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Review Article

THE PERFORMANCE STUDY OF A SOLAR FLAT PLATE TYPE AIR COLLECTOR WITH NATURAL AND FORCED CONVECTION

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ABSTRACT

In developing world, the usage of fossil fuel and electricity charges are being increased day by day and they produce more environmental pollution. In intention of the above factor, there is need to develop alternative energy with low cost. Solar power is one of the best ways to produce energy. Solar flat plate type air collector (SFPTAC) is widely used for many solar applications. Drying of agricultural food products is attractive and cost –effective application of solar power as it becomes a potentially viable substitute for fuel-wood in major development of the world. A SFPTAC is 2 × 1 m2 area and 5 mm thick aluminium sheet is coated with a black paint. An insulated collector of about 10cm thickness and inside is covered by the glass wool of thickness 25 mm are used on the surface of the enclosure. These tests were conducted to gather data from different atmospheric conditions. The results were examined by both the free and forced convection.

INTRODUCTION

The sun is the composed of all renewable energy sources. This renewable energy should be clean, safe and free. Application of these sources of energy is utilised by millions of people at various places. One of the most excellent in future development area of the application of solar energy is SFPTAC.

SFPTAC with the help of solar energy is utilised for a variety of purposes. These devices are simple and easy to construct at low cost. A SFPTAC consists of transparent glass cover, absorber plate, insulating materials, drying trays and air blower. The air is passed through in between the absorber plate (AP) and the transfer glass cover. At the same time solar radiation is absorbed by AP and the absorbed heat air is passed through the channel into the drying trays. This heated air can be utilized into many more applications such as drying agricultural products, space, water and industrial process heating and air conditioning. Technically, there are two methods used for usability solar energy; they are Convectional and Non-convectional heating. An example for Convectional solar techniques is natural circulation without external force and Non-convectional solar techniques like forced convection includes pumps, air blower or fans.

LITERATURE REVIEW

Reviews of the literature survey are very useful to analyse the experiments. At the expense of growth in the world's energy consumption, sources of conventional energy are the emergent need of the world. But conventional energy sources such as fossil fuels have two main limitations. First, they are limited in size, and they produce environmental pollution. Hence there is a need for alternative fuel renewable energy source to eliminate the demerits. There is less knowledge about the sources and replacement systems and the usage of these resources. Hence

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out of all the renewable energy sources the energy of solar has been found to be cost effective and the most promising energy that is abundantly available, clean and inexhaustible is available worldwide. The solar plate converts solar radiation into heat energy to meet the needs. The solar systems consist of many parts. SFPTAC is one of the important parts of the system where the flat-plate collector absorber plate transfers the solar power to the liquid flowing through pipes. A lot of research work has been expanded flat plate collector thermal efficiency (Rai, 2012). Ljiljana *et al.* investigated that reflectors, to improve thermal efficiency solar flat plate type water heater proposed an optimal position. For that they were being investigated and the flat plate collectors for solar radiation heat without reflectors (Ljiljana, *et al.*, 2012). Khatik *et al.* investigated the work based on the AP and concavity AP. The result showed that rate of heat transfer concavity AP is 5.12% increased because of the cavities area surface for reducing the radiation reflection losses (Rhushi, *et al.*, 2010). Prasad *et al.* performed a study with an angle of 28° with the horizontal towards the south-facing two identical cover, placed in flat-plate collector. To improve the efficiency of a collector, a collector was fixed and the other at an angle of 30° tilted manually every two hours (Khatik, *et al.*, 2014). Martinpoulos *et al.* performed a study on polymer solar collector experimentally and simulated model. This was done to identify that the efficiency of collector by working fluid is involvement of conventional methods of heat transfer. Temperature, velocity distribution over a surface area and collector efficiency were found to be good agreement between both experimental and CFD modelling (Missirlis, *et al.*, 2014; Chii-Dong Ho, *et al.*, 2011) investigated double –pass SFPTAC with fin attachment. The double-pass SFPTAC was designed for supplying the air into absorber plate of upper and lower channels. They conducted number of experiment and finally concluded that area of solar collector is double extended the fin area (Chii-Dong, Ho, *et al.*, 2011). (Benli, 2013) had investigated different types solar air collector, such as collector is reverse, straight corrugated trapeze and a base flat-plate collector. The experiment was conducted at the same time at same day with same solar radiation. From the result analysis, flat type collector had more heat transfer coefficient and pressure drop take place (Benli, 2013). Faith Bayraka *et al.* investigated the performance of the initial energy and exergy of solar air heater inserted porous baffles with different thickness such as 6 mm and 10 mm and its area surface 50 cm^2 are used as passage element inside the heater. The measured parameters are the inside and outside temperature, absorber plate, atmospheric temperature and the solar radiator. This experiment was performed by two air flow rates of 0.016 kg/s and 0.025 kg/s. From these investigations they obtained result as 6 mm thickness and flow rate 0.025 kg/s which had higher collector efficiency and high temperature difference when compared to mass flow rate 0.016 kg/s (Bayraka).

