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Analytical and experimental investigations of packed bed solar air heaters under the collective effect of recycle ratio and fractional mass flow rate

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ABSTRACT

This research work presents the thermal performance of a packed bed solar air heater under the combined effect of recyclic flow and fractional total mass flow rate. The investigated solar air heater consists of three air flow ducts and the fraction of total mass flow rate serves as an input to first and second ducts of the solar air heater. Based on the inputs, the first duct consists of single air pass whereas the second and third ducts are operated under recyclic air flow. In order to produce the recyclic effect, air exiting from the outlet of the second duct is recycled back through the third duct to the inlet of the second duct and gets mixed with inlet fraction of the total mass flow rate of the air. In order to predict the effect of fractional total mass flow rate two cases are considered i.e. when two streams of i) equal fraction ii) unequal fraction of mass flow rate flowing through the first and second duct of solar air heater by dividing the total mass flow rate. Moreover, results of this solar air heater are compared with another recyclic type solar air heater under similar geometric and operational flow parameters. The results indicate that the thermo-hydraulic efficiency of the proposed solar air heater is significantly higher at lower recycle ratio and the equal fraction of total mass flow rate.

1. Introduction

For many years, solar air heaters have gained great importance across the world among several researchers and proved to be one of the promising technologies for several thermal applications [1]. However, the literature survey spanned past few years depicts that numerous new designs configurations of solar air heater have been investigated worldwide. It has been reported that new designs of solar air heaters can deliver up to 20%–60% higher thermal performance as compared to the corresponding conventional designs. The novelty of such designs compared with conventional designs of solar air heater is in terms of increased heat transfer area and the air flow passages. Studies revealed that increase in heat transfer area can be achieved by attaching fins [2,3], fins plus baffles [4,5], fin plus porous media [6,7], porous media [8–10], flow arrangement [11–15] and artificial roughness [16] to absorber plate. As far as the increase in air flow passages is concerned it can be achieved by increasing number of ducts.

The recent designs of solar air heater consist of three ducts, however one of the three ducts formed between two glass covers involves natural convection due to fixed mass of air [8]. It is reported that fixed mass of air works as an insulator and reduces the losses through glass covers. However, the current literature is lacking in the area of investigations based on the influence of air flow and forced convection through the duct formed between the two glass covers. Moreover, incorporation of the same with simultaneous flow of air through other two ducts on the thermal performance of solar air heater.

In the present work, thermal performance of recyclic type solar air heater is enhanced by using three air flow ducts and provisions i.e. first, by increasing heat transfer area using porous media above the absorber plate; second, by providing recyclic flow arrangement and; third, by providing single pass through glass covers. Further, the effect of fractional mass flow rate on the thermal performance is investigated. Therefore, thermal and thermohydraulic efficiencies of the proposed solar air heater under effect the fraction of total mass flow rate as input to first (glazed) duct to provide single

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air pass, and second duct consisting of porous media to provide recyclic air flow through third duct is investigated both analytically and experimentally. Furthermore, the effect of various input parameters on thermohydraulic efficiency is also presented.

2. Experimental setup

Experimental investigation is critical and considered as a systematic procedure which is usually conceded in heat transfer problems in order to demonstrate or establishing the validity of the phenomena. The present chapter emphasizes the details of experimental setup, instrumentation and experimental procedure used to investigate thermal performance of proposed recyclic type packed bed solar air heater designs. Moreover, measurements carried out in this investigation provide a set of experimental data that is used to calculate the performance and validate the analytical models of solar air heater. The present experimental work involves designing and construction of two recyclic double pass packed bed solar air heater designs, categorized as Design-I and Design-II. The setups were designed and tested according to the Beckman et al. [17] and ASHARE standard 93–77 [18].

2.1. Description of experimental setup

The experimental setup of the proposed solar air heaters consist of an absorber plate and a back plate each of 2 mm thick galvanized iron sheet with blackboard painted black surfaces on both sides and two glass covers of 4 mm thickness. Twelve layers of the wire mesh as a packed bed material were placed one above the other on the upper side of the absorber plate. Sides of the duct were made up of 45 mm thick softwood which acts like well insulated walls of the solar air heater. There is a glass wool insulation of 50 mm thickness placed below the 12 mm plywood below the back plate [18]. Both of the glass covers are maintained at a distance of 20 mm from each with the help of two rectangular grooves provided to the soft wooden sides of the heater [20].

