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Review Article

EXPERIMENTAL STUDY ON THE THERMAL EFFICIENCY OF THE FORCED CONVECTION EVACUATED TUBE SOLAR AIR COLLECTORS WITH AND WITHOUT ABSORBER PLATE

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ABSTRACT

For the present world, the energy requirement is very high. To fulfill the demands for energy in future, renewable source energy is used. As the usage of fossil fuel was increased, it causes more pollutants in the environment. In considering the above factors, cost effective alternate energy is being developed. Solar energy is one of its best energy sources. The current methods of industrial process heating employ huge amount of fossil fuel which in turn increase the import of fuels. Shifting the methods to greener technologies give potential savings in foreign exchange and reduction in dependence of fuel from other countries. The proposed technologies clearly shows the industries can get a good amount of cost saving immediately (lower payback period) and also emission control contributing to lower carbon foot prints. Drying of agricultural food products is one of the most attractive and cost–effective application of solar energy as it becomes a potentially viable substitute for fuel-wood in much of the developing world. Numerous types of solar dryers have been designed and developed in various parts of the world, yielding varying degrees of technical performance.

The objectives of the experiment were to investigate the thermal performance on evacuated tube solar air collector with and without absorber plate by testing various air flow rates. The experiment consists of four main parts such as evacuated tube, manifolds, blower, and absorber plate. Evacuated tube collector based air heating system has 30 Numbers of modules having 4.8 m2 apparatus area. The manifold channel consists of two parts. The first part is made up of Outer hollow circular tube and second part by inner circular tube. Air is made to flow through inside tub, he processed to heat, then by pressure difference the air flows through the outside manifold. The proposed innovative system i.e., evacuated tube solar air collector to reduce the auxiliary power (Blower) requirement, since the air flow friction through evacuated type collector is very high in magnitude, it draws high blower power requirement. The absorber plate is made up of aluminum block coated sheet. The performance efficiency of the solar air collector evacuated tubes increased by enhanced absorber plate which is inserted at the bottom of the evacuated tube. Comparing with evacuated tube solar air collector without absorber plate, high outlet temperature and better efficiency is seen with the absorber plate.

INTRODUCTION

Presently, India spends around 100 million tones of fossil fuels every year for various uses, where 40% is solely consumed by the industries. Approximately, 40% to 50% nearly 15 million tones of fuel oil per year is used for heating application below 250°C catering to a huge annual energy requirement of approximately 150 GW/hr in India. Solar energy which is abundantly available can be harnessed effectively to provide the heating requirements of various industries. One such important application is the use of heated

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air for drying application in automobiles, plastic packing, printing, food and beverage, drags and chemical industries. Presently available commercial technologies for air heating employ flat plate collectors where the maximum attained temperature is limited to 80°C and heat losses are higher. One of its best applications of the solar energy is solar evacuated tube air collector. Drying of agricultural food products is one of the most attractive and cost -effective application of solar energy as it becomes a potentially viable substitute for fuel-wood in much of the developing world. Numerous types of solar dryers have been designed and developed in various parts of the world, yielding varying degrees of technical performance.