(Sethi, *et al.*, 2012) analysed the effect of air heater solar duct that is fixed in front side with angular shaped roughness elements on absorber plate. The specification of the duct has an ratio of width and height of 11, roughness of relative pitch range of 10-20, relative roughness height range of 0.021-0.036 m, arc angle range of 45 to 75 and Reynolds number range from 3600 to 18000. The experiment used to development Nusselt number and friction factors correlation of roughness surface at different operating parameters (Sethi, *et al.*, 2012). (Yadav, *et al.*, 2013) experimentally analysed the characteristics of the heat transfer and friction factor for turbulent air flow through rectangular duct with roughness and smooth surfaces. The flow passage of roughed surface in built up circular shape element arranged in arc angular fashion. The roughed wall is heated over one wall while other three walls are kept insulated. These experiments stated that the maximum heat transfer and friction factor 2.89 and 2.93 times more than the smooth surface duct (Yadav, *et al.*, 2013). Sunil chamoli *et al.* investigated the thermal efficiency of double pass solar heater transfers heat more than the single pass solar heater. This was investigated with different techniques like extended surfaces, packed bed, corrugated absorber (Chamolia, *et al.*, 2012). Ming Yang *et al.* performed a study to fabricate more efficient and low cost solar type air heater. A number of experiments based on ASHRAE standard 93-2003 was tested heater under the following parameters like time constant, thermal efficiency, indicant angle modifier and the synthetically resistance coefficient. From the result, the maximum instantaneous thermal efficiency 0.40 was achieved at low flow rate of air 100 m^3/h, solar irradiance on the collected area 600 W/m^2, temperature at inlet and outlet are 14°C and -5°C, solar incident angle 20°C and fan work at 290W power (Yang, *et al.*, 2014). Anil Singh yadav investigated CFD model analysis for turbulent flow type solar air heater. They were tested five different turbulent models by using ANSYS FLUNT V12.1 software and appear the performed calculation from Renormalisation group K-e model. Finally, they concluded that two dimensional convectional type solar air heater transfers more heat and efficient model (Yadav and Bhagoria, 2013). Groundout *et al.*

proposed the concept of advanced solar water heater. According to them, Flat plate type collectors generally its losses more heat and less efficiency since only the upper side of the absorber plate, heat is exposed to the sun (Groenhout, *et al.*, 2002). Mohammadia *et al.* performed a study with convectional and upward single pass -type solar air heater internally fitted with fin and baffles. The performance analysis showed that upward single pass type solar air heater had more increased outlet temperature and efficiency when compared to Convectional type solar air heater (Mohammadia and Sabzpooshani, 2013). Pin –yang Wang performed a study with the evacuated tubular glass air heater with fixed parabolic concentrator. The system is making of 10 liked tubes; each tube fixed with one parabolic concentrator. Air is gradually passed through U-tube evacuated tube and gets heated. In the model of heat transfer was established outlet temperature of air, the heat power and its efficiency are calculated (Pin–yang, *et al.*, 2014). Abhishek Saxena *et al.* performed a study to improve the simple fabricated solar air heater efficiency. In the model, the made up of absorption medium is granular carbon. The performance is carried out on four different configurations by operating without forced and forced convection (Saxena, *et al.*, 2013). Bahrehmand *et al.* developed an analytical model of single and two-glass solar type air heater systems with convectional flow. It derived the heat balance equations for various elements of the collectors like tin metal sheet in absorber plate, rectangular, triangular fins with different width, length, shape and also to find out the initial energy and exergy. The results stated that two-glass collector is more efficient then the single –glass at the same times triangular fin is more efficient then rectangular fin (Bahrehmand and Ameri, 2015).

