Heat Transfer Augmentation Using V-Shaped Fins in Solar Absorber Plate

Shyam Kumar[1], Prof. Balaji Nelge[2], Prof. Mahesh Bhong[3]
[1, 2, 3] Indira College of Engineering and Management,Pune,India

Abstract- *In the present work, it is aimed to improve the thermal performance of solar absorber plate by applying v-shaped fins on the collector surface. An experimental analysis has been done to investigate and compare the thermal performance of flat plate and plate with v-shaped fins (α=60º) in natural sunlight. The investigation is spread for mass flow rate ranging from 0.007kg/sec to 0.025kg/sec for fixed relative pitch of 15cm. The black coated aluminium absorber plate of area 1.4 m2 is placed in the mid position of duct covered with acrylic glass. After analysis comparison is made indicating that useful heat gain in v-shaped finned plate is 23.07% more than the flat plate at the particular day and time. Various losses also accounted during the analysis. Convective heat transfer coefficient has been increased up to 23.5% at the cost of pumping losses.*

Keywords- thermal energy gain, solar air heater, fins, mass, flow rate

I. INTRODUCTION

A conventional solar air heater generally consists of an absorber plate with a parallel plate below forming a small passage through which the air is to be heated and flows. A solar air heater is simple in design and requires little maintenance. Because of their simple in construction and low cost, solar air collectors are extensively used in the world for heating purposes.

Solar air heaters are effective device to harness solar radiation. It has very good applications in space heating, swimming pool water heating and agricultural product drying. During various studies it is found that flat plate solar collectors have poor performance in comparison to finned plates. It is because of low convective heat transfer coefficients between flat plates and flowing air. It results in the increase of temperature of flat plate surfaces leading to heat losses to the environment Several methods, including the use of fins, artificial roughness and packed beds in the ducts, have been proposed for the enhancement of thermal performance. By applying the fins in the form of different geometries cause the change in fluid flow characteristics. The roughness causes flow separations, reattachments and generations of secondary flows. Thin laminar sublayer formed in the vicinity of flat plate is broken by fins. Various geometries of fins create turbulence results in the better intermixing of air. Thus useful energy gain as well as thermal performance is improved.

Few studies were carried out before conducting the experimentations. K.Mohammadi and M.Sabzpooshani investigates the influence of fins and baffles attached over the absorber plate on the performance of the upward type single pass solar air heater. A steady state mathematical model is presented and solved theoretically. The performance evaluation is studied in terms of different performance indicators, such as outlet air temperature, efficiency and effective efficiency. It is found that attaching fins and baffles effectively increases the outlet air temperature and efficiency in comparison to a simple conventional device. However, it is observed that increasing the number of fins and baffles parameters can reduce effective efficiency even less than a simple conventional device in some cases due to the high required pump work. [1]

In the work of Abdul et al, results of an experimental investigation of the effect of geometrical parameters of V-shaped ribs on heat transfer and fluid flow characteristics of rectangular duct of solar air heater with absorber plate having V-shaped ribs on its underside have been reported. The range of parameters for this study has been decided on the basis of practical considerations of the system and operating conditions. The investigation has covered a Reynolds number (Re) range of 2500–18000, relative roughness height ($e=D_h$) of 0.02–0.034 and angle of attack of flow (a) of 30°–90° for a fixed relative pitch of 10.

The maximum enhancement of Nusselt number and friction factor as a result of providing artificial roughness has been found to be respectively 2.30 and 2.83 times that of smooth duct for an angle of attack of 60°. It was observed that the same angle of attack corresponds to the maximum values of both Nusselt number and friction factor. It appears that the flow separation and the secondary flow resulting from the presence of V-shaped ribs and the movement of resulting vortices combine to yield an optimum value of angle of attack. [2]

The thermal performance of a single pass solar air heater with five fins attached was investigated experimentally by Foued et al. Longitudinal fins were used interior the absorber plate to increase the heat exchange and render the flow fluid in the channel uniform. The effect of mass flow rate of air on the outlet temperature, the heat transfer in the thickness of the solar collector, and the thermal efficiency were studied. Experiments were performed for two air mass flow rates of 0.012 and 0.016 kg s_1. Moreover, the maximum efficiency values obtained for the 0.012 and 0.016 kg s_1 with and without fins were 40.02%, 51.50% and 34.92%, 43.94%, respectively. [3]