THE LITERATURE REVIEW

The literature review is very useful for designing and developing evacuated tube solar air heater. Umayal Sundari et al. designed and fabricated the evacuated tube collector and its performance was studied for drying ginger under the meteorological condition of Thanjavur District, Tamil Nadu. They found that when compared to natural sun drying, the drying time of ginger has been reduced from 13 hrs to 6 hrs (Lamnatou, *et al*., 2012) developed a novel solar dryer with evacuated tube integrated with heat pipe and proved that the warm outlet air of the collector attains the temperature levels suitable for drying of agricultural products without the head of preheating. Thus, the collector was used as the heat source for a drying chamber in the frame of the development of a novel, convective, indirect solar dryer. The fact is that the literatures show a few studies about these types of collectors in conjunction with solar drying applications. They depicted that, for drying larger quantities of the products than those considered with the high efficiency of the collector. (Pin-yang, *et al*., 2014) investigated a new type-all-glass evacuated tubular solar air heated with simplified compound parabolic concentrator (CPC). The system is made up of 10 linked collecting panels and each panel includes a simplified CPC and an all –glass evacuated tube with a U-shaped copper tube heat exchanger installed tub air is gradually heated when passing through an U-shaped copper tube. The heat transfer model of the solar air heater is established and the outlet air temperature, the heat power and heat efficiency are calculated and experimental results showed that the present experimental system can provide the heated air exceeding 200°C. The whole system has an outstanding high –temperature (Bal, *et al*., 2011). Kirk and Chakravertty investigated to find out the empirical relationship for overall heat loss coefficient of evacuated tube collectors with the combination of series and parallel type. They made many analyses which are carried out at different analysis variables and values. Finally, they concluded that the efficiency is decreased in series type and constant for Parallel system (Garg and Chakravertty, 1988). (Kumar, *et al*., 2001) investigated to express the thermal performance of a solar pressure cooker based on evacuated tube collector. Morrison et al. investigated a number of heat transfer method that influenced into the solar evacuated tube. The heat transfer rate, simplicity and low manufacturing cost are high where water is used as a medium. (Shah and Furbo, 2004) performed tests on the vertical evacuated tube collectors. The collector is made up of tubular absorber which absorbed solar radiations in all the direction. The thermal efficiency of the evacuated solar collector when compared with the flat plate solar collector yields an optimum tilt and orientation. (Morrison, *et al*., 2004) developed Numerical analysis of heat transfer and fluid flow in a single ended glass tube. (Kim and Seo, 2007) investigated thermal performance of the evacuated tube solar collector by experimental and numerical methods. From the investigation, four different type absorption patterns were taken to find the absorption patterns. Among them, absorber by tube solar collector is considered to be the best. (Shah and Furbo, 2007) investigated the evacuated tube collectors inside the glass structure for operating different conditions by means of computational fluid dynamics. The design of the collector based on the evacuated tube connected in horizontal into vertical manifold channel. The findings showed that only small variation in the efficiencies by operating different conditions. (Budihardjo and Morrison, 2009) investigated the performance of the evacuated tube solar collector over the flat plate solar collectors. It showed that the performance efficiency of evacuated tube of 30-pipes had lower than 2-panel array plate, working medium used as water. (Ma, *et al*., 2010) analytically investigated to find the heat loss coefficient and heat efficiency factor for the individual glass evacuated tube and also studied the influence of the air layer between copper tube and fin heat absorption capacity. The results showed that evacuated solar collector-glass tube with heat loss coefficient, the temperature difference between the absorber coating surface and ambient air was nonlinear.

(Yadav and Bajpai, 2011) experimentally investigated the thermal efficiency of one ended evacuated solar air collector at parallel and counter flow rate is based on the position of the blower. They said that the counter flow rate had more efficient and higher flow rate when compared to parallel flow rate. (Hayek, *et al*., 2011) practically investigated water-in-glass evacuated tube solar collector and heat pipe designs evacuated tube solar collector based on overall performance. Heated pipe solar collector had 15-20% higher efficiency than that of water-in-glass evacuated tube solar collector. (Lamnatou, *et al*., 2012) experimentally investigated the evacuated tube collector solar dryer for drying apples, carrots and apricots. This experiment was based on the minimum entropy generation for the mass flow rate, along with maximum collector and liquid exit temperature. From the results found that without preheating, the agricultural products are dried. A solar dryer was designed, fabricated, and evaluated for drying of large cardamom at College of Agricultural Engineering and Post-Harvest Technology, Central Agricultural University, Ranipool (27° 20′ N, 88° 40′ E), Gangtok, Sikkim. It was observed that on an average 55.7% of higher temperature was obtained in the solar dryer over the ambient temperature. The result showed that the net saving 50% of drying time for the solar dryer in comparison to the open sun drying (Medugu, 2011). (Bala, *et al*., 2009) investigated the performance of the solar tunnel dryer for drying mushrooms. The dryer was made up of UV stabilized plastic covered flat plat collector and drying tunnel unit consists of 3 fans with 40 Watts solar module. (Zhijian, *et al*., 2015) investigated the heat transfer coefficient and heat loss coefficient for water-glass evacuated tube based on 915 measured samples of water-in-glass evacuated tube solar water heaters. The results analyzed by the personal computer and Android platforms. (Saravanakumar and Mayilsamy, 2010) integrated with the different sensible heat storage material and tested the performance of solar collector under meteorological conditions for natural and forced convection. (Umayal, *et al*., 2014) investigated evacuated tube collector with assisted solar dryer designed by drying Kinetics of Muscat grapes. The study showed that the outlet temperature of the collector and temperature within the chamber varies from 74°C to 130°C and 50°C to 87°C respectively, while the ambient temperature ranges from 29.5°C to 33.2°C and the maximum drier efficiency for musket grapes is found to be 29.92% during the drying period. (Rajendra and Rupesh, 2016) investigated alumina bricks as a thermal energy system used for reduction in drying time and an improvement of the product quality. The reduction in drying time was between 30 - 50% compared with natural drying thermal storage. Although the initial cost is relatively high, the running cost is low and the payback period is less than two years. From the experimental analysis, it is suggested that for best economy and efficiency, mass of commodities can be increased to utilize the thermal energy developed.

