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Investigation of single and double pass solar air heater with transverse fins and a package wire mesh layer

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ABSTRACT

The purpose of this work is to construct and test single-pass and double-pass solar air heaters (SAHs) with four transverse fins. These fins were painted dark black and placed transversely to create four equal-spaced sections. Sixteen steel wire mesh layers were located between these fins as an alternative to an absorber plate; they had a cross-sectional area of 0.18 cm × 0.18 cm and an internal diameter of 0.02-cm. In this project, the thermal efficiency and outlet temperature were studied in a geographic area located in the city of Famagusta, North Cyprus. The experimental results indicate that the thermal efficiency increases as the air flow rate increases for the range of (0.011-0.032) kg/s. The maximum efficiency obtained using the 7.5-cm high collector was 62.50% for the double-pass SAH and 55% for the single-pass SAH at an air flow rate of 0.032 kg/s. Moreover, the thermal efficiency further increases by decreasing the height of the lower air pass of the double-pass SAH. The difference between the inlet temperature and outlet temperature, ΔT, indicated an inverse relationship with air flow rate: ΔT increased as the air mass flow rate decreased. The maximum differences (ΔT) observed were 45.30 K for the double-passes SAH and 39.9 K for the single-pass SAH at 0.011 kg/s, which were recorded during the middle of the day with a maximum solar intensity. The results demonstrate a significant improvement in the thermal efficiency and outlet air temperature.

1. Introduction

Heating air with solar energy is much cheaper and cleaner than heating air with fossil fuel, the delivered heat from an air solar device can be used by various industries for drying agricultural products and as auxiliary heaters in buildings to save energy during winter [1]. The classical design of a solar air heater consists of a duct made of wood or other material in which the top side of the duct is covered with either a glass or transparent plastic sheet. The other sides of the duct and the bottom are thermally insulated. The absorber plate is placed inside the hot air duct parallel to the transparent cover, in which air blowers are used if it is an active system.

Different factors affect the air heater efficiency such as collector dimensions, type and shape of absorber plate, glass cover, inlet temperature, wind speed, humidity, air path, and height of the channel. Among all, the collector glass cover, the absorber plate shape factor, and air path are the most important parameters in the design of any type of air heater. Major heat losses from flat-plate solar collectors are found to be through the top cover; heat losses from the bottom and the sides of the collector are low as they are adequately insulated. Minimising the heat loss from the cover definitely will lead to increase the thermal performance of SAH. For this reason a double glazing was performed [2–7] or by using the counter flow (double pass) [5,8–12]. In double pass SAH, air will pass between the first glass, cover, and the second glass and then changing its direction to pass between the second glass and the bottom of the channel. Several researchers have suggested inserting the absorber plate at mid channel to divide the channel into two equal parts [3,4]. The air in this case will pass above and under the absorber plate in the same direction. El-Sebaii and Shalaby [4] recorded that the maximum difference between inlet and outlet air temperatures was about 28 °C for upper channel at a 0.0223 kg/s flow rate and 580 W/m^2 solar intensity. It has been also suggested to insert an absorbing plate into a panel to have a double pass channel where the air flows from above and then below the absorber plate [13–15] or vice versa [16–18]. In general, the principle of using doubles pass or passing the flow from above and then from below is to increase the airflow path length inside collector. This leads to increase the heat transfer coefficient between the flowing air, the glass cover and the absorber

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Nomenclature

A_c	area of the collector (m^2)	ΔT_{bed}	temperature difference of bed ($T_{bed} - T_{in}$) (K)
C_p	specific heat of the fluid (kJ/kg K)	ΔT_g	temperature difference of glass ($T_g - T_{in}$) (K)
h	fluid deflection inside the incline manometer (m)	ρ	density of air (kg/m^3)
I	solar radiation (W/m^2)	η	efficiency of the solar collector (–)
m	air mass flow rate (kg/s)	ω_m	uncertainty for the mass flow rate (–)
p	pressure (Pa)	ω_p	uncertainty for the pressure differences (–)
Q	volume flow rate (m^3/s)	ω_{Tair}	uncertainty for the film air temperature (–)
T_{in}	inlet temperature (K)	ω_I	uncertainty for the solar radiation (–)
T_{out}	outlet temperature (K)	ω_η	uncertainty for the solar thermal efficiency (–)
ΔP	pressure difference, $\Delta P = \rho gh \sin 15°$ (N/m^2)	Φ	porosity (–)
ΔT	temperature difference ($T_{out} - T_{in}$) (K)		

plate. The transversely fins along the bed used by [19] divided the channel to three; five and seven equally spaced sections. In this way, air flows in a snake path picking up heat as it goes along the passage channel. As the path length was increased by increasing the number of fins, the velocity of air was also increased for the same air mass flow rate as the cross-sectional area of the air passage channel decreased. The longitudinal fins used by Omojaro and Aldabbagh [10] divided the lower channel to five equal spaces. They set up a bed with seven wire mesh layers (1.5 m × 1 m) and fins with a height of 7-cm. The maximum efficiency obtained from their work is 51% at a mass flow rate of 0.035 kg/s.

