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ORIGINAL ARTICLE

Experimental study on double pass solar air heater with thermal energy storage

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KEYWORDS

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Experimental analysis

Abstract A double pass solar air heater was fabricated and integrated with thermal storage system. Paraffin wax is used as a thermal storage medium. The performance of this heater was studied for different configurations. The solar heater integrated with thermal storage delivered comparatively high temperature. The efficiency of the air heater integrated with thermal storage was also higher than the air heater without thermal storage system. The study concluded that the presence of the thermal storage medium at the absorber plate is the best configuration.

1. Introduction

Energy crisis and global warming lead to find an alternative way to overcome the above worsening situation. Renewable energy plays a major solution and thereby meets our energy demand and reduces the CO_2 emission which reduces the greenhouse effect. In the renewable energy side, Sun is the mother for all sources and harnessing the solar energy in proper ways can eliminate the energy crisis of the world. To harness the solar energy, collectors are used and for low temperature application side flat plate collectors are used. In solar air heater, solar energy is collected by means of an absorbing plate and the collected heat energy is transferred to heat transferring medium such as air.

Number of researches is going on to improve the performance of the air heater by integrating flat plate collector with packed bed and energy storage systems. The packed bed with iron turnings (Cheema and Mannan, 1979), crushed glass (Collier, 1979), slit and expanded aluminium foils (El-Wakil et al., 1965; Shoemaker, 1961), wire mesh screens (Ahmad et al., 1996; Prasad and Saini, 1993; Sharma et al., 1991), hollow spheres (Swartman and Ogunlade, 1996), iron chips, aluminium chips and pebbles (Mishra and Sharma, 1981), and rings made of hard plastic (Demirel and Kunc, 1987) were used to increase the performance of the air heaters. Mittal and Varshney (2006) investigated the performance of the heater with wire mesh as packed bed and found that the thermal gain was relatively higher as compared to smooth collectors. El-Sebaii et al. (2007) investigated the double pass solar collector with iron packed bed and found that the efficiency of the system was 22–27% higher than that of the system without packed bed. The heat transfer and friction characteristics of packed bed solar air heater were investigated by Prasad et al. (2009) using wire mesh as packing material and found that the lowest value

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Nomenclature

m	mass flow rate, kg/s
Cp	specific heat capacity of air, J/kg.K
T	temperature, K
I	solar radiation intensity, W/m^2
A	area, m^2

Subscript

o	outlet
i	inlet

of porosity leads to better performance and heat transfer coefficient increases with a decrease in porosity. Aldabbagh et al. (2010) investigated that the single and double pass solar air heaters with wire mesh as packed bed achieved 45.93% efficiency for single pass solar air heater and 83.65% for double pass solar air heater. Omojaro and Aldabbagh (2010) investigated the single and double pass solar air heaters with wire mesh as packed bed and observed that efficiency increases with an increasing air mass flow rate. For the same flow rate, the efficiency of the double pass was 7–19.4% higher than that of the single pass.

Enibe (2003) analysed the natural circulated solar air heater with phase change material energy storage system and predicted the performance. Jain and Jain (2004) analysed the inclined multi pass solar air heater with in-built thermal storage on deep-bed for drying application and found that the bed moisture content decreases with the time of the day and also the drying rate increases with the increase in the depth of drying bed. Mahmud et al. (2011) studied the solar air collectors with thermal storage units and found that the PCM with high latent heat were required for optimum thermal performance of solar air heater.

In this work, a double pass solar air heater was fabricated and tested with energy storage system. Paraffin wax in cylindrical capsules is used as phase change energy storing material. Experiments were conducted and performances were compared for different configurations. In each configuration, the paraffin capsules were placed in different locations.

2. Experimental setup

A double pass solar air heater of 750 mm length, 500 mm width and 182 mm height was fabricated using mild steel plate as shown in the Fig 1. To reduce the heat losses to the atmosphere, the collector bottom and lateral sides were insulated with 20 mm thick glass wool and to reduce convective losses, the collector top side was covered with a 4 mm glass plate.

To maintain a uniform distributed flow inside the collector, a conical inlet and exit sections were provided. Using a blower, the air was forced through the upper channel in the double pass collector between the top glass cover and the absorber plate and then recirculated in opposite direction through the lower channel between the absorber plate and back plate. The heater was tilted with an angle of 9° 11’ (local latitude angle) with respect to the horizontal position facing south direction to receive the maximum solar radiation. The detailed technical specification of the collector and the pipes used for thermal storage are listed in the Table 1.

