International Journal of Applied Research 2017; 3(6): 318-322

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2017; 3(6): 318-322
www.allresearchjournal.com
Received: 27-04-2017
Accepted: 29-05-2017

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Experimental investigation on performance of a Solar Air Heater having artificial roughness of multiple Arc with gap accompanying Thermal Storage System

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Abstract
The heat transfer coefficient of a smooth surface is quite low in an air heater. This is due to the formation of laminar sub layer. To break this formation of layer artificial roughness in the form of projections in the underside of absorber plate is used. In this way heat transfer rate can be enhanced. In the present paper multiple arcs with gap is used in the form of artificial roughness for a better efficiency. The experiments were conducted at Reynolds number of 11000. The outlet air temperature of modified duct was higher than that of smooth duct. There has been use of oil in the form of thermal storage that starts showing its result after 4:00 pm when solar radiation starts decreasing. In this way an extra 2.5 hours of time was utilised i.e. up to about 06:00 pm. In the beginning of reading from 11:00 am to 2:00 pm the outlet air temperature of smooth surface was higher than roughened surface. But even as the solar radiation starts diminishing a higher air temperature was still received at the outlet of roughened surface due to the release of heat from oil heat storage. Thus, it is observed that use of oil enhance the effectiveness of solar air heater.

Keywords: Heat transfer, solar air collector, artificial roughness, solar energy, thermal storage, multiple arc with gap

1. Introduction

Augmentation in heat transfer in an air heater duct is very important in various industries. It has a vast variety of industrial applications such as in heat exchangers, cooling systems, solar collectors etc. When heat transfer rate is high it increases the efficiency and lowers the thermal load of the working system. One of the efficacious techniques to increase heat transfer is by using artificial roughness on absorber plate surface. The main motive to provide artificial roughness on an absorber plate is to break the formation of laminar sub layer. There are various techniques by which we can provide artificial roughness such as by wire fixing, mesh, ribs etc. [1]. Over the years different rib geometries have been designed to investigate heat transfer and friction characteristics of solar air heater [2].

Aharwal *et al.* [3] studied repeated square cross-section inclined split-rib with a gap on a duct having width to height ratio (W/H) of 5.84, relative roughness pitch (P/e) of 10, relative roughness height (e/Dh) of 0.0377, and angle of attack (a) of 601. The gap width (g/e) and gap position (d/W) in the range of 0.5–2 and 0.1667–0.667, respectively. The Reynolds numbers was varied from 3000 to 18,000. This arrangement increases the Nusselt number and friction factor by 2.59 and 2.87 folds of that of the smooth duct, respectively.

Hans *et al.* [4] conducted experiments to study the effect of multiple v-rib roughness on heat transfer coefficient and friction factor in an artificially roughened solar air heater duct. The experiment covers Reynolds number (Re) from 2000 to 20000, relative roughness height (e/D) values of 0.019– 0.043, relative roughness pitch (P/e) range of 6–12, angle of attack (α) range of 30–75°C and relative roughness width (W/w) range of 1–10. The maximum heat transfer occurred at a relative width value of 6 while friction factor occurs at 10.

Lanjewar *et al.* [5] experimentally investigated the heat transfer and friction factor characteristics of rectangular duct roughened with W-shaped ribs arranged at an inclination with respect to flow direction. Duct has width to height ratio (W/H) of 8.0, relative roughness pitch (p/e) of 10, relative roughness height (e/D_h) 0.018-0.03375 and angle of attack of flow (α) 30°-75°. Reynolds number covers the range of 2300 -14,000.

Maximum increase in Nusselt number and friction factor by using artificial roughness was observed to be 2.36 and 2.01 times, respectively as compared to that of smooth duct for an angle of attack of 60°. For relative roughness height of 0.03375 and at angle of attack of 60°, W-shape ribs increase the Nusselt number by 2.21 times over smooth plate at Reynolds number of 14,000.