Amir et al. carried the investigation on flat plate solar air collector. The absorber of solar collector made by steel plate with an area of $2\times1m^2$ and thickness of 0.5mm in the form of window shade has been developed for increasing the air contact area. The surface of absorbent plate was covered by black paint. To insulate the collector, the glass wool with the thickness of 5cm was used.. The results showed that the collector efficiency in forced convection was lower, but the low temperature difference between inlet and outlet of the collector decreased its heat loss. In addition, the average air speed in forced convection was about 21% higher than the natural convection [4]

Three designs namely (i) plane absorber (ii) transverse V- porous ribs and (iii) inclined V-porous ribs of absorber was tested by Sunil et al . All the experiments were conducted with artificial solar radiation and in natural convection. Performances of these three designs were compared on the basis of overall thermal efficiency and thermal gradient along normal to the base. The overall thermal efficiencies of these designs were found as 14.91%, 17.24% and 20.04% respectively. It has also been seen that thermal gradient tends to reduce with increase in efficiency. [5]

Arvind et al did the experimentation on solar dryer with baffled plate. He found that the moisture content and weight of chilies was reduced from 90% to 13% and 2 kg to 0.232 kg in three days respectively. Result of the present study shows that the drying time is reduced and quality of the final products are superior. [6]

Atul et al did the investigation on heat transfer and friction in solar air heater duct with W-shaped rib roughness on absorber plate. Duct had width to height ratio (W/H) of 8.0, relative roughness pitch (p/e) of 10, relative roughness height (e/D_h) 0.018-0.03375 and angle of attack of flow (α) 30-75°. Air flow rate was corresponding to Reynolds number between 2300 -14,000. Maximum enhancement of Nusselt number and friction factor as result of providing artificial roughness was found to be respectively 2.36 and 2.01 times that of smooth duct for angle of attack of 60°. [7]

II. THERMAL PERFORMANCE OF SOLAR AIR HEATER

It was pointed out earlier that the low thermal efficiency of solar air heaters can be improved by using artificial roughness in the form of different shapes fabricated in various arrangements to create turbulence near the wall or to break the viscous sublayer. As a result, increasing the heat transfer coefficient, thermal efficiency can be increased but at the same time creating turbulence requires additional energy which has to be supplied by fan or blower at the expense of electrical energy.

The collector efficiency, η, is a measure of the collector performance and is defined as the ratio of the useful heat energy gain over a time period to the incident solar radiation over the same time period. [8]

$$\eta_{th} = \frac{Q_u}{IA_c}$$

The following equations have been used for the evaluation of relevant parameters:

The rate of useful energy collected is expressed by considering enthalpy rise of the air as

$$Q = mC_p(T_o - T_i)$$

Heat transfer coefficient of air is calculated by using the formula

$$h = Q/[A_c \times (\overline{t_p} - \overline{t_f})]$$

Temperature of plate is taken average of the temperature sensors placed at nine locations

$$T_p = \frac{T_1 + T_2 + T_3 + T_4 + T_5 + T_6 + T_7 + T_8 + T_9}{9}$$

Nusselt number of finned plate is determined by the given formula

$$Nu_r = (h \times D_h)/k$$

Friction factor for finned plate is calculated by the given equation

$$f_r = D_h \times \Delta p/(2 \times L \times V^2 \times \rho)$$

To calculate the temperature of fluid, generally average of inlet and exit temperature of fluid is taken as given below-