To improve the system performance, the thermal storage system i.e. phase change material was integrated with double pass solar air heater. Paraffin waxes in the six aluminium capsules (each 4 cm diameter and 60 cm length) were used to store the excess thermal energy. The absorber plate and aluminium capsules are painted with black colour to absorb max-

Table 1 Physical parameters of solar air heating systems.

S. No.	Design materials/ parameters	Specifications
Collector		
1.	Tilt angle	9° 11’ (south facing)
2.	Glass area	0.375 m^2
3.	Collector glazing	Window glass with 4 mm thickness
4.	Absorber plate	Width: 460 mm, length: 650 mm
5.	Bottom plate	Width: 460 mm, length: 725 mm
6.	Bottom insulation	20 mm thickness of glass wool
7.	Side insulation	20 mm thickness of glass wool
Storage material		
1.	Pipe, inner diameter	4 cm
2.	Pipe, outer diameter	4.6 cm
3.	Pipe length	60 cm
4.	Total no. of pipes	6
5.	Weight paraffin per capsule	0.595 kg.

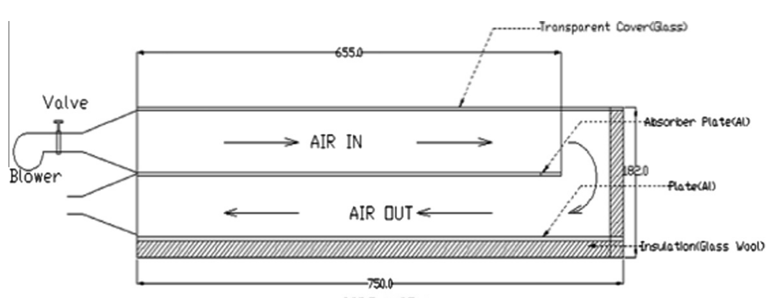

Figure 1 Schematic diagram for double pass solar air heater.

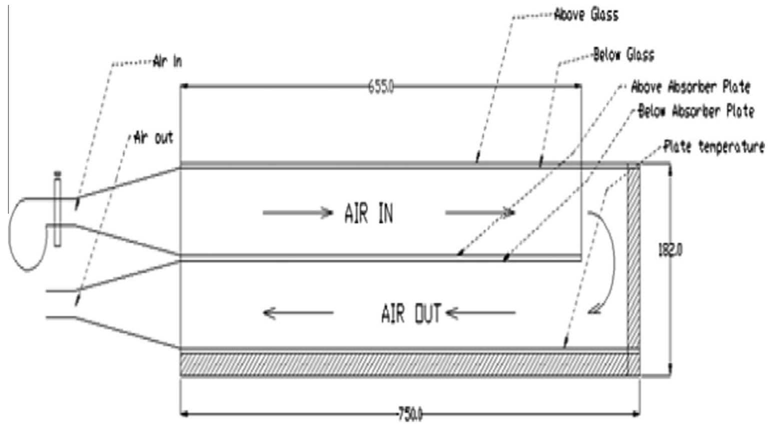

Figure 2 Position of thermocouples.

Table 2 Accuracies and errors for various measuring instruments.

S. No.	Instrument	Accuracy	Range	% error
1	Thermometer	± 1 °C	0–100 °C	5
2	Thermocouple	± 0.1 °C	0–100 °C	0.5
3	PV type sun meter	± 1 W/m^2	0–1500 W/m^2	2.5
4	U-Tube mano meter scale	± 1 mm	0–1000	1

Figure 3 Photograph of double pass solar collector.

imum solar radiation. The capsules are arranged in different configurations on the absorber plate and on the back plate.

Blower is connected to the inlet of the air heater through a gate valve, orifice meter and U-tube manometer. Gate valve is used to control the mass flow rate of air and U-tube manometer is used to find out the mass flow rate by measuring the head difference across the orifice. To measure the inlet and exit air temperatures, absorber plate temperature and back plate temperature, K type thermocouples were placed at different locations as shown in the Fig. 2 and connected to the digital indicator. Sun meter is used to measure the solar radiation intensity (Table 2).

The photograph for the double pass solar air heater experimentation setup integrated with thermal storage medium was shown in the Fig 3.

3. Experimental procedure

Experiments were conducted with solar air heater for four different configurations. In configuration 1, no thermal energy storage system was used, where as in other configurations the capsules were placed in different places in line with flow direction. In configuration 2 (Fig. 4), the capsules are placed above the absorber plate, in configuration 3 (Fig. 5), the capsules are attached below the absorber plate and in configuration 4 (Fig. 6), the capsules are placed above the back plate.

