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Experimental performance investigation of air heating solar collector with fins and twisted tapes

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Abstract: The current work outlines the experimental findings of an air heating solar collector integrated with fins and twisted tapes of twist ratio 'Y=2.66' for the range of air flow rate from 0.007 kg/s to 0.0158 kg/s. The effects air flow rates on the performance of this new design of the collector have been investigated. The outcomes have also been compared with those of the conventional solar air heater. The performance of the collector with fins and twisted tapes has been perceived to be improved substantially as compared to conventional solar air heater.

Keywords: Fins, twisted tape, solar air collector

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1 Introduction: Air heating solar collector is a device which absorb the energy emitted from the sun and transform it into heat energy of the air. Its major applications include space heating, crop drying, seasoning of timber, etc. [1]. However, the thermal conversion efficacy of conventional solar air heater is poor. The efficacy of such a heater can be improved by augmenting the rate of heat transfer from the absorber plate to the air. It can be accomplished by employing various passive heat transfer augmentation techniques, e.g., fins [2-3], ribs [4], roughness [5-7], twisted tape inserts, etc. [8]. Yao et al. [9] numerically analyzed the heat transfer in turbulent regime in an evacuated tube solar water heater with twisted tapes. The findings indicated that the heat transfer in case of twisted tapes with twist ratio Y=2.5 and 4 are respectively 9.29 % and 1.07 % larger than the smooth tube water heater. Ghadirijafarbeigloo et al. [10] numerically studied the solar concentrating collector with perforated louvered twisted-tape of twist ratio 2.67, 4, and 5.33 in the receiver tube. Results showed a significant increase in heat transfer and pressure drop in comparison with a plain twisted tape in the tube and plain tube. Jaisankar [11] performed an experiment with solar water heater equipped with helical twisted tapes for development of correlations to predict the heat transfer and friction factor characteristics. Raja Sekhar et al. [12] studied for the improvement of heat transfer in a tube by using Al_2O_3 nano-fluids and twisted tapes. Saha and co-workers [13–14] carried out an experiment in laminar flow through the square and rectangular ducts fitted with vortex generator along with ribs and wire coil inserts. This work emphasis the experimental enhancement of heat transfers in solar air collector by using fins in combination with twisted tapes.

2. Experimentation: The test setup is schematicallly shown in Figure (1). It comprises of two similar ducts of dimension 1.2 x 0.4 x 0.02 m^3, one each for smooth and finned absorber, which makes the test section. A glass of 4 mm thickness is used as transparent cover, black coated G.I sheet of 1mm thickness and area 1.2 x 0.4 m^2 is used as absorber plate. The absorber plate is welded with fins of fin pitch 3 cm and the twisted tapes of twist ratio *Y=2.66* has been inserted in space formed by two fins. A 6 cm thick layer of glass wool is used as an insulation to the bottom. Air blower with flow control valve is used to supply the required quantity of air.

