PERFORMANCE STUDY OF A SOLAR AIR HEATER

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ABSTRACT

In the present work an attempt has been made to experimentally investigate the performance of a flat plate solar air heater. Experiments were performed to find the energy and exergy efficiency at different mass flow rate of air. It is observed that for a 16% increase in mass flow rate of air, energy efficiency increases by 20%, whereas exergy efficiency increases by 36%.

INTRODUCTION

Solar air heater is widely used because it is simple in design, and easy to fabricate, easy to maintain and it required cheap material for construction. The main problem with these systems is low rate of heat transfer from absorber plate to flowing air. Researchers have attempted to improve the performance of solar air heater by focusing intensive studies on design and operating parameter. Many researchers [1-4] have attempted to increase heat transfer rate from absorber plate to flowing air by adding fins on absorber plate. Several studies [5-10] have been done by providing the roughness on absorbing plate. Some researchers [11-14] have used packed bed material where as in several different studies corrugated surface mainly V corrugated, cross corrugated have been used. Many researchers [15-19] have used recycle of flowing air with different duct. Owning to increase frictional losses higher pump work is required which puts further restriction on increasing surface roughness to improve heat transfer rate from absorber plate to flowing air.

In order to balance the quality of energy gain and friction losses the exergy analysis is done. The exergy analysis has proven to more powerful tool to design and optimize the performance of energy system [20]. In the present work an attempt has been made to perform energy and exergy analysis of solar air heater at different mass flow rate of air.

EXPERIMENTAL SETUP

A solar air heater was constructed of galvanized iron absorber plate of size 1.2 m and cover plate of glass of thickness 5 mm. absorber plate is painted black to absorb solar radiation. Absorber plate is properly insulated to reduce heat losses. As shown in photograph.

Experiments were conducted in the solar energy laboratory of SHIATS Allahabad, ($25^0$28'N, $81^0$54'E) UP, India in the month of May. A fan is used to force the air in the system. The flow rate is controlled by fan regulator. Solar intensity is measured by solarimeter (SURYAMAPI). Wind velocity is measured by anemometer. The temperature at the different points of the system is measured by J-type thermocouple.

Fig. 1 shows the photograph of the experimental setup

THEORETICAL ANALYSIS

Energy Analysis

The theoretical model employed for the study of the solar collector that operates in unsteady state is made using a thermal energy balance [20]:

[Accumulated energy] + [Energy gain] = [Absorbed energy] + [Lost energy] (1)

For each term of Eq. (1) the following expressions are formulated:

[Accumulated energy] = $M_pC_p\,(dT_{p,ave}/dt)$, (2)

[Energy gain] = $\dot{m}C_p\,(T_{out} - T_{in})$, (3)

[Absorbed energy]= $\eta_o IAc$, (4)

[Lost energy] = $U_C\,(T_{p,ave} - T_e)\,IAc$ (5)

By combining Eqs. (2)– (5), the thermal energy balance equation necessary to describe the solar collector functioning is obtained:

$$M_pC_p\,(dT_{p,ave}/dt)+ \dot{m}C_p(T_{out} - T_{in})= \eta_o IA_c +U_C\,(T_{p,ave} - T_e)IA_c \quad (6)$$

The optical yield (η_o) and the energy lose coefficient (U_C) are the parameters that characterize the behaviour of the solar collector. Note that η represents the fraction of the solar radiation absorbed by the plate and depends mainly on transmittance of the transparent covers and on the absorbance of the plate [20].

The energy loss coefficient includes the losses by the upper cover, the laterals, and the bottom of the collector. The upper cover losses prevail over the others, depending to a large extent on the temperature and emissivity of the absorbent bed, and besides, on the convective effect of the wind on the upper cover. The thermal efficiency of the solar collectors (η) is defined as the ratio between the energy gain and the solar radiation incident on the collector plane:

$$\eta = \dot{m}C_p(T_{out} - T_{in})/IA_c \quad (7)$$

Exergy Analysis

The mass balance equation can be expressed in the rate form as

$$\sum\dot{m}_{in} = \sum\dot{m}_{out} \quad (8)$$

Where ṁ is the mass flow rate, and the subscript in stands for inlet and out for outlet. If the effects due to the kinetic and potential energy changes are neglected, the general energy and exergy balances can be expressed in rate form as given below

$$\sum\dot{E}_{in} = \sum\dot{E}_{out} \quad (9)$$

$$\sum\dot{E}x_{in} - \sum\dot{E}x_{out} = \sum\dot{E}x_{dest} \quad (10a)$$

Or

$$\dot{E}x_{heat} - \dot{E}x_{work} + \dot{E}x_{mass,in} - \dot{E}x_{mass,out} = \dot{E}x_{dest} \quad (10b)$$