Hussain H Al-Kayiem *et al.* had conducted the experiment on convectional flat plate type solar heater hold with rectangular duct. The size of the rectangular was 0.48 m width, 0.07 depth and 2 m length. The AP was made up of 1 mm gauge of aluminium. The performance of the AP was measured by tilting the absorber plate at angle of 30°, 50°and 70°. From the investigation it showed that inclined angle 50° had most heat transfer rate and Nusselt number (Al-Kayiem and Tadahmun, 2015). Bahrechmand *et al.* deployed a mathematical model for single and two glass cover with solar type air collector systems with external forced convection flow. In this model, good agreement to analysis for solved and derived the energy equation (Bahrehmand, 2015). Ravi Kant Ravin *et al.* analysed to reduce losses of the heat and improves the efficiency of double pass conventional type solar air heater. Various performance techniques i.e., using packed bed materials, fins and corrugated/grooved surface enhanced the double pass air convectional type solar heater to improve the efficiency (Ravi and saini, 2016). Sarath Kumar *et al.* investigated dense improved solar collector model produced conventional solar concept. They tested the model in two stages. Without this mechanism, the concentration in the first and second phase of the concentration has been tested. They conducted experiments in two different phases. The trial of the first phase was conducted without parabolic concentrator. The collector is attached to it and testing conducted after dark. Efficient than conventional flat plate type solar water heater obtained results improved to 15.3 percent (Sarath, *et al.*, 2012). Manjunath *et al.* investigated AP with dimples and AP in both causes compared to conventional method, carried out a CFD analysis. The convectional type AP temperature is 50 degrees Celsius when the above the dimple surface (Manjunath, *et al.*, 2012).

Many researchers had to contact experiment based on water heating flat plat collector. The objective of current experiment is based on convectional and Non-convectional air heating system. There are several advantage of solar flat plate type air heater systems.

1. Simple in construction and easy to maintain. After the set-up construction the maintenance cost is low.

2. There is no fuel expenditure.

3. There is no corrosion and leakage when compared with water heating system.

4. The green house effect system has zero gas emission.

5. To export drying agricultural products etc.

Some of the disadvantages are as follows:

1. These systems have the low thermal coefficient when compared to water heating system. If low thermal coefficient leads to low thermal efficiency of flat plat type air solar heater.

2. To rectify these problem to modified configurations and designs of the solar air heater have been proposed. To rectify these problem to modified configurations and designs of the solar air heater have been proposed. The experimental setup installed at Kotturpuram is a district of Chennai in Tamil Nadu, India (13°02′ (latitude) North and 80°53′ (longitude).

EXPERIMENTAL SETUP

Solar air heaters may be classified into two parts. The first part is based on the air channel flow configuration and the second part is related to the air channel design. The objective of the experiment to increase the efficiency by choosing single flow single pass air channel configuration as a first part, and second part is based on the flat plate absorber. The experimental setup consists of transparent glass wool, AP, and blower, glass wool insulation, drying chamber, temperature sensor, concave chamber and chimney as shown in Fig. 1. The size of the SFPTAC is 2 × 1 × 0.10 m. The collector wall made of iron plate with blue coated paint is with the thickness of 10 cm. The glass wool is made of 25 mm thickness that has good transparent and absorber property.

The AP is made of 5 mm thickness aluminium with black coating. To decrease the loss of heat from the AP by below with hold black coated insulated sheet at thickness 25 mm. Air is gradually flow through the AP upper hand over the surface in between the gap thickness 50 mm. To observe the value of air temperature by one is placed in front of absorber plate and other sensor is placed into drying chamber. The drying chamber is made of four cross section as shown in Fig. 2. In each section to cover with aluminium sheet because of the sheet maintained the temperature for long time. The tests were carried out for one week (from 20 to 26 February 2017 and local time 8.00 am to 6.00 pm) in each and every one hour temperature readings had been taken. The readings had taken for both natural as well as forced convection. To conduct the experiment during the period, almost atmospheric conditions were uniform and where the data are collected from the collector.