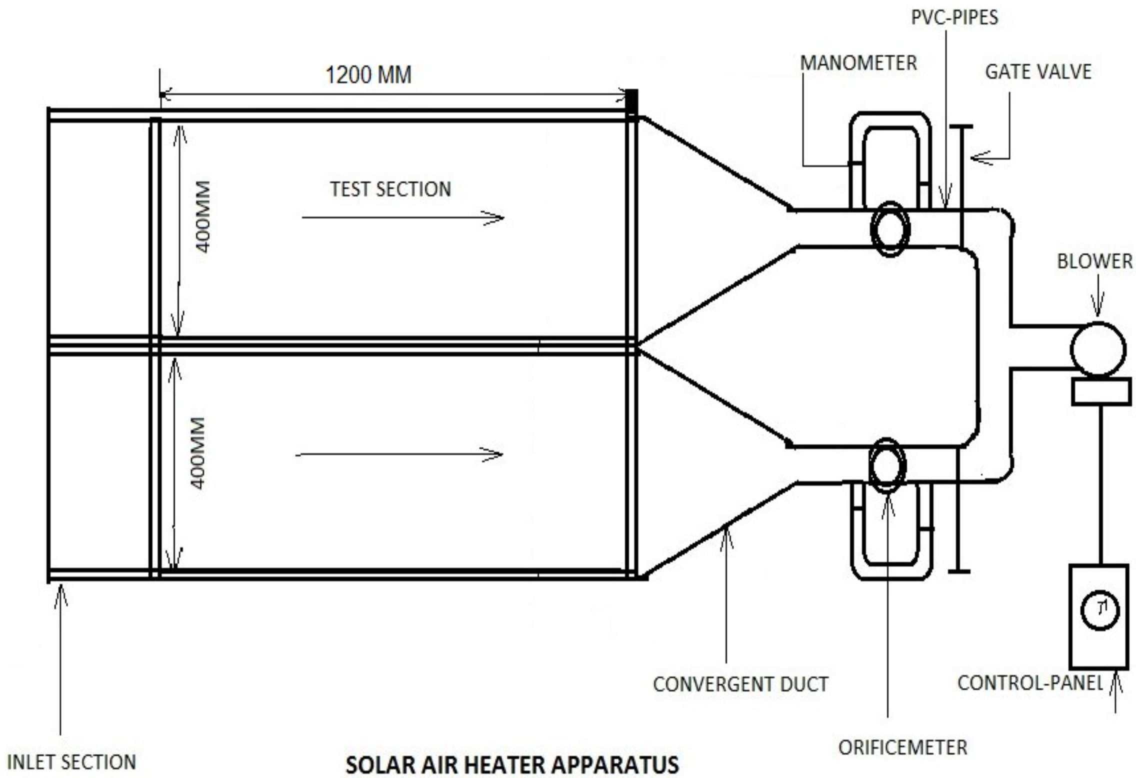

Figure (1): Solar air heater apparatus.

The air flow rate is quantified with pre-calibrated orifice meter. The pressure drop through the test length is quantified by a digital micromanometer. The temperatures of the absorber plate, inlet, and outlet air are estimated by J-type thermocouples connected with digital data analoger. Solar radiation is measured by pyranometer. The experiments were carried in the actual outdoor condition in clear sky days of March 2017 from 10 am to 2 pm.

3. Data Reduction: Experimentally measured parameters are used to evaluate the air temperature increment, Nusselt number, and thermal efficiency. Methods to evaluate the required parameters are discussed below.

3.1 Nusselt Number (Nu): The useful heat gain by the air, Q_u from the absorber surface, can be equated as

$$Q_u = \dot{m}c_p(T_o - T_i) = h_{c,p-f}A(T_p - T_f) \tag{1}$$

where, *A* is the total surface area and can be determined as

$$A = L_1L_2 + N(2L_1H_f + L_1t) \tag{2}$$

in which '*N*' is the number of fins. L_1 and L_2 are the length and width of the solar collector respectively, H_f and t is height and thickness of fins respectively. From equation (1), heat transfer coefficient can be intuited and the Nusselt Number can be evaluated as:

$$Nu = h_{c,p-f}D_h / k_{air} \tag{3}$$

3.2 Thermal efficiency (η_{th}): Thermal efficiency of the heater is the ratio of useful energy gain by air to the total energy incident on the collector during same period of time. Higher thermal efficiency indicates more heat absorption to the air.

$$\eta_{th} = \frac{Q_u}{IA_c} \tag{4}$$

4. Results and Discussion: The current section presents the experimental results of the studied solar air collector in terms of Nusselt number, temperature rise of air and thermal efficiency. Figure (2) shows the variation of solar efflux against the day time of all those days for which the analysis has been carried out. The solar intensity as anticipated raised with advancement of time to a uttermost value in between the 12.00 hr. to 13.00 hr. and then decreased afternoon. The daily average solar flux during the study was found to be 794.10 W/m^2, 804.70 W/m^2, 790 W/m^2, and 804 W/m^2. The value of daily mean solar radiation intensity suggested that the solar flux was stable as all mean radiation were within the close range.

