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Comprehensive study on solar air heater with circular and V-type turbulators attached on absorber plate

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ABSTRACT

Performance enrichment in a single pass SAH (solar air heater) with circular and V-shape inserts are considered in this paper. Two identical SAH: conventional and modified SAH are tested with different Reynolds number ranging from 6000 to 12,000. Circular and V-shape turbulators are fixed in the absorber plate of modified SAH at six different configurations; inline arrangements with 4 × 4 (type-a), 5 × 4 (type-b), 6 × 4 (type-c) and 6 × 4 zigzag arrangement of circular inserts (type-d). Experiments are extended by introducing V-type inserts in convex (type-e) and concave shape (type-f) to create additional turbulence motion. Experiment results revealed that the system efficiency increases with Reynolds number and number of turbulators in absorber plate. Air temperature reaches an upper value of 66 °C in type-f with the mass flow rate of 57.7 kg/hr. Nusselt number increases with the Reynolds number and reaches the maximum of 210 for type-f turbulators at Reynolds number of 11615. Thermal enhancement factor decreases with increase in Reynolds number for all modifications. First law, thermohydraulic and second law efficiency increases up to 85%, 63% and 45% respectively for type-f at Reynolds number of 11615. Theoretical analysis also carried out and agrees well with experimental results.

1. Introduction

Energy is a crucial driving factor in today's world and plays major role in economic growth and industrialization. Population growth and its material needs increase the demand of energy every year. On the other side, consumption of fossil fuel reduces the available resource and cause to environmental degradation and it creates the awareness towards renewable energy sources. Considering other alternatives, solar energy stands a promising future of renewable energy. Solar energy is free and provides an infinite and eco-friendly reservoir of energy. The easiest way to utilize solar energy is by converting it into thermal energy using solar collectors.

Air heating is one of the major solar thermal applications, used for space heating and process heating like laundry, desalination, crop drying and other drying processes. Utilizing of conventional electrical energy for this process will increase the process cost as well as pollute the environment. Using solar energy for air heating will reduce the operational cost of the system, environmental free and reduce the consumption of conventional energy.

Conventional air heaters are typically low efficient due to its high thermal resistance and low heat transfer rate. Heat transfer rate can be improved by creating turbulence in the flow field. Mohammadi and Sabzphoosanim [1] investigated the influence of fins and baffles attached with the absorber plate of single pass SAH and the results revealed that attaching fins and baffles effectively increases the outlet air temperature and efficiency, in comparison to a simple conventional device. Karsli et al. [2] fabricated a single pass flat plate collector for drying applications and concluded that efficiency depends on solar radiation and the surface geometry of solar air collectors. Krishnananth and Murugavel [3] investigated the ability of a double pass SAH to store the heat with paraffin wax and found that the efficiency of SAH integrated with thermal storage medium is higher than the conventional one.

Gupta and Kaushik [4] conducted an exergetic performance and parametric studies of a solar air heater. The exergy evaluation criterion routed an optimal value of aspect ratio and duct depth, which depends on mass flow rate. Sabzpooshani et al. [5] studied the exergetic analysis for single pass air heater with baffles and established that, increasing the baffle width, reducing the distance between baffles and increasing the number of fins are effective at low mass flow rates and the inverse trend in higher mass flow rate.

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Singh et al. [6] made an exergy analysis on air heater having v-down rib roughness on absorber plate and resulted in better performance compared with conventional air heater under same climatic conditions. Lanjewar et al. [7] experimentally studied the heat transfer and friction factor in duct with w-shaped rib roughness on absorber plate and concluded that thermo-hydraulic performance improves with angle of attack of the flow with maximum at 60° and relative roughness height. Sun et al. [8] studied the influence of duct depth on the performance of solar air heaters and discovered an optimum height of 10 cm for single pass and for double pass, the ratio of upper to down channel height should not be less than 11 cm.

Sebaii et al. [9] considered the double pass flat and v-shaped corrugated plate solar air heaters and concluded that v-shaped air heater displays 11–14% more efficiency and better thermo hydraulic performance than the flat plate double pass air heater. Tanda [10] tested the SAH with different types of ribs on absorber plate and concluded that repeated ribs were considered as effective way to improve convective heat transfer and also that all other rib configurations are better than smooth channel air heater.

Karwa and Chitoshiya [11] examined the SAH having v-down ribs on absorber plate and found that 12.5–20% more thermal efficiency than the normal smooth duct. Aldabagg et al. [12] reported the performance of single and double pass air heaters with wire mesh as packing bed instead of flat absorber plate and found that efficiency of double pass is 34–45% greater than single pass and also displays that packed bed collector indicates a substantial enhancement in thermal efficiency over the conventional collector. Ramadan et al. [13] stated that double pass SAH with packed bed materials like limestone and gravel exhibits increased thermo hydraulic performance.

