Available online at http://www.journalajst.com

INTERNATIONAL JOURNAL OF CURRENT RESEARCH

International Journal of Current Research
Vol. 5, Issue, 06, pp.1468-1472, June, 2013

ISSN: 0975-833X

RESEARCH ARTICLE

TRANSIENT BEHAVIOR OF A FLAT PLATE SOLAR AIR HEATER

***Anuradha, A. and Dr. Rachel Oommen**

Department of Phyiscs, Avinashillingam Institute for Home Science and Higher Education for Women Coimbatore – Tamil Nadu – 641 043

ARTICLE INFO

Article History:
Received 08th March, 2013
Received in revised form
26th April, 2013
Accepted 14th May, 2013
Published online 15th June, 2013

Key words:
Solar air heater, Efficiency,
Time constant, Flat plate collector,
Inlet temperature.

ABSTRACT

In solar air heater, flat plat collectors are the best heat transfering devices. An experiment was performed with the flat plate solar air collector of area 1.87m2 to describe its transient behavior. The experiment was carried out for different range of inlet temperatures (40 °C, 50 °C, 60 °C, 70 °C, 80 °C and 90 °C) for a period of three months (April, May and June). The efficiency found for different range of input temperatures varies from 20 – 37 %.Efficiency and output temperature values are calculated theoretically and are in close agreement with experimental values. Collector time constant of the collector was also calculated.

INTRODUCTION

Energy is considered a prime agent in the generation of wealth and a significant factor in economic development. The importance of energy in economic development is recognized universally and historical data verify that there is a strong relationship between the availability of energy and economic activity (1). Energy is a vital need in all aspects and due to the increasing demand for energy coupled with its inefficient consumption, the environment has been polluted either directly or indirectly. To prevent this from becoming a global disaster, it is inevitable to strengthen efforts of energy generation and utilization using sustainable means and progressively substituting the fossil fuels for renewable sources of energy (2). There are many alternative energy sources which can be used instead of fossil fuels. The decision as to what type of energy source should be utilized must, in each case, is made on the basis of economic, environmental and safety considerations. Because of the desirable environmental and safety aspects it is widely believed that solar energy should be utilized instead of other alternative energy forms, even when the costs involved are slightly higher(1).

Unlike other sources of energy, solar energy allows independent systems to be constructed. This energy possesses a thermal conversion mode which necessitates a simple technology which is adapted to the site and to the particular region for many applications (3). A solar collector is a very special kind of heat exchanger that uses solar radiation to heat the working fluid (2). Solar air system is a type of system which collects solar energy and transforms it into heat. The general idea is that the air is flowing through solar collector and heat from sun naturally raises the temperature of the air. Flat plate solar air heaters are non-adiabatic radiative heat exchangers; they are essentially used at low temperature levels ($T < 375K$) in air heating and drying systems (4). Flat-plate solar air collectors have potential applications in space-heating ,air conditioning, industrial process heat, and also for heating domestic water(5). Recently many studies have been conducted on the efficiency and energy analysis of solar air heater. Sukhmeet Singh *et al*., 2012 studied analytically the exergetic efficiency of a solar air heater having discrete V-down rib roughness and the results obtained are compared with that of a conventional flat-plate solar air heater. Flow Reynolds number and rib-roughness parameters, viz., relative roughness pitch, relative gap position, relative gap width, angle of attack and relative roughness height have combined effect on heat transfer as well as fluid friction. The exergy based criterion suggests use of the discrete V-down rib roughened solar air heater for the Reynolds number range normally used in solar air heaters. It was found that there exist optimum roughness parameters of the discrete V-down rib for a given Reynolds number (or temperature rise parameter) at which the exergetic efficiency is highest.