The upper channel and lower channel of the solar air heaters are provided by inserting an absorber plate between the lower glass cover and back plate and separating them at a distance of 60 mm each from the absorber plate, respectively. The schematic views of the duct of double pass solar air heaters i.e. Design-I and Design-II are shown in Figs. 1 and 2, and Figs. 3 and 4, respectively, while the schematic view of the test rig is presented in Figs. 5 and 6, respectively.

In order to achieve the uniform distribution of air through the packed bed, a diverging and convergent section made of plywood was provided at the inlet and outlet of the upper duct of the system. The experimental set-up was supported on a frame made of mild steel angle iron of size 25 × 25 × 5 mm with an extra facility to hold the solar simulator. Two perforated aluminium plates, 1 mm thick and equal to the cross section area of the passage were placed perpendicular to the flow direction to allow proper mixing of the air at the exit and to facilitate the measurement of air temperature after mixing at exit of solar air collector. The inlet section was connected to blower through a G.I pipe and flexible pipes. Two blowers each of 2.2 kW (3.0 HP) capacity were used to regulate the air through the air heating system. One centrifugal blower was used to force the ambient air into heater through the diverging section, whereas the other is used to regulate the recycled air flow through the heaters ducts. The air mass flow rates were calculated by measuring the pressure difference through well calibrated orifice using a vertical U-tube manometer filled with water. The pressure drop across the air heater's ducts was measured using a digital micro- manometer. Calibrated K-type thermocouples were employed to measure the temperature of the glass covers, the wire mesh, the absorber and back plates at various locations within the heaters ducts and the flowing air at the inlet and outlet. Calibration of the thermocouples was done using digital multi-meter. The effect of ambient wind was provided by a fan. The ambient air temperature was maintained by using an air conditioner. The incident solar radiations were simulated using an artificial solar simulator consists of equally spaced 45 halogen

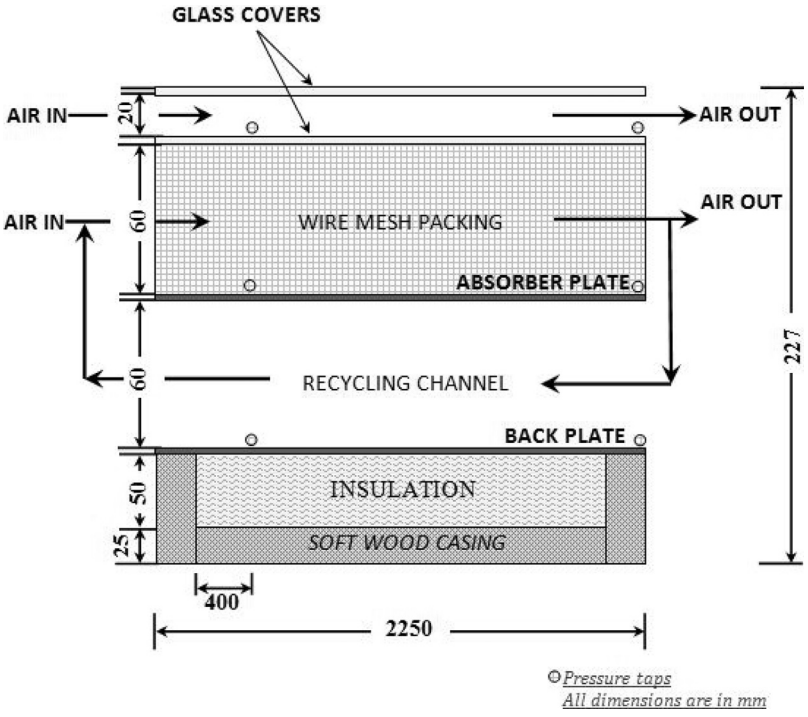

Fig. 1. Schematic diagram of recyclic double pass packed bed solar air heater Design-I.