Chaube et al. [14] studied the different geometries square, rectangular, chamfered, semicircular, circular rib for a Reynolds number range from 3000 to 20,000 and the best thermal performance was found with chamfered ribs. Nowzari et al. [15] considered the single and double pass SAH with partially perforated covers and packed mesh and concluded that efficiency of double pass is always 5–22.7% greater than single pass SAH. Sara et al. [16] investigated the performance of flat plate collector fitted with rectangular and perforated blocks and confirmed that energy gain of about 20% larger than the channel without perforated blocks. Gentry and Jacobi [17] achieved an average of 50–60% heat enhancement in a flat plate collector using delta-wing vortex generators. Zhou and Ye [18] stated that curved trapezoidal winglet has best thermo-hydraulic behavior at fully turbulent flow region.

Alvarez et al. [19] reported that SAH with aluminium cans on absorber plate has maximum efficiency of 74%. Ozg et al. [20] experimentally investigated the double flow air heater with aluminium cans and it also leads to improved thermal efficiency than the single flow SAH with aluminum cans fitted on absorber plate.

Aforementioned literatures explained that the ability of solar air heater is considerably improved by creating the turbulence effect in flow field. In previous works, fins with baffles, different types of rib (v shape, w shape, square, rectangular, circular, chamfered and semi circular), corrugated plate, wire mesh, packed bed materials, perforated duct, rectangular and solid block, delta wing vortex generator, trapezoidal winglet and aluminium cans were used as insert in SAH. Presence of these turbulators enhances the heat transfer rate in the solar air heater. Thus the present objective of this work is to impact the recasting of a solar air heater with different new configurations namely circular and V - shape turbulators in the flow field to augment its efficiency. Initially, experiments are carried out with circular turbulator in the flow passage as inline arrangement with number of insert ranging as 4 × 4, 5 × 4, 6 × 4 and then number of insert with 6 × 4 zigzag arrangement for optimized result. To create the additional turbulence in the flow field, two V-type inserts are placed inside the 6 × 4 zigzag circular turbulators at convex and concave shape. A conventional SAH is simultaneously experimented with modified SAH for comparison purpose.

2. Experimental setup and procedure

A graphic view of the conventional single pass SAH is displayed in Fig. 1. Both solar air heaters consist of a sheet metal enclosure (1 mm thickness) with the size of 0.75 × 0.95 × 0.1 m^3 which makes the test section of SAH. This enclosure is extended as duct in both sides with the reduction in breath from 0.75 m to 0.2 m in 0.3 m length. Window glass of 6 mm thickness used as transparent cover. Black coated steel plate with the thickness of 1.6 mm and area of 0.7 × 0.9 m^2 is used as an absorber plate in both SAH. Thermocol of thickness 5 cm is used as insulation material to reduce the heat loss through the side and bottom. SAH is placed at an inclination of 10° equal to latitude of Madurai to receive possible utmost radiation (Fig. 2).

Modified SAH is designed with same features of conventional SAH except providing turbulators (Circular and V-type turbulators) in the absorber plate to create turbulence effect. Circular turbulators are made by hollow steel pipes of 2 inch diameter with 10 cm length. V-type turbulators are made by L-angles with the size of 5 × 2 × 0.03 cm. The modifications and number of turbulators are given in Table 1 and in Fig. 3.

Air blower (1 hp) is connected with the flow control valve to provide appropriate quantity of air and flow rate is measured by adopting an orifice meter setup. Pressure drop across the test section is measured with the help of U-tube manometer. The temperature of the systems is measured in absorber plate (4 points), glass cover (2 points), inlet and outlet air by using K-type thermocouple. Thermocouples are linked with digital temperature indicator and selector switch arrangement. Solar radiation is measured with the help of solarimeter. All the experiments were carried out from 9 am to 4 pm local time at Thiagarajar College of Engineering, Madurai, India in the month of June to September 2014. Due to varying climatic condition, the experiments are operated at different days and discussion is made for average solar radiation and ambient temperature condition within the deviation of 10% for comparison purpose.

3. Theoretical analysis

One dimensional steady state energy balance is formulated for the single pass solar air heater considered in this work. Some assumptions are made to simplify the analysis: (i) There is no air leakage from the heater and negligible edge los; (ii) Air inside the heater does not absorb the solar radiation; (iii) Air has uniform velocity inside the heater; (iv) The air temperature varies in the flow direction only. On the basis of above assumptions, the following energy balance equations are formulated as follows for conventional solar air heater.

Energy balance at absorber plate [21]

$$I\alpha_p\tau_g A_p = m_p C_{p,p}\frac{dT_p}{dt} + q_{c,p-a} + q_{r,p-a} + q_{loss} \tag{1}$$

Energy balance for fluid medium [21]

$$q_{c,p-a} + q_{r,p-a} + q_{c,g-a} = m_a C_{p,a}\frac{dT_a}{dt} \tag{2}$$

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