Experimental Analysis of Heat Transfer and Losses in Solar Absorber Plate

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Abstract- *In the present work, An experimental analysis has been done to investigate and compare the average heat gain and heat losses of flat plate and plate with v-shaped fins (α=60º,45°,30°) 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 more than the flat plate at the particular day and time. Heat losses occurs through the solar air heater and and it is found that at lower Reynolds number (10000,15000,20000) losses are high and at higher Reynolds number losses are comparatively less. Flat plate shows very less variation in losses for all Reynolds number.*

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=Dh) 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. 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 2×1m2 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/Dh) 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]

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]

〖η_th=Q_ /IA〗_p

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)

Loss coefficient

The electrical analogy of loss coefficients are given in which following following abbreviations are used:

Ta= ambient temperature

Tpm = mean plate temperature

Rs = (1/UsAp) =side thermal resistance

Rt = (1/UtAp) = top thermal resistance

Rb = (1/UbAp) = bottom thermal resistance

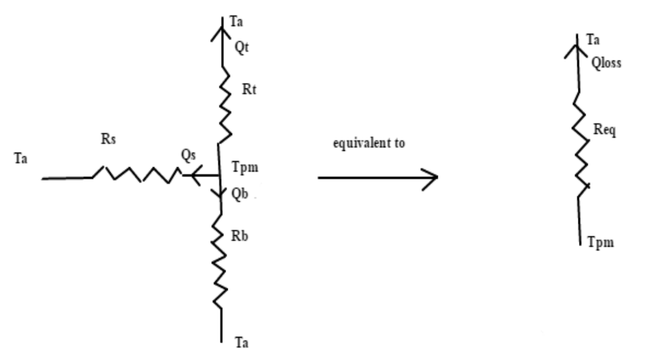
R eq = (1/U/Ap) = equivalent thermal resistance

Qs = side heat loss

Qt = top heat loss

Q b= bottom heat loss

Q loss= overall heat loss



Klein has developed the following convenient empirical equation for calculating the top loss coefficient.

$$U_t = \left[\frac{M}{\left(\frac{C}{T_{pm}}\right)\left(\frac{T_{pm}-T_a}{M+f}\right)^{0.33}} + \frac{1}{h_w}\right]^{-1} + \left[\frac{\sigma\left(T_{pm}^{\ 2}+T_a^{\ 2}\right)\left(T_{pm}+T_a\right)}{\frac{1}{\varepsilon_p + 0.05M\left(1-\varepsilon_p\right)} + \frac{(2M+f-1)}{\varepsilon_c} - M}\right]$$

Where f= coefficient related to wind heat transfer coefficient

f=(1-0.04h_w+0.0005h_w^2)(1+0.091M)

C- Coefficient related to collector tilt angle

C=365.9(1-0.00883β+0.0001298β^2)

Where β -Collector tilt angle in degree

M - Number of glass cover

h_w= Convective heat transfer coefficient of air

The above formula for top loss coefficient is used because it satisfies the following experimental criteria.

$320K \le T_{pm} \le 420K$

$0.1 \le \varepsilon_p \le 0.95$

$0 \le V_\infty \le 10m/s$

$1 \le M \le 3$

$0 \le \beta \le 90^\circ$

Bottom loss coefficient

$$U_b = \frac{K}{X}$$

Where

K= thermal conductivity of the wooden material

X= thickness of the wooden material

Heat transfer coefficient at the top cover

The convective heat transfer coefficient (h w) at the top of cover is often referred to as the wind heat transfer coefficient. It is generally calculated from following empirical correlation suggested by McAdams

