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Experimental Analysis on Thermal Performance of a Solar Air Heater at Different Angular Positions

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Heat transfer enhancement and hence performance of solar air heaters can be improved by absorbing maximum amount of solar insolation. Absorption rate in solar air heater is increased when it is oriented all the time in perpendicular direction to solar insolation. Hence inclination of solar air heater along with other geometrical and operating parameters plays an important role to decide its thermal performance. In the present work a double pass packed bed solar air heater is experimentally tested to know the effect of its inclination to solar insolation on its thermal performance. Experiments are conducted at different mass flow rate of air in the range of 0.038 to 0.0508 kg/sec and at different inclination of solar air heater in the range of 5^o to 25^o to the horizontal surface. It was found that efficiency of solar air heater is lower at 5^o and 10^o inclinations for all mass flow rates of air. Efficiency increased and reaches to its maximum value for 15^o and 20^o inclinations of the solar air heater and it decreases with further increase in inclination to 25^o at all mass flow rates of air.

***Keywords*:** Solar air heater, Heat transfer, Thermal performance, Convection

1. Introduction

Solar air heaters (SAHs) can be integrated with many industrial applications like preheaters in boiler furnaces, moisture removal from agricultural products, paper and pulp, space heating and cooling, supply process heat in sugar industries etc. Solar air heater is a heat exchanger which converts solar energy into heat and transfer the same to air passing over its absorber plate. Thermal performance of SAHs can be improved passively by providing artificial ribs on its absorber plate Rajaseenivasan et al. [1], Mahmood et al. [2], Lakshmi et al. [3], Varun et al. [4], Varshney and Saini [5], packed beds Mahmood et al. [2], Lakshmi et al. [3], Mittal and Varshney [6], Prasad and Saini [7], Mukesh et al. [8], Paisarn Naphon [9], Panna Lal et al. [10], Prashant Dhiman et al. [11], Prashant Verma et al. [12], Sopian et al. [13], Thakur et al. [14], Paul et al. [15], Chii-Dong Ho et al. [16] and attaching thermal storage units either with sensible or latent heat storage materials Lakshmi et al. [3], Hassan E. S. Fath [17], Aymen et al. [18], Salwa et al. [19], Pavel et al. [20], Sinem et al. [21], Ciril et al. [22]. Comprehensive review on performance analysis of SAHs with thermal energy storage units are given in Jose and Philip [23] and Kinga and Krzysztof [24].

It is found from the literature that studies on the effect of inclination of SAH on its thermal performance are limited. Hence in the present work experiments are conducted on SAH with different mass flow rates of air in a range of 0.038 kg/s to 0.0501 kg/s and at different inclinations of the solar air heater in a range of 5^o to 25^o towards solar insolation.

2. Experimental Setup and Procedure

A double pass packed bed SAH present at the roof top of Mechanical engineering department, GVP College of Engineering (A), Vizag is used to conduct the experiments. Experimental setup used in the present work is shown in Fig. 1. Dimensions of SAH are given in Table 1 and various

Fig. 1. Experimental setup

equipment used in experiment along with their specifications are given in Table 2. Experiments are conducted for twenty continuous days between 11 am to 1 pm every day. SAH is fixed at different inclinations in the range of 5^o to 25^o to the horizontal and variable speed blower is operated to supply air at different mass flow rates in the range of 0.038 kg/s to 0.0508 kg/s. On first day of the experiment SAH is fixed at 15^o inclination and blower is operated to supply air at a mass flow rate of 0.038 kg/s. Thermocouples are attached at various locations in the experimental setup and temperatures are observed at regular time interval between 11 am to 1 pm. Temperature of air at SAH inlet (T_1), packed bed (T_2, T_3), absorber plate (T_4, T_5), upper glass (T_6) and air at SAH exit (T_7) are manually recorded. Solar insolation (I) is measured with solar meter by placing it perpendicular to the upper glass. Experiment is repeated on 2nd, 3rd and 4th day of the experiment with same inclination of SAH and mass flow rate of air equal to 0.041 kg/s, 0.047 kg/s and 0.0508 kg/s respectively. After that experiments are repeated at 10^o, 15^o, 20^o and 25^o inclinations of SAH and at different mass flow rates of air in the range of 0.038 kg/s to 0.0508 kg/s.

2.1. Mathematical Modelling

Thermal efficiency of SAH (η) is defined as the ratio of useful amount of heat absorbed by air (Q_u) to total amount of radiation incident on SAH (Q_i). Average values of air temperature at SAH exit and inlet are used to find Q_u. Similarly average value of solar radiation incident within a time period between 11 am and 1 pm is used to calculate Q_i.

Table. 1. Dimensions of SAH

Part	Specification
Upper channel	120 cm×80 cm×10 cm
Aspect ratio	8 as per ASHRAE standards
Glass	Thickness 0.5 cm 9600 cm^2 surface area
Packed bed	3 cm thick Mild Steel chips
Absorber plate	GI sheet of 0.4 cm thickness
Insulation	2 cm thick polystyrene
Absorber coating	Black board paint

Table. 2. Equipment with specifications used for the experiment

Equipment	Specification
Air blower	Variable speed motor with 0.74 hp
Temperature indicator	Digiqual 12 channel
Thermocouples	J-type (10 in number)
Solar power meter	WACO TM-206 model

Expressions for Q_u and Q_i are given in Eq. (1) and Eq. (2).

$$Q_u = mC_p(T_7 - T_1) \tag{1}$$

$$Q_i = IA \tag{2}$$

$$\eta = \frac{Q_u}{Q_i} = \frac{mC_p(T_7 - T_1)}{IA} \tag{3}$$

In Eqs. (1) to (3), m is the mass flow rate of air in kg/s, C_p the specific heat of air in J/kgK and A is the collector surface area in m^2.

