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THE EFFECT OF PARTITIONING SINGLE PASS MESH WIRE PACKED BED SOLAR AIR HEATER

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ABSTRACT

Two single pass Solar air heaters (SAHs) having two and six fins (partitions) respectively were constructed and experimentally investigated. The aim of the partitions is to increase the airflow path length. The path followed by the working fluid was increased due to increase in the number of partitions. Wire mesh layers were used within the partitions instead of an absorber plate. The effect of thermal partition on the thermal efficiency was investigated experimentally. The range of mass flow rate through the collectors is varied from 0.12 to 0.36 kg/s. Thermal efficiencies obtained for the two and six partitions were 80.6% and 83.1% respectively with a mass flow rate of 0.36 kg/s in each case. The maximum temperature differences obtained for the two and six partitions were 48.2 °C and 58.4 °C respectively with a mass flow rate of 0.12 kg/s in each case.

INTRODUCTION

A solar air heater is a simple device to heat air by utilizing solar energy, which has many applications in drying agricultural products, such as fruits, seeds, and vegetables [1]. In addition, solar air heaters are utilized for heating buildings with auxiliary heaters to save energy in wintertime.

Conventional solar air heaters mainly consist of panels, insulated hot air ducts and air blowers if it is an active system. The panel consists of an absorber plate and a transparent cover. To increase thermal efficiencies, heat has to be transfered efficiently from the absorber to the flowing air.

Several configurations of absorber plates have been designed to improve the heat transfer coefficient between the following air and the absorber plate. Esen [2] investigated experimentally and indicated that the introduction of the obstacles in the air channel fixed on the absorber plate, is very important factor for the improvement of collector efficiency. An experimental study has been carried out to investigate the efficiency of SAHs duct provided with transverse and inclined ribs as artificial roughness elements on the absorber by Varun et al. [3]. Mittal et al. [4] reported that there is a considerable enhancement in the effective efficiency of SAHs having roughened duct provided with different types of roughness elements. Youcef-Ali and Desmons [5] indicated that the offset rectangular plate fins increase the heat transfer coefficient between the absorber plate and the fluid. Ozgen et al. [6] investigated experimentally the effect on efficiency by inserting an absorbing plate made of aluminum cans into the double-pass channel in a flat-plate SAH. Their configuration substantially improved the collector efficiency by increasing the fluid velocity and enhancing the heat transfer coefficient between the absorber plate and air. Romdhane [7] introduced comparative study by introducing baffles to favor the heat transfer in air solar collectors. The studies on various types of baffles placed in air passage showed that the introduction of suitable baffles in SAHs increases both the efficiency and outlet temperatures.

