International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 8 (2018) pp. 5877-5880

Forced Convective Solar Air Heater: Effect of Thermal Storage Materials

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Abstract

Solar energy, being one of the most promising, abundant and cheap source of renewable energy, is being utilized in various forms of energy generation. Due to high demand and expensive price of non-renewable fossil fuels, solar energy is opted to be the best among all sources of renewable energy in meeting the demands and reducing pollution to the environment. Air heaters are one among the most extensively used applications using solar energy. An air heater is designed & constructed and the thermal performance is studied by taking into considerations the various thermal storage materials like aluminum, sand, pebbles etc. A blower is being used to provide the forced circulation of the working fluid. The air heater is positioned at an angle of 23° towards south-east for maximum exposure. Amongst the combination for the SAH, Aluminum cans with sand have provided the maximum temperature (64 ºC) at the outlet and highest efficiency of the SAH (44.45%).

Keywords: Air heater; forced convection; thermal storage

INTRODUCTION

The energy usage globally has been grown significantly due to the exponential growth for demand of energy. With the industrial revolution, the worldwide energy consumption and per capita energy consumption has been grown at a very fast pace. The general energy requirements has been most med by the conventional fossil fuels and thereby it became an indispensable part of the modern civilization. Hence, very less share is being contributed from the other sources like wind, hydro, nuclear etc. According to recent studies, a mere exploitation of 5% of solar energy will be able to provide 50% more than the present energy requirement of the world. Solar energy is regarded as one of the most promising and clean source of energy. There are mainly two forms at which the solar energy is being utilized. The first one being the photovoltaic and the latter being the thermal energy of the sun in the form of infra-red. There are various ways of harnessing the thermal energy of the sun, and one such are the solar heaters. Solar air heaters (SAH) are one of the important emerging method in utilizing renewable energy (solar energy) for conversion and application in other usable forms. There has been tremendous changes in the design and construction of the solar air heaters in order to improve the efficiency and effectiveness in harnessing thermal energy of the sun.

Premanik R N et al. [1] have designed and fabricated a solar air heater with bottom extended surfaces with forced convection, while subjecting the set-up at an inclination of 15° to 17°. The air flow rate is fluctuated using a DC suction fan. They have concluded that the efficiency and outlet temperature of air increased by about 69% and 94°C respectively. Another important study for solar air heater for using it into spray drying was conducted by Jongpluempiti J et al. [2]. The designed air heater has a dimension of 1.2 m x 1.6 m x 0.2 m with flat black plate of galvanized steel of 3.04 m^2. They have obtained air outlet temperature of 83.92°C during noon (12:00 to 13:00 hrs.) while inclining the set-up at 15°. The proposed model was able to save up energy by about 30 kWh, with a payback period of 34 days. Trapezoidal corrugated solar air heaters using sensible heat storage systems have been found to have thermal efficiency of 36.6%, as compared to flat plate solar air heaters (8.5%) and trapezoidal corrugated solar air heaters (12.2%) [3]. Sensible heat storage materials like sand, pebbles, aluminum filings have been proven to have increased the thermal efficiency of the system. And amongst the sensible storage materials, sand have been found to be most effective in storing maximum thermal energy. Applications include solar drying of grapes, bitter gourd etc. [4]. Latent heat storage media also serves an important aspect in storing additional heat into the system. They can be effectively used in applications like solar drying of food commodities like black turmeric [5], etc. Phase change materials (PCM) like paraffin wax is also an important latent heat storage media which can increase the thermal efficiency of solar air heaters by 33% [6], solar water heaters [7] etc. Other PCM like lauric acid can also be successfully applied for storing excessive heat into the system [8]. Combining both PCM and baffle arrangements with air mass flow rate of 0.017 kg/s have been proven to provide maximum energy efficiency [9]. The presence of thermal storage materials at the absorber plate is also a proven method in increasing the thermal efficiency of the system and higher outlet temperature of the working fluid [10]. Another method of increasing the thermal efficiency of solar air heaters is the combined apparatus of finned plate solar air heaters and paraffin wax as phase change materials [11].