Bhushan and Singh [6] had investigated the effect of artificial roughness with protrusion shape on the absorber plate. Various parameters related were as follows: relative short way length (S/e) 18.75–37.50, relative long way length (L/e) 25.00–37.50, relative print diameter (d/D) 0.147–0.367, relative roughness height 0.03, aspect ratio 10 and Reynolds number 4000–20000. Maximum Nusselt number and friction factor were found to be 3.8 and 2.2 times, respectively as compared to the duct having smooth surface. Increase in heat transfer for relative short-way length was 31.25, relative long way length was 31.25 and relative print diameter was 0.294, respectively.

Sethi *et al*. [7] deal with the effect of artificial roughness in air heater duct with dimple shaped elements maintained in angular fashion (arc). The aspect ratio (W/H) of 11, relative roughness pitch (p/e) range of 10–20, relative roughness height (e/Dh) range of 0.021–0.036, arc angle (α) range of 45–75° and Reynolds number (Re) ranged from 3600 to 18,000. In the range of above parameters Nusselt number and friction factor were observed to be ±8% and ±8%, respectively.

Layek *et al*. [8] studied rectangular duct having repeated integral transverse chamfered rib-groove roughness. The research was done at Reynolds number in the range of 3000–21,000; relative roughness pitch of 4.5–10, chamfer angle of 5°–30°, relative groove position of 0.3–0.6 and relative roughness height of 0.022–0.04. It was observed that the Nusselt number and friction factor increased by about 3.24 times and 3.78 times, respectively.

Saini and Verma [9] investigated the effect of roughness and operating parameters on heat transfer and friction factor in a roughened duct provided with dimple-shape roughness geometry. The investigation encompassed the range of Reynolds number (Re) from 2000 to 12,000, relative roughness height (e/D) from 0.018 to 0.037 and relative pitch (p/e) from 8 to 12. The maximum value of Nusselt number found corresponds to relative roughness height (e/D) of 0.0379 and relative pitch (p/e) of 10. While minimum value of friction factor has been found correspond to relative roughness height (e/D) of 0.0289 and relative pitch (p/e) of 10.

Lian *et al*. [1] studied on a solar air collector with hemispherical protrusion/dimple on the absorber plate, and analyses the performance from the two criterions: optical and thermal. Simulation was done by TRACEPRO software. It was inferred that the hemispherical dimple is the best in term of the optics. The investigation has covered Reynolds number (Re) ranging from 3000 to 11,000, relative roughness height (e/Dh) from 0.033 to 0.1and relative pitch (p/e) from 3.5 to 5.5. The maximum value of Nusselt number has been found corresponds to relative pitch (p/e) of 5.

Pandey *et al*. [10] studied heat transfer and friction factor in rectangular channel with multiple-arc shaped with gaps as roughness geometry. The investigation covers Reynolds number (Re) ranging from 2100 to 21,000, relative roughness height (e/D) ranges from 0.016 to 0.044, relative roughness pitch (p/e) ranges from 4 to 16, arc angle (α) values are 30–75°, relative roughness width (W/w) ranges from 1 to 7, relative gap distance (d/x) values are 0.25–0.85 and relative gap width (g/e) ranges from 0.5 to 2.0. The maximum increase in Nusselt number (Nu) and friction factor (f) was 5.85 and 4.96 times in comparison to the smooth duct.

In the present work, multiple-arc shaped with gaps as roughness element underside the absorber plate has been employed in a solar air heater duct. A thermal storage system has been employed for extending the time period for which hot air can be utilized. An experimental study was undertaken to determine the flow and heat transfer characteristics and comparison was carried out with the solar air heater with smooth surface.