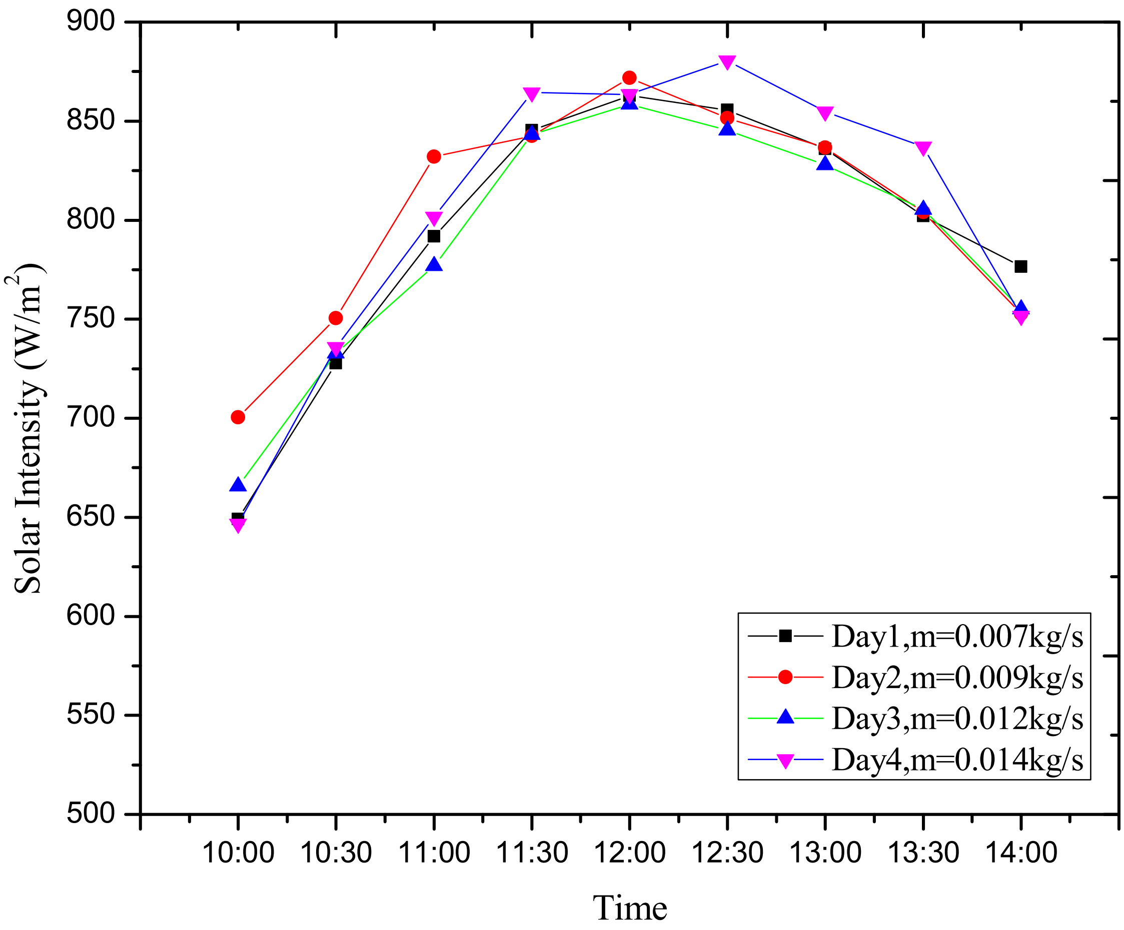

Figure (2): Variation of solar intensity with time.

Figure (3 and 4) report the fluctuation of air temperature rise, $\Delta T = T_o - T_i$, for the heaters having smooth absorber and absorber with fins and twisted tapes with respect to the local time of the day for various air flow rates. It is evident from the figure that the temperature rises of air increases parabolically from morning to afternoon with little fluctuation over the days. The figure also conveyed that temperature rise increased to a peak value of 21.02 ºC and 30.33 ºC respectively for the smooth absorber solar collector and collector with fins and twisted tapes. This peak value of air temperature rise occurred during 12.00 hr. to 13.00 hr. for the air flow rate of 0.007 kg/s. The increase in air flow rate resulted in a decrease in air temperature rise.