3. Results and Discussion

Values of Q_u, Q_i and η are calculated using Eqs. (1) to (3). At 15^o inclination of SAH and mass flow rate of air equal to 0.041 kg/s, variation of temperatures at various locations in SAH and solar intensity with time is shown in Fig. 2. As absorber plate is coated with black paint and placed almost perpendicular to the direction of insolation it absorbs maximum solar radiation and converts it into heat. As a result its temperature is higher compared to any location in the experimental setup. Out of total heat available at the absorber plate a fraction is transferred by convection to the air moving over its top and bottom surfaces, a fraction is lost by conduction through walls, a fraction is lost by convection to the lower glass and remaining is stored in the packed bed. Hence at any given instant of time temperatures of packed bed and glass are higher than air temperature at SAH inlet. Air absorbs heat from packed bed and absorber plate and leaves SAH at temperature higher than its value at SAH inlet but lower than the absorber plate temperature. Similar trends of temperatures with time are observed for other mass flow rates of air and inclinations of SAH. It is observed that solar intensity gradually increases between 11 am to 12 noon reaches to a maximum value at 12 noon and thereafter decreases up to 1 pm.

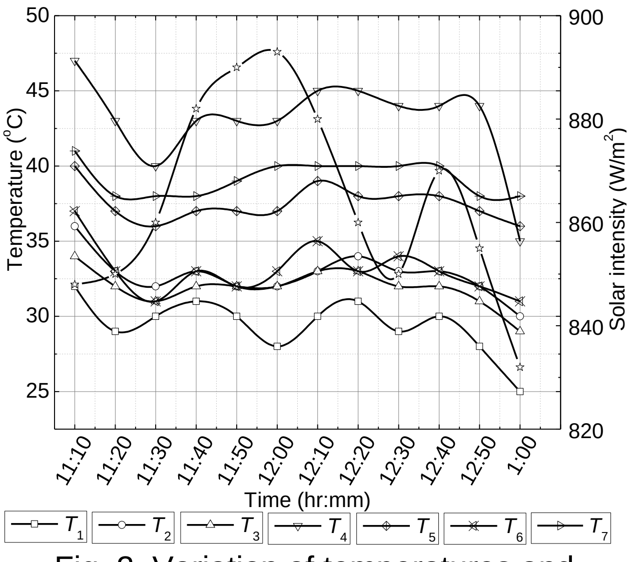

Fig. 2. Variation of temperatures and solar intensity with time

Average values of air temperature at SAH exit (T_7) are calculated from the observations and its variation with inclination of SAH for different mass flow rates of air is shown in Fig. 3. It is observed that T_7 is small at lower inclinations of SAH at all mass flow rates of air. It increases with increase in inclination of SAH and reaches maximum for inclinations in between 15^o to 20^o. Thereafter it decreases with increase in inclination of SAH for all mass flow rates of air.

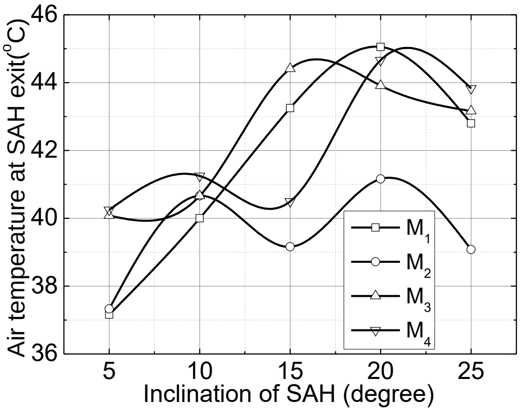

Fig. 3. Variation of air temperature at SAH exit with inclination of SAH

Efficiency of SAH is calculated with average values of air temperature at SAH inlet and exit and its variation with SAH inclination for different mass flowrates of air is shown in Fig. 4. It is observed that efficiency of SAH shows similar trends as air temperature at SAH exit with inclination of SAH at different mass flow rates of air. In Fig. 3 and Fig. 4 M_1, M_2, M_3 and M_4 corresponds to mass flow of air equal to 0.038 kg/s, 0.041 kg/s, 0.047 kg/s and 0.0508 kg/s respectively.

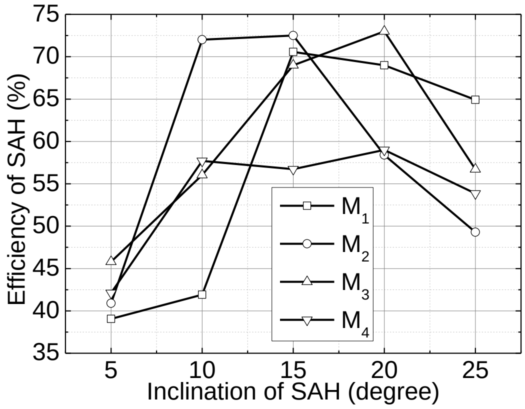

Fig. 4. Variation of efficiency of SAH with inclination of SAH

4. Conclusion

Experiments are conducted to know the effect of inclination of double pass packed bed Solar Air Heater (SAH) on its thermal performance at different values of mass flow rate of air. It is found that air temperature at SAH exit and efficiency of SAH are strong function of inclination of SAH. Efficiency and air exit temperature are lower for small inclination of SAH. They increase with increase in inclination and reaches maximum values when the inclination is in between 15^o and 20^o. Thereafter these values are observed to be decreasing with further increase in inclination of SAH.

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