Experimental investigation on performance of air heater having multiple V-ribs as artificial roughness with thermal storage in forced convection

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ABSTRACT - *In the present article, investigations were carried out to study the heat transfer rate in a solar air heater with multiple V- ribs artificial roughness with a thermal storage system consisting of vegetable oil. The experiments were carried out at Reynolds number of 11000. During the initial stages, the outlet air temperature of conventional solar air heater (CH) was found to be higher than the modified solar air heater (MH) because the solar radiation was utilized to increase the temperature of the oil. But as the sufficient temperature of the oil was reached at 1:30 PM, the outlet air temperature of MH started increasing as compared to CH. Afterwards, till the end of the experiment i.e. at 07:00 PM, the outlet air temperature of MH was found to be higher at all stages. The maximum temperature increase of air outlet temperature of MH and CH was 11°C which occurred at 1:30 PM. The temperature of upper surface of absorber plate of CH was higher than that of MH till 02:30 pm. After the sufficient temperature gain of oil, the temperature of upper surface of absorber plate of MH starts increasing. The temperature of oil was higher than that of ambient temperature throughout the experimentation.*

Key Words Heat transfer, artificial roughness, solar energy, thermal storage, multiple continuous V-rib roughness, absorber plate, Reynolds number

1.INTRODUCTION

Solar energy is one of the easily available and cheap sources of renewable energy. Air heaters have a wide range of applications like moisture removal in crops and vegetables, space heating, timber seasoning drying of concrete / clay buiding components. The application of solar energy in air heaters offers less pollution as no combustion of fossil fuel takes place. The formation of laminar sublayer on the back side of absorber plate creates hindrance in transfer of heat to the flowing air. For disturbing the laminar sublayer, artificial roughness, in the form of multiple ribs, wire mesh or expanded metal mesh, protrusion-shape geometry etc. are provided on the surface of absorbing plate.

Karwa et al. [1] studied transfer of heat and friction factor for roughness of chamfered ribs in rectangular duct of air flow. They found that Stanton number and friction factor got increased 2-3 times. Bhagoria et al. [2] conducted the effect of artificial roughned wedge shaped transverse integral ribs on heat transfer rate in rectangular duct of air heater which leads to increase in Nusselt number by 2.5 times and friction factor by 5.3 times as compared to smooth duct. Prasad and Mullick [3] investigated on the augmentation of heat transfer coefficient and efficiency factor of protruded wires artificial roughned of absorber plate. For 40000 Reynolds number, the efficiency factor improved from 0.63 to 0.72 of unglazed collector with a corrugated galvanized iron absorber plate. Gupta et al. [4] presented the correlation for friction factor and Nusselt number for transverse wire roughness on rectangular solar air heater ducts and conducted experiments for Reynolds number in the range of 3000-18000, relative roughness height range 0.018-0.052 and relative roughness pitch 10. Sahu and Bhagoria [5] studied coefficient of heat transfer using broken transverse ribs roughness with pitch, ranging from 10-30mm and height 1.5mm on the underside of absorber plate. The performance of solar air heater with roughened surface duct was compared with the smooth surface duct. The heat transfer rate of roughened absorber plate increased by 1.25 to 1.4 times as compared to smooth surface duct.

Karmare and Tikekar [6] analyzed the heat transfer and friction factor correlation for artificially roughened duct with metal grit ribs and compared with smooth surface duct. For optimum performance, roughened surface have taken with relative roughness height 0.035 to 0.044, relative roughened pitch 12.5 to 36 and variation of Reynolds number 4000 to 17000. Momin et al. [7] investigated heat transfer rate and fluid flow characteristics for continuous V-shaped artificial roughness in a rectangular solar air heater duct. At optimum angle of attack, α=60º, of V-shaped ribs augmented the Nusselt number by 1.14 times as compared to other inclined. Singh et al.[8] analyzed Heat transfer and friction factor correlations of artificially roughened discrete V-down ribs of rectangular solar air heater ducts. The Reynolds number, relative roughness pitch, angle of attack and relative roughness height have been in range of 3000-15000, 4-12, 30º-75º, 0.015-0.043, respectively. Saini and Saini [9] presented correlations for Nusselt number and friction factor of arc-shaped wire as artificial roughness in solar air heater duct. They worked between 2000 to 17000 Reynolds number for optimum value of Nusselt number and friction factor. As compare to smooth surface rectangular duct, the Nusselt number augmented by 6.74 times and friction factor increased by 6.37 times of roughened surface rectangular duct. Kumar et al. [10] introduced the results of geometrical parameters of multiple discrete V-shaped ribs on heat transfer and fluid flow characteristics. The enhancement in Nusselt Number and friction factor was recorded as 6.32 - 6.12 times of that of the smooth duct. Sawhney et al. [11] presented the wavy-up delta winglet vortex artificial roughened surface of solar air heater duct. The heat transfer and friction factor characteristics of roughened surface conducted in the range of 4000 to 17300 Reynolds Number. At 4000 Reynolds Number, the Nusselt number enhance 223% and friction factor increased by 10.3 times over the smooth plate plate.