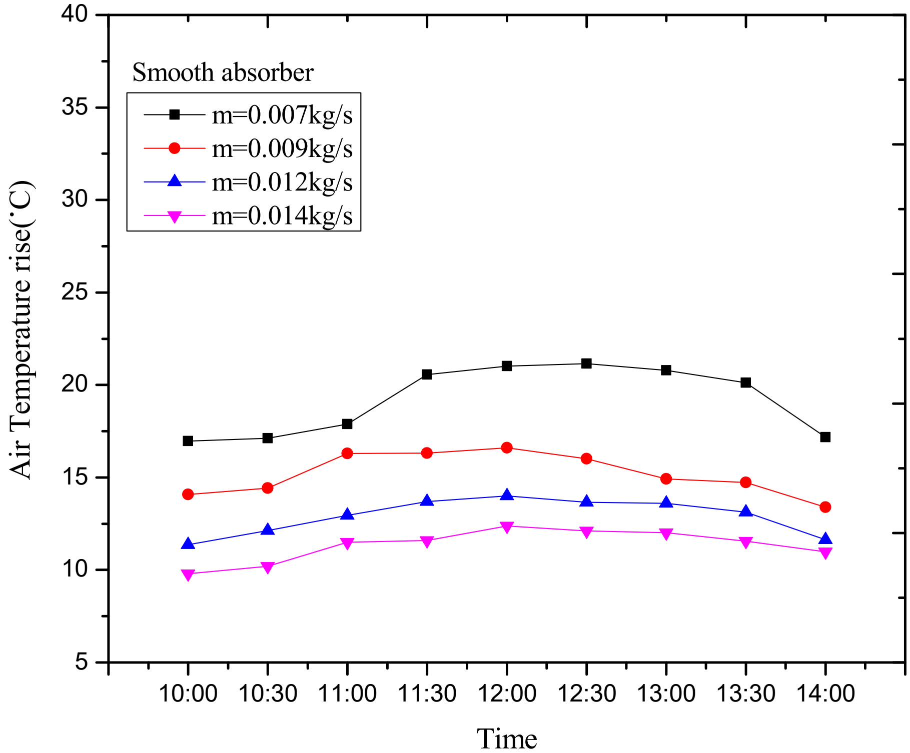

Figure (3): Variation of the temperature rise of the air with time for the heater with the smooth absorber.

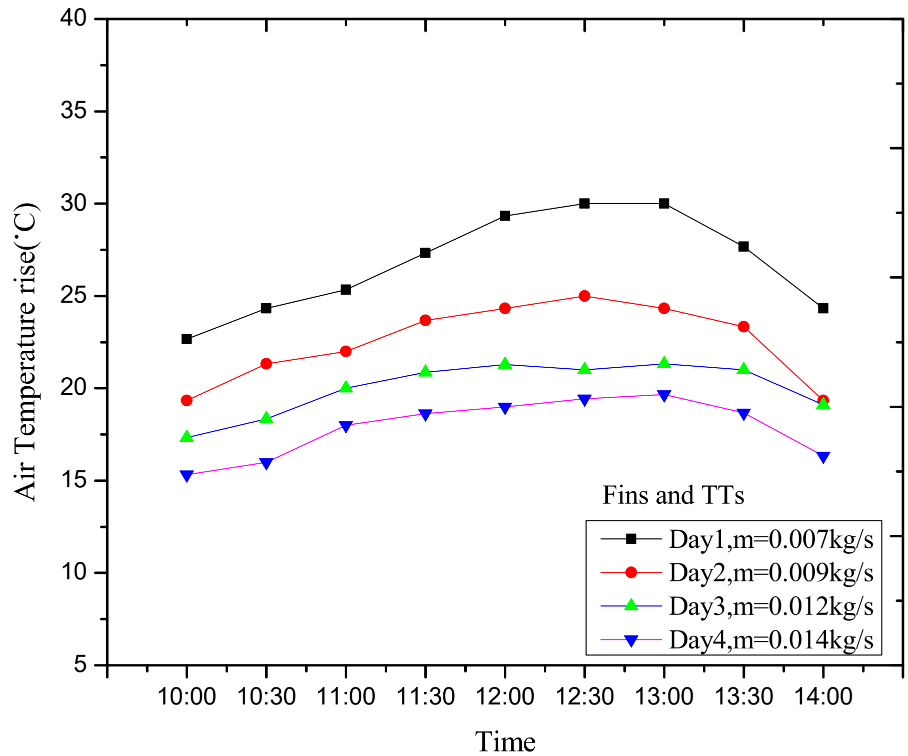

Figure (4): Variation of the temperature rise of the air with time for air heater with absorber fitted with fins and twisted tapes.

The variation of Nusselt number against the air flow rate is presented in Figure (5) for both the smooth absorber solar collector and the collector with fins and twisted tapes of twist ratio Y=2.66. Figure shows that the Nusselt number increases with increase in flow rate of air and the Nusselt for fins and twisted tape absorber is found to be greater than that of the smooth absorber. This is attributed to increased heat transfer area due to addition of fins and better fluid mixing because of twisted tapes and hence improved heat transfer coefficient.