(Satish, *et al*., 2014) investigated the drying of copra by natural and forced mode of convection. The experimental analysis showed that natural convection drying is more moisture content when compared with forced convection. (Avadhesh, 2011) experimentally showed that upward flow could not achieve the temperature more than 60°C because of some heat losses occurred where downward flow achieved maximum temperature. (Gumus, and Ketebe, 2013) experimentally calculated moisture content and drying rate at varying temperatures of 110°C, 120°C and 130°C. The drying temperature at 110°C was the best in all favourable condition and yielding uniformly dried corn and ogbono. (Chanchal, 2012) investigated the experiment based on a forced convective cabinet dryer to study characteristics for sliced ginger. The study characteristic for ginger were carried out with four different drying air temperatures of 45°C, 50°C, 55°C and 60°C with fixed air velocity at 1.3 m/s and also determined the thermal conductivity of ginger at moisture contents. (Pranav, 2015) investigated the various kinetics studies, mathematical models and enhancement techniques on the indirect type solar dryers to improve their effectiveness. (Pranav, 2008) investigated indirect forced convection solar dryer and it showed that forced convection solar dryer is more suitable than sun drying for producing high quality copra for small holders. (Onkar, 2016) investigated solar dryers by using thermal storage Phase change materials with different techniques such as infrared radiation, mechanical drying, direct solar grapes dryer, grapes dryer with mixed mode natural convection type. Their experiment showed that natural convection drying system was better when compared to other system. (Ezekoye, 2006) successfully developed passive grain solar dryer. Their experiment was carried out at different temperature and finally to found out moderate temperature of 67^{o}C. (Bala, 2009) experimented the solar tunnel drier which can be operated by a photovoltaic module independent of electric grid. The photovoltaic driven solar tunnel drier must be optimized for efficient operation. (Mohan and Chandrasekar, 2009) investigated the variations of temperature of air at solar collector outlet and ambient temperature during drying of copra. It showed that in an average drying air inlets dryer is 50.4°C and maximum, minimum drying air inlet dryer is 68°C and 43°C. From the above reviews, report was written by the present investigator based on the solar dryer and evacuated tube solar air collector. The objective of the experiment is to produce hot air solar system which contains thirty number of evacuated tubes horizontally connected with vertical circular manifolds and to evaluate the collector efficiency of producing hot air by hour base. The experimental setup is installed at Kotturpuram, Chennai district in Tamil Nadu, India. North to South 13°02′ (Latitude) and 80°53′ (longitude).

EXPERIMENTAL SETUP

The objective of the experiment is to find out the thermal efficiency of evacuated tube solar air collector with forced convection by using with and without absorber plate and to produce hot air. The experimental setup consists of thirty tubes; Outer, inner diameter and length of the evacuated tubes are 0.04 mm, 0.02 mm and 1.5 mm respectively. The surface area of the evacuated tube solar air collector is 3.6 m^2. The one end of evacuated tubes is connected to the circular manifold channel and other end is supported by frame. The Manifold channel is made up of hollow circular tube with Outer, inner diameter and lengths of 0.40 m, 0.20 m and 3.6 m fold channels. The Blower is fixed at the end of the manifold which rotates at fixed speed is used to the blow the air in the evacuated tube at varying air flow rates. The experimental setup consists of the main parts evacuated tubes, Circular manifold channel, blower and absorber plate. The evacuated tube collector mainly comprises of double glass–walled long evacuated tubes in which the outer surface is transparent to absorb solar radiation easily and its inner tube is coated with a selective absorber coating for solar heat collection. In between these tubes aluminum fossil sheets are inserted for absorbing more solar radiation. The Evacuated tube absorbs solar energy and converting it into heat to use in air heating.