$$T_f = \frac{T_i + T_o}{2}$$

III. DESCRIPTION OF EXPERIMENTAL SETUP

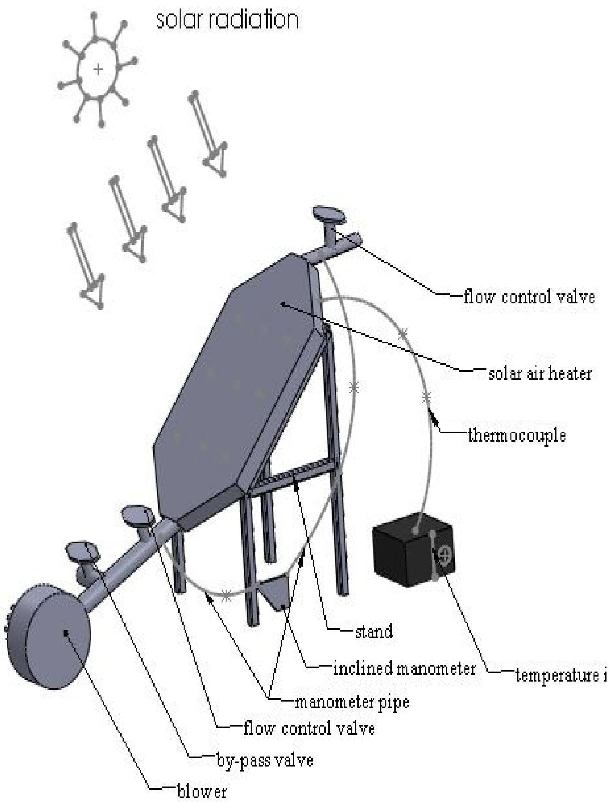

Fig1a. A schematic diagram of the experimental setup

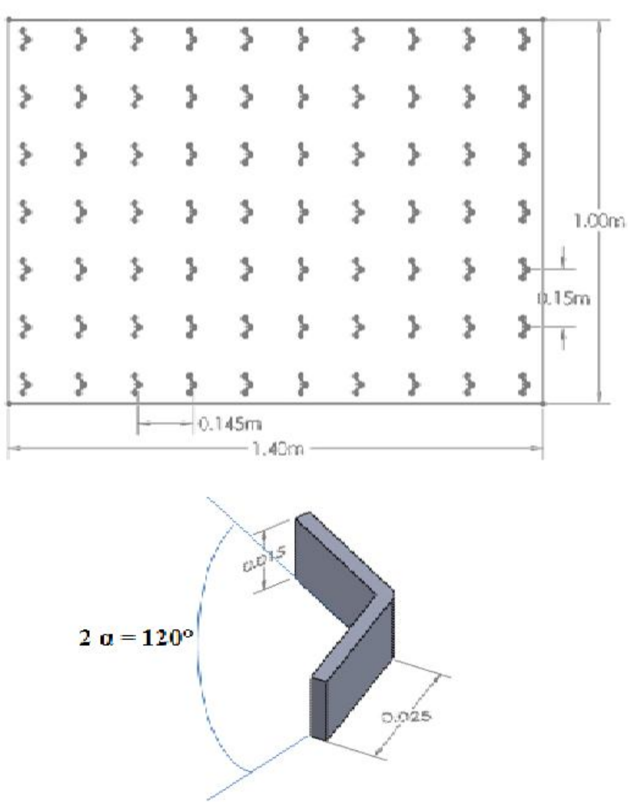

Fig1b.A schematic diagram of plate and fin specification

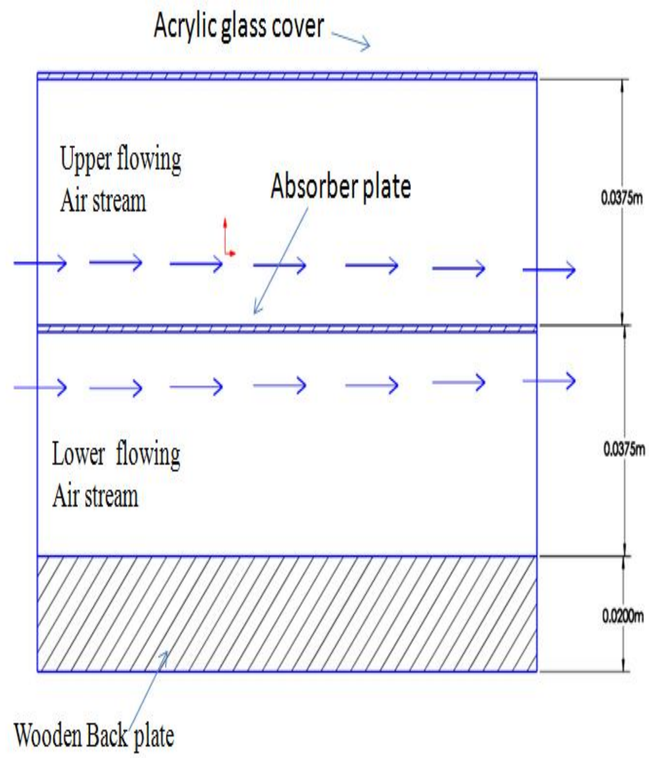

Fig2. A schematic diagram of the double pass flat plate Solar air heater

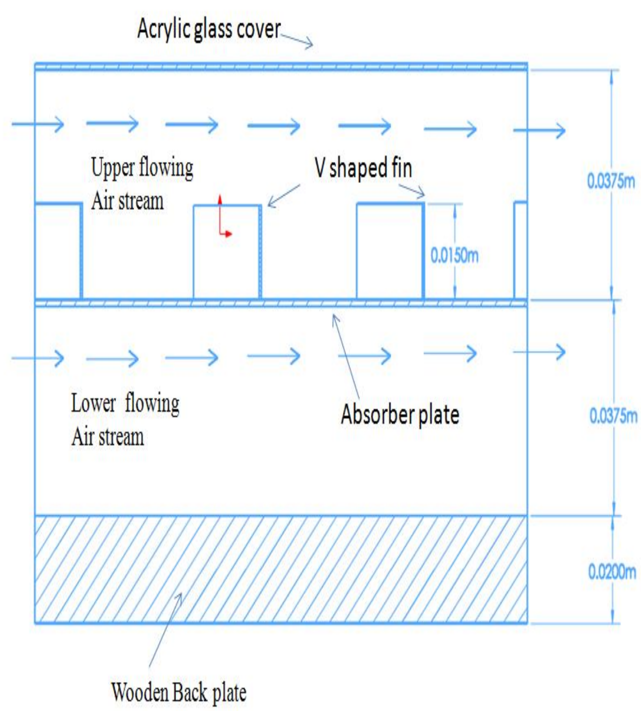

Fig3. A schematic diagram of the plate with v-shaped fins solar air heater

A schematic view of the experimental setup has been shown in the **fig1a**. Inclined setup is supported by a firm stand. The rectangular duct ends at both sides in taper form.

Electric power supply is given to the motor which drives the blower. Blower sucks the atmospheric air and directs it to flow through the absorber plate. Solar radiation falls on the acrylic glass plate which transmits almost 90% of the radiation to the absorber plate. Flow control valve has been used for controlling the inlet air. In the schematic view of **fig1b,** geometry of fins has been shown. Total numbers of fins are 70 which are uniformly spaced. The pitch of fin is 15 cm and vertical distance between two fin is 14.5cm**.** Fin height is taken as 1.5cm and thickness is 0.5mm. All the fins are attached over the surface of absorber plate with the fast drying epoxy glue. The material of absorber plate is aluminium and its thickness is taken as 3mm whereas as its surface area is $1.4m^2$.