The Efficiency of Collector Calculation

From Hematian*et al.*, 2012 and (Kurt bash and Durmush, 2004) stated that the thermal efficiency of the SFPTAC is the ratio useful heat gain by the air to incident solar radiation on the absorber plate.

$$\eta_{collect} = \frac{P_{useful}}{P} \times 100 \text{ in } \% \quad (1)$$

$$P_{useful} = mc_p\,(T_2 - T_1) \text{ in W} \quad (2)$$

$$P = I_\beta \times A_c \text{ in W} \quad (3)$$

$$m = \rho\, s\, V \text{ in Kg/sec} \quad (4)$$

Where Q_{useful} is the useful heat gained by the solar air collector (W) and Q is the solar incident radiation absorbed by AP (W). m is the mass rate of air flow through the collector (Kg/s), C_P is at constant pressure specific heat in (J/Kg°K). T_1, T_2 are inlet temperature of inside and outlet temperature of collector tray. I_β is the solar intensity Radiation which was measured by solar meter with accuracy ± 10 W/m^2 and resolution 0.1 W/m^2. A_C is the area of the solar collector and V is the velocity of the air at outlet of collector tray is measured by a speed meter type with precision of 0.1 m/s. ρ is the density of the air in Kg/m^{3}and S is the area of drying chamber in m^2.

Natural Convection

These analyses methods without any external device evaluate the collector efficiency. The test is carried out in different days and the average values of solar collector were taken. The air conventionally is passing through the AP of the collector and leaves at

Fig. 1 Flat plate solar air collector; Pre-heating chamber.

insulated the collector tray. To measure the AP inlet as well as outlet temperature of collector tray was recorded at every one hour.

The value of the useful power output of the collector in equation 2 is obtained by to measuring the air mass flow rate (m), Constant pressure specific heat capacity of the air (C_p) is taken from the thermodynamic steam table and the temperature difference between inlet and outlet (ΔT). The mass flow rate of the air is obtained in equation 4 measuring the air density, surface area (S) and velocity of air density (V). The power output of the collector is obtained by using the equation 3 by measuring the solar radiation of air per square meter (β) and collector Area (A_C). The efficiency of the collector in equation 1 is obtained by the ratio of the useful power output and power output.

According to Fig. 2, in the middle of the day at a time of 1-2 pm the collector efficiency is more occurred in natural convection because of maximum air temperature difference between the inlet and outlet of collector and also the higher rate of mass flow. At the same time., end of the day the collector efficiency will be decrease spontaneously. In Fig. 3, the maximum temperature difference occurred at the middle of the day at time 12-1 pm at the higher rate of mass flow and spontaneously the temperature is decreased from 2-3 pm. In Fig. 4, the collector efficiency gradually increased up to maximum at time 1-2 pm and spontaneously decreased from 2-3 pm.

Forced Convection

In this method, the designed blower is located on between the outlet of the collector or in front of the concave chamber. The specifications of the blower had 15V, 1 amps and 8 W respectively. The test is carried out on different days; the average values

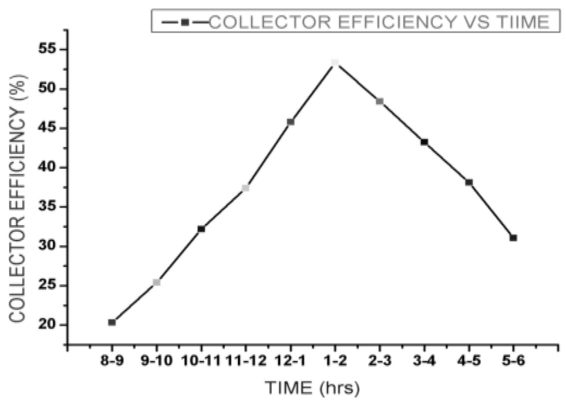

Fig. 2 The collector efficiency of the average values in natural convection during the period.