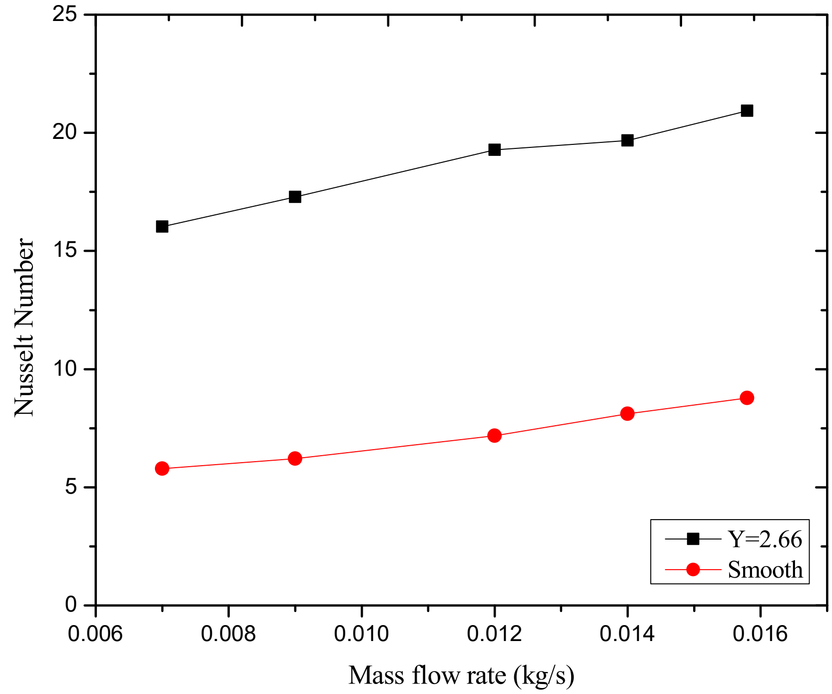

Figure (5): Variations of average Nusselt number as the function of mass flow rate.

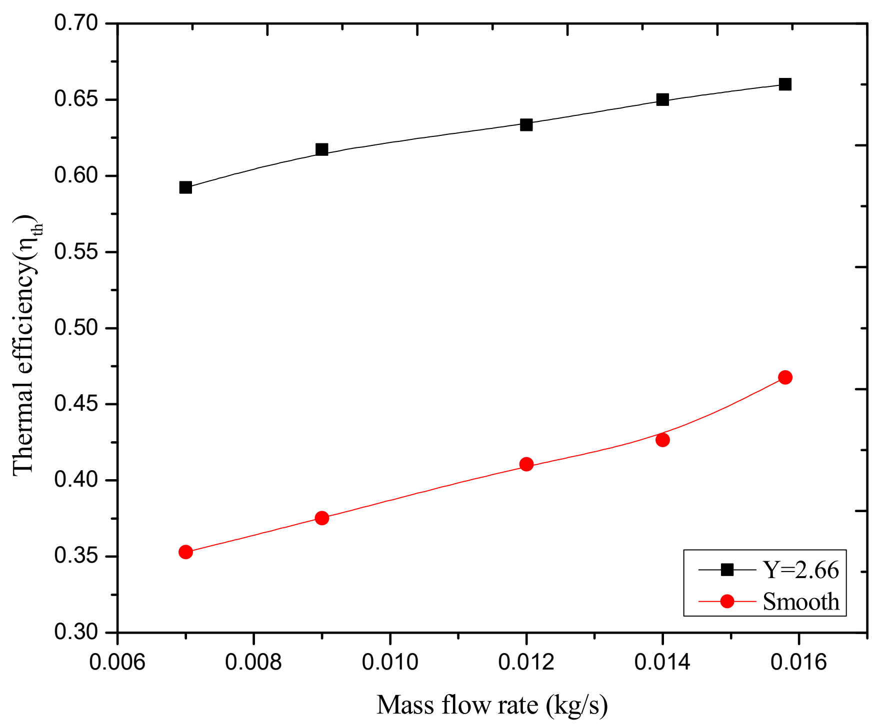

Figure (6): Variations of the thermal efficiency against the mass flow rate of air.

Figure (6) shows the variations of the thermal efficiency of smooth absorber and the absorber with fins and tape with twist ratio, Y=2.66, against the flow rate of air. The figure indicates that the thermal efficiency is increasing with increase inflow rate for both collectors. This is because of amplified air velocity at higher mass flow rate. The thermal efficiency of the heater with finned and twisted tape absorber is perceived to be higher than the collector without fins and twisted tapes. At air flow rate of 0.012kg/s, integrating fins and twisted tapes of twist ratio Y=2.66 to the absorber plate leads to enhance the thermal efficiency of the smooth absorber collector from 41 % to 63.3 %.

5. Conclusions: Based on the test results, following conclusions can be drawn.

a. Increment in air temperature is maximum in between the 12 to 13 hr. The maximum temperature increment of the solar collector with fins and twisted tapes is 10°C higher than that of smooth absorber collector.
b. The temperature rises of air decreases with increase in air flow rate from 0.007 kg/s to 0.0158 kg/s.
c. At $\dot{m}$ =0.012 kg/s, attaching fins and twisted tape to the absorber plate and leads to enhancement in the thermal efficiency from 41 % to 63.3 %.
d. Increasing flow rate of air from 0.007 kg/s to 0.0158 kg/s makes the thermal efficiency, η_{th}, of the smooth absorber collector and the collector with fins and twisted tapes to increase from 35.27 % to 46.75 % and 59.2 % to 65.9 % respectively.

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