The authors in the paper have attempted to study the thermal efficiency (instantaneous) and outlet temperature of a solar air heater in using aluminum cans with sensible heat storage media like sand, pebbles etc. The experiment is conducted in the premises of the department of Mechanical Engineering, National Institute of Technology Manipur, Langol, Imphal West, Manipur (24.4984° N and 94.0753° E).

NOMENCLATURE

Symbol	Abbreviation
A_c	across section area of the collector exit pipe (m^2)
Ap	the heater projected area (m^2)
d	diameter of the collector exit pipe (m)
I	the total solar radiation incident on the heater (W/m^2)
Q_u	the useful heat gain by the air (W)
T	the average value of absorber plate temperature (ºC)
T_a	the average air temperature in the heater (ºC)
V_a	the measured air velocity at the collector exit pipe (m/s)
μ	dynamic viscosity of the flowing air which calculated at the average air ($N\text{-}s/m^2$)
ρ_a	density of air (kg/m^3)

MATERIALS AND METHODS

Solar air heater (SAH)

The solar air heater has been designed and fabricated in the premises of the department of Mechanical Engineering, National Institute of Technology Manipur, Langol, Imphal West, Manipur (24.4984° N and 94.0753° E). Table 1 provides the detailed specification of the constructed solar air heater. Wood is chosen for constructing the SAH as it serves as an excellent insulator of heat. The inside surface of the SAH is painted with black paint for maximum absorptivity, while the outer surface is painted with white. A glass of 2mm thickness is placed above the SAH. Aluminum cans painted with black are positioned inside the SAH. Sand and pebbles are chosen as thermal storage materials for the study, combining with Aluminum cans. A CAD diagram of the constructed SAH with Aluminum cans is represented in Figure 1. All the data have been recorded as per the meteorological condition of Langol, Imphal (India) in the month of March, 2018. An average incident radiation of 340 W/m^2 is recorded for the study.

Table 1. Specification of the solar air heater

Sl. No.	Particulars	Value
1.	Length (m)	0.395
2.	Breadth (m)	0.340
3.	Height (m)	0.165
4.	Inclination (°degree)	23° towards E-W
5.	Location of the solar air heater	24.4984° N and 94.0753° E
6.	Material of solar air heater	Wood painted with black

