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Thermal Characteristics of Solar Air Heater Having Artificial Roughness of Multiple ARC Type with Thermal Storage System

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ABSTRACT

An experiment analysis was performed to find the thermal characteristics of a solar air heater with artificial roughness and thermal storage system. The aluminium wire was used for the artificial roughness with a diameter of artificial roughness 2 mm. Geometry of artificial roughness was in the form of continuous arc shape without gap, pitch 20 mm, relative angle of attack (α/90) = 0.66. Oil has been used as the thermal storage system. Oil absorbs heat during the sun shine hours and after sun set releases the heat to heat up the air. Oil provides heat to the air extra two hour after sun set. The experiments were performed at Reynolds number 11000. It was found that the outlet air temperature of conventional solar air heater (SH) is higher than that of modified solar air heater (RH) in the time period of 9:30 AM to 1:00 PM. In time interval between 1:00 PM and 4:00 PM outlet air temperature of RH was more or less equal to that of SH. After 4:00 PM outlet air temperature of RH was higher than that of SH till 7:00 PM due to the role of thermal storage system. It was found that the outlet air temperatures in both the heaters were higher than that of ambient air temperatures during the period of experimentation.

Keywords: Thermal Characteristics, Solar Air Heater, Artificial Roughness ARC, TRACEPRO, Intensity of Radiation, Inlet Air Temperature, Surface Temperature, PVC

I. INTRODUCTION

Energy is primary or basic need to human life. The sun provides the necessary energy needed to sustain life on earth. Solar energy is showing signs of future needs of the humanity. A solar air heater is a device in which the air is passed through a duct and gets heated up. Absorber plate is placed over the rectangular cross-sectional duct and entire length of absorber plate is coated in black colour, to absorb the maximum amount of solar radiation incident on it. The heated air is used for various applications e. g. air pre-heating of air for combustion process, drying minerals, coal, paper, bricks, crops etc. Toughened glass is placed over the absorber plate to reduce the heat losses from the heated absorber plate. Thermal efficiency of conventional solar air heater is low because the heat transfer between absorber plate and air is low. To improve the thermal efficiency of collector use of artificial roughness on air flow side of the solar air heater is a very effective method. Artificial roughness provides the turbulence in the direction of flow of air which results in increase in fluid mixing and also for breaking of thermal boundary layer and hence increases the heat transfer.

Saini and Saini carried out experiments in a solar air heater having arc-shape artificial roughness. The effective parameters of a system such as relative roughness height (e/d) and arc angle (α/90) have been performed on friction factor (f) and Nusselt number (Nu) with Reynolds number (Re) varied from 2000 -17000. At a relative arc angle (α/90) of 0.3333 and at relative roughness height of 0.0422 obtained 3.80 folds maximum enhancement in Nusselt number and 1.75 folds increment in friction factor.

Jaurker et al. investigated a rib-grooved artificial roughness on the underside of absorber plate of solar air heater duct on Reynolds number (Re) from 3000 - 21000, relative roughness pitch (p/e) 4.50 – 10.0, relative roughness height (e/D_h) 0.0181–0.0363, and groove position to pitch ratio 0.3–0.7. As compared to smooth duct, rib-grooved roughened duct performed better under similar flow conditions. At relative roughness pitch of about 6.0 maximum heat transfer co-efficient was obtained. The Nusselt number increased 2.7 times and friction factor increased 3.6 times in the presence of rib grooved artificial roughness duct as compared to smooth duct.

Shui-lian et al. conducted the experiments to improve the heat transfer characteristics of a solar air heater duct with hemispherical protrusion dimple roughness on underside of the absorber plate. Simulations were done through TRACEPRO software. It has been concluded that the solar air heater with hemispherical dimple have better performance as compare to other artificial roughness. The investigation has been carried out at Reynolds number ranging from 3000 – 11000, relative pitch (p/e) from 3.50 - 5.50 and relative roughness height (e/D_h) from 0.033 - 0.10, at relative pitch (p/e) of 5.

Yadav et al. studied the thermal characteristics of turbulent flow of air passing through rectangular solar air heater duct with surface artificially roughened circular protrusions on underside of absorber plate. The Experiments encompassed Reynolds number (Re) from 3600 - 18100, roughness pitch (P/e) from 12 - 24, relative roughness height (e/D) 0.015 - 0.03 and arc angle (α) of protrusion from 45° to 75°. The increment in heat transfer and friction factor was 2.89 and 2.93 folds as compared to smooth duct.