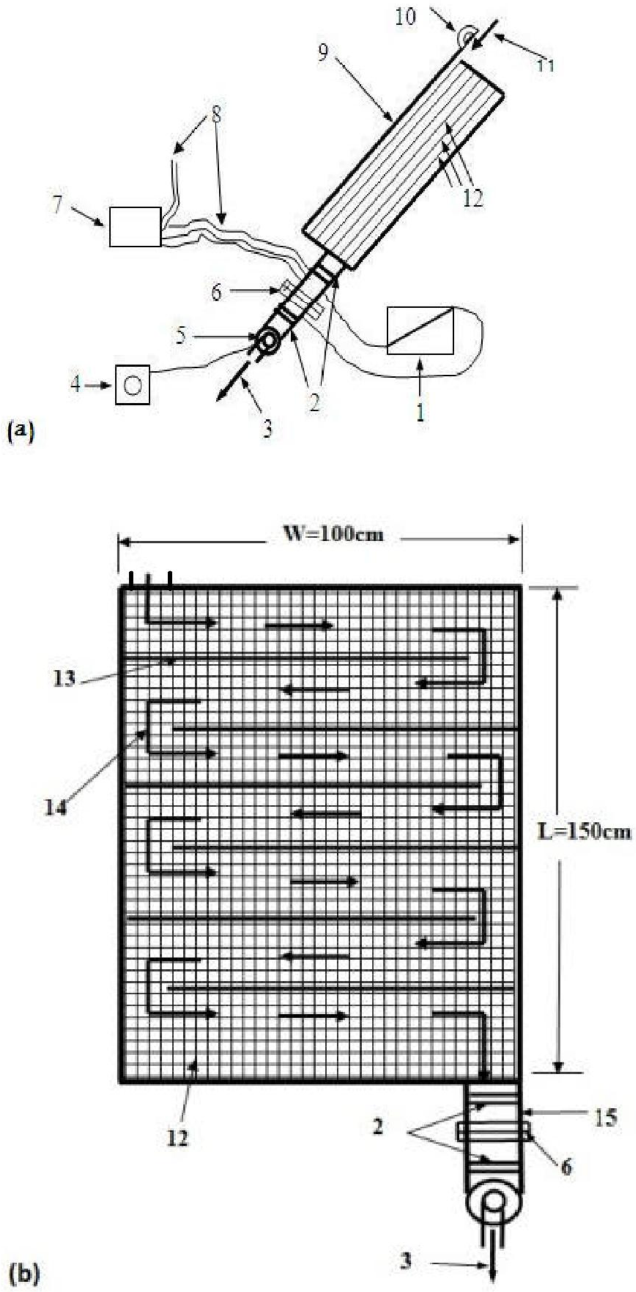
Including the use of packing of porous materials like wire screens, cross rod matrices, and aluminum-foil matrices in the duct of a SAH have been proposed for the enhancement of thermal performance. Kolb et al. [8] suggested a new design in order to overcome the physical problems of a conventional flat-plate air collector as well as the technical problems of a matrix air collector (such as heat transfer rates, friction losses, low durability, and weight). It was reported that such a design yield an improved thermal performance with higher heat transfer rates to the airflow and small friction losses compared to flat-plate air collectors of conventional design. Ozturk and Demirel [9] investigated experimentally the thermal performance of a SAH having a flow channel packed with metallic rings. They found that the net energy efficiency reached up to 33.78%. El-Sebaii et al. [10] reported that the thermal efficiency with gravel is 22-27% higher than that without the packed bed. Mohamad [11] introduced a new type of SAH which combines double air passage with porous media and reported that the thermal efficiency of such collector is significantly higher than conventional SAHs. Parasad et al. [12] presented an experimental investigation, which has been carried out on a packed bed SAH using wire mesh as packing material. The thermal efficiency of the packed bed SAH was compared with that of a conventional SAH to determine the enhancement. The efficiency was found to be a strong function of the system and operating parameters of the collector. Tchinda [13] introduced a mathematical model for computing the thermal performance of an air heater with a truncated compound parabolic concentrator and investigated the effects of the air mass flow rate, collector length and wind speed on the performance of the SAH. Yeh et al. [14] reported that the collector efficiency of baffled SAHs is greater than flat plate heaters without fins.

The purpose of this work is to investigate experimentally the single pass SAH with porous media and fins (partitions) in the channel acting as an absorber plate. The porous media used consists of steel wire mesh layers arranged in a way to give high porosity. In order to increase the airflow path length, transverse fins were fixed within the channel as shown in Fig. 1. The second aim of this work is to investigate the effect of the number of the transverse fins i.e., partitions on the thermal performance of the solar air heater. Tests were conducted under actual outdoor conditions. The obtained results showed that the efficiency of the wire meshed with six transverse fins SAH is higher compared to two-finned SAH by 3.5% to 16.9 % depending on the air mass flow rate.