Using equation the rate form of the general exergy balance can be expressed as follow:

$$\sum\left(1 - \frac{T_e}{T_s}\right)Q_s - W + \sum\dot{m}_{in}\psi_{in} - \sum\dot{m}_{out}\psi_{out} = \dot{E}x_{dest} \quad (11)$$

Where,

$$\psi_{in} = (h_{in} - h_e) - T_e(s_{in} - s_e) \quad (12)$$

$$\psi_{out} = (h_{out} - h_e) - T_e(s_{out} - s_e) \quad (13)$$

Equation (12) and (13) are substituted in equation (14), it is arranged as below:

$$\left(1 - \frac{T_e}{T_s}\right)Q_s - \dot{m}[(h_{out} - h_{in}) - T_e(s_{out} - s_{in})] = \dot{E}x_{dest} \quad (14)$$

Where Qs is solar energy absorbed by the collector absorber surface and it is evaluated with the expression given below:

$$Q_s = I(\tau\alpha)A_c \quad (15)$$

The changes in enthalpy and entropy of the air at collector are expressed by:

$$\Delta h = h_{out} - h_{in} = C_p\left(T_{f,out} - T_{f,in}\right) \quad (16)$$

$$\Delta s = s_{out} - s_{in} = c_p \ln\frac{T_{f,out}}{T_{f,in}} \quad (17)$$

By substituting equations (15)-(17) onto equation (18) the equation below can be derived

$$\left(1-\frac{T_e}{T_s}\right)I(\tau\alpha)A_c - \dot{m}C_p(T_{out}-T_{in}) + \dot{m}C_pT_e ln\frac{T_{f,out}}{T_{f,in}} = \dot{E}x_{dest} \quad (18)$$

The exergy destruction or irreversibility may be expressed as follows:

$$\dot{E}x_{dest} = T_e S_{gen} \quad (19)$$

The exergy analysis efficiency of a solar collector system can be calculated in terms of the net output exergy of the system or exergy destructions in the system. Exergy efficiency of SAH system has been evaluated in terms of the net output exergy of the system.

The second law efficiency is calculated as follows:

$$\eta_{\|} = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} = \frac{\dot{m}[(h_{out}-h_{in})-T_e(s_{out}-s_{in})]}{\left(1-\frac{T_e}{T_s}\right)Q_s} \quad (20)$$

RESULTS AND DISCUSSIONS

Fig. 2 shows variation in solar intensity for different days when mass flow rate of air taken as 0.036, 0.039 and 0.042 kg/s.Fig.3 shows the variation in wind speed for these days.

Fig.4 shows variation of temperature difference of air from outlet to inlet. This is high for higher value of mass flow rate. Fig. 5 shows variation in energy efficiency at different mass flow rate. The daily energy efficiency of 46.65% is obtained with lower mass flow rate 0.036 kg/s. When mass flow rate increases to 0.039 kg/s energy efficiency is 51.35%, maximum of 56% daily efficiency is obtained with mass flow rate of 0.042 kg/s. A maximum instantaneous efficiency of 91% is obtained with 0.042 kg/s for lower solar intensity I (t). The effect of mass flow rate is minimized at low solar intensity. Fig.6 shows the exergy efficiency at different mass flow rate. Daily exergy efficiency of 1.2% is obtained with mass flow rate 0.036 kg/s. With 0.039 kg/s exergy efficiency is 1.4085%. Maximum daily exergy efficiency of 1.46 % is obtained with maximum mass flow rate of 0.042 kg/s. Maximum instantaneous exergy efficiency of 3.48 % is obtained at a mass flow rate of 0.042 kg/s.