2. Experimental setup

The photo of experimental setup is shown in Figure 1. There were two setups, one duct had smooth absorbing plate while another one had roughened absorbing surface. The setup consists of flow section which has blower for entrance of air, air entry system, various measuring system and air exit system. The duct in which air flows was made of galvanised iron (GI) sheet of 5 mm thickness. Size of duct was 1900 mm×900 mm×50 mm. The diameter of pipe through which air flows was 100 mm. To reduce heat loss from the experimental setup a 50 mm thick layer of glass wool which is a good insulating material was provided at all side of the duct. Arc with gap geometry of artificial roughness was provided under the sheet. Roughness was provided to break the formation of laminar sub layer which enhances the heat transfer rate. The roughened surface duct was provided with an oil box measuring 1540mm×540mm×50mm. Oil box also had 8 numbers of iron rod penetrated from one side to other side of the box. The rods were provided to transfer the heat of top surface of oil box to the roughened surface through conduction. The internal body of the duct which was facing radiation of sun was painted with blackboard paint to absorb high amount of radiation. Toughened glass was used to fully pack the duct from its upper side to lessen the heat loss. The experiments were conducted at the premises of Radharaman Institute of Research and Technology, Bhopal, India having east longitude 77.36°, 23.16° north latitude. The setup was placed in south direction having slope angle of 23° with respect to horizontal line which was in accordance to the geographical condition. The whole readings were taken in summer season for good results. Time duration in which reading were taken was from 11:00 am to 7:00 pm. The oil is used for thermal storage system which continues its working even after sunset. In this way an extra usable time was achieved which enhance the effectiveness of the system.

Fig 1: Experimental setup of solar air heater (smooth and roughened surface)

2.1 Instrumentation

2.1.1 Temperature measurement

J-type thermocouple wires having accuracy of 0.1 °C were used for measuring temperature. Digital temperature measuring device was used as an indicator which indicated temperature. Ambient temperature was recorded by thermometer having alcohol as rising material. 12 thermocouple wires were used in the modified duct for measuring temperature at various places, while 9 thermocouple wires for smooth duct for deeply analysing the study.

2.1.2 Measurement of radiation intensity

The solar radiation was measured with the help of pyranometer. The angle at which radiation was measured was same as the angle of our setup i.e. 23°. The intensity measurement device was of digital type and hence the reading can be read directly.

2.1.3 Airflow measurement

The air flow rate was being measured by digital anemometer. The velocity of inlet and outlet both were measured. Flow of air was controlled with the help of PVC valve having same diameter as of pipe i.e. 100 mm.

2.1.4 Pressure drop measurement

U-tube manometer was used for measuring both pressures that is static pressure and dynamic pressure. The pressure loss was measured at both inlet and outlet sections of setup.

3. Experimental procedure

The initial step to start the experiment was to switch on the blower after ensuring about any leakage from every part of the system. The flow rate of air was controlled by valve provided in blower as well as PVC valve from the pipe. This helped in getting exact amount of air flow needed for the system. The air flow rate was fixed, then after readings were taken by using various instruments. There were various parameters which were measured during experiment.

1. Inlet air temperature
2. Outlet air temperature
3. Duct air temperature
4. Ambient temperature
5. Radiation

4. Results and Discussion

In the presence of solar radiation the outlet air temperature of conventional air heater was recorded higher as compared to modified one. But when solar radiation starts decreasing with time the outlet air temperature of roughened duct increased because of the use of oil in the modified duct.

