collector absorbs heat by trapping solar radiation and converts it into heat which can be further transferred to a fluid. The energy gathered by the collector is carried by the working fluid to the thermal energy storage tank, or any desired place and this captured energy is used to heat water. There are two types of solar collector concentrating or non-concentrating. In non-concentrating type of collectors, the collector area (receiving area) is same as absorber area (area that absorbs radiation). In these type of collectors the radiation is absorbed by whole area of solar panel. These collectors are mostly used in residential, industrial and in commercial buildings. Concentrating type collectors have a bigger collector area than the absorber area and are used in concentrated solar plants to generate electricity. Flat plate solar collector is most common type of collector which is widely used for hot water heating, indigenous households and space heating. It has no optical concentration and they are mostly stationary. It is basically a black surface and this collector has found ample applications. It is easy to fabricate as well as economical to install and maintain.

Himanshu Bhowmik et al. [1] investigated a method to enhance the efficiency and performance of collector using flat plate collector with and without reflector. From the experiment it was observed that collector without reflector had 51% efficiency while collector with reflector had 61% efficiency. The overall efficiency of collector with reflectors was increased by 10%. Nigussie Mulugata et al. [2] worked on improving the efficiency of collector integrated with reflectors. Here the model was developed for a south-directed flat plate solar collector at tilt angle β that is sufficient for latitude space with respect to the horizontal plane. Flat plate solar reflectors made of four aluminum foils were placed on the four sides of the flat plate solar collector to absorb more solar energy. Hence solar collector has left, right, bottom and top reflectors respectively. By introducing four reflectors on 4
sides of collector outlet temperature was relatively more as compared to collector where reflector was not used.

Francesco et al. [3] investigated the finite-volume model of an un-glazed and non-insulated flat plate photovoltaic-thermal collector. The numerical results performed by the simulation were compared to the dynamic data measured by the experimental setup. The performance of the collector was evaluated with the discretionary computational domain. The linearity of the temperature distribution within the collector layers allows using the lumpy version of the developed model to calculate the integrated parameters. Ankit Mukherjee et al. [4] studied the performance of an open thermochemical energy storage system integrated with a flat plate collector. Considering the charging phase during the summer day and the discharge phase during the winter night, a model for heating application was evaluated. And simplified energy balance equations for reactive packed beds and therefore flat plate collectors have been developed and verified against previous reported works.

Alkilani et al. [5] built and studied, an indoor test system consisted of integrated solar heaters with phase-changing materials. The high thermal conductivity of aluminum powder led to a 70% reduced charging time for the composite compared to pure paraffin wax. The thermal efficiency of the solar heater for the indoor condition reached a maximum which was 71.9% and 77.18%, respectively for pure paraffin wax and compound paraffin wax (paraffin wax with 0.5% mass aluminum powder). Jahar Sarkar [6] studied the performance analysis of flat plate collector using CO₂ and used discretization technique for the change in thermophysical properties. After the experiment he predicted that higher value of heat transfer coefficient of CO₂ can be obtained for the outlet temperature up to 60°C. Because of better thermal and heat transfer properties CO₂ has better performance as compared to water. For the given range maximum performance were improved by using CO₂ as transfer fluid was obtained 18 %. Z Badie, et al. [7] worked on improving the performance of flat plate collector by using phase changing material (PCM) and they developed 3 dimensional Computational Fluid Dynamics model to investigate flat plate collector with layers of PCM. Fins were also integrated with PCM. The average flat plate collector efficiency was increased from 33% to 46% in summer for the PCM.

The objective of the present work is to improve the efficiency of the collector. From the studied literatures it can be seen that the efficiency of the collector can further be improved by

- Increasing the transmission of heat energy from the collector to the working fluid.
- Minimizing the heat losses from the collector to the surroundings by reducing conductive, convective and radiation losses.

2. Experiment Setup and Procedure

2.1. Experimental set up

Outer structure of flat plate solar thermal collector was made with plywood of thickness 6mm and upper part of flat plate collector was covered with glazing material (i.e., glass plate of 4mm) and the absorber plate was placed below the glass plate. Flat plate collector was designed in such a way that hot water can flow from inlet to outlet at constant flow rate. The upper part of absorber plate was painted black color and it was covered with transparent glass material so that it can absorb maximum incident radiation and a copper pipe of 7.2m is attached with absorber plate in zig-zag manner to pass the hot water from inlet to outlet. To decrease the heat loss by conduction from absorber plate, glass wool is used to insulate the inner part of collector. To measure the temperature, thermocouples were
connected with inlet, outlet, absorber plate and glass plate of collector and these thermocouples were linked with digital temperature indicator to show the values. The prime source for hot water is the parabolic dish collector receiver, which heats up the water passing through it. The water thus heated is collected in a water container of 10L capacity, placed near the collector. The photograph of combined system of collector is shown in Figure 1 and Figure 2.