The schematic diagram of the evacuated tube solar air collector is shown in (Fig. 1). In this operation, the inlet air flows through the circular directional aluminium tubes into the evacuated tubes where it gains heat due to the solar radiations and heats up, and then it exits from the outer circular pipe of the manifold channel. The purpose of the aluminium tube is to separate the hot air from the incoming cold air.

MEASURING DEVICES

The objective of the experiment to find out the thermal efficiency of the evacuated tube solar air collector by measuring devices are inlet and outlet air temperatures, solar intensity, velocity of air and air flow rate.

Resistive temperature device PT100 that exhibit changes in resistance with change in temperature is measured at different point with a resolution of 0.1°C up to temperature range 450°C. It is made up of metallic elements or alloys such as copper, nickel or nickel-iron.

Fluke 59 Max+ Infrared Pyrometer is used for measuring the air flow rate. Precise laser technology is used for more accurate and repeatable measurements. AcuRite 613 Indoor Humidity Monitor is easy-to-read display and also registers daily highs and lows for both temperature and humidity.

At the beginning of the experiment, the air flow rate is measured by using Testo 410-1 type air velocity vane Anemometer. This instrument is used for

Fig. 1 The evacuated tube absorbs solar energy.

measuring the velocity range from 0.4 – to 20 m/s its revolution 0.1 m/s and accuracy of air velocity 0.2 m/s + 2% of MV. The operating temperature ranges from 10°C to 50°C.

THE FORMULA USED

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

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

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

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

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

A_C = Number of tubes × 2 × Outer diameter × length.

(5)

Where P_{useful} is the useful heat gained by the solar air collector (W) and P is the solar incident radiation absorbed by absorber plate (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 and T_2 are inlet temperature of inside absorber collector 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.

RESULTS AND DISCUSSION

The objective of the experimental setup was to monitor the average values of calculation and measuring parameters in evacuated solar air collector with and without absorber plate. The collector surface area= 3.6 m^2. The experiments were carried out during the month of March 2nd week of 2017 that is, summer-like conditions, taken the readings for 7 days and which during the period the temperature varied from 30.2°C to 39.9°C. The experiments were carried out from 8:00 am to 6:00 pm for 7 days.

Two cases have been taken for discussing the results.

- The average values of calculation and measuring parameters in evacuated solar air collector without absorber plate.
- The average values of calculation and measuring

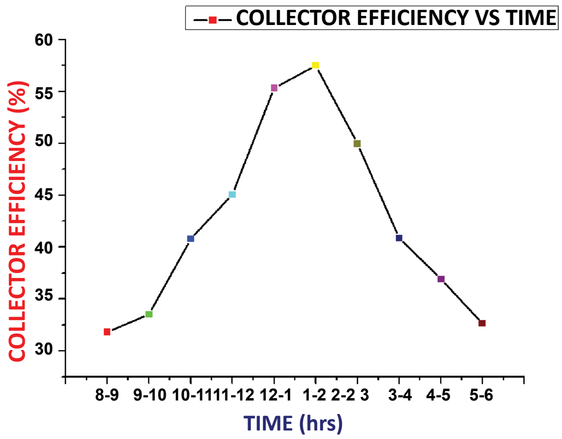

Fig. 2 The average values of collector efficiency vs. time for the evacuated solar air collector without absorber plate. The collector surface area=3.6 m^2.

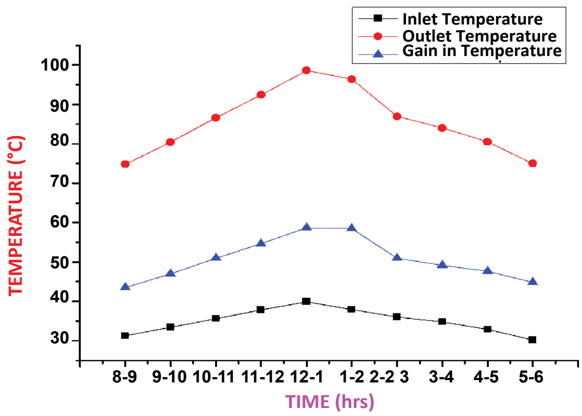

Fig. 3 The average values of temperature vs. time for the evacuated solar air collector without absorber plate. The collector surface area=3.6 m^2.

