Applied Energy 87 (2010) 3759–3765

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Experimental performance of single and double pass solar air heater with fins and steel wire mesh as absorber

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ARTICLE INFO

Article history:
Received 29 December 2009
Received in revised form 8 June 2010
Accepted 22 June 2010
Available online 17 July 2010

Keywords:
Double pass solar air heater
Packed bed
Wire mesh
Fins
Thermal efficiency
Solar air heater

ABSTRACT

Thermal performance of a single and double pass solar air heater with fins attached and using a steel wire mesh as absorber plate was investigated experimentally. The effects of air mass flow rate range between 0.012 kg/s and 0.038 kg/s on the outlet temperature and thermal efficiency was studied. The bed heights were 7 cm and 3 cm for the lower and upper channels respectively.

Result shows that, the efficiency increase with increasing air mass flow rate. For the same flow rate, the efficiency of the double pass is found to be higher than the single pass by 7–19.4%. Maximum efficiency obtained for the single and double pass air heater was 59.62% and 63.74% respectively for air mass flow rate of 0.038 kg/s. Moreover, the thermal efficiency further decreases by increasing the height of the first pass of the double pass solar air heater. The temperature difference between the outlet flow and the ambient, ΔT, reduces as the air mass flow rate increase

The result of a single or double solar air heater using steel wire mesh arrange in layers as an absorber plate and packing material when compared with a conventional solar air heater shows a much more substantial enhancement in the thermal efficiency.

1. Introduction

Solar air heater is a simple device that heats air by utilizing solar energy from the sun. Its wide range of applications involves drying of agricultural products, such as seeds, fruits, vegetables and space heating [1]. Also, solar air heaters are used as pre heaters in industries and as auxiliary heaters in buildings to save energy during winter times [2]. Conventional solar air heaters mainly consist of a panel, insulated hot air ducts, a glass cover and air blowers if it is an active system. The panel consists of an absorber plate which is placed inside the hot air duct. The hot air duct is made from either wood or other metallic and non metallic materials. This is thermally insulated from the bottom and all the sides are also insulated. A glass or plastic cover is fixed above the absorber plate to form a passage for air flows.

There are different factors affecting the air heater efficiency, these include collector length, collector depth, type of the absorber plate, glass cover, wind speed, inlet temperature, etc. Among all, the collector glass cover and the absorber plate shape factor are the most important parameters in the design of any type of air heater.

Major heat loss from flat-plate solar collectors is found to be through the top cover because the bottom and the sides of the collector are insulated adequately. In order to minimize the heat losses and improve the efficiency, double glazing was recommended [3,4]. It was also suggested to insert an absorbing plate into double-pass channel in a flat-plate solar air heater. The airs flow then pass above the absorber plate and then turns to pass below it [5–8] or vise versa [9,10]. This is to increase the heat transfer coefficient between the flowing air, the glass cover and the absorber plate. The works of [11–13] suggest passing the air from above and below the absorber plate at the same time in a double-flow solar air heater.

Best thermal efficiency can be achieved in a double-flow solar air heater when the cross-section area of upper and lower channels are constructed equally and at the same fixed mass flow rates [11]. It was recently suggested to use double glass and double pass solar air heater with air passing above the absorber plate before turning to pass below it [14,15]. A result for multi-pass solar air heater was presented by Jain and Jain [16]. In their work, the air first passes in between the upper and lower glasses and then turns to pass above the absorber plate and finally turning to pass below it.

Another modification to solar air heater is by Mohamad [17]. He presented an analysis of a double pass (counter-flow) solar air heater with various porous media in the lower channel. His main idea was to minimize the heat losses from the top cover of the collector and to maximize heat extraction from the absorber. In his analysis, the air is first pass in between the upper and lower glasses channel. Then, it flows downward passing through the lower channel which is filled with porous media acting as an absorber plate. Qenawy and Mohamad [2] reported an analysis for double pass (counter-flow) solar air heater for cold climate. From our acknowledgements, the

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doi:10.1016/j.apenergy.2010.06.020

Nomenclature

A_c	area of the collector (m^2)	T_{out}	outlet temperature (°C)
C_p	specific heat of the fluid (kJ/kg. K)	ΔT	temperature difference ($T_{out} - T_{in}$) (°C)
h	fluid deflection inside the incline manometer (m)	η	efficiency of the solar collector $\eta = \frac{mC_p(T_{out}-T_{in})}{IA_c}$
I	solar radiation (W/m^2)	ρ	density of air (kg/m^3)
m	air mass flow rate (kg/s)	ΔP	pressure difference, $\Delta P = \rho gh \sin 19°$ (N/m^2)
Q	volume flow rate (m^3/s)	ω_m	uncertainty for the mass flow rate
T_{in}	inlet temperature (°C)	Ø	porosity

last two authors [2] and [17] obtained the maximum numerical efficiencies reached (85% and 88% respectively) for the solar air heater which are achieved up to now.