h_w=5.7+3.8V_∞

Where V_∞ = wind speed in m/s

Description of experimental setup

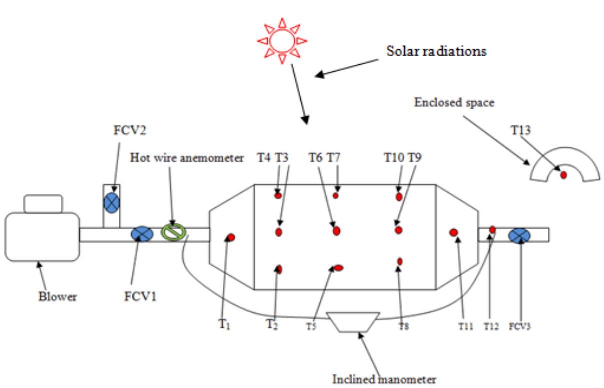
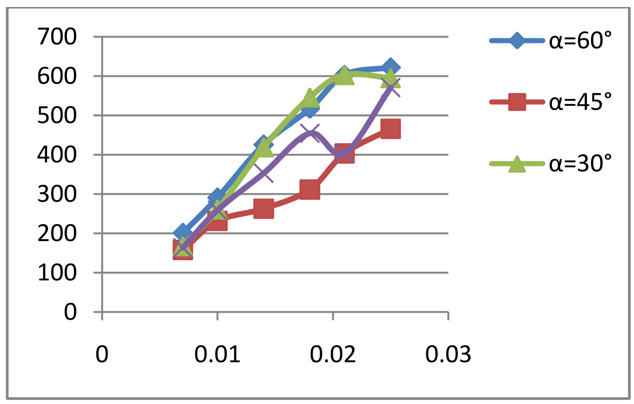


Fig 1 . A schematic diagram of the experimental setup

The whole fabrication and experimentation work was conducted in the Indira College of Engineering and Management, Pune. It is located at latitude 18.5204°N, 73.8567°E. A schematic view of the experimental setup has been shown in the above figure. Inclined setup is supported by a firm stand. The inclination angle is kept at 35° to the horizontal for appropriate result. The rectangular duct ends at both sides in taper form. Electric power supply is given to the motor which drives the blower. The motor used is 0.5HP, 1425RPM, 220V. 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. Total numbers of fins are 70 which are uniformly spaced. The pitch of fin (P) is 15 cm and vertical distance between two fins is 14.5cm. Fin height (e) is taken as 1.5cm and thickness (t) is 0.5mm. Pitch to roughness ratio (P/e) is fixed as 10. All the fins are attached over the surface of absorber plate with the fast drying epoxy glue. The material of absorber plate is aluminum and its thickness is taken as 3mm whereas as its surface area is 1.4 m2



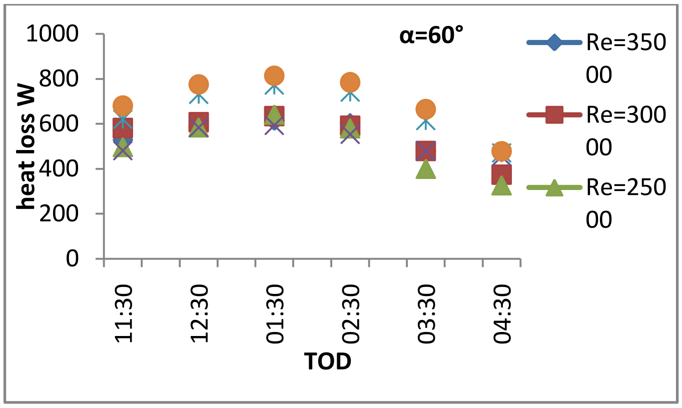
Graph1: Average heat gain Vs mass flow rate

Average heat gain with respect to mass flow rate is graphically represented below and it is found that there is linear relationship between mass flow rate and average useful heat gain. It means average useful heat gain increases on increasing the mass flow rate of air. But at higher mass flow rate slope of increment is low. 60° plate shows highest average heat gain followed by 30°, flat plate and 45°. The poor result of 45° plate was only due to cloudy and rainy experimental conditions.

