

**Experimental study on Heat Transfer Enhancement of a Solar Air Heater with
Absorber Plate having Multi V-shaped Rib with Gap and Thermal Storage**Amod Kumar ^a, Rajiv Varshney ^b^a M. Tech. Scholar, Department of Mechanical Engineering,
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Abstract- Artificial roughness provided underneath the absorber plate breaks the viscous sub layer which, in turn, increases the intensity of turbulence in the duct and causes increase in heat transfer from the roughened surface. In the present work, a solar air heater has been designed and fabricated with multi V-shaped rib with gap below the absorber plate. A thermal storage system with oil was used which releases heat at the time of low solar radiation. The performance of this modified solar air heater is investigated and compared with that of conventional solar air heater. It was concluded that, initially outlet air temperature of RH was lower than outlet air temperature of SH up to 11:00 am. After 11:00 am outlet air temperature of RH was found to be higher than outlet air temperature of SH until the end of the experiment i.e. 7:00 pm. The maximum outlet air temperature of RH was 73°C and that of SH was 69°C. The maximum difference between these outlets temperatures was recorded as 10°C at 2:30 pm. Performance of RH was extended up to two hours after the sun set. Thermal efficiency of RH was lower up to 11:00 am and after that higher than SH almost at every moment. Maximum thermal efficiency of RH was 68% and SH was 40%. Thus, the increase in maximum thermal efficiency was 28%.

Keywords: - solar energy, solar air heater, artificial roughness, rib geometry, thermal storage, thermal efficiency, multi V-shaped rib with gap, absorber plate

1. Introduction

In the nature, there is ample amount of solar energy, which may be substantially used as an energy source. Solar energy utilization for a nation has become one of the most important factors. Solar energy has a key position in viable and feasible energy sources. The utilization of this energy is almost pollution free. Solar collectors play significant part in the applications of solar energy system. Solar collectors are broadly classified as solar water heating collector and solar air heating collector (SAHC) as per the fluid used. Solar air heater is one among solar thermal systems which is greatly used for heating purposes like drying of crops, space heating, home heating, seasoning of timber, etc. Though the efficiency of SAHC is low as air's thermodynamic properties are poor in term of heat exchange compared to liquid, it is still prominently used globally due to the benefit of simple structure, easy installation and maintenance. In solar air heater duct, heat is transferred from the heated wall comprising the absorber plate to incoming air and the other walls are thermally insulated. The heat transfer coefficient between absorber plate and air is low, which lowers the efficiency of the solar air heater. To enhance heat transfer coefficient of solar air collectors, many new techniques are developed and used. One of these techniques is to create fully turbulent flow in these systems. By providing artificial roughness, the efficiency of the solar air heater increases. Artificial roughness thus provided disturbs the viscous sub layer which increases the intensity of turbulence in the duct and causes increase in heat transfer from the roughened surface. The other method to increase the efficiency is to change the absorber surface shape. However, this system increases friction in the duct which in turn increases pumping power required for air through the duct [1, 2].

Kumar et al. [3] explored thermal characteristics of solar air channel fitted with discretized broken V-pattern baffle on the absorber plate. The air channel had a width to height ratio, W/H of 10. The relative baffle gap distance, D_d/L_v and relative baffle gap width, g_w/H_b has been varied from 0.26 to 0.83 and 0.5-1.5, respectively, Reynolds number, Re from 3000 to 21,000 with the relative baffle height, H_b/H range of 0.25-0.80, relative baffle pitch, P_b/H range of 0.5-2.5; and angle of attack, α range of 30° to 70°. For Nu_{rs} the maximum improvement of the 4.47 times with that of 'without channel' has been obtained. The absolute maximum thermal hydraulic performance parameter was found on D_d/L_v of 0.67, g_w/H_b of 1.0, H_b/H of 0.50, P_b/H of 1.5, and α_a of 60°. The highest value of the thermal hydraulic performance parameter was 3.14.

Li et al. [2] studied four types of air solar collectors: sinusoidal corrugated plate, protrusion plate, sinusoidal corrugated and protrusion plate and a base flat-plate. The efficiency of the collector improved with increasing mass flow. When the surface

roughness is increased, both the heat transfer and pressure loss increases. The corrugated absorber surface has a relatively large heat exchange area, so the heat transfer was increased. The protrusion absorber plate surface can produce swirl and secondary flows, which cause the convection coefficient of the heat transfer to increase.

Al-Kayiem and yassen [4] conducted experimental investigations on a rectangular duct comprising a flat plate-glass cover as the solar air heater with 0.48m width \times 0.07m depth \times 2m length. The measurements were performed at inclination angles of 30°, 50° degrees, and 70° degrees. The optimum inclination angle to achieve the best collector performance was found to be 50 degrees.

Acir et al. [5] studied the effects of the circular ring turbulators (CRTs) having different pitch ratio and hole number on heat transfer enhancement in a new