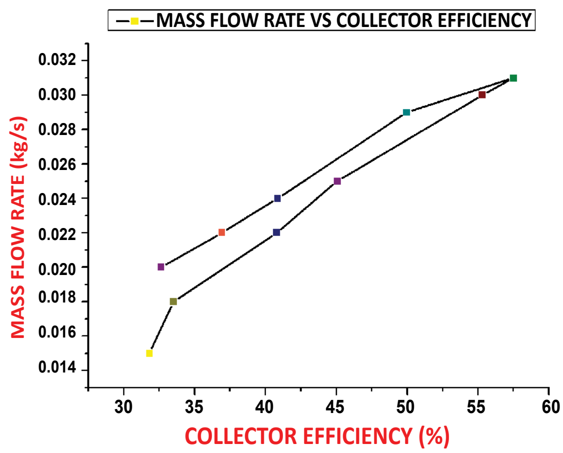

Fig. 4 The average values of mass flow rate vs. collector efficiency for the evacuated solar air collector without absorber plate. The collector surface area=3.6 m^2.

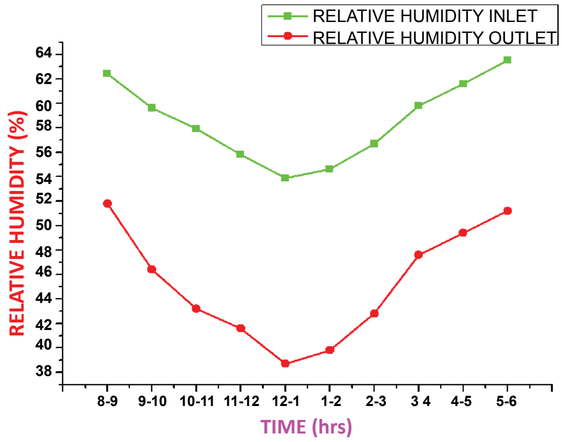

Fig. 5 The average values of relative humidity vs. time for the evacuated solar air collector without absorber plate. The collector surface area=3.6 m².

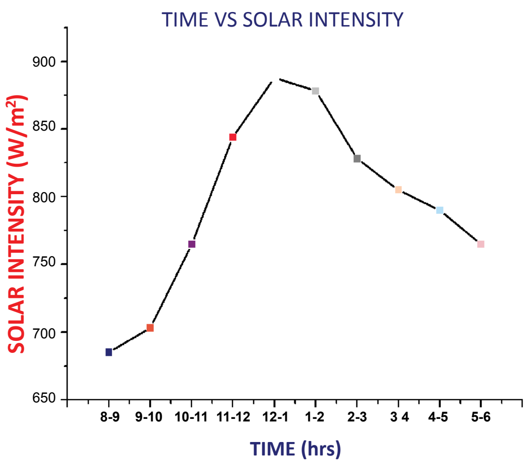

Fig. 6 The average values of solar intensity vs. time for the evacuated solar air collector without absorber plate. The collector surface area=3.6 m².

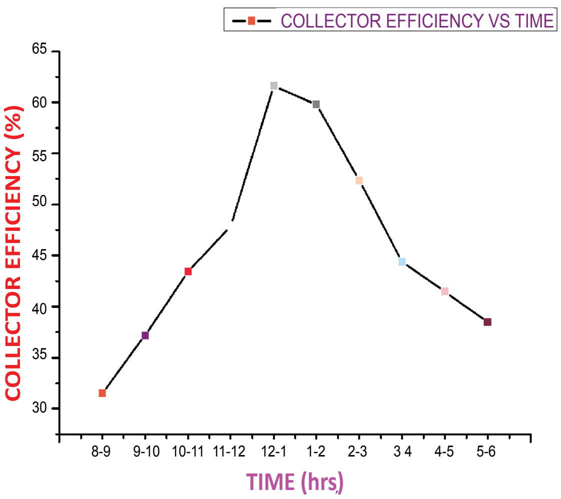

Fig. 7 The average values of collector efficiency vs. time for the evacuated solar air collector with absorber plate. The collector surface area=3.6 m².