Saini and Verma presented the effect of artificial roughness on friction factor and heat transfer rate in a air heater duct provided with dimple-shape roughness geometry. The experiments deals with Reynolds number ranges between 2000 and12,000, relative roughness height (e/D) ranges in 0.018 to 0.037 and relative pitch (p/e) from 8 to 12 respectively. At the value of relative roughness height (e/D) of 0.0379 and relative pitch (p/e) of 10 maximum value of Nusselt number was found. While at e/D of 0.0289 and p/e of 10 the Nusselt number was found minimum.

Karwa et al. presented his results on investigation on artificial roughness of repeated chamfered rib type for improvement in heat transfer in a duct. The parametric range in which this investigations were conducted are Reynolds numbers: 3000 to 20000, relative roughness heights range in 0.0141 to 0.0328, the relative roughness pitch of 4.5, 5.8, 7.0, and 8.5 whereas rib chamfer angles was taken as 15, 0, 5, 10, 15 and 18° respectively.

Sahu and Prasad analysed that exergy efficiency of a solar thermal systems in a duct roughened by arc-shaped wire rib under the absorber plate and compared the performance of smooth and roughened duct on various parametric features. The maximum increment in exergy efficiency of roughened surface over smooth surface was 56% with respect to relative roughness height (e/D) 0.0422.

Singh et al. investigated the effect of multi arc shape type artificial roughness on a rectangular duct on parameters like heat transfer and friction factor. The experiments covered Reynolds number (Re) ranges in between of 2200–22,000, relative roughness height (e/D) ranges in 0.018–0.045, relative roughness width (W/w) from 1 to 7, relative roughness pitch (p/e) range of 4–16 and angle of attack (α) ranges from30 ° to 75°. The thermo-hydraulic performance was best at relative roughness width of (W/w) of 5.

Singh et al. investigated thermal and fluid flow characteristics of a rectangular duct artificially roughened with 'discrete V-down rib'. Reynolds number (Re) was in the range of 3000-15000 having relative gap width (g/e) 0.5-2.0 and relative gap position (d/w) of 0.20-0.80. Relative roughness pitch (P/e) was taken between 4-12, angle of attack (α) was in range of 30°-75° and relative roughness height (e/D_h) was 0.015-0.043. The maximum rise in Nusselt number and friction factor of roughened duct over that of smooth duct was 3.04 and 3.11 times respectively. The maximum increment in Nusselt number and friction factor was found at following parameters: d/w 0.65, g/e 1.0, P/e 8.0, α =60 °and e/D_h 0.043.

II. EXPERIMENTAL PROGRAM

2.1 Experimental Set-up

In this experiment two rectangular cross-sectional ducts are constructed, in which first one has absorber plate artificially roughened (this modified duct is named RH) and other one has smooth absorber plate (this conventional duct is named SH). Dimension of the ducts were 1900mm ×900mm×50mm which were same for both the set-ups. A 0.5mm thickness of galvanized iron sheet was used for the making of duct. The diameter of the entry and exit section of the duct was 100mm. The base of the duct was insulated by a 50 mm thick layer of glass wool glass wool and ply-wood having thickness of 12mm to minimize the heat losses from the duct. Roughened duct and smooth duct of the system was divided into three sections: entry taper section, rectangular section and exit taper section. Artificial roughness was provided on the underside of the absorber surface. Oil is used as thermal storage system. The experiments were performed at the Radharaman Institute of Research and Technology. Bhopal, India having 77.36° East longitudinal, 23.16° North latitude. The absorber plate was placed facing south at a slope angle of 23° based on the latitude the city. Figure 1 shows the set-ups used.

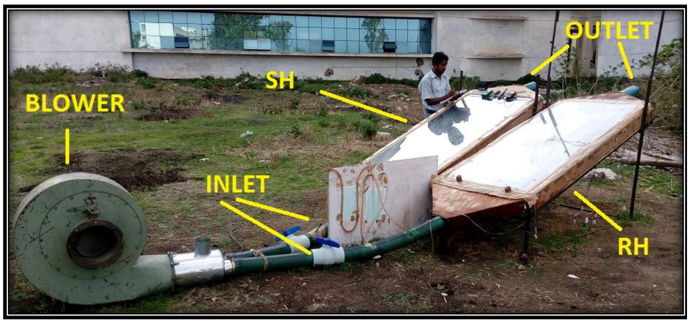

Figure 1. Experimental set-up

2.2 Instrumentation

(a) Temperature measurement

J-Type thermocouple wires were used to measure the temperatures of the absorber plate at different position. Twenty two thermocouples wires have been inserted on the upper and inner surface of the absorber plate for measuring temperature in both the set-ups. The thermocouple output was recorded with the help of the digital display unit. An alcohol thermometer was used for measuring the ambient air temperature.