![Figure 1. Experimental setup (Front view)](image1)

![Figure 2. Experimental setup (side view)](image2)

### 2.2. Experimental Procedure

The experiment was carried out over a span of four days i.e., the first two days without hot water (case 1) and the following two days with hot water (case 2). For case 1, the flat plate collector was set at an angle of 70° from the ground facing the sun. This was done in order to allow better convective flow of air in the duct of the collector. K-type thermocouples were fixed to the inlet, outlet, glass and the absorber plate. These thermocouples were in turn attached to a 12 point K-type digital temperature indicator which was used to get the temperature readings of the respective points. A pyranometer was used to record radiation and ambient temperature for every thirty minutes starting from 9.00 am till 5:00 pm. The temperature readings of the collector were also taken at the same time and recorded.

### 3. Results and Discussions

The experiments were conducted on clear sunny days for both the cases and the results of the experiments are compared and analysed with respect to the thermal efficiency of the collector for both the cases with and without hot water.

#### 3.1 Comparison of performance of solar collector for case 1 and case 2

For both the cases, average values of the performance indicators were calculated and graphs were plotted as shown in the Figures 3 – 8.
Figure 3. Comparison of the variation of the inlet temperature with time

Figure 3 shows the comparison of inlet temperature against time for both the cases. The highest temperature of 39.1°C was recorded from 12 noon to 2 pm. The lowest temperatures were witnessed from 9 am to 11 am. The inlet temperature was increasing from 11 am and it reaches maximum around 1 pm after that it starts decreasing slowly.

Figure 4. Comparison of the variation of the radiation with time

Radiation values were recorded using a pyranometer for the days when the experiments were conducted and plotted. The least average radiation was noted as 498 W/m² while the highest being around 821 W/m². Radiation for the cases were similar as it can be seen in figure 4, it was increasing
from 10 am and reaches its peak around 1.30 pm, after that it starts decreasing. Highest radiations were witnessed between 12 noon to 2 pm and the lowest were witnessed between 9 am to 11 am. Radiation directly affects the heat collected as well as the efficiency of the collector hence has been plotted for both the cases to compare the difference in heat gain and efficiency of the collector. Figure 5 and Figure 6 give us the estimated loss in temperature when heat is transferred from the absorber plate to the working fluid i.e., air.

**Figure 5.** Comparison of the variation of outlet temperature with time

Figure 5 shows the comparison of outlet temperature against time for both the cases. The highest outlet temperature was recorded when the solar radiation was at its peak around midday. The values of outlet temperature for the case with hot water is relatively more as compared to the case without hot water, as more heat is added to the working fluid (air) from the additional hot water heat source. Outlet temperature for the case with hot water was 80°C at around 1 pm and for the case without hot water it was case it was 70°C at around 1.30 pm.

**Figure 6.** Comparison of the variation of the absorber plate temperature with time
The average temperature loss is 7.1°C (approximately) which can be observed in Figure 5 and Figure 6. Figure 6 shows the comparison of the variation rate of the absorber plate temperature with time. Absorber plate temperature in case 2 is more due radiation absorption and added heat from the additional heat source. The absorber plate temperature was increasing from 11 am and it reaches maximum around 1 pm after that it starts decreasing slowly.

![Heat Gain Graph](image1)

**Figure 7.** Comparison of the variation of the heat gain with time

![Efficiency Graph](image2)

**Figure 8.** Comparison of the variation of thermal efficiency with time

Heat gain and thermal efficiency were calculated using the data recorded and their values were plotted. Figure 7 shows comparison of the variation of heat rate with time. Difference in temperature between inlet and outlet was high for case 2 leading to better heat gain. The values of heat were lowest around 9 am, it starts increasing around 11 am and it reaches maximum around 1.30 pm for both the cases. Figure 8 shows comparison of the variation rate of the efficiency with time. As case 2 exhibited higher
heat gain, its efficiency was also higher compared to case 1. The values of efficiency were lowest around 9 am and it reaches maximum around 1 pm in hot water case and reaches maximum around 1.30 pm in without hot water case. Due to added heat from the additional heat source to the solar collector Figure 7 and Figure 8 shows clear increase in the heat gain and efficiency of the collector.

4. Conclusion

Following are conclusions drawn from the results of the experiment

- The average efficiency without hot water was calculated to be 41.70%
- The average efficiency with hot water was calculated to be 57.29%
- The solar collector efficiency of the case using additional heat source (case 2) exhibited better increases in efficiency by 15.58%.

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