The photographs of two different absorber plates of the collectors and the view of the absorber plate in the collector box are shown in Fig.2 and fig.3. In this study, two modes of the absorber plates were used. The absorbers plate was made up of aluminium sheet with black paint coating. The plate thickness of two collectors was 3 mm. The upper cover, the acrylic glass of 3 mm thickness, was used as glazing. Single transparent cover was used for two collectors. Thermal losses through the collector backs were mainly due to the conduction across the insulation (thickness 2 cm), and those caused by the wind and the thermal radiation of the insulation were assumed negligible. Nine thermocouples were positioned evenly, on the top surface of the absorber plates, at identical positions along the direction of flow, for both collectors. Inlet and outlet air temperatures were measured by two well insulated thermocouples. The output from the thermocouples was recorded in degrees Celsius by using 8 channel temperature indicator of resolution, 1°C. The pressure was measured by inclined manometer. For measuring the pressure, inlet and exit of the solar air heater was connected to the manometer with suitable piping. The ambient temperature was recorded by placing the probe of a pt-100 thermocouple in a enclosed area in the open atmosphere. The setup was placed in north-south direction. The measured variables were recorded at intervals of one hour and include inlet and outlet temperatures of the working fluid circulating through the collectors, ambient temperature, absorber plate temperatures at several selected locations. All tests began at 11:30 AM and ended at 4:30 PM.