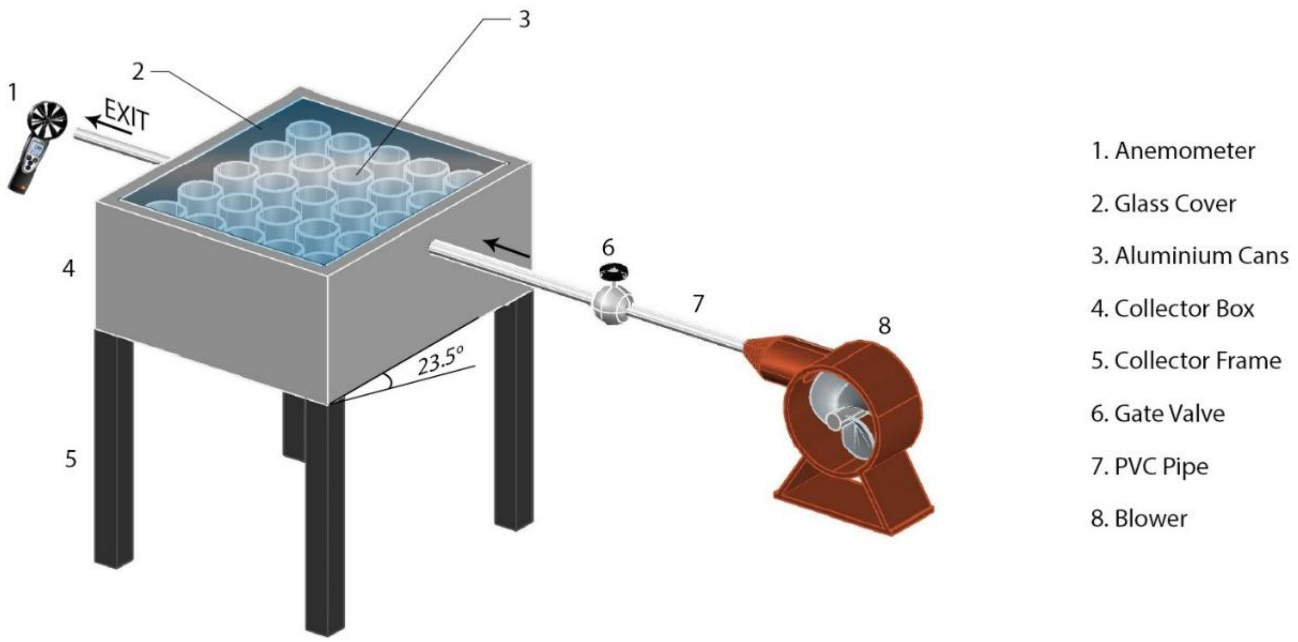

Figure 1. Computer aided view of SAH

Instrumentation

A digital thermometer and a hygrometer is being used for the experiment. Additionally, a sun meter is used for determining incident radiation. An anemometer is used for calculating the flow rate of air during inlet and outlet. An electric blower (DC) is used for supplying forced air inside the SAH. Equation (1) gives the uncertainty of the SAH. The overall uncertainty of the experiment is ±2.397, which is considered to be within the acceptable range.

$$Total\,Uncertainty = \sqrt{\left\{(Thermometer)^2 + (Hygrometer)^2 + (Anemometer)^2 + (Sunmeter)^2\right\}} \quad (1)$$

In order to perform performance analysis of the SAH, the following equations are used, equations (2) to (6). Equation (2) gives the useful heat gain from the SAH. The air mass flow rate (m) is calculated using equation (3). The Reynolds number for the flow is calculated using equation (4). The heat transfer co-efficient (h) is calculated from equation (5). The thermal efficiency of the SAH is determined using equation (6). Table 2 shows the variation of Reynolds number with change in velocity of fluid, in the SAH.

$$Q_u = m^{\cdot} C_P \Delta T_a \quad (2)$$

$$m^{\cdot} = \rho_a A_c V_a \quad (3)$$

$$Re = \frac{4m^{\cdot}}{\pi d \mu} \quad (4)$$

$$h = \frac{Q_U}{A_P\left(T - T_a\right)} \quad (5)$$

$$\eta = \frac{Q_U}{I A_P} \quad (6)$$

Table 2. Variation of Reynolds number for various velocity of flow in SAH

Sl. No.	Location	Temperature (T)	Velocity (V)	Dynamic viscosity (μ)	Mass flow rate (m)	Reynolds number
1.	Inlet of SAH	T_1 = 32 °C	3.4 m/s	18.7 x 10^{-6} N-s/m^2	0.00187 Kg/s	6690.63
2.	Outlet of SAH	T_2 = 54°C	1.9 m/s	19.72 x 10^{-6} N-s/m^2	0.000633 Kg/s	2248.23
		T_3 = 64 °C	1.86 m/s	20.17 x 10^{-6} N-s/m^2	0.000649 Kg/s	2152.98
		T_4 = 61 °C	1.84 m/s	20.03 x 10^{-6} N-s/m^2	0.000642 Kg/s	2144.66

RESULTS AND DISCUSSION

Variation of temperature with time

The SAH is subjected to 7 days of continous reading, from which a bright sunny day with good thermal radiation is being taken for the plotting of graph for the temperature with respect to time. A 12 hour continous reading is plotted for ambient temperature, SAH with Al Cans, SAH with AL can & Pebbles and SAH with Al cans & Sand is shown in figure 2. From the graph it can be seen that during the initial stages, the thermal storage media (except for Aluminum) – sand and pebbles takes more time in absorbing the thermal energy from the sun, and hence lower temperature can be observed in the SAH. With gradual increase in the temperature of the ambient, the sensible heat storage media accumulates the heat, which can be seen during noon, from the graph. The peculiar characteristics of thermal storage materials is the ability to release heat at a slower pace than the ambient. This is clearly shown by the slow emission of thermal energy from 15:00 hrs onwards by sand and pebbles.

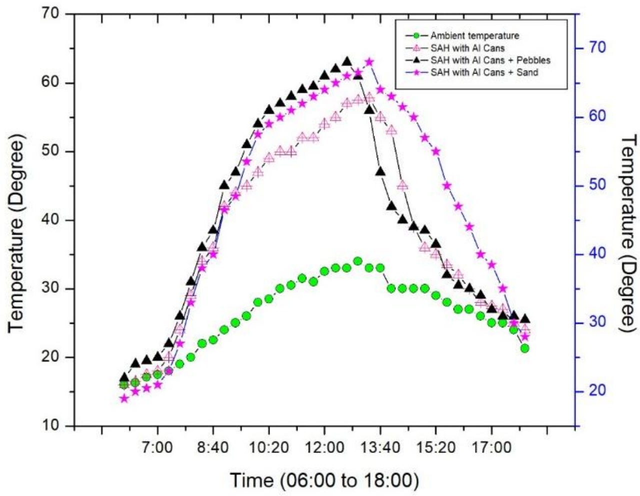

Figure 2. Variation of temperature with time of SAH

Efficiency of SAH with different combinations

The SAH coupled with various combinations of thermal storage media are presented and their corresponding thermal efficiency are shown in Figure 2. It can be seen from the graph that, the SAH coupled with Aluminum cans and sand have the

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 8 (2018) pp. 5877-5880
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best heat storage capability, as compared to other systems. It can also be noted that the aluminum cans coupled with pebbles have more heat storing tendency, as compared with the SAH with aluminum cans only. The maximum efficiency of 44.45% is obtained in SAH with Aluminum cans and sand.

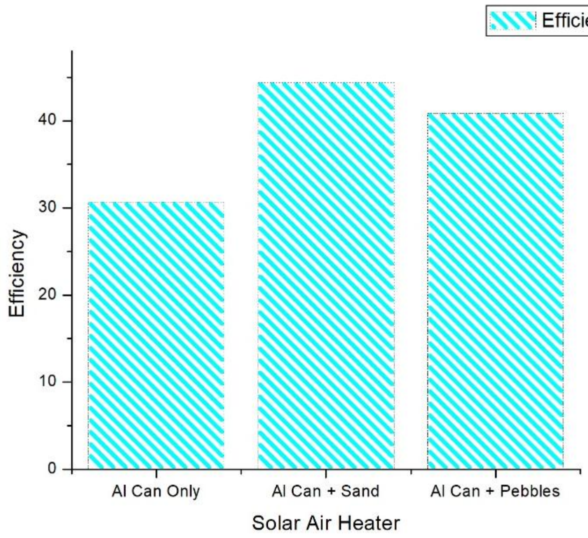

Figure 3. Efficiency of SAH with various combinations

CONCLUSION

A SAH is designed and coupled with sensible heat storage materials like Aluminum cans, Sand and Pebbles. A performance analysis is being conducted for different combinations of SAH.

- SAH can deliver more heat on the working fluid than the ambient temperature.
- SAH coupled with sensible heat storage materials are able to increase the temperature of the working fluid.
- Amongst the combinations, SAH with Al cans + Sand have been found to have the most thermal efficiency (44.45%), while delivering maximum temperature (64 ºC).

Thus, such a SAH coupled with Al cans painted with black and filled with sand, be successfully used for other applications requiring high temperature in the working fluid, like convective drying of food and other perishable agricultural products.

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