ENERGY ANALYSIS OF A SOLAR AIR HEATER WITH AN ABSORBER PLATE MADE OF POROUS MATERIAL

by

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In this study, the energy analysis of a solar air heater with an absorber plate made of different obstacles was made. Absorber plate of the solar air heater was created with porous steel wool. Three different absorber plates were used for the experimental study. Complex plate (Type I) was used as the first type of absorber plate, less complex plate (Type II) as the second type absorber plate, and flat plate (Type III) the third type absorber plate. On these plates, which are manufactured as three different absorber plates, steel wools are placed in a complex and less complex way. One absorber plate was left empty. In the experiments, the mass-flow rate of the air passing through the air passage channels was taken as 0.05 kg/s and 0.025 kg/s, and the optimum flow rate was found as 0.05 kg/s. In order to make heater efficiency calculations, heater inlet temperature, outlet temperature, absorber plate temperature, ambient temperature and solar radiation values were measured. Efficiency values for different absorber plate were found between 23% and 74%.

Key words: *solar heater, absorber plate, obstacle, energy, thermal efficiency*

Introduction

Energy is the ability to perform a work in thermodynamics and is an integral part of industrialized societies. Solar energy is a reliable source and does not require high and special technology in its widespread use. It does not create any significant environmental pollution during its use [1]. Solar air heaters (SAH) are a type of heat exchanger that transfers solar energy. Some innovations have been used to improve the heat transfer coefficient between the absorber plate and the air, and different shapes have been introduced in [2-6]. Various designs with different shapes and sizes of air-flow passage were tested in plated SAH. Double-pass type SAH have been introduced to increase the heat transfer area, resulting in improved thermal performance [7-9].

In the literature, various configurations of SAH have been developed. Esen [10], conducted the energy and exergy analysis of a SAH with an absorber plate consisting of different obstacles. Akpinar and Kocyigit [11], experimentally examined the SAH, which they designed for four different absorber plates and two different mass air-flow rates, and presented the results in graphs and tables. Ozgen *et al.* [12], experimentally examined the thermal performance of an SAH heater whose absorber plate is made of cylindrical cans. The highest efficiency was achieved for Type I. Arabhosseini *et al.* [13], numerically and experimentally

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examined the performance of a porous SAH equipped with a recycling system for three air-flow rates (0.009, 0.018, and 0.036 kg/s). Ucar and Inalli [14], examined the effect of different shape and arrangement of the absorber plate on the techniques of increasing heat transfer in their experimental study. Albizzati [15], conducted a study on the thermal performance of a SAH with a porous absorber plate. In this study, air inlet and outlet temperatures, air velocity, solar radiation values were measured at several points of the heater. Karim *et al.* [16], investigated the performance of flat plated, finned and V-shaped SAH both experimentally and theoretically. Moummi *et al.* [17] conducted a study on the thermal performance of a collector by placing rectangular absorber plates perpendicular to the flow. In this study, the thermal performance of three types of SAH was experimentally examined the results showed that the thermal performance of Type I was better.

Experimental study

Design of heaters

In this study, the thermal performance of a SAH whose absorber plate is made of porous material was experimentally examined. The heater frame is 120 cm long, 80 cm wide, and 40 cm high. In the heater, 4 mm thick window glass was used as a transparent cover, chipboard wood was used as the frame material, and 3 cm thick Styrofoam was used as the insulation material. The photograph of the experimental set-up is shown in fig. 1.

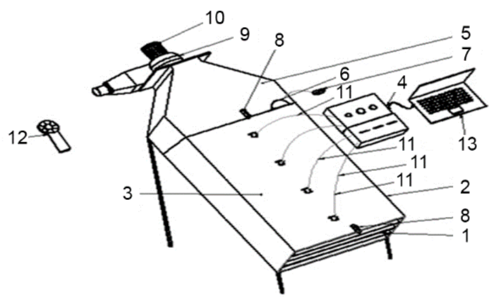

Figure 1. Photograph of the experimental set-up; *1 – absorber plate, 2 – collector box, 3 – glass cover, 4 – temperatures scanner, 5 – sheet, 6 – pyranometer, 7 – pyranometer recorder, 8 – thermometers, 9 – fan, 10 – fan engine, 11 – thermocuples, 12 – anemometer, and 13 - computer*

To create the absorber plates, 180 porous steel wool was collected, and these wires were adhered to both the top and the bottom of the 1.5 mm thick galvanized sheet using a type of silicone glue. After the adhering process, this sheet is painted with black matte paint to form an absorbing plate. In the first of these absorber plates formed, a total of 102 steel wools were complexly placed (Type I) as seen in fig. 2(a), and 78 steel wools were placed in a regular row (Type II) as seen in fig. 2(b). Wires were not used on the third absorber plate that we used in our study and the absorber plate that we specified as the flat (Type III) type is shown in fig. 2(c). The images of these absorber surfaces inside the heater frame are also seen in fig. 2.