Table 1a.Experimental data for plate using fins (α=60°) corresponding to the mass flow rate 0.025 kg/sec on 24th April 2015 for Re=35000

	Temp(°C)													pressure diff
Time	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	Tamb	ΔP(mm)
11:30	41.6	64.7	58.8	71.5	77.7	78	80.8	77.8	83.7	85.1	63.8	66.9	36.2	4
12:30	41.7	68.1	60.8	73.7	83.2	82.5	84.9	84.3	84.1	90.7	67.6	70.7	36.3	
1:30	42.8	69.3	61.4	73.9	85.1	83.7	85.7	87.7	91.7	92.9	69.9	72.6	36.7	
2:30	42.7	68.1	60.5	71.7	83.7	82	83.2	86.9	90.6	91.1	70.2	72.1	35.8	
3:30	42.2	62	55.5	63.9	75.1	73.1	72.7	78.3	81.9	80.5	64.3	66.1	35.6	
4:30	40.2	54.4	49.5	55.7	65.4	62.9	61.6	68	71.3	68.5	56.5	57.6	34.5	

Table1b.Experimental data for flat plate corresponding to the mass flow rate 0.025 kg/sec on 16th May 2015 for Re=35000

	Temperature													pressure diff
Time	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	Tamb	ΔP(mm)
11:00														
11:30	40.3	67.1	62.4	69.5	80.9	80.4	82	77.5	81.5	82.7	63	63.5	40.5	2
12:00														
12:30	43.2	70.4	65	72.7	86.3	84.2	86	84.4	87.9	87.6	68	67.4	39.3	
1:00														
1:30	44.3	70.9	65.9	72.4	87.6	85.2	86	87.3	91	89.7	70	70	41	
2:00														
2:30	44.7	69	63.9	69.5	83.5	80.6	80	83.7	86	86	68	67	42.5	
3:00														
3:30	41.3	62.4	59	62.6	76.1	73.6	72	77.6	81.1	78.9	62	62	38.9	
4:00														
4:30	38.7	53	51.8	53	63.1	61.3	60	65.6	69.5	66.6	54	54.2	38.3	

Table2a.Experimental data for plate using fins (α=60°) corresponding to the mass flow rate 0.025 kg/sec on 24th April 2015 for Re=35000

Tp (°c)	Tf (°c)	ΔT(°c)	ΔTf(°c)	Q(watt)	h($wm^{-2}k^{-1}$)	Nur	Fr
75.34	54.25	25.3	21.09	648.45	21.96	117.81	0.007092
79.14	56.2	29	22.94	743.29	23.14	124.15	
81.27	57.7	29.8	23.57	763.79	23.15	124.21	
79.76	57.4	29.4	22.36	753.54	24.08	129.18	
71.44	54.15	23.9	17.29	612.57	25.30	135.74	
61.92	48.9	17.4	13.02	445.97	24.46	131.25	

Table2b.Experimental data for flat plate corresponding to the mass flow rate 0.025 kg/sec on 24th April 2015 for Re=35000

Tp (°c)	T_f(°c)	ΔT_f(°c)	ΔT (°c)	Q (watt)	h ($wm^{-2}k^{-1}$)	Nus	Fs
76	51.9	24.1	23.2	603.09	17.87	95.90	0.003558
80.49	55.3	25.19	24.2	629.09	17.84	95.71	
81.77	57.15	24.62	25.7	668.08	19.39	104.01	
78.07	55.85	22.22	22.3	579.70	18.64	100.00	
71.51	51.65	19.861	20.7	538.10	19.35	103.83	
60.4	46.45	13.95	15.5	402.93	20.63	110.69	

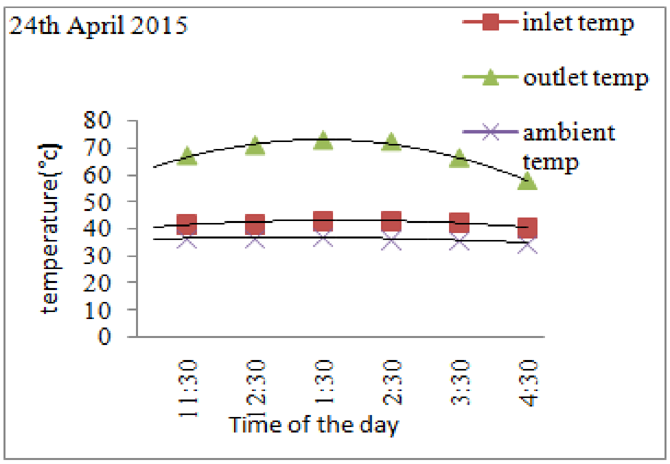

Fig.4a Temperature versus different standard local time during days for double pass solar air heater of the flow rate at 0.025kg/sec, corresponding to the outlet, inlet and ambient temperature of a solar collector with using fins.