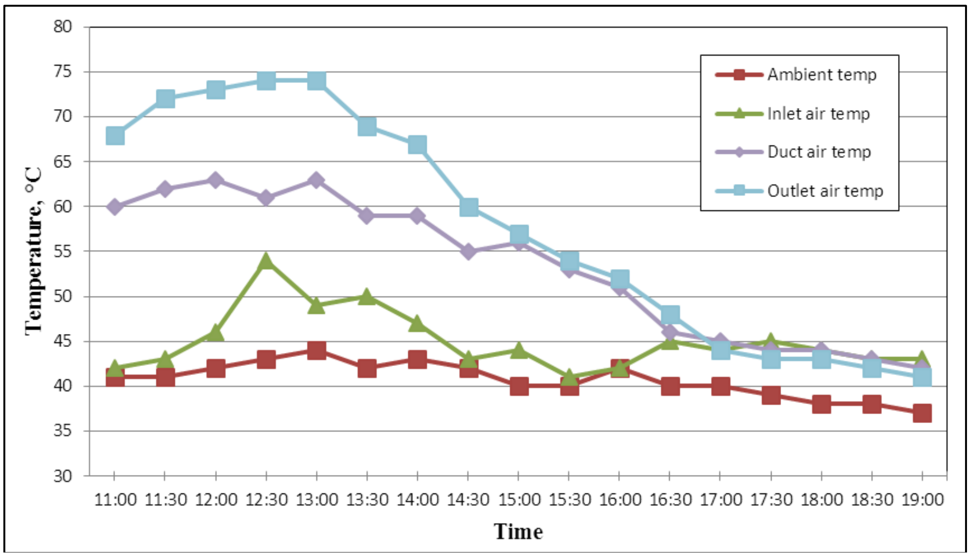

Fig 2: Variation of temperature with time at various locations in smooth surface duct

Figure 2 shows the variation of ambient air temperature, inlet air temperature, duct air temperature and outlet air temperature of smooth surface with time. The range of time is between 11:00 am to 7:00 pm. The outlet air temp was higher than inlet air temp as well as duct air temp till 4:30 pm. But due to fall in solar radiation outlet air temp starts falling slowly. But this fall in temperature was not steep as the duct air utilizes the heat from the thermal storage. The maximum temperature difference between inlet and outlet air was recorded as 29 ºC. In the same way the maximum temperature difference between duct air temp and outlet air temp was 19 ºC. The maximum ambient temperature was 44 ºC at 1:00 pm and therefore all the parameters recorded at that time were at its peak.

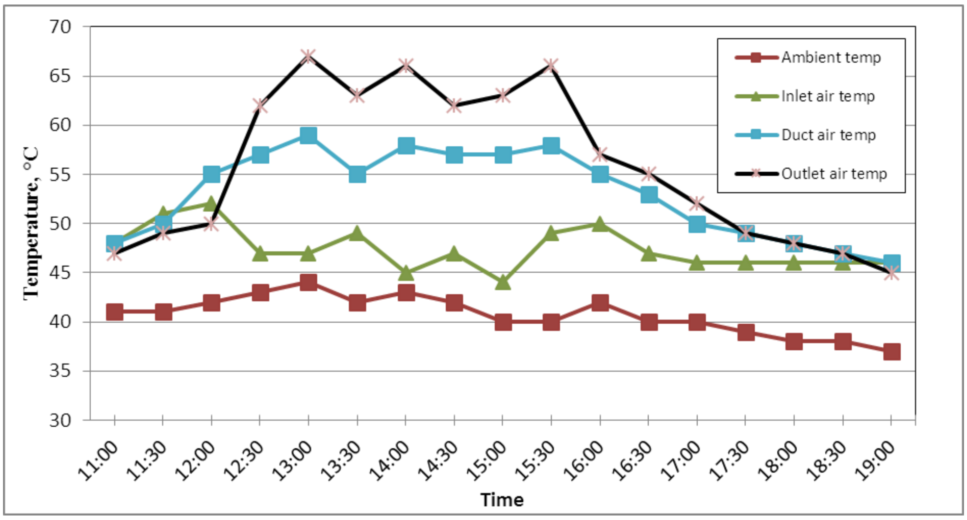

Fig 3: Variation of temperature with time at various locations in roughened surface duct

Figure 3 shows the variation of ambient air temperature, inlet air temperature, duct air temperature and outlet air temperature for the roughened duct. It is clearly shown that the outlet temperature was higher than duct and outlet after 11:00 pm till the last reading i.e. up to 7:00 pm. The inlet and duct air temperature was higher than outlet air temperature in between 11:00 am to 12:00 pm because the radiation was utilized to heat up the oil. The maximum temperature difference between inlet and outlet was 20 ºC and the maximum difference between duct and outlet air temperature was 13 ºC.