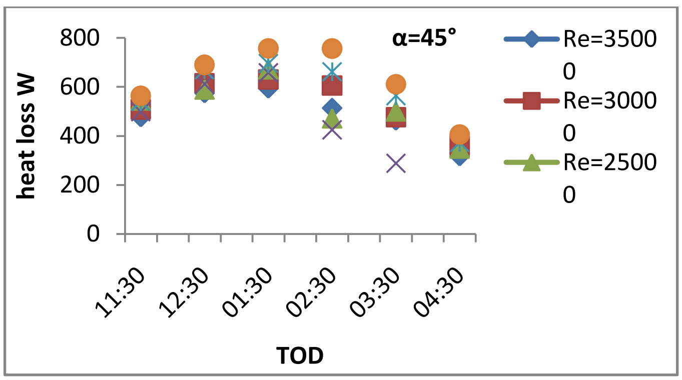
The highest average heat gain for 60° plate is 621.27W followed by 594 W for 30° plate and 570W for flat plate

Heat loss with respect to Time of the day

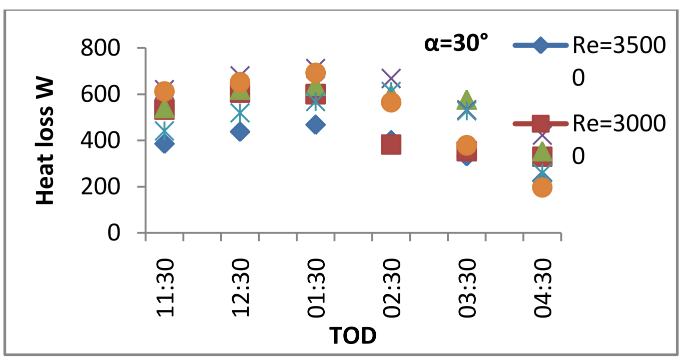
The below given graphs represent the variations of heat losses through the solar air heater for different plate angle.



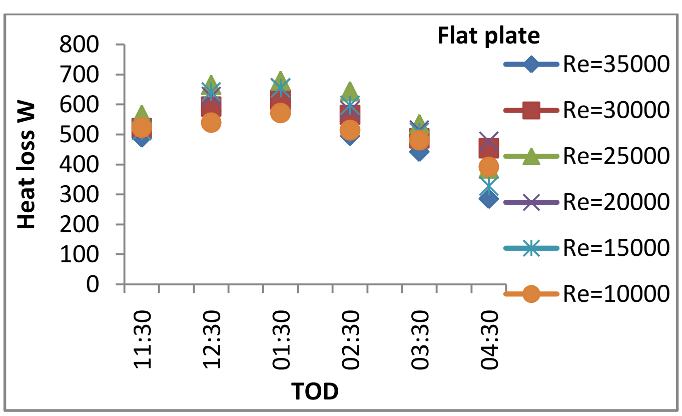
Graph2: Heat loss Vs TOD



Graph3: Heat loss Vs TOD



Graph4: Heat loss Vs TOD



Graph5: Heat loss Vs TOD

To minimize the heat loss from the solar air heater is a bigger challenge. A lot of researcher is working on finding suitable insulating material. But some of the natural factor like wind velocity, solar intensity humidity and dust particles which remains unavoidable during the experimentations. Summary of losses are given for different angle of plate and for different Reynolds number.

CONCLUSION

1. It is found that there is linear relationship between mass flow rate and average useful heat gain. It means average useful heat gain increases on increasing the mass flow rate of air. But at higher mass flow rate slope of increment is low. 60° plate shows highest average heat gain followed by 30°, flat plate and 45°. The poor result of 45° plate was only due to cloudy and rainy experimental conditions.

2. The highest average heat gain for 60° plate is 621.27W followed by 594 W for 30° plate and 570W for flat plate.

3. It is seen that heat losses at lower Reynolds number (10000, 15000) is higher in comparison to higher Reynolds number (20000, 25000, 30000 and 35000). It is also observed that heat losses for flat plate at different Reynolds number are comparatively close.

4. **Nomenclature**

A_p= 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)

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