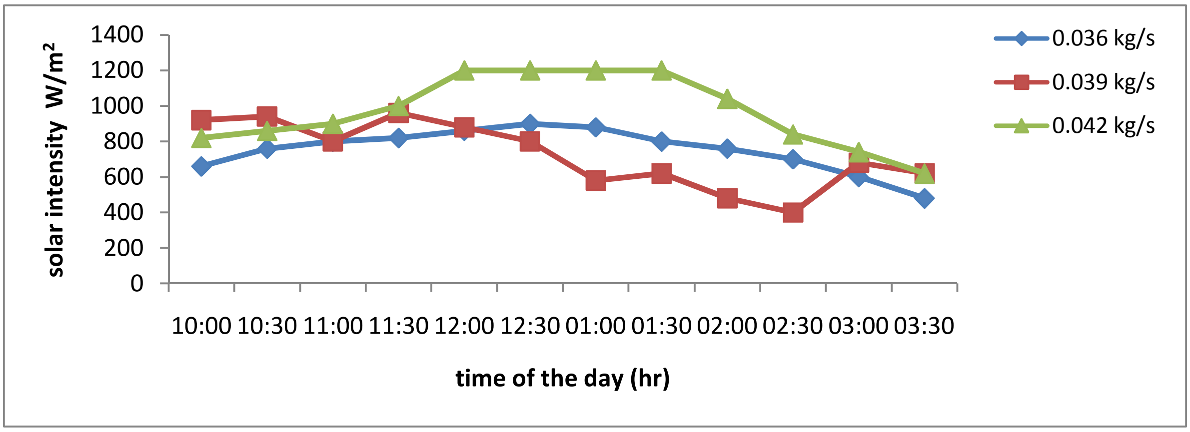

Figure 2. Variation of solar intensity with time of the day at different mass flow rate

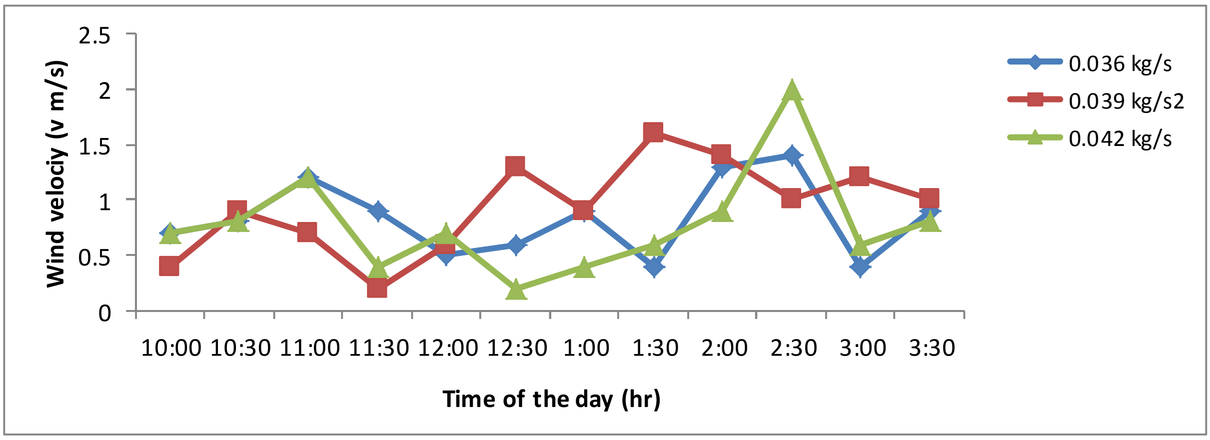

Figure 3. Variation of wind velocity with time of the day at different mass flow rate

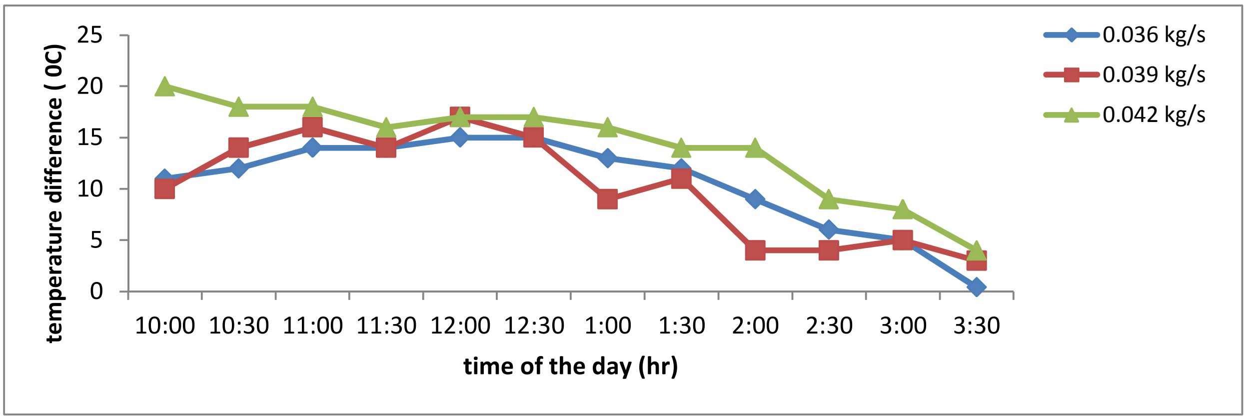

Figure 4. Variation of temperature difference between inlet and outlet with time of the day at different mass flow rate.