As we mentioned before the absorber plate is the most important parameter that can play important roles in a solar air heater. Increasing the absorber area definitely will increase the thermal efficiency. Different modifications have been suggested and applied to increase the surface area of the absorber plate [20]. Used roughness obstacles and baffles to increase the surface area of the absorber plate and in same time to increase the turbulence inside the flowing channel. For the same purpose [3] used v-corrugated absorber plate. Many researchers have used transverse ribs [2,9,21] or longitudinal fins [10,22,23] as such obstacles and some used transversely fins [19]. A gravel-packed bed used by El-Sebaii [5] and the iron chips packed bed used by Sharma et al. [24] improved the thermal performances of SAH by increasing the outlet air temperature and the thermal efficiency of the system. Another modification to absorber plate of solar air heater is by [8]. He presented an analysis of a double pass (counter-flow) solar air heater with various porous media (different porosity) in the lower channel. 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 [10]. [5,11,12,14,20,25,26] also use of porous media in constructed their SAH. While wire mesh screen was used as the porous material packed into the solar air collector to serve as the porous media by [8,10,19,22,27]. These modifications, using the porous matrix, enhance the thermal efficiency significantly but also increase the pressure drop, which becomes important at high volume flow rates of the air. For this reason [10,19,27,28] found some method in arranging the wire mesh inside the collector to reduce the pressure drop through the solar air heater.

The first aim of this study in this article is to study the effect of increasing the path of the following air inside the channel of a single and double pass solar air heater with porous media in the lower channel without an absorber plate. For this purpose a transverse fin was used and fixed inside the duct to direct the air inside the channel to give a path shape like 8 letters (Fig. 1). Those fins will increase the area of the absorber bed besides they will divide the channel to four equal sections. In this case the air at the entrance will be divided into two equal parts, one part moved to the left and the other part to right, and then the two parts will enter to the second section of the channel through the two opening made at the two sides. The mixed two parts of the air flow at the mid section of the second part of the channel will pass to the third section through the opening made at the mid second fin, and in this way the path of the air will be repeated. The wire meshes used in this collector are similar to the ones which were used by [10,19,27,28] with a difference in the total number of layer, number of layer in each matrix and the distance between the matrices in order to reduce more the pressure drop. The second aim of this work is to investigate the effect of the second pass height on the thermal performance of the solar air heater. Tests were conducted under actual outdoor conditions.

2. Experimental set-up and equipment

2.1. Experimental set-up

Flat-plate SAHs were constructed to perform thermal efficiency experiments in Famagusta, North Cyprus. This investigation used a collector made of wood that was 147 cm × 100 cm and 7.5-cm high (Fig. 1), and a wooden frame that was 4-cm thick with an upper rectangular 36 cm × 4 cm hole for the air flow inlet. The design and operating parameters are shown in Table 1. All the sides of the bed were painted dark black, and three sides were insulated with Styrofoam with the exception of the upper side of the channel. Normal window glass of 4-mm thicknesses was used as glazing. The distance between the first glass and the second glass, was 2.5-cm. The single pass air collector could be achieved by removing the first glass at the top of the collector. Sixteen wire mesh layers with a cross-sectional opening of 0.181 cm × 0.181 cm were also used, which were constructed in three group's located 0.5-cm apart from each other. The first and second sets each contained six wire mesh layers that were fixed to the bottom of the channel and parallel to the glass cover. The third group that consisted of four wire mesh layers was located 0.5-cm above the first two groups. All of the layers (Φ = 0.981) were painted black before being installed in the channel. Four aluminium fins were also painted black and positioned transversely along the channel to divide it into four equal parts. These fins were all 7.2-cm high and 0.3-cm thick. Two of them were 80-cm long, while the other two were 45-cm long. A black slot rubber band, 0.5-cm wide and 0.3-cm thick, was used to prevent the fins from touching the glass and to prevent air from passing between them. In this way, the air flows along the pattern, gaining heat as it passes through the channel (Fig. 1a and b). In the case of the double-pass SAH, the flow first enters from above the exit part of the lower channel and passes inside the upper channel. The flow then reverses direction in the lower channel prior to turning to flow from the top side to the bottom side through a 36 cm × 4 cm opening in the middle of