A transient model of 50 m^2 area of flat plate solar collectors was developed by Rodríguez-Hidalgo *et al*., 2011 to experimentally validate its performance. Using the model capabilities to predict the collector performance under transient working conditions, the influence of the operating conditions on the collector efficiency and on the useful heat produced is studied individually. The relevance of those conditions is ranked as follows: the wind (velocity magnitude and direction) was the most influential, followed by the aging of the collector surfaces, convective heat losses, thermal inertia and the incident angle of irradiance. Natural convection heat transfer in a vertical flat-plate solar air heater of 2.5 m height and 1 m width, with one- and two glass covers was studied experimentally by Hatami *et al*., 2008. Totally six cases of airflow (two for air heater with one glass cover and four for air heater with two-glass covers) were considered. These case included states that air could flow within spaces between absorber plate and glass covers or air was enclosed in such spaces. Absorber plate temperature, back-plate temperature, glass cover temperatures, mass flow rates of air within channels and the solar radiation were measured. The efficiency of the air heater was determined in various cases. The maximum efficiency was found for when the air heater had two glass covers and air could flow in all channels. A parametric study on the thermal performance of a solar air collector with a v-groove absorber has been investigated by Tao Liu *et al*., 2007. In a single-cover collector, the air flowing in the channel formed by the v-groove absorber and the bottom plate—

***Corresponding author:** A. Anuradha
Department of Phyiscs, Avinashillingam Institute for Home Science and Higher Education for Women, Coimbatore – Tamil Nadu – 641 043

which is flat and insulated—is along the groove, aiming at enhanced heat transfer rate between the air and the absorber by increasing the heat transfer surface area, which is crucial to the improvement of thermal performance of a solar air collector. The thermal performance of these two types of solar air collectors is analyzed and compared under various configurations and operating conditions. The results show that the v-groove collector has considerably superior thermal performance to the flat-plate collector. It is also found that to achieve better thermal performance, it is essential to; use a small size of the v-groove absorber for the v-groove absorber collector and to maintain a small gap between the absorber and the bottom plate for the flat-plate collector; to use selected coatings that have a very high absorptivity of solar radiation but a very small emissivity of thermal radiation on the absorber and glass cover; to maintain an air mass flow rate above 0.1kg/m2s; and to operate the collectors with the inlet fluid temperature close to that of the ambient fluid. In the present study a flat plate collector of 1.87m^2 area is used.

Experimental Set Up

The solar air heater is used for crop drying. The specification of the test collector is as given below. The absorber plate is v-corrugated type made of galvanized steel of 2mm thickness. It is coated with black plaint to absorb the maximum solar radiation. Normal window glass of 4mm thickness is used as the single glazing. The absorber plate is placed directly behind the transparent glass cover. The heat transfer fluid – air – passes in between the glazing and the absorber. Glass wool and thermocole sheets were used as insulation material with 50mm thickness. The bottom and sides of the collector was insulated to avoid heat losses. Silicon rubber is used as sealant. The collector was fitted with thermocouples for measuring temperatures at different locations. The thermocouple that measured the ambient temperature was kept in a standard weather housing to protect it from direct sunlight. Pyranometer were used to measure solar radiation in the plane of the collector. Anemoneter was used to measure the wind velocity. The airflow rate was calculated from the air velocity measured by the air velocity meter at the collector outlet and the known cross sectional area of the duct.

The experiment was performed at Sun best Factory, Theni (Latitude: 10° 01', North. Longitude: 77° 28', East) for three months (April, May and June). The basic method of measuring collector performance is adopted by exposing the operating collector to solar radiation and measuring the fluid temperature and fluid flow rate. In addition to radiation on collector, ambient, inlet and outlet temperatures were also recorded. The velocity of the air is measured at the collector outlet. Tests were made with a range of inlet temperature conditions (40 ^{o}C, 50 ^{o}C, 60 ^{o}C, 70 ^{o}C, 80 ^{o}C and 90 ^{o}C). To minimize effects of heat capacity of collectors, tests were made in symmetrical pairs, one before and after solar noon. Thus two types of information are available: data on the thermal output and data on the conditions producing that thermal performance. These data permit the characterization of the collector by parameters that indicate how the collector absorbs the energy and how it losses the energy to the surroundings.

Heat loss calculations

The solar thermal efficiency depends essentially on thermal losses from outer surfaces of the collector. These losses are classified into three main types.

(1) The top heat loss coefficient
(2) The bottom heat loss coefficient
(3) The edge loss coefficient.