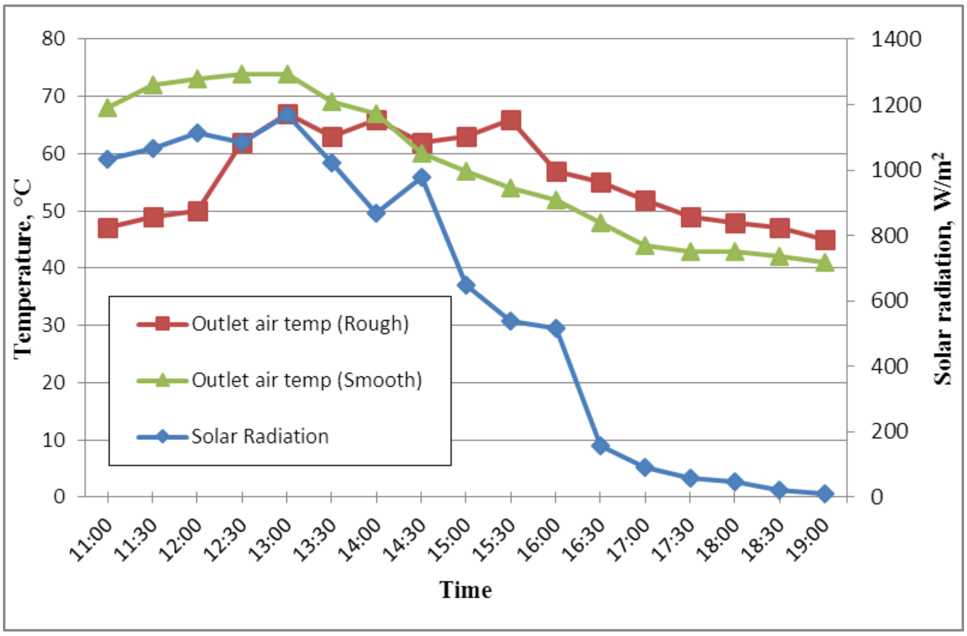

Fig 4: Comparison of outlet air temperatures of smooth and roughened surface air duct with time and radiation

Figure 4 shows the comparison of outlet air temperatures of smooth and roughened surface air duct with time and radiation. As per the graph the outlet air temperature of smooth surface air duct was higher than roughened surface air duct in the time interval of 11:00 am to 2:00 pm. After 2:00 pm the outlet temperature of roughened surface air duct was found to be higher up to 07:00 pm as the roughened surface enhances the heat transfer. Moreover, as the radiation starts decreasing rapidly after 04:00 pm, we still get the hot outlet air temperature in the modified solar air heater. There has been use of oil box in the roughened surface duct as thermal storage. The use of oil is to store the solar radiation in the form of heat energy which we can use further after sunset. The solar radiation starts diminishing after 4:00 pm. The oil which was used starts playing its role and attained a maximum and mean temperature of 71 ºC and 58.9 °C, respectively. An extra use of 2.5 hours by the air heater was recorded at low radiation hours.

5. Conclusions

Solar air heater has vast applications for industrial purpose such as for heating space, for timber drying, in textile industries, in chicken brooding and caring, drying concrete and building materials etc. The performance of an air heater with rough absorber plate is higher than that of a smooth absorber plate. Roughness can be provided by means of protrusions on the absorber plate artificially. In the present research roughness was provided artificially by means of aluminium wire. The roughness which was used in this experiment was of multiple arc shape having gap provided beneath of the absorber plate. The experiment was carried out at Reynolds number 11,000. The performance graph of artificial roughness having multiple arcs with gap is demonstrated in the study. Thus, it is confirmed that the thermal characteristics of duct having artificial roughness on their absorber plate and thermal storage system has higher heat transfer rate as compared to conventional one. There are many other parameters like inlet air temperature, outlet air temperature, duct air temperature of smooth duct as well as duct having artificial roughness is also studied. It was inferred that outlet air temperature of duct having artificial roughness on their absorber plate and thermal storage system was higher as compared to conventional one

6. References

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