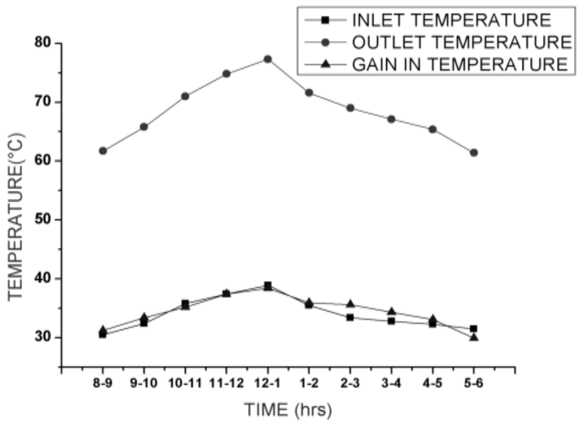

Fig. 3 The different temperature of the average values in natural convection during the period

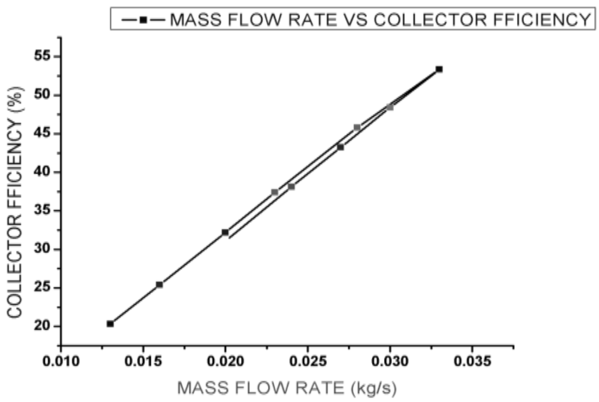

Fig. 4 The collector efficiency vs. various mass flow rates of the average value in natural convection during the period.

of solar collector were taken. The air sucked by the blower is passing through the absorber plate of the collector and leaves at insulated the collector tray. To measure the absorber plate inlet temperature as well as outlet temperature of collector tray was recorded at every one hour.

To determine the collector efficiency should be follow the same procedure for natural convection. From the results showed that the collector efficiency of forced convection is lower than the natural convection because of to sudden changes cloudy and weather condition which affect the inlet and outlet temperature which case to decrease inlet and outlet temperature of the collector. By decreasing the outlet temperature, the speed of outlet air and spontaneously reduced the air flow rate and as a result the collector efficiency decreased. At time 1-2 pm, the mass flow rate of air in forced convection is 25% higher than the natural convection. It can be very useful for drying juicy fruits slices. This case can be useful in the solar dryer for drying juicy fruits slices.

According to Fig. 5, in the middle of the day at a time of 1-2 pm the collector efficiency is more occurred in forced convection because of maximum air temperature difference between the inlet and outlet of collector and also the higher rate of mass flow. At the same time., end of the day the collector efficiency will be decrease spontaneously. In Fig. 6, the maximum temperature difference occurred at the middle of the day at time 12-1 pm at the higher rate of mass flow and spontaneously the temperature is decreased from 2-3 pm. In Fig. 7, the collector efficiency gradually increased up to maximum at time 1-2 pm and spontaneously decreased from 2-3 pm.

In Fig. 8, it showed that, the collector efficiency of the natural convection is more than forced convection. At time 1-2 pm, the collector efficiency of the natural convection is 18.6% is more than forced convection because of its heat loss is high due to the large temperature difference between inside and outside of the collector. In order to increase the collector efficiency of the forced convection by increased the absorber surface area and also could cause the output air warm faster (Fig. 9).

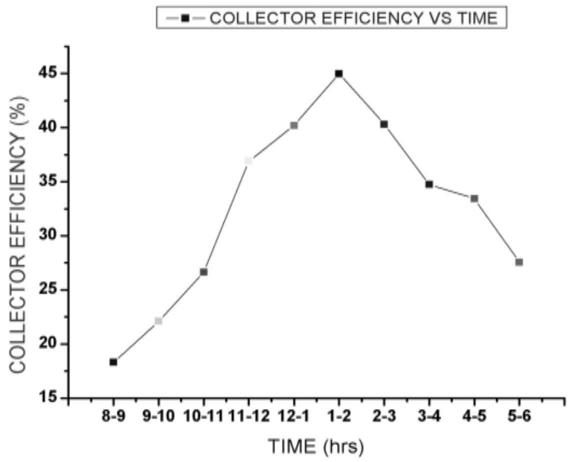

Fig. 5 The collector efficiency of the average values in forced convection during the period.