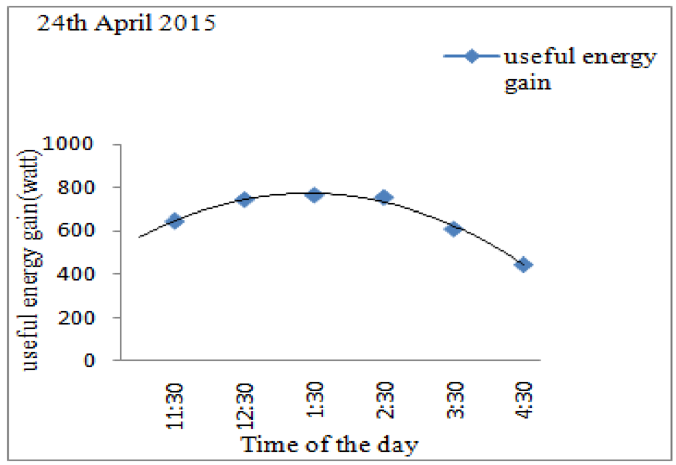

Fig.5a.Useful heat gain versus different standard local time during days for double pass solar air heater of the flow rate at 0.025kg/sec,for a plate using fins solar collector.

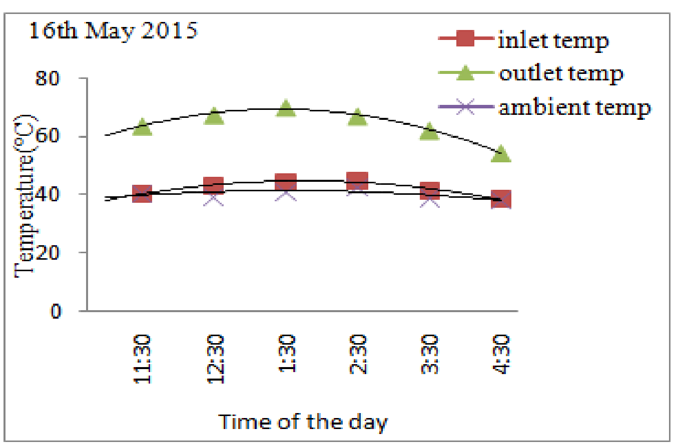

Fig.4b Temperature versus different standard local time during days for double pass solar air heater of the flow rate at 0.025kg/sec, corresponding to the outlet, inlet and ambient temperature of flat plate solar collector.

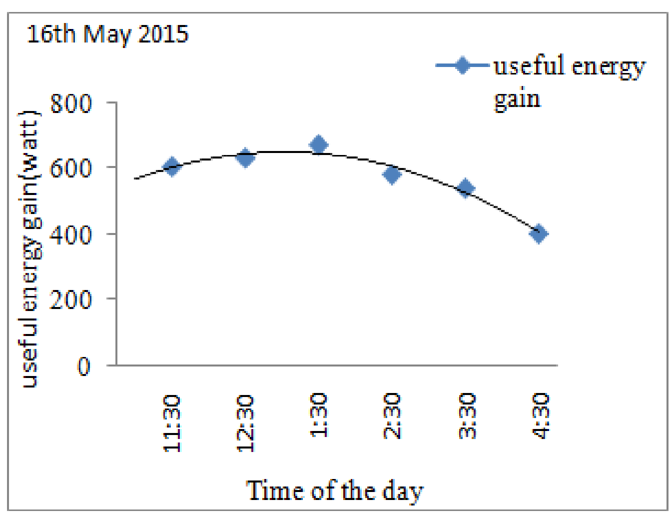

Fig5b.Useful heat gain versus different standard local time during days for double pass solar air heater of the flow rate at 0.025kg/sec, for a flat plate solar collector.