Experiments were conducted on different configurations of double pass solar air heater from 6 AM till evening 6 PM during March–May 2010 at Energy park of the National Engineering College, K.R. Nagar (9°11'N, 77°52'E), India. The solar radiation, temperature and manometer readings were

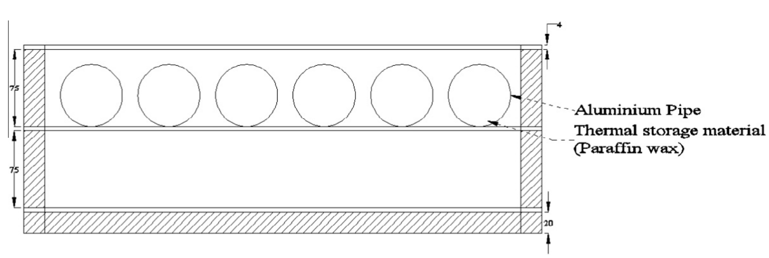

Figure 4 Configuration 2, capsules above the absorber plate.

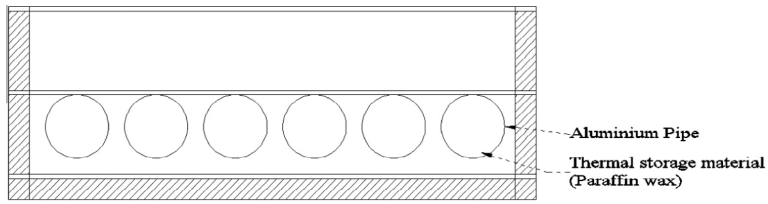

Figure 5 Configuration 3, capsules below the absorber plate.

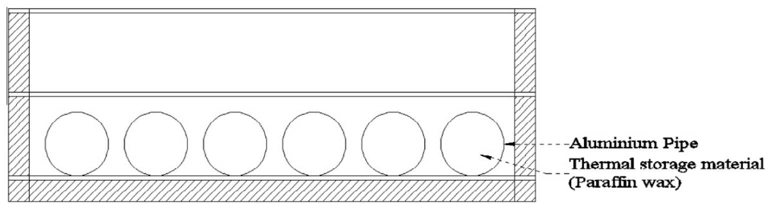

Figure 6 Configuration 4, capsules above the back plate.

observed and recorded for every one hour. For each configuration, the readings were taken for two or three days. The observations on these days of similar radiation conditions were considered for analysis.

4. Results and discussion

The average solar radiation intensity and atmospheric temperature variations during the experimental period were as shown in Fig. 7. The maximum solar radiation intensity recorded was 900 W/m^2 at 12:30 pm. From the morning till the evening, the ambient temperature was between 30 and 40 °C and the mass flow rate was estimated by using U-tube manometer as 0.02 kg/s.

The typical variation of different temperatures of solar air heater with configuration 2 was as given in Fig. 8. The variation pattern was similar for all configurations. All the temperatures were varying with radiation intensity. The absorber plate is the hottest part in the air heater and it reached 70 °C around noon. The glass also reached the maximum temperature with absorber plate during noon. The exit air temperature closely varied with capsule surface temperature. The exit air temperatures reached a maximum value of 55 °C around noon.

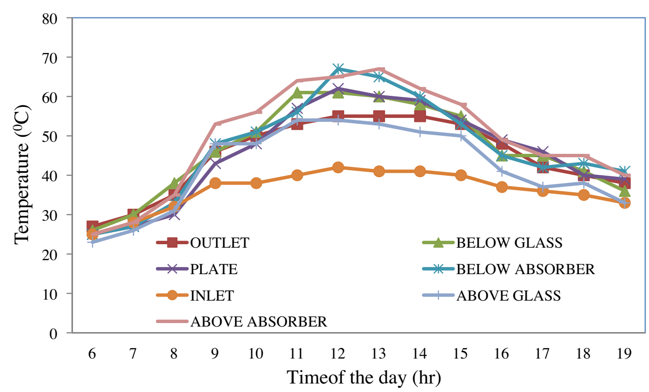

Figure 8 Variations of different temperatures for configuration 2 on 5th May 2011.

Only after 8 AM, there was an appreciable rise in all temperatures and after 5 PM all temperatures reached the low value.

Fig. 9 compares the exit air temperature for different configurations. When there is no energy storing material, the maximum temperature reached by the air is comparatively less and during the evening there was a high fall rate in the temperature.