Hans et al. [12] deduced correlations of heat transfer and friction factor for a solar air heater duct roughened artificially with multiple continuous V-ribs. The optimum parameters of multiple continuous V-ribs were $G_d/L_v = 0.69$, $g/e = 1.0$, $e/D = 0.043$, $P/e = 8$, $W/w= 6$ and $\alpha= 60°$. A maximum enhancement of Nusselt number and friction factor was found to be 6 and 5 times, respectively, in comparison to the smooth duct. The maximum heat transfer enhancement has been found to occur for a relative roughness width (W/w) value of 6 while friction factor attains maximum value for relative roughness width (W/w) value of 10. It has also been found that Nusselt number and friction factor attain maxima corresponding to angle of attack value of 60°. Maximum increase of Nusselt number and friction factor has been reported corresponding to relative roughness pitch (P/e) value of 8.

Shui-lian et al.[13] studied a solar air collector with hemispherical protrusion on the absorber plate. Simulations were performed using TRACEPRO software. It was observed the hemispherical dimple is the best in term of the optics. The investigation encompassed Reynolds number (Re) ranging from 3000 to 11,000, relative roughness height (e/D_h) from 0.033 to 0.1 and relative pitch (p/e) from 3.5 to 5.5 and correlations for Nusselt number and friction factor were developed. Srivastava et al.[14] investigated the feasibility of Lauric acid as a phase change material (PCM) to store excess solar energy and release it when the energy is insufficient or unavailable for solar drying process. Focus was given on the heat transfer characteristics of the PCM during the charge and discharge periods.

Present research focuses heat transfer rate in a solar air heater with multiple V- ribs artificial roughness. The experiments were conducted on Reynolds number of 11000. A thermal storage system consisting of vegetable oil was incorporated which releases the heat at the time of insufficient solar radiation i.e cloudy weather or after the sun set.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

2.1 Experimental setup

Two experimental setups were designed and constructed with same geometrical dimensions (Photo of figure 1). One being the Conventional Solar Air Heater (CH) having smooth absorber plate and the other having multiple continuous V-shape roughness underside the absorber plate named as Modified Solar Air Heater (MH). The duct has rectangular section which is divided into three sections: entry, test and exit. The dimensions of setup were 1900mm×900mm×60mm (excluding insulation) which was constructed by G.I. sheet having a thickness of 0.60 mm and the dimension of air channel were: 1900mm×900mm×25mm. A rectangular oil box inbuilt in a center of absorber plate having a dimension of 1540mm×540mm×50mm. was filled with vegetable oil. All upper parts of absorber plate were coated with black paint. The glass wool insulation was provided around the rectangular duct having a thickness of 50 mm which was covered with 12 mm thick wooden panel. Flexible pipes of 100 mm diameter were provided at entry and exit section. The top of the rectangular duct was covered by 5 mm thick toughened glass. For forced convection heat transfer, a 7.5 HP blower was installed at inlet section side. A control valve, anemometer and pressure measuring device were installed in the flexible pipe. The set up was placed in the South direction (because of summer season) with angle of slope 23º (latitude of Bhopal, India) with respect to horizontal line.

2.2 Instrumentation

2.2.1 Radiation intensity measurement

The intensity of solar radiation has been measured by digital pyrometer named Solar Power Meter (Make- TENMARS, Model- TM-207).The unit of solar radiation intensity measured in W/m^2.The maximum limit of solar power meter measured up to 2000 W/m^2.

2.2.2 Temperature measuring instrument

For temperature measurement of upper side of absorber plate, underside of absorber plate, vegetable oil, entry and exit section J- type thermocouple wire have been used. The temperature range of J- type thermocouple wire was 0º-600ºC. Seven thermocouple wires were attached with roughened solar air duct and all temperatures were recorded with digital temperature measuring instrument.

2.2.3 Air velocity measurement

The velocity of air flow was measured with digital anemometer (make- Lutron AM-4201). At the entry section of rectangular solar heater duct, the anemometer was inserted in the flexible pipe.