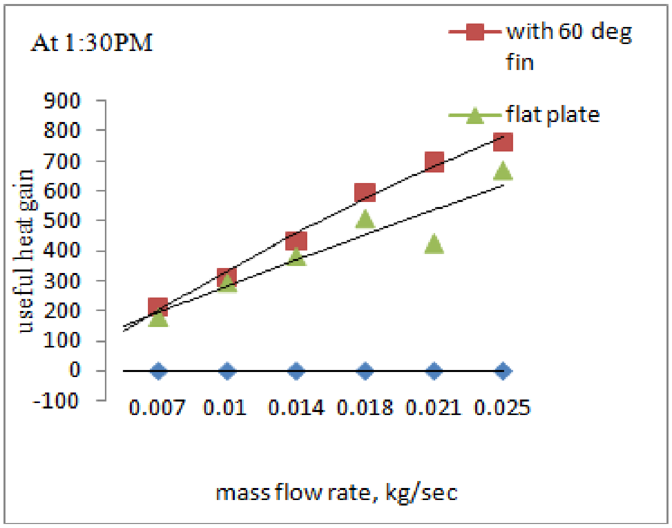

Fig.5c.Useful heat gain versus different standard local time during days for double pass solar air heater of the flow rate at 0.025kg/sec, for a flat plate solar collector and plate using fins.

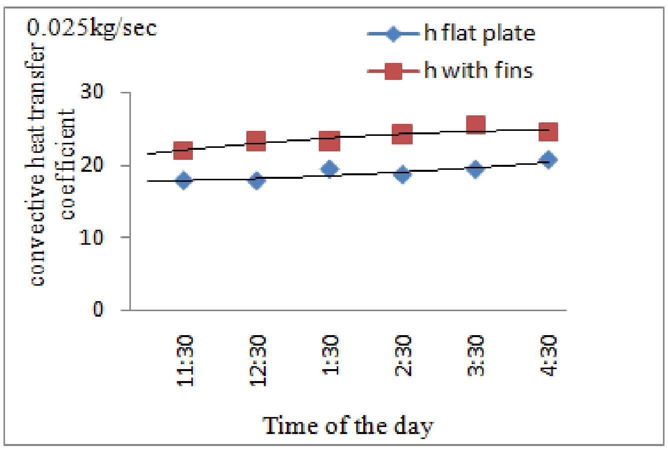

Fig 6 Convective heat transfer coefficient versus different standard local time during days for double pass solar air heater of the flow rate at 0.025kg/sec, for a flat plate solar collector and plate using fins.

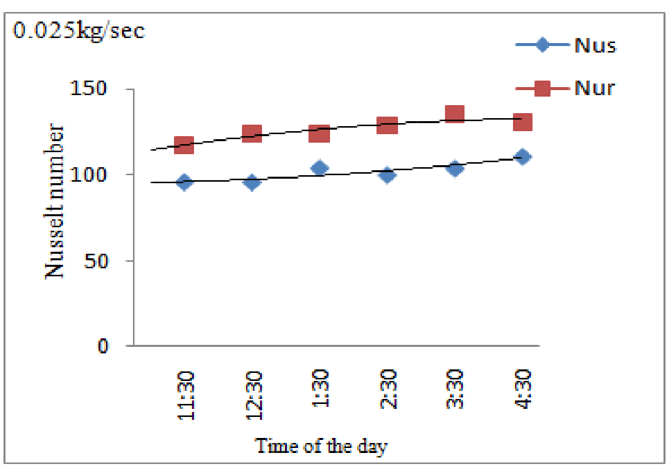

Fig7.Comparison of Nusselt number for flat plate and plate using fins for same mass flow rate with respect to different standard local time

IV. DISCUSSIONS

In the present investigation, thermal analysis of solar absorber plate has been discussed. **Fig.4a** and **Fig.4b** shows temperature versus different standard local time during days for double pass solar air heater of the flow rate at 0.025kg/sec, corresponding to the outlet, inlet and ambient temperature of flat plate solar collector and plate using fins. There is very less difference in ambient and inlet temperature but outlet temperature is appreciably high. The outlet fluid temperature is 70°c in flat plate and 72.6°c in plate using fins. **Fig.5a** and **fig.5b**.shows useful heat gain versus different standard local time during days for double pass solar air heater of the flow rate at 0.025kg/sec, for flat plate and using fins. The useful heat gain is 23.07% higher and highest value of heat gain is obtained at 1:30PM. Fig.5c shows the variation of useful heat gain with respect to mass flow rate. The useful thermal energy of both plate increases with increasing the mass flow rate (0.007 kg/sec to 0.025kg/sec) assuming solar intensity constant and maximum at 1:30PM for the same location. **Fig7**.Shows Comparison of Nusselt number for flat plate and plate using fins for same mass flow rate with respect to different standard local time. Nusselt number for plate using fins is found higher; at the same time friction factor is also substantially higher indicating the obstruction created during the flow.