(b) Measurement of radiation intensity

Solar radiation intensity was measured by the means of digital pyranometer inclined at 23°.

(c) Airflow measurement

The flow rate of air was measured with the help of a digital anemometer. The flow of air was controlled by valve fitted on the blower. For further control of air PVC valves were used fitted into the flexible pipe.

2.2 Experimental procedure

Firstly, the power switch of blower motor is switched on. Blower motor impeller runs at very high rpm. Due to runs of impeller air flowing through the blower enters in the flexible pipe. PVC valves are used to control the air flow for desired Reynolds number. The rate of flow air was adjusted according to the Reynolds number. The following readings at various locations were recorded.

1. Inlet air temperature
2. Upper surface temperature of top wall of duct
3. Inner surface temperature of top wall of duct
4. Oil temperature
5. Outlet air temperature
6. Ambient air temperature
7. Intensity of radiation

III. RESULTS AND DISCUSSION

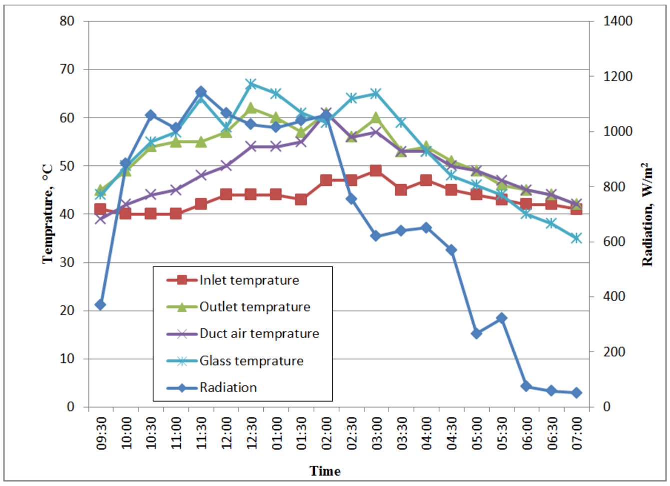

Figure 2. Variation of temperature with time at various locations in RH

Figure 2 shows the variation of inlet air temperature, glass temperature, outlet air temperature, duct air temperature and intensity of radiation with time. Maximum glass temperature was observed as 69°C at 2:00 PM. Minimum air inlet temperature was 40°C at 10:00 AM and maximum 49°C at 3:00 PM. Maximum outlet air temperature was 62°C at 12:30 PM. Maximum temperature difference between outlet and inlet air temperature was 18°C at 12:30 PM. The minimum duct temperature was 38°C at 9:30 AM and maximum 61°C at 2:00 PM. Maximum Intensity of radiation was observed at12:00 PM which was 1066 W/m^2. After 2:00 PM intensity of radiation was falls down. Outlet air temperature was higher than that of inlet air temperature at the time of experiment. Duct air temperature was found to be higher than the inlet air temperature.

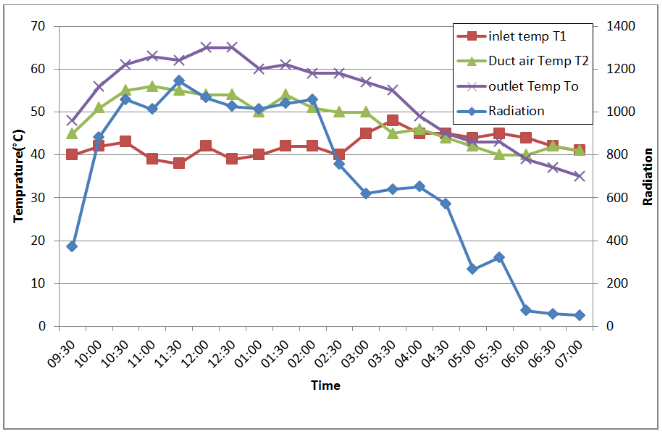

Figure 3. Variation of temperature with time at various locations in SH

Figure 3 shows the variation of air inlet air temperature, duct air temperature, outlet air temperature and radiation. During sun shine outlet air temperature was maximum between 12:00 PM and 12:30 PM. Inlet air temperature was minimum at 12:00 PM. Intensity of solar radiation is maximum at 12:00 PM. After sun set inlet air temperature and duct air temperature were same afterwards 6:30 PM.