EXPERIMENTAL SET-UP AND EQUIPMENTS

The schematic diagram of an experimental set-up is shown in Fig 1. The set up was designed and constructed in order to obtain data for the investigation. The set-up consists of a wooden bed 1.5 m long and 1 m wide. The frame of the collector was made of 2 cm thick plywood painted with black and externally insulated with 2cm thick Styrofoam. Normal window glass of 0.4 cm thick was used as glazing. The distance between the glass and the bottom of the collector was fixed to be 10 cm. Two and six metallic fins each 90 cm long and 10 cm in height with 0.3 cm thickness were positioned across the air passage channel. Figure 1b shows front view of a six finned setup. To increase the absorbtivity and reduce the reflectivity of the fins, all the fins were painted with black before fixing them in the channel. For the two finned setup, fins were fixed inside the air heater channel such that the collector is divided into 3 equal parts (i.e., 50 cm apart). Six fins were used in the second experiment where seven equal passage sections were formed in the channel. The air will flow like a snake path along the passage channel, and heat will transfer from the collector to air as it passes through the channel. Each matrix in the bed was packed using ten steel wire mesh layers having one cm gap in between. The wire screen matrices are placed between the fins and were painted with black before installing (Fig. 1b).

These matrices replaced the absorber plate in the traditional solar air collectors; hence, the design is cheaper compared to the SAHs having absorber plates. The pressure drop, due to the addition of the porous matrix to the collector, in this case is very small and can be neglected since the porosity is high (more than 0.85 as expected). An axial blower (Type GEC-



1-Incline manometer | 2-Straightener
3-Discharged air | 4-Speed controller
5-Fan | 6-Orifice meter
7-Digital thermometer | 8-Thermocouples
9-Glass | 10-Pyranometer
11-Inlet flow | 12-Wire mesh
13-6 transverse fins (Bariers) | 14-Air flow direction
15-Steel pipe

Figure 1 (a) schematic assembly of the SAH system (b) front view of collector

XPEL AIR) is connected to the discharge of the heater through a pipe (11 cm in diameter). A calibrated orifice meter is installed inside the pipe for measuring the volume flow rate of the air. The orifice meter was designed according to Holman [15] and installed inside the pipe between the discharge gate and the axial blower. Two flow straighteners are installed inside the pipe before and after the orifice meter to obtain a uniform flow through the orifice meter. Each straightener consisted of plastic straw tubes having 0.595 cm diameter and are 3 cm long. The pressure difference through the orifice was measured by using an inclined manometer filled with alcohol having density of 803 kg/m^3. The angle of the manometer was fixed at 19^o. Different mass flow rates were obtained by using a speed controller which is connected to the axial fan in order to control the fan speed. The outlet temperature, T_{out}, and the inlet temperature, T_{in}, were measured by using five T-type thermocouples. Three thermocouples were fixed inside the pipe before the orifice meter to measure the outlet temperature of the working fluid from the bed and two were fixed underneath the solar collector to measure the ambient air temperature. The temperature readings were recorded by Ten-channel Digital Thermometer (MDSSi8 Series digital, Omega) ±0.5 ^{o}C accuracy. A calibration test showed that the accuracy of the thermocouple readings were within ±0.15 ^{o}C. The global solar radiation incident on an inclined surface was measured using an Eppley Radiometer Pyranometer (PSP) coupled to an instantaneous solar radiation meter model HHM1A digital, Omega 0.25% basic dc accuracy and a resolution of ±0.5% from 0 to 2800 W/m^2. The pyranometer was fixed beside the glass cover of the collector. In order to maximize the solar radiation incident on the glass covers, the SAH was mounted on a fixed track and tilted angle of 36^o facing south (tilt angle for Cyprus).

RESULTS AND DISCUSION

This experimental work investigates the effect of partitioning single pass mesh wire packed bed SAH under Famagusta prevailing weather conditions during the summer months, 2.06.2009 - 20.07.2009, with clear sky condition. Famagusta is a city in Cyprus located on 35.125^o N and 33.95^o E longitude. The mass flow rate of the air was varied from 0.012 to 0.036 kg/s. The uncertainty of the mass flow rate is calculated to be 32 % [2].