V. CONCLUSION

The present study aims to review designs and analyze thermal energy gain of solar air heater. This experimental study compared a solar collector without using fins and with using fins attached at the surface of absorber plate. The thermal energy gain of the solar air collectors depends significantly on the solar radiation, mass flow rate, and surface geometry of the collectors. Thermal energy gain of the collector improves with increasing the day time at mass flow rate of 0.025kg/sec. it is found that maximum thermal energy gain is at 1:30PM.It again starts decreasing with decrease in the solar radiation as well as day time. The highest thermal energy gain and air temperature rise were achieved by the finned collector whereas the lowest values were obtained from the collector without using fins i.e.; (flat plate)

- The useful thermal energy gain for plate using fins is 23.07% higher than flat plate.
- The convective heat transfer coefficient of air for plate using fins is also 23.5% higher than the flat plate.
- The useful thermal energy of both plate increases with increasing the mass flow rate (0.007kg/sec to 0.025kg/sec) assuming solar intensity constant and maximum at 1:30PM for the same location.

- Nusselt number for plate using fins is found higher; at the same time friction factor is also substantially higher indicating the obstruction created during the flow.
- Inlet temperature is slightly higher (3 to 5°c) than ambient temperature. Maximum elevation in outlet fluid temperature is 29.8°c for plate using fins and 25.8°c for flat plate.

NOMENCLATURE

A_c= Area of collector plate (m^2)
Q= Useful thermal energy gain (watt)
T_p= Average temperature of plate (°c)
T_f= Average temperature of fluid (°c)
T_o= Outlet fluid temperature
T_i= Inlet fluid temperature
C_p= Specific heat of air at constant pressure (J/kg/k)
D_h= Hydraulic diameter of duct (m)
L= Length of collector plate (m)
V= Velocity of air (m/sec)
ρ= density of air (kg/m^3)
m= Mass flow rate of air (kg/sec)
K= Thermal conductivity of air (W/mk)
Nus= Nusselt number of flat plate
Nur= Nusselt number of plate using fins
Fs= Friction factor of flat plate
Fr= Friction factor of plate using fins

REFERENCES

[1] K. Mohammadi and M. Sabzpooshani, "Comprehensive performance evaluation and parametric studies of single pass solar air heater with fins and baffles attached over the absorber plate".

[2] A.-M. E. Momin, J. Saini and S. Solanki, "Heat transfer and friction in solar air heater duct withV-shaped rib roughness on absorber plate," International Journal of Heat and Mass Transfer 45 (2002) 3383–3396.

[3] F. Chabane, N. Moummi and S. Benramache, "Experimental study of heat transfer and thermal performance with longitudinal fins of solar air," Journal of Advanced Research (2014) 5, 183–192.

[4] A. Hematian, YahyaAjabshirchi and A. A. Bakhtiari, "Experimental analysis of flat plate solar air collector efficiency," Indian Journal of Science and Technology Vol. 5 No.8 (August 2012) ISSN: 0974- 6846.

[5] S. Vyas and D. S. Punjabi, "THERMAL PERFORMANCE TESTING OF A FLAT PLATE SOLAR AIR HEATER USING OPTICAL MEASUREMENT TECHNIQUE," International Journal of Recent advances in Mechanical Engineering (IJMECH) Vol.3, No.4, November 2014.

[6] A. K. Singh, P. K. Sharma and H. Sharma, "Experimental Analysis on Solar Air Dryer," International Journal of Engineering, Management & Sciences (IJEMS)ISSN: 2348 –3733, Volume-1, Issue-12, December 2014.

[7] A. Lanjewar, J. Bhagoria and R. Sarviya, "Heat transfer and friction in solar air heater duct with W-shaped rib roughness on absorber plate," Energy 36 (2011) 4531-4541.

[8] A. Kumar, R.P.Saini and J.S.Saini, "A review of thermohydraulic performance of artificially roughened solar air heaters," Renewable and Sustainable Energy Reviews 37(2014)100–122.