Top loss coefficient

The top loss coefficient (U_L) is required in performance models of solar collectors. This coefficient determines the sum total of energy lost from the absorber to the ambient by the combined processes of convection and radiation.

$$U_t = \left\{ \frac{N}{\frac{c}{T_p}\left(\frac{T_p - T_a}{N + f}\right)^e} + \frac{1}{h_w} \right\}^{-1} + \frac{\delta(T_p^2 - T_a^2)(T_p - T_a)}{\frac{1}{d} + \frac{(2N+f-1)}{\varepsilon_g} - N}$$

$$C = \frac{204.429(\cos\ \beta)^{0.252}}{L^{0.24}}$$

$$d = \varepsilon_p + 0.0425N(1 - \varepsilon_g)$$

$$f = \left(\frac{9}{h_w} - \frac{30}{h_w^2}\right)\left(\frac{T_a}{316.9}\right) 1{+}0.091N$$

$$h_w = 5.7 + 3.8\ V$$

$$e = 0.252$$

The bottom heat loss coefficient

Energy dissipation from the bottom of the collector is the collective effect of conduction from the absorbing surface to the insulator at the bottom and convection and radiation from the outside wall to the ambient surroundings. Thermal loss coefficient from the bottom could be calculated as follows

$$U_b = \frac{ki}{xi}$$

The total heat loss coefficient is given by the following:

$$U = U_t + U_b \qquad \text{---------- (1)}$$

Collector heat removal factor, F_R is mathematically given by

$$F_R = \frac{mC_p}{A_cU_L}\left[1 - \frac{S/U_L(T_o - T_a)}{S/U_L(T_i - T_a)}\right] \qquad \text{--------- (2)}$$

The maximum possible useful energy gain (heat transfer) in a solar collector occurs when the whole collector is at the inlet fluid temperature, heat losses to the surroundings are at the minimum.

$$Q_u = A_cF_R\ [S - U_L\ (T_i - T_a\ )]$$

Qu useful heat gain can be obtained:

$$Q_u = \dot{m}\ C_p\ (T_o - T_i\ ) \qquad \text{-------- (3)}$$

Efficiency of the solar collector is given by

$$\eta = \frac{Q_u}{I_tA_c} = \frac{\dot{m}C_p(T_o - T_i)}{I_tA_c} \qquad \text{-------- (4)}$$

The values of collector heat removal factor (F_R), Fin efficiency (F’) and overall heat loss coefficient (U_L) were calculated for the collector from the equations (1) to (4) and given below.

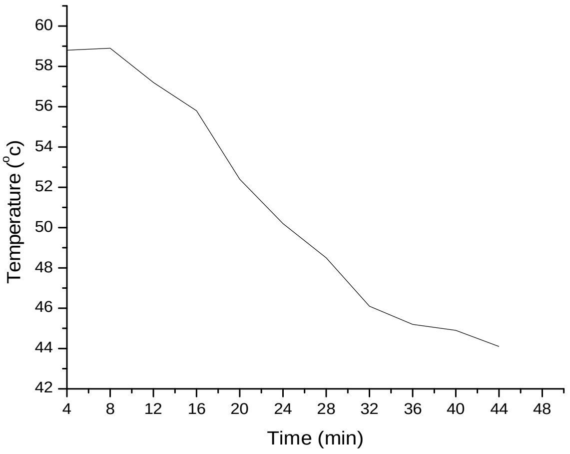
Collector heat removal factor (F_R): 0.785
Collector efficiency factor (F'): 0.824
Overall heat loss coefficient (U_L): 7.8 W/m^2 °C

Collector time constant

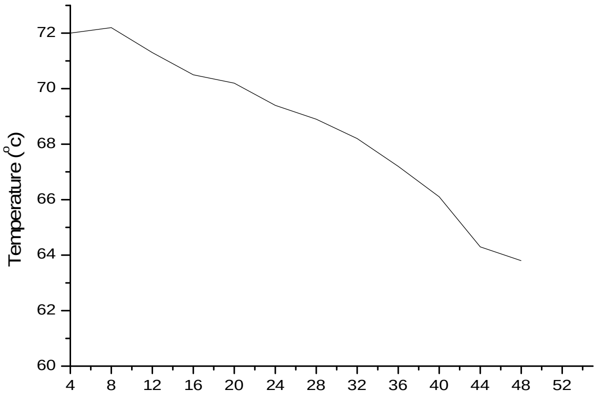
One of the aspects of collector testing is the determination of the heat capacity of a collector in terms of a time constant. It is also necessary to determine the time response of the solar collector in order to be able to evaluate the transient behavior of the collector, and to select the correct time intervals for the quasi-steady state or steady-state efficiency tests.(1) The time constant test consists of two steps. First, the collector is exposed to the sun and its inlet temperature is temperature-controlled to match the prevailing outdoor air ambient dry bulb temperature. After steady-state conditions are achieved, the collector is abruptly shielded from receiving insolation by covering the collector with an opaque surface. Immediately thereafter, the collector inlet (controlled) and outlet (uncontrolled) temperatures are continuously observed. The decrease in collector outlet temperature over time provides information needed to estimate the collector's thermal time constant (10). The collector time constant represents the time needed for the temperature difference between outlet and inlet to decrease to 0.368 (1/e) of its initial value. The collector time constant is a measure of the time required for the following relationship to apply