Figure 2 shows the hourly variation of temperature difference, ? T = $T_{out} - T_{in}$, for different mass flow rates and hourly measured solar radiation on a clear day in Cyprus for the two fins SAH. The highest daily solar radiation obtained was 1126 W/ m^2 at 13:00 hours. The solar radiation was increasing from morning to a peak value of 1126 W/m^2 at noon and then, was decreasing in the afternoon until sunsets. As expected, the temperature differences increased until noon to a peak value and decreased in the afternoon. The temperature difference increased as the number of the fins increased (Fig. 3). The maximum temperature difference was about 48.2 ^{o}C at noon for the two fins heater with air mass flow rate of 0.012 kg/s, while the maximum temperature difference was 58.4 ^{o}C for the 6 fins heater with the same mass flow rate. In general, ?T decreases with increasing air mass flow rate (Fig. 4). In addition, the temperature differences for the two models become closed to each other at higher flow rate, m=0.036 kg/s. The ? T for 6 fins is always higher than that of 2 fins model for the same time of the day (Fig.4).

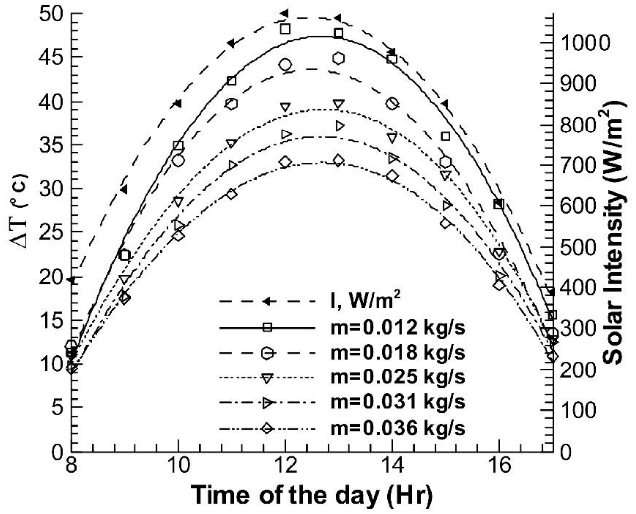


Figure 2 Temperature and flux variation with time of a day for 2-fins SAH

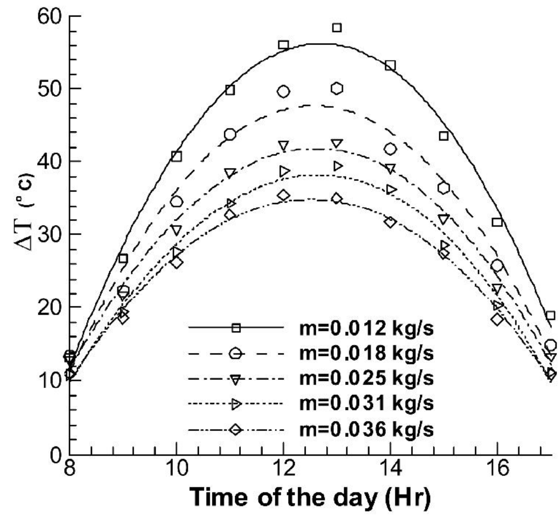


Figure 3 Temperature variation with time of a day for 6-fins SAH

The obtained results are compared with several SAHs available in the literature. The maximum temperature difference recorded by Esen [2] was about 23 ^{0}C at solar radiation of 880 W/m^2 and mass flow rate of 0.02 kg/s. The reported data of Sopian et al.

[16] with a double-pass solar air collector indicated that the maximum temperature difference was 40 ^{0}C where the flux was 950 W/m^2 with airflow rate of 0.0995kg/s. Ramadan et al. [17] investigated experimentally and theoretically a double-glass double pass solar air heater with a packed bed above the heater absorber plate. They reported that the maximum ?T was 35 ^{0}C where the flux was 850 W/m^2 and the mass flow rate of air was 0.0105 kg/s.