Kipp *δ,* Zonen CM3 Pyranometer was used to measure the total radiation intensity on the unit horizontal surface. The heater is connected by way of a pipe to the inlet port of the air circulation fan with a flow rate of 800 m^3/h. A digital anemometer (AM-4206M) measuring air velocity and a mercury thermometer (0-100 °C) measuring the temperature of the air at the inlet and outlet of the heater were used. The *T*-type Cu-constantan thermocouples were connected to four points at equal intervals of 24 cm to measure the temperatures of certain points of the absorber plates. The other ends of the thermocouples were connected to the CR 510 Data Logger and the values were read.

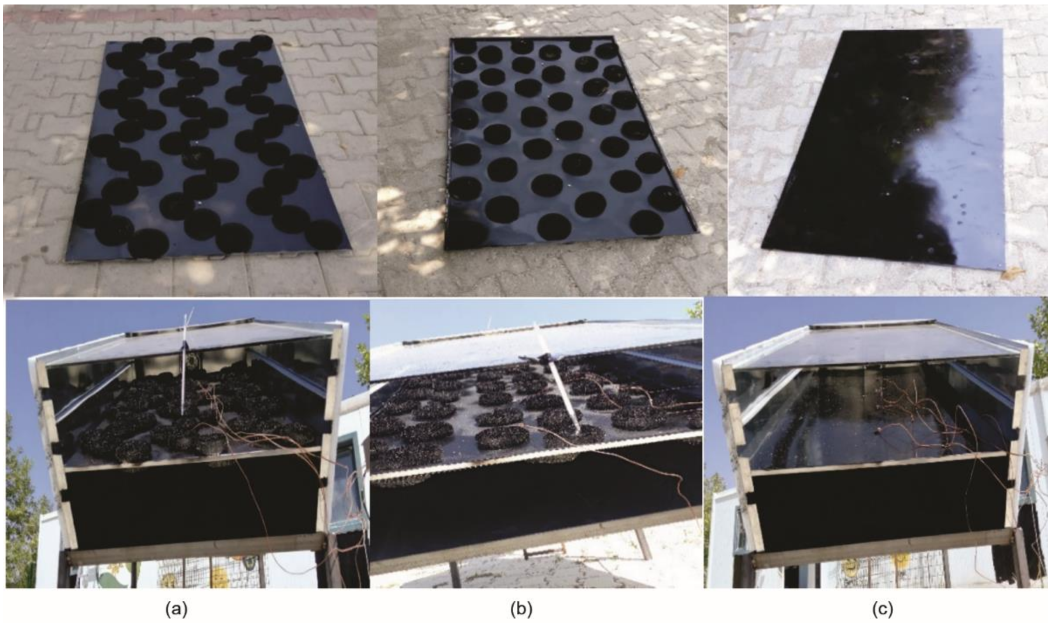

Figure 2. Absorber plate types and the appearance of these absorber plates in the heater frame; (a) Type I, (b) Type II, and (c) Type III

Thermal analysis

Experiments were carried out between July 1-30, 2020 in the workshop area of Fırat University, Faculty of Technology, Department of Mechanical Engineering. The theoretical model for the operation of the unstable solar heater is made using a thermal energy balance [10].

$$\text{[Accumulated energy] + [Energy gain] = [Absorbed energy] – [Lost energy]} \tag{1}$$

The following expressions are formulated for each term of eq. (1):

$$\left[\text{Accumulated energy}\right] = M_p C p_p \left(\frac{\mathrm{d}T_{p,\text{ave}}}{\mathrm{d}t}\right) \tag{2}$$

$$\left[\text{Energy gain}\right] = \dot{m} C p (T_\text{out} - T_\text{in}) \tag{3}$$

$$\left[\text{Absorbed energy}\right] = \eta_0 I A_c \tag{4}$$

$$\left[\text{Lost energy}\right] = U_c (T_{p,\text{ave}} - T_e) A_c \tag{5}$$

By combining eqs. (2)-(5), the thermal energy balance equation necessary to explain the operation of the solar heater is obtained:

$$M_p C p_p \left(\frac{\mathrm{d}T_{p,\text{ave}}}{\mathrm{d}t}\right) + \dot{m} C p \left(T_\text{out} - T_\text{in}\right) = \eta_0 I A_c - U_c (T_{p,\text{ave}} - T_e) A_c \tag{6}$$