$$\frac{T_{ot} - T_i}{T_{oi} - T_i} = \frac{1}{e} = 0.368$$

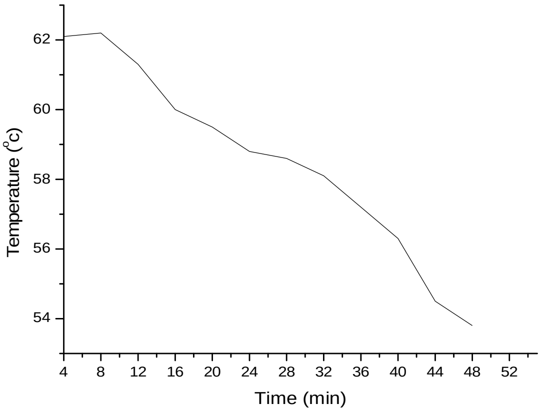
where T_{ot} is the collector outlet temperature after time t (°C); Toi is the collector outlet initial temperature (°C); T_i is the collector inlet water temperature (°C)(1). A time-temperature plot for a flat plate air heater showing temperature drop on sudden interruption of the solar radiation on the collector for different input temperatures is given in Fig. 1. (1a – 1f).



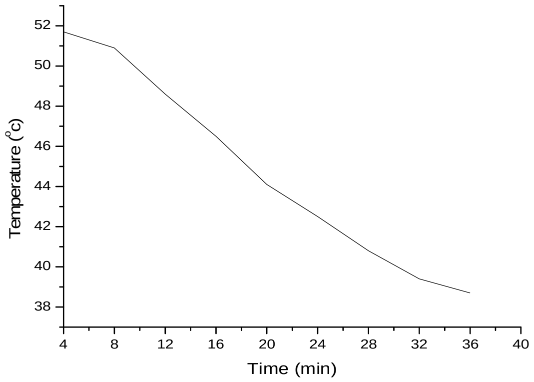
(1a) 40°C



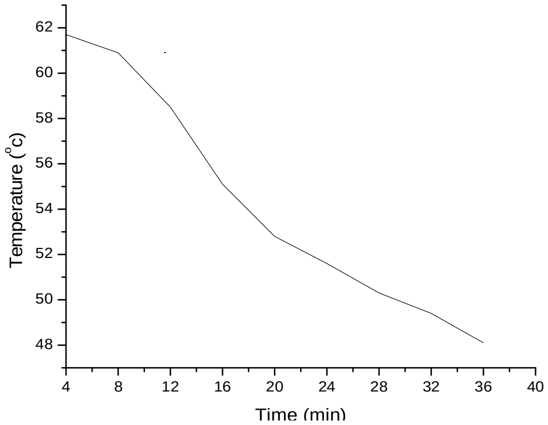
(1b) 50 °C



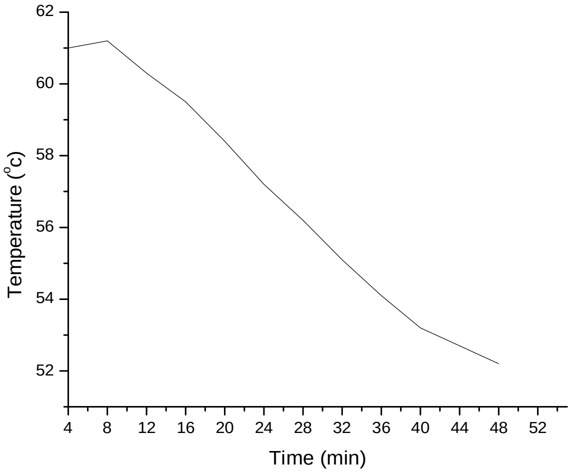
(1c) 60 °C



(1d) 70 °C



(1e) 80 °C



(1f) 90°C

Fig. 1. (1a-1f). A time-temperature plot for a flat plate air heater showing temperature drop on sudden interruption of the solar radiation on the collector for different input temperatures

It is seen that the outlet temperature decreases when the solar radiation is shut off by shading the collector after solar noon. Collector time constant was calculated and it is found to be 10.8 mins.