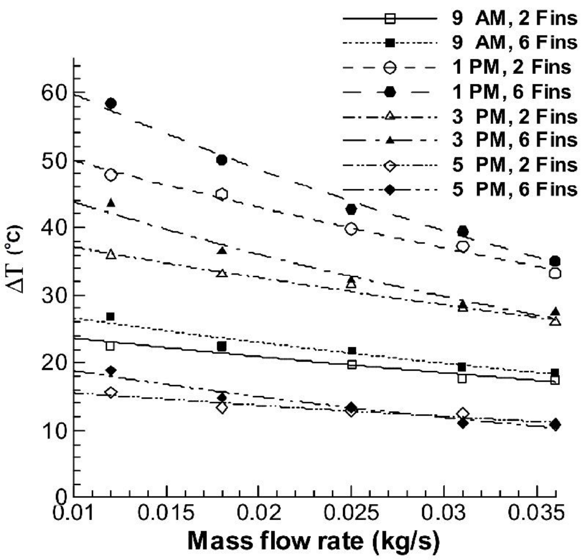


Figure 4 Temperature difference versus air mass flow rate at diference time of the day for 2 and 6 fins SAH

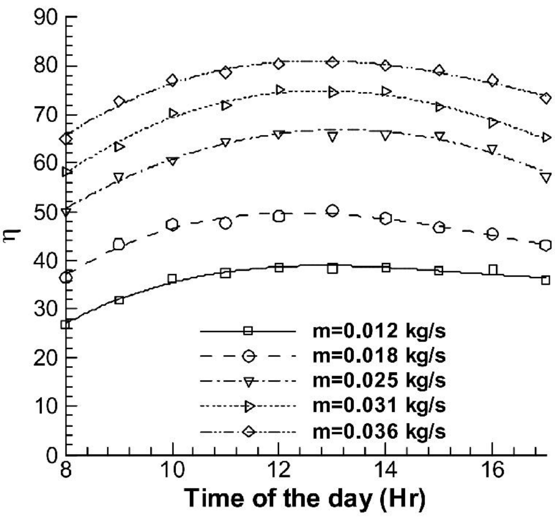


Figure 5 Efficiency variation with time of day for 2 fins SAH

Efficiency versus time at various air mass flow rates for 2 fins and 6 fins heaters are presented in Figs. 5 and 6 respectively. The efficiency of the solar collector, ?, is defined as the ratio of energy gain to solar radiation incident on the collector plane,

$$\eta = \frac{m\, C_p\, (T_{out} - T_{in})}{I\, A_c} \tag{1}$$

Where m is the air mass flow rate, C_p is the specific heat of air, A_c is the area of the collector.