$$\eta = \dot{m} C p \frac{T_\text{out} - T_\text{in}}{I A_c} \tag{7}$$

Experimental results

Calculated values and obtained data for the days when the experiments were conducted are shown in graphs. In these graphs, the temperature change of the air entering and leaving the collector for flow rates of 0.025 kg/s and 0.05 kg/s, the variations of the efficiency and temperature values, which were measured with the help of thermocouples placed on the absorber plate at equal intervals and over time, are seen. The efficiency variation of these three types of heaters with time is shown in fig. 3 for the mass-flow rate of $\dot{m}$ = 0.025 and $\dot{m}$ = 0.05 kg/s. Efficiency at high flow varies between 46% and 74% for Type I, between 40% and 63% for Type II, and between 30% and 62% for Type III. Maximum efficiency for high flow rate is 74%, 63%, and 62% for three heaters, respectively. Efficiency for low flow varies between 28% and 62% for Type I, 27%, and 56% for Type II, and between 23% and 49% for Type III. Maximum efficiency at low flow rate is 62%, 56%, and 49% for three heaters, respectively.

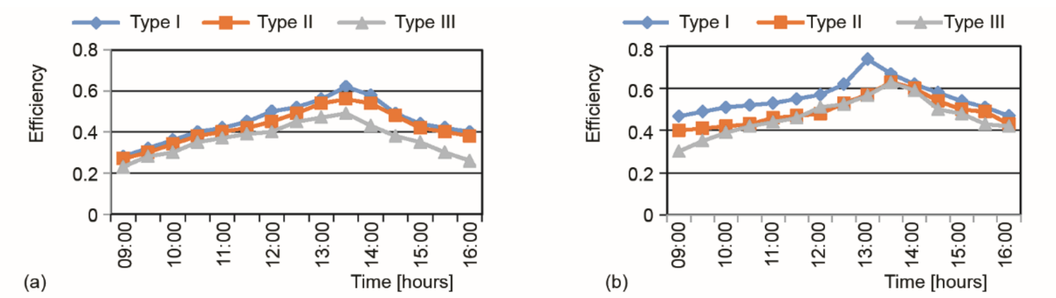

Figure 3. Efficiency variation with time for different types of absorber plates; (a) $\dot{m}$ = 0.025 kg/s and (b) $\dot{m}$ = 0.05 kg/s

As can be seen from the figures, the efficiency of Type I is higher than that of Type II. This provides the highest heat transfer coefficient, the highest absorber temperature and reduced thermal heat loss. The variation of absorber plate temperatures and solar radiation values over time for Type I, Type II and Type III collectors is shown in fig. 4 for 0.025 kg/s and 0.05 kg/s air-flow rates. It can be clearly seen from the graphs that the temperature variation increases until 13:00 in the afternoon in parallel with the change in the radiation intensity on the absorber plate, then decreases with the decrease in the radiation intensity. In fig. 4, the highest hourly measured solar radiation intensity value was 970 W/m^2 for 0.025 kg/s and 995 W/m^2 for 0.05 kg/s.

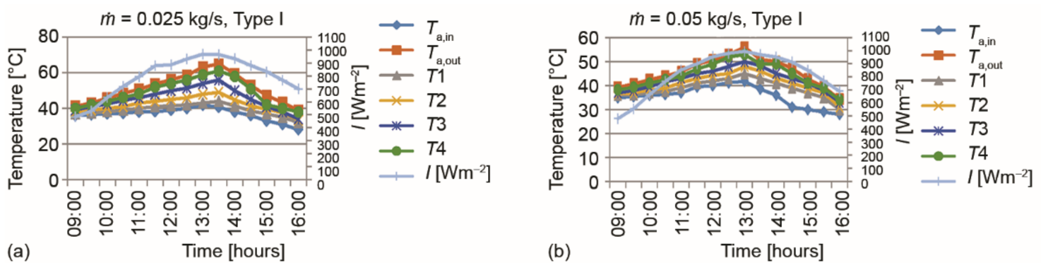

Figure 4. Variation of surface temperatures and radiation value over time for Type I; (a) $\dot{m}$ = 0.025 kg/s and (b) $\dot{m}$ = 0.05 kg/s

Conclusion

In order to obtain a high efficiency, porous steel wools were placed above and below the absorber plate in the heater Type I and Type II. In this study, three types of SAH were investigated. Absorber plates were specified as Type I, on which the wires were complexly placed, Type II, on which the wires were arranged in a regular row, and Type III with a flat absorber plate. The thermal performances of these three heaters for air-flow rates of 0.025 kg/s and 0.05 kg/s were experimentally investigated. The efficiency of Type I is higher than that of Type II. The Type III has less efficiency than other heaters. It stems from the fact that this heater has a flat absorber plate and its heat transfer area is less than the others. The heater Type I, on which the wires were complexly placed on the absorber plate, is designed to have double air pass. Having a double air pass has a positive effect on the heater performance. The efficiency obtained from this heater reaches up to 74%, which is satisfactory for a SAH.

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