RESULTS AND DISCUSSION

In a series of experiments conducted, data were recorded for different operating variables to determine the performance of solar air collector .The input temperature is set with help of temperature controller and the solar radiation, ambient, input & output temperatures and volume flow rate were recorded. Table 1 gives the efficiency of the system calculated from equation (4) for different range of input temperatures. The efficiency of collector varies from 20 – 37 %. It is found that the efficiency of the system increases as the input range increases.

Table 1. Predicted and experimental efficiency and outlet temperature for different inlet temperature

Inlet Temp (°C)	Outlet Temperature (°C)		Efficiency (%)	
	Expt	Predicted	Expt	Predicted
40	44	46	20	22
50	47	49.5	22	25
60	51	55.3	26	29
70	56	60.4	27	33
80	61	65	30	35
90	67	72	32	37

Fig. 2. shows the typical efficiency curve obtained from the present experimental study and its comparison with the predicted values at 40°C. Some scatter values can be seen in the experimental data. Fluctuations in the meteorological variables have contributed to the scatter in the results. Experimental and predicted results show better agreement. At higher inlet temperatures, experimental results deviate constantly from the predicted results. The slope of the curves represents the overall loss coefficient, which indicates greater loss coefficient in experimental study. The possible reason for this disagreement is the edge loss.

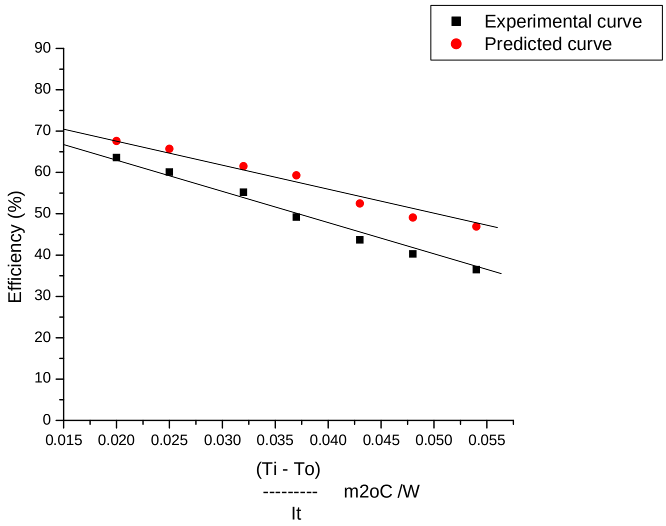


Fig. 2. Variation of predicted and measured efficiency curves at 40°C

Fig. 3. shows the experimental and predicted efficiency curves at different mass flow rates at 90°C. From the figure, it can be seen that, as flow rate increases, efficiency increases considerably. The reason for the significant increase in efficiency can be attributed to changes in flow condition from laminar to turbulent. It can, also, be seen that slope of the efficiency curves decreases, meaning decrease in loss coefficient, with increase of flow rates. Collector outlet temperature is an important parameter for drying applications. The variation of experimental and predicted outlet temperature with flow rate at 60°C is shown in Fig. 4. Simulation and experimental results show that outlet temperature decreases continuously with flow rate. As outlet temperature of fluid decreases with flow rate, efficiency gets correspondingly increased due to decreased thermal losses to the environment. It also shows the relationship between efficiency and outlet temperature with flow rate.