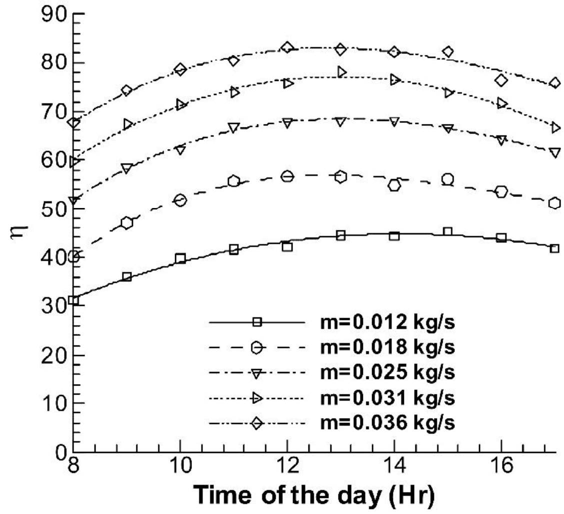


Figure 6 Efficiency variation with time of day for 6 fins SAH

The efficiencies of both models increased to a maximum value between 12:00-13:00 hrs, and then decreased in the afternoon. The uncertainty of the efficiency is calculated to be 2.4 % [2]. The efficiency of the six fins collector is higher than that of the two fins collector by 3.5 % -16.9 % depending on the air mass flow rate. The thermal efficiency in both collectors was increased as the air mass flow rate increased (Fig. 7). The maximum efficiency of SAH having two fins was linearly increased from 38.4% to 80.6% as the mass flow rate was increased from 0.012 to 0.36 kg /s. The maximum efficiency was increased from 45.2% to 83.1% at the same mass flow rate used for the six fins collector.

The aim of adding fins is to increase the effective passage length of the collector and to have a uniform flow through the entire collector. The thermal efficiency of the collector has been increased with increasing the number of the fins.

The comparison of the thermal performance of the six fins SAH with other SAHs reported in the literature is presented in Fig. 8. It is clear that the proposed six-finned SAH has higher efficiency at high flow rates.

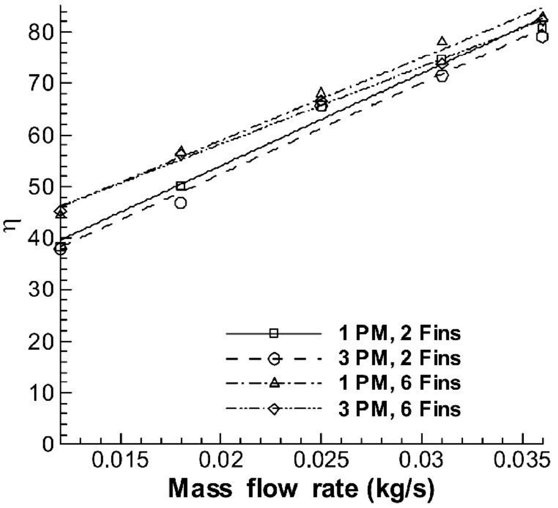


Figure 7 Variation of efficiency for 2 and 6 fins SAH for different mass flow rate at 1& 3 PM

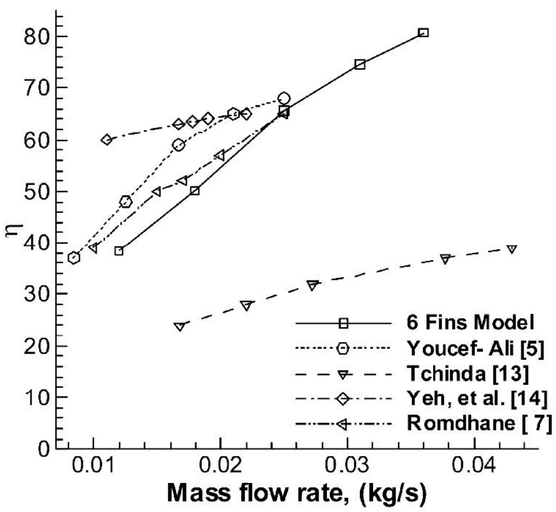


Figure 8 Comparison between the thermal efficiency with published data

CONCLUSION

This paper presents the design procedure, test results and the comparison between the measured temperatures of two different models of single pass SAH having two and six fins. The obtained results show that the thermal efficiency was increased with increasing mass flow rate of air, between 0.012 kg/s and 0.036 kg/s.

The temperature difference between the outlet flow and the ambient, ?T, was decreased with increasing mass flow rate of air. In addition, for the same air mass flow rate the thermal efficiency was increased with increasing number of the fins. The maximum efficiencies of the proposed SAHs reached were 83.1% and 80.6% at flow rate of 0.036 kg/s for the six and two fins SAH respectively. Introducing porous media between the fins in the proposed design has incresed the heat transfer area. Finally the thermal efficiency of the 6 fins SAH was compared with some of the reported ones. It is found that in the proposed model the rate of increase in thermal efficiency is higher compared to other models.

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