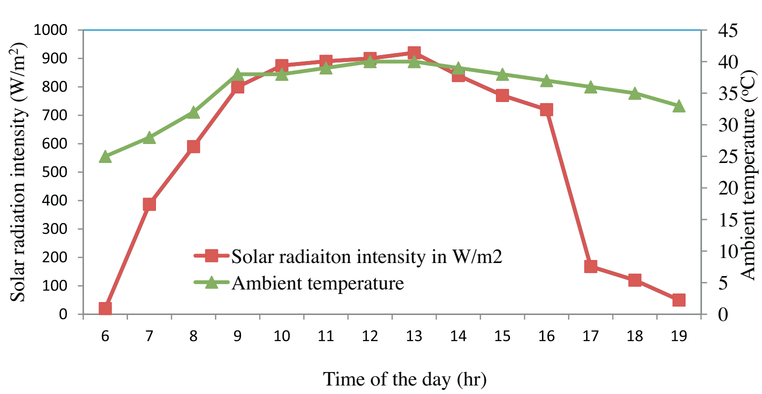

Figure 7 Solar radiation intensity and atmospheric temperature variation on 5th May 2011.

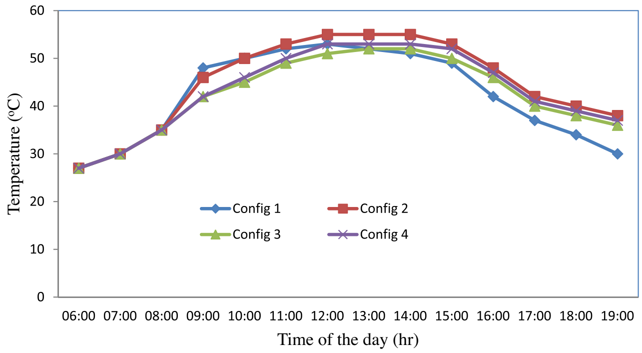

Figure 9 Exit air temperature for various configurations.

For configuration 2, better performance was observed. The air was maintained maximum from 9 AM to 7 PM.

Thermal efficiency of solar air heater is determined from the following equations:

$$\eta = \frac{mCp(To - Ti)}{IA}$$

The efficiency of the solar air heater was calculated using the radiation received by the heater and the enthalpy rise of the air. The variation in efficiency for different configurations is given in Fig. 10. When no energy storage system was used, the efficiency was proportional to the radiation received. When energy storage material was used, the excess energy stored in the morning was released during evening. Hence the efficiency of the air heater with energy storage materials is higher and efficiency increased during evening hours. The solar air heater with configuration 2, with capsules on the absorber plate was having better performance over others.

Fig. 11 compares the efficiency of this air heater with configuration 2 with some of the previous works carried out by Prasad and Saini (1993) and Omojaro and Aldabbagh (2010). It is observed that, the efficiency of the air heater with energy storage and packed bed was better during evening hours.

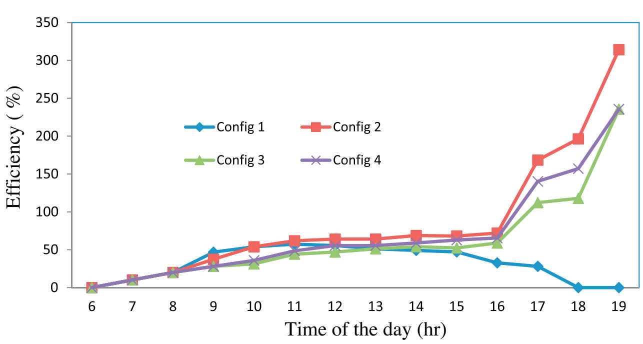

Figure 10 Efficiency variation.

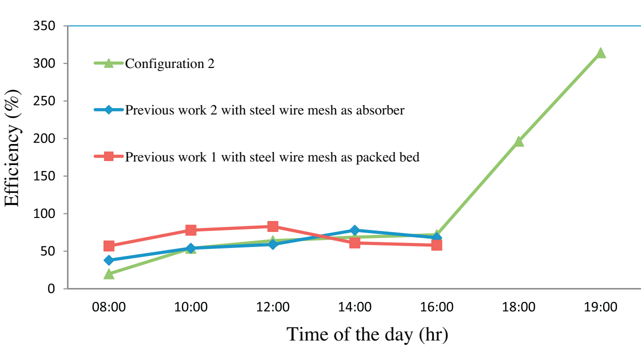

Figure 11 Comparison with previous work.

5. Conclusions

A detailed experimental study was conducted to evaluate the performance of the double pass solar air heater with various configurations under the metrological conditions of K.R. Nagar (9°11'N, 77°52'E), Tamil Nadu, India. Paraffin wax with aluminium capsules was used as phase changing energy storing material. Experiments were conducted to study the performance of the air heater with and without energy storage materials.

From the experimental results, it was observed that, the solar air heater with paraffin wax as energy storage material delivers comparatively high temperature air throughout the day. The efficiency is also higher during evening hours. The double pass solar air heater with capsules placed on the absorber plate is the efficient one.

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