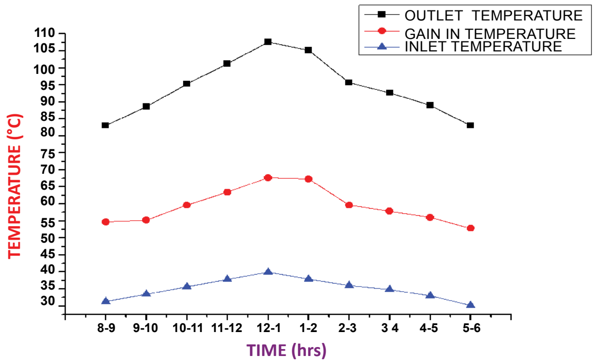

Fig. 8 The average values of temperature vs. time for the evacuated solar air collector with absorber plate. The collector surface area=3.6 m².

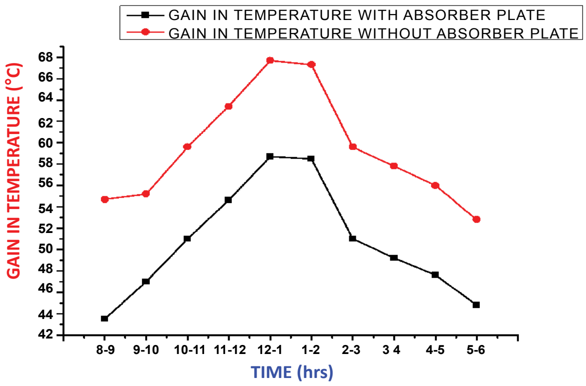

Fig. 9 The average values of gain in temperature vs. time for the evacuated solar air collector with and without absorber plate. The collector surface area=3.6 m².

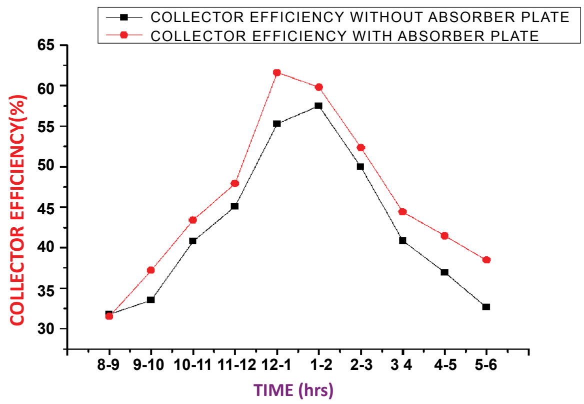

Fig. 10 The average values of collector efficiency vs. time for the evacuated solar air collector with and without absorber plate. The collector surface area=3.6 m².

parameters in evacuated solar air collector with absorber plate (Fig. 2-10).

CONCLUSION

Solar air heating is a technology based on solar thermal energy in which energy from the sun is captured by an absorbing medium and used to heat the circulating fluid i.e., air. It is renewable energy heating technology used to heat air using heat applications in temperature range of 40°C to 130°C. The following conclusions have been made from the experiment by the investigator.

(i) The maximum outlet temperature and temperature difference of air is achieved at flow rate of 0.030 kg/sec are 98.6°C and 39.9°C at 12.00 to 1.00 p.m. without absorber plate.

(ii) The maximum efficiency air is achieved at flow rate of 0.031 kg/sec is 0.575 at 1.00 to 2.00 p.m. without absorber plate.

(iii) The maximum outlet temperature and temperature difference of air is achieved at flow rate of 0.027 kg/sec are 107.6°C and 67.7°C at 12.00 to 1.00 p.m. without absorber plate.

(iv) The maximum efficiency air is achieved at flow rate of 0.027 kg/sec is 61.6 at 12.00 to 1.00 p.m. without absorber plate.

The experiment concluded that the efficiency of the evacuated tube collector can be significantly increased with the use of absorber plate. In future, with increased number of evacuated tubes with absorber plate will be more evident to use as an effective method of solar collectors.

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