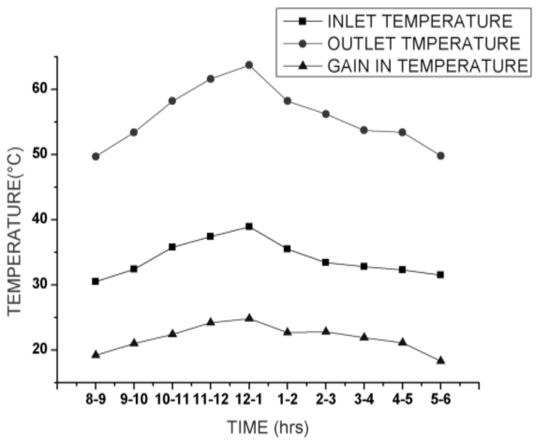

Fig. 6 The different temperature of the average values in forced convection during the period.

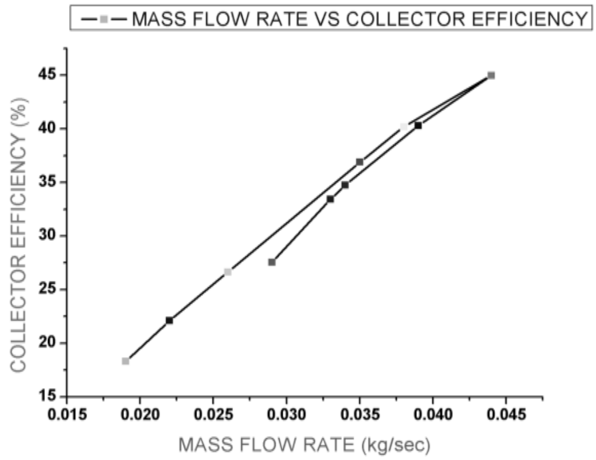

Fig. 7 The collector efficiency vs. various mass flow rates of the average value in forced convection during the period.

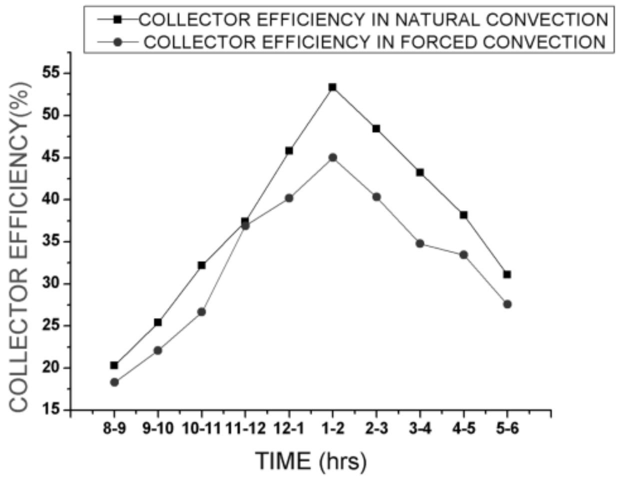

Fig. 8 To compare the collector efficiency of the average values in natural as well as forced convection during the period.

CONCLUSION

From the above experiment, the designed and development of a flat plate solar air collector has been studied in both natural and forced convection and it has been found that the collector efficiency in natural convection gave high efficiency when compared to collector with the forced convection. However, the heat loss in the forced convection is considerably lower than the natural convection. Furthermore, the results showed that the average air speed in the forced convection was about 25% higher than the natural convection which is important in solar dryers. At a mid-time, the collector efficiency of natural convection is 18.6% times more than the collector efficiency of forced convection.

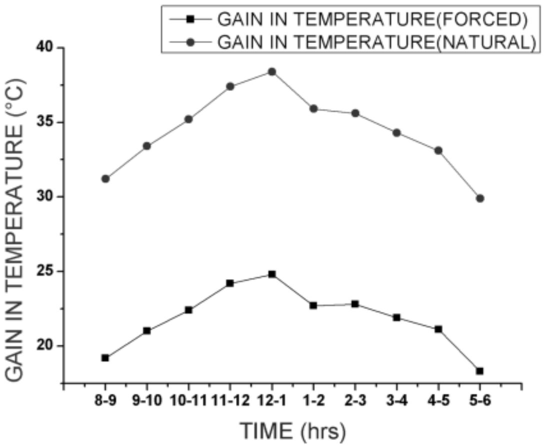

Fig. 9 To compare the gain temperature of the average values in natural as well as forced convection during the period.

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