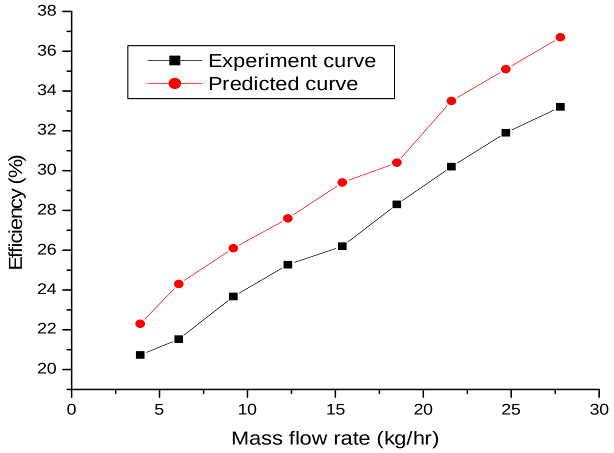


Fig. 3. Variation of efficiency for different mass flow rate for 90°C

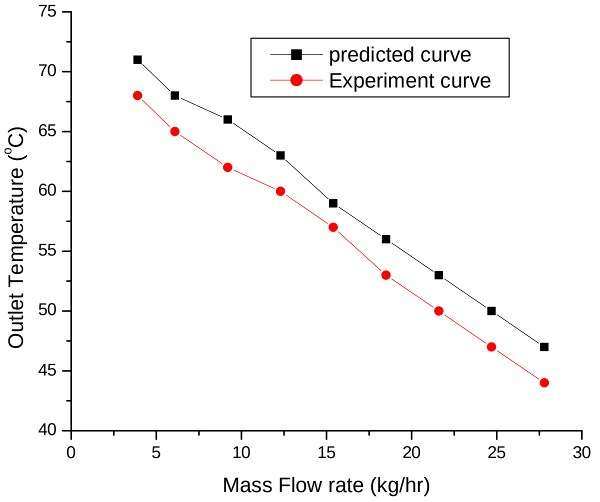


Fig. 4. Variation of outlet temperature with Mass flow rate of 60°C

Variation of efficiency and insolation with time of the day for 80°C is shown in Fig. 5. Figure shows that efficiency of the collector is higher at higher insolation and remains high long after the solar noon.

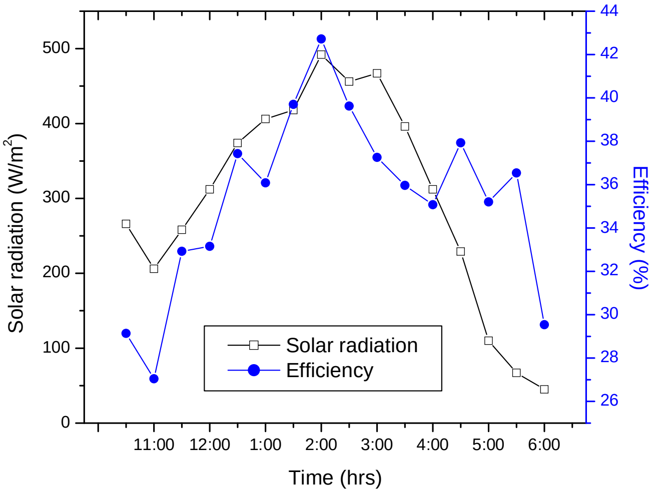


Fig. 5. Variation of efficiency and insolation with time of the day for 80°C

Variation of different temperature with time at 70°C is shown in Fig. 6. All the temperatures reaches the maximum value at 12:30 noon. In the later part of the day, when solar insolation is lower, heat absorbed by the collector is released to the flowing air and the outlet temperature is kept reasonably high than ambient.

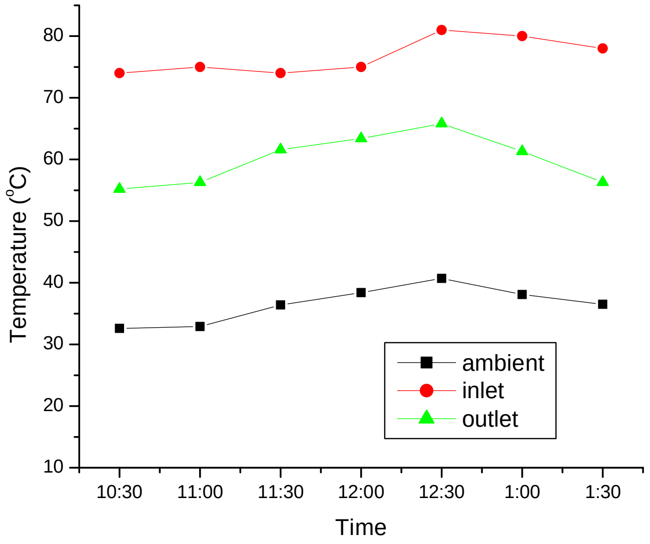


Fig. 6. Variation of temperature with time at 70°C on 3.5.2011

Fig. 7. shows the efficiency curves for different inlet temperatures. It is seen that as the temperature increases the efficiency increases and least square fit of the experimental data shows that all the measured data points fit to the straight line value for the y intercept from 68 to 76 for 40°C to 90°C respectively.