2.2.4 Airflow controller

The flow rate of air was controlled with the help of PVC control valve for each set up which was attached in the attached in flexible pipe (100 mm diameter) at the entry.

2.3 Parameters and geometry of artificial roughness

The roughness geometry of multiple continuous V-shape was investigated under the present investigation. The parameters covered chosen were: Reynolds number as 11000, roughness height as 1.5 mm, Roughness pitch as 12mm, angle of attack 60°.

3. EXPERIMENTAL PROCEDURE

Before commencing the experiments, cleaning was done and dust or other dirt was removed from toughened glass. After that, all measuring instruments like anemometer, U-tube manometer, control valve, temperature measuring instrument etc were set at specific position and the blower was stitched on. The exit air of blower is distributed in three branches: one is attached in CH, second into MH and third one is opened to the environment which is treated as by pass. The air flow of all the three branches was controlled by separate control valves. Through control valve and anemometer the air flow velocity was set at 11000 Reynolds Number. The experiments were performed from 9:30 am to 7:00 PM in the premises of Radharaman Institute of Research and Technology, Bhopal, M.P., India. All the readings were recorded regularly at every half hour.

The following parameters were measured for each set of readings:

(1) Temperature of the upper surface of absorber plate
(2) Air inlet temperature
(3) Outlet air temperature
(4) Ambient temperature
(5) Oil temperature
(6) Solar radiation
(7) Air velocity

Fig- 1: Photograph of experimental setup

4. RESULTS AND DISCUSSION

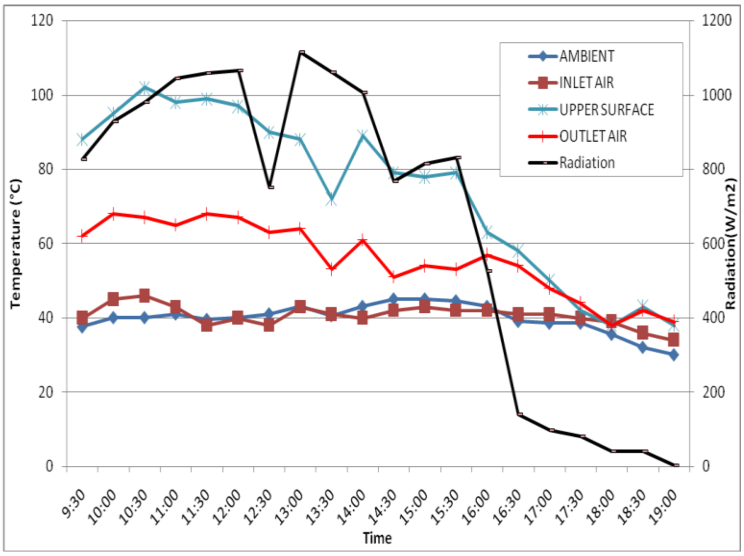

Chart- 1: Variation of temperature with time and radiation (smooth surface)

Chart- 1 shows the variation of temperature with time and radiation of smooth surface solar air heater. This reading was taken on 24th May 2017. In a smooth surface solar air heater the maximum temperature of outlet air was 68°C. The maximum difference between outlet and inlet air temperature was 30°C which was attained at 11:30 AM. Due to setting of sun after 4:30 PM, the intensity of radiation decreased and temperature of outlet air also decreased. But still the outlet temperature was higher than inlet temperature up to 07:00 PM.

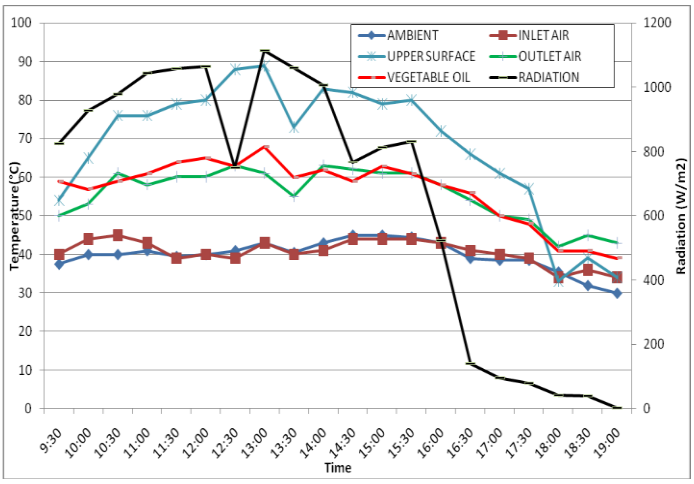

Chart- 2: Variation of temperature with time and radiation (Roughened surface)

Chart- 2 shows the variation of temperature at different locations of roughened surface solar air heater with time and radiation. The maximum outlet air temperature was 63°C attained at 12:30 PM and 2:00PM. Due to setting of sun after 4:30 PM, the intensity of sun light decreased but because of heat released by heat storage (vegetable oil), the temperature of outlet air was still higher. Good outlet temperature was obtained up to 7:00 PM and this was continued to few hours of night. The maximum temperature difference between inlet and outlet obtained 24°C at 12:30PM.