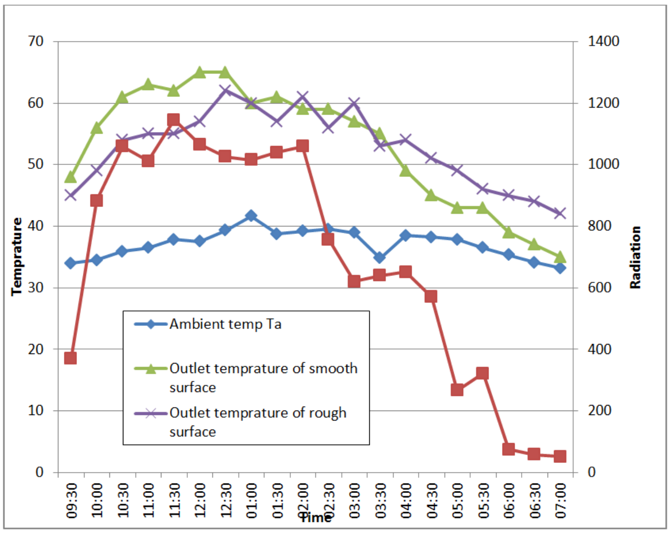

Figure 4. Comparison of outlet air temperature with time and radiation

Figure 4 shows that the outlet air temperature of SH is higher than that of RH between of 9:30 AM and 1:00 PM. Outlet air temperature of RH was more or less equal to that of SH between 1:00 PM and 4:00 PM. After 4:00 PM outlet air temperature of RH was higher than that of SH till 7:00 PM. It was observed that the outlet air temperatures in both the heaters were higher than that of ambient air temperatures during the period of experimentation. The maximum intensity radiation was 1066 W/m^2 occurred at 12:00 noon.

IV. CONCLUSIONS

Solar air heater are used in various industrial purposes such as air pre-heating for combustion process, drying minerals, coal, paper, brick, food etc. Artificial roughness provided in the form of continuous arc shape on the underside of the absorber plate of a solar heater breaks the laminar sub-layer which reduces the thermal resistance and creates turbulence nearby artificial rough surface. Thus, the heat transfer rate increases. Artificial roughness provided on inner side of the absorber plate used to be an efficient method to increase the thermal efficiency of solar air heater. In the present research, artificial roughness made of aluminium wire having 2 mm diameter has been provided on the absorber plate. The experiments were performed at Reynolds number 11000. From the experiments, it was concluded that heat transfer by roughened duct was higher than that of smooth duct and, thus, the efficiency of the modified solar air heater was higher in comparison with conventional solar air heater. After the carrying out the study, following conclusions are drawn.

1. In case of RH, the maximum glass temperature was observed as 69°C at 2:00 PM. Minimum air inlet air temperature was 40°C at 10:00 AM and maximum 49°C at 3:00 PM. Maximum outlet air temperature was 62°C at 12:30 PM. Maximum temperature difference between outlet and inlet temperature was 18°C at 12:30 PM. The minimum duct temperature was 38°C at 9:30 AM and maximum 61°C at 2:00 PM. Maximum Intensity of radiation was observed at 12:00 PM which was 1066 W/m^2. After 2:00 PM intensity of radiation was falls down. Outlet air temperature was higher than that of inlet temperature at the time of experiment. Duct air temperature was found to be higher than the inlet temperature.

2. In case of SH, the outlet air temperature was maximum between 12:00 PM and 12:30 PM. Inlet air temperature was minimum at 12:00 PM. Intensity of

solar radiation is maximum at 12:00 PM. After sun set inlet air temperature and duct air temperature were same afterwards 6:30 PM.

3. The outlet air temperature of SH is higher than that of RH in the time period of 9:30 AM to 1:00 PM. In time interval between 1:00 PM and 4:00 PM outlet air temperature of RH was more or less equal to that of SH. After 4:00 PM outlet air temperature of RH was higher than that of SH till 7:00 PM. It was found that the outlet air temperatures in both the heaters were higher than that of ambient air temperatures during the period of experimentation. The maximum intensity radiation was 1066 W/m^2 occurred at 12:00 noon.

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