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Experimental determination of natural convection heat transfer coefficient in a vertical flat-plate solar air heater

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Abstract

In this study, natural convection heat transfer in a vertical flat-plate solar air heater of 2.5 m height and 1 m width, with one- and two-glass covers was studied experimentally. Totally six cases of airflow (two for air heater with one glass cover and four for air heater with two-glass covers) were considered. These cases included states that air could flow within spaces between absorber plate and glass covers or air was enclosed in such spaces. Absorber plate temperature, back-plate temperature, glass cover temperatures, mass flow rates of air within channels and the solar radiation were measured. The following relations are suggested:

For channels in which air could flow:

$Nu = 0.7362Ra^{0.2579}$

For enclosures:

$Nu = 0.1377Ra^{0.2229}$

In the first relation, the characteristic length in *Ra* and *Nu* is the height of the air heater and in the second relation this length is the distance between the two vertical plates.

The efficiency of the air heater was determined in various cases. The maximum efficiency was found for when the air heater had two glass covers and air could flow in all channels.

Keywords: Solar energy; Flat plate solar air heater; Natural convection; Heat transfer coefficient; Experimental method

1. Introduction

Flat-plate collectors are classified into two groups according to fluid used. Water is usually used in liquid collectors and air, in gas collectors. Since the air has worse thermodynamic properties in terms of heat transfer compared with liquid, the efficiency of solar air heaters is naturally low. For this reason, several types of solar air heaters have been proposed over the recent years in order to improve their performance.

Flat-plate solar air heaters are simple devices to heat air by utilizing solar energy and employed in many applications requiring low to moderate temperature below 60 °C, such as crop drying and space heating. Solar collectors have low manufacturing and maintenance costs. In these air heaters buoyancy is the main force to create airflow. The principal types of these heaters are; the single pass with front duct, rear duct, double duct and double pass (Forson et al., 2003). Air heater considered in this study has three channels.

Recently, many studies have been conducted on the efficiency and energy analysis of solar air heater.

Elenbaas (1942) carried out the first work on heat transfer coefficient evaluation in vertical channels. Bodoia and

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Osterle (1962) simulated (2-D) airflow between two vertical flat plates. Aung (1972) studied heat transfer in vertical channels with non-symmetry thermal boundary conditions experimentally and numerically. Bar-Cohen and Rohsenow (1984) revised the Elenbass relation and proposed new correlation for heat transfer coefficient in vertical parallel plates. Azevedo and Sparrow (1985) studied heat transfer in sloping channels. Lapica et al. (1993) proposed correlations for natural convection heat transfer coefficient in a vertical channel. Incropera and Dewitt (1996) proposed correlations for natural convection heat transfer coefficient between absorber and glass cover of an air heater. Rodono and Voples (1998) studied natural convection in an air solar collector. Rodrigues et al. (2000) modeled natural convection in a heated vertical channel for room ventilation. Ong and Chow (2003) proposed a mathematical model of a solar chimney.

MacGregor and Emery (1969) studied natural convection heat transfer in vertical enclosures. Hollands et al. (1975) studied natural convection heat transfer in sloping enclosures.

In the present study new correlations are being for natural convection heat transfer coefficient in vertical channels and enclosures of considered solar air heater.

2. Description of solar air heater considered in this work

The solar air heater constructed and used in this study is shown in Fig. 1. This air heater is used in space heating. It is a rectangular box of 2.5 m height, 1 m width and 0.35 m depth. There are maximum three passages that air could flow within them. A black-painted iron plate of 2 mm thickness was used as absorber. An iron flat plate of 2 mm thickness was used as back plate and an insulation plate (polystyrene) of 2.5 m height, 1 m width and 0.1 m thickness was used to insulate back plate. Two-glass covers of 2.5 m height; 1 m width and 3 mm thickness were used. Four plates mentioned (back plate, absorber and two-glass covers) were installed in parallel and with equal distance between them (5 cm). Therefore there were three channels (between absorber and back plate, absorber plate and first glass cover and first glass and second glass covers). Other parts of devise are made of wood. Air could flow into the channels from bottom and back of the air heater and come out of them from top and with higher temperatures. Description of various parts of considered solar air heater are shown in Fig. 2.

Fig. 1. Constructed solar air heater.

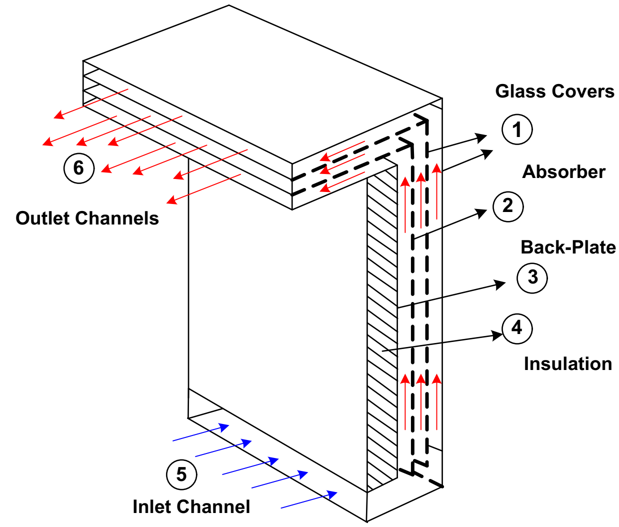

Fig. 2. Description of various parts of considered solar air heater.

There are six operational modes that have been studied created by using one or two-glass covers, opening and closing the channels. These case studies are shown in Fig. 3. In this figure, letters a, b, fg and sg refer to back-plate, absorber, first glass cover and second glass cover, respectively.

3. Experimental setup

Schematic cross-section of experimental setup used in this study is shown in Fig. 4. Also, measuring instruments are illustrated in Table 1. A Testo digital thermocouple reader was used to read temperature. Instruments were calibrated by DKD (Deustsher Kalibrierdienst) Calibration Institute. The experiments were implemented in 2005 (Sharif University of Technology, Tehran, Iran). The solar air heater was oriented facing south and exposed to solar radiation. The absorber is heated by solar radiation and warm air can flow within the channels caused by buoyancy force. Various parameters including velocity and temperature of outflow air, temperature profile of plates in vertical direction (four points), solar radiation incident to the outer glass cover, inflow air temperature, ambient temperature (under Shadow) and velocity of wind, were recorded manually at 15 min time intervals. Measurement of temperature profile in horizontal direction was implemented once (three