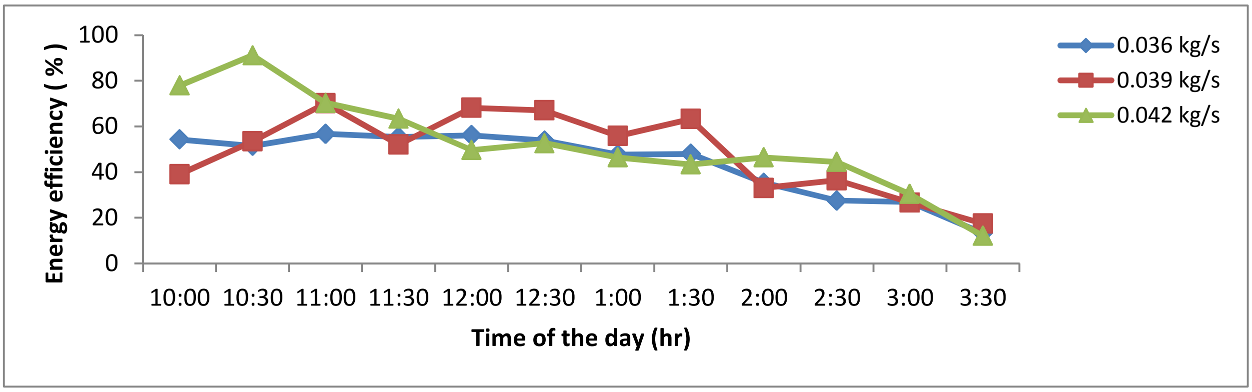

Figure 5. Variation of energy efficiency with time of the day at different mass flow rate

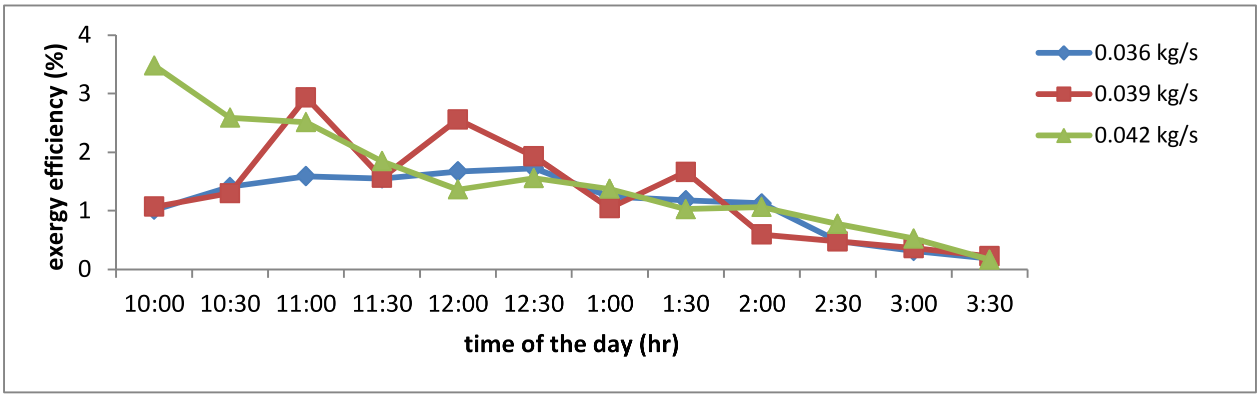

Figure 6. Variation of exergy efficiency with time of the day at different mass flow rate

CONCLUSION

In the present work experiments were conducted on a solar air heater to find the effect of mass flow rate of air on energy and exergy efficiency. The measured parameters were solar intensity, wind speed, inlet outlet temperature of air, absorbing plate temperature and ambient temperature. Daily energy efficiency of solar air heater is increased with increasing mass flow rate of air. Maximum energy efficiency of 56 % was obtained at mass flow rate of 0.042 kg/s. Compared with daily energy efficiency, daily exergy efficiency value is very low. Exergy efficiency increases from 1.21% to 1.67% for increasing mass flow rate from 0.036 to 0.042 kg/s.

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