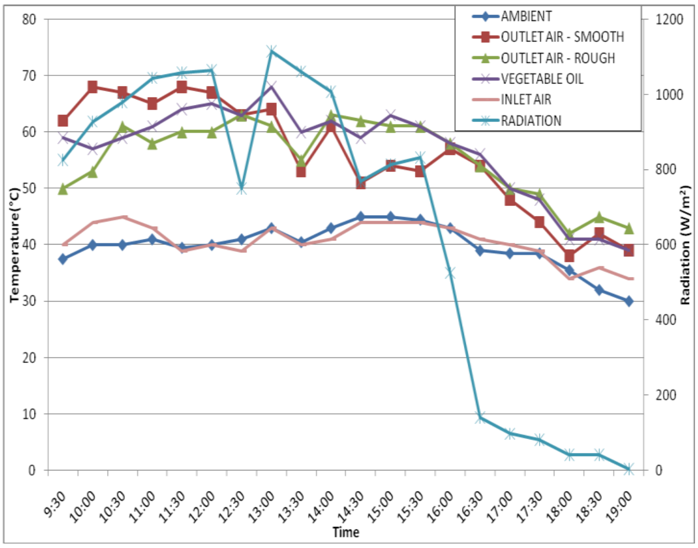

Chart- 3: Comparison of outlet air temperatures of CH and MH

Chart- 3 shows the comparison the outlet air temperature of smooth and roughened surface of the solar air heater duct. In the initial stages, the outlet air temperature of CH was found to be higher than the MH because the solar radiation was utilized to increase the temperature of the oil. But as soon as the sufficient temperature of the oil was reached (at 1:30 PM), the outlet air temperature of MH started increasing as compared to CH. Then, till the end of the experiment i.e. at 07:00 PM, the outlet air temperature of MH was found to higher at all stages. The intensity of sun light started decreasing at 4:30 PM and till the end of the experiment. The maximum temperature increase of air outlet temperature of MH and CH was 11°C which occurred at 1:30 PM.

5. CONCLUSION

The formation of laminar sublayer on the back side of absorber plate creates hindrance in transfer of heat to the flowing air. Present research focuses heat transfer rate in a solar air heater with multiple V- ribs artificial roughness. The experiments were conducted on Reynolds number of 11000. A thermal storage system consisting of vegetable oil was incorporated which releases the heat at the time of insufficient solar radiation. After conducting the experiments following conclusions were drawn.

1. In the smooth surface solar air heater the maximum temperature of outlet air was recorded as 68°C. The maximum difference between outlet and inlet air temperature was 30°C which was attained at 11:30 AM. Due to setting of sun after 4:30 PM, the intensity of radiation decreased and temperature of outlet air also decreased. In spite of this, the outlet temperature was higher than inlet temperature up to 07:00 PM.
2. The maximum outlet air temperature was found to be 63°C which was attained at 12:30 PM and 2:00 PM. Due to the heat released by heat storage, the temperature of outlet air was still higher, in spite of the setting of sun after 4:30 PM. Good outlet temperature was obtained up to 7:00 PM and this was continued to few hours of night. The maximum temperature difference between inlet and outlet obtained 24°C at 12:30PM.
3. During the initial stages, the outlet air temperature of CH was found to be higher than the MH because the solar radiation was utilized to increase the temperature of the oil. But as the sufficient temperature of the oil was reached at 1:30 PM, the outlet air temperature of MH started increasing as compared to CH. Afterwards, till the end of the experiment i.e. at 07:00 PM, the outlet air temperature of MH was found to be higher at all stages. The maximum temperature increase of air outlet temperature of MH and CH was 11°C which occurred at 1:30 PM.
4. It was observed that the temperature of upper surface of absorber plate of CH was higher than that of MH till 02:30 pm. After the sufficient temperature gain of oil, the temperature of upper surface of absorber plate of MH starts increasing. The temperature of oil was higher than that of ambient temperature throughout the experimentation.

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