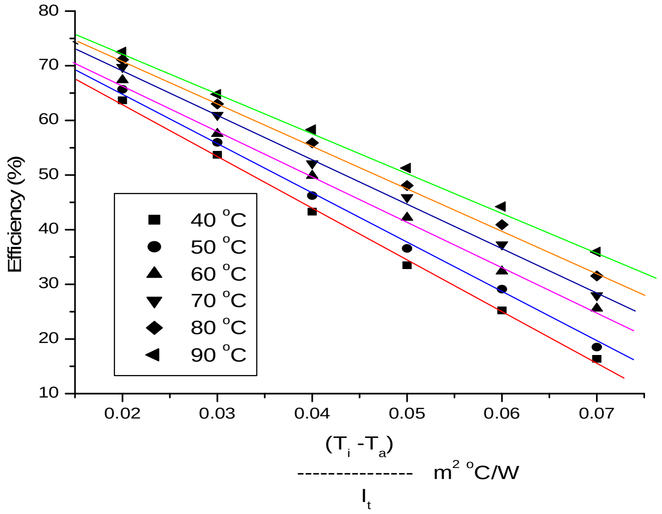


Fig. 7. Experimental Thermal Efficiency curves for different range of input temperatures

Conclusion

- Experimental and analytical results show a good thermal performance of a v-groove collector. Satisfactory qualitative and quantitative agreement between experimental and analytical results was achieved. Efficiency of the collector is very much dependent on airflow rate
- Efficiency of the solar air heater was found for different input range. Efficiency curve and collector time constant graph were drawn.
- Increasing the inlet temperature increases the efficiency.

Acknowledgement

The authors wish to thank Department of Science and Technology for their financial support to carry out the work. We sincerely acknowledge Dr. Palaniappan, chairman, Planters Energy Network, Theni for his constant support throughout the work.

REFERENCES

1. Soteris A. Kalogirou 2004. Solar thermal collectors and applications. Progress in Energy and Combustion Science. 30. 231–295
2. Jae-mo koo. 1999 .Development of a flat-plate solar collector design program. M.Sc thesis University of Wisconsin-Madison.
3. A. Abene, V. Dubois, M. le. Ray, A. Ouagued. 2004. Study of a solar air flat plate collector: use of obstacles and application for the drying of grape. Journal of Food Engineering .65 .15–22.
4. Hossein Ajam, Saeid Farahat and Faramarz Sarhaddi 2005. Exergetic Optimization of Solar Air Heaters and Comparison with Energy Analysis. Int. J. of Thermodynamics. 8 pp. 183-190.
5. Pradhapraj. M., Dr. V. Velmurugan and H. Sivarathinamoorthy. 2010. Review on porous and nonporous flat plate air collector with mirror enclosure. International Journal of Engineering Science and Technology. 2(9). 4013-4019.
6. David Luna, Yves Jan not, Jean-Pierre Nadeau. 2010 An oriented-design simplified model for the efficiency of a flat plate solar air collector. Applied Thermal Engineering 30. 2808 -2814
7. A. Alvarez, O. Cabeza, M.C. Muñiz, L.M. Varela. 2010. Experimental and numerical investigation of a flat-plate solar collector. Energy. 35.3707 -3716.
8. John. A. Duffie and William A. Beckman. 1980. Solar Engineering of Thermal Processes. John Wiley & Sons. 25, 258 & 260.
9. M.C. Rodríguez-Hidalgo, P.A. Rodríguez-Aumente, A. Lecuona, G.L. Gutiérrez-Urueta, R. Ventas 2011. Flat plate thermal solar collector efficiency: Transient behavior under working conditions. Part I: Model description and experimental validation. Applied Thermal Engineering .31. 2394- 2404.
10. D. Rojas, J. Beermann, S.A. Klein, D.T. Reindl. 2008. Thermal performance testing of flat-plate collectors. Solar Energy 82. 746–757.

****