The absorber plate shape is another parameter that can play important rolls in a solar air heater. The heat transfer coefficient between the absorber plate and the airstream is always low, resulting in the low thermal efficiency of the solar air heater. Increasing the absorber plate shape area will increase the heat transferred to the flowing air. The effect is always an increase in the pressure drop and as a result increases the required power consumption by the fan of the solar air heater. Therefore, different modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air. This will increase the outlet temperature and also, improve the efficiency of the solar air heater.

These modifications include using an absorber with fins attached [6,10–13,18]. Also, porous materials are packed inside the solar air collector. Limestone and gravels were use as porous media by Ramadan et al. [14]. El-Sebaii et al. [15] investigation involved the use of limestone, gravels and iron scraps. While wire mesh screen was used by Qenawy and Mohamad [2], Mohamad [17] and Thakur et al. [19] as the porous material packed into the solar air collector to serve as the porous media. The use of porous media tends to increase the surface per unit volume ratio substantially and was found to improve the thermal efficiency in the air solar heater. Experimental work on several configurations of copper screen mesh was demonstrated by Tian et al. [20] to identify referable orientation for maximizing thermal performance. They showed that the overall heat transfer depends on porosity and surface area density but weakly on orientation. Thermal efficiency when using gravel was reported to be 22–27% higher than that without the packed bed [15].

The study by Thakur et al. [19] showed that, the higher efficiency can be achieved with lower porosity. Such modifications, using the porous matrix enhance the thermal efficiency significantly. These also increase the pressure drop, which becomes important at high volume flow rates of air. Thermal performance of a solar air heater packed with wire screen matrices for different geometrical parameters was investigated [21]. Minimizing pumping power due to different arrangement was presented in their studies.

The purpose of this work is to investigate experimentally the single and double pass (counter-flow) solar air heater with porous media in the lower channel acting as an absorber plate. The porous media used consist of steel wire mesh layers arranged from bottom to top 1 cm above each other so as to give high porosity and to reduce the pressure drop across the solar air heater. In order to increase the surface area of the collector, longitudinal fins was installed and fixed along the lower and upper pass of the solar air heater (Fig. 1). The second aim of this work is to investigate the effect of the first pass height on the thermal performance of the solar air heater. Tests were conducted under actual outdoor conditions. The obtained results show that the efficiency of a double pass is higher than that of a single pass collector by 7–19.4% depending on the air mass flow rate.

2. Experimental setup and equipments

A schematic view of the single and double pass air collector is shown in Fig. 1a. Plywood of 2 cm thickness, painted with black color from inside and outside was used to make the frame of the collector. All sides and bottom of the collector were insulated with 2 cm thick Styrofoam adequately. The solar air heater frame has a dimension of 150 cm in length (L), by 100 cm width (W). Normal window glass of 0.3 cm thicknesses was used for glazing while the distance between the first glass and the second glass (h), was 3 cm. The distance between the second glass and the bottom of the collector (H), was 7 cm. The single pass air collector can be achieved by removing the first glass at the top of the solar air heater.

Four metallic fins of 150 cm length by 7 cm height painted black were positioned longitudinally along the channel creating five equal sections for air passage (Fig. 1b). For the case of the double pass solar air collector, four metallic fins with the same characteristic were used and its dimension was 150 cm in length by 3 cm height. The metallic fins were also positioned longitudinally along the upper channel creating another five equal sections for air passage (Fig. 1c). In this way the collector was divided into five equal sections for both the upper and lower channels.

Each air pass section was fixed with seven steel wire mesh layers of 0.2 cm × 0.2 cm in cross sectional opening. Transverse pitch to diameter ratio of the wire is unity. The distance between the wires mesh layers was 1 cm and it was painted black before installing it in the air passage. With this arrangement, the seven wire mesh layers act as an absorber plate. An absorber plate at the bottom of the solar air heater is no longer necessary since, the solar intensity of the sun cannot penetrate to the bottom of the second pass channel. Therefore, the cost of the solar heater can be reduced considerably because the wire mesh is readily available in the market and very cheap. In addition, the new design of the porous matrices will minimize the pressure drop because of the porous media in the solar air heater. Thus, the pressure drop is very small and can be neglected where the porosity is very high and measured to be about 0.98. The porosity, ϕ, of a porous medium is defined as the fraction of the total volume of the medium that is occupied by void space. The pressure drop as a result of adding the porous matrices to the collector is calculated by using the inclined tube manometer and is found to be 12.82 Pa.

The upper channel of the collector was varied for separate height of 3 cm, 5 cm and 7 cm for the same air mass flow rate. In operation, hot air flowing through the five equal sections of the lower section channel will be forced through the converging section and then into the orifice meter. In order to get a uniform flow through the orifice meter, two flows straighter were made and installed inside the pipe. One installed before the orifice meter and the other installed after the orifice meter. Each straighter consists of plastic straw tubes with 0.595 cm diameter and 3 cm length. Calibrated orifice meter has been used in the pipe to measure the air flow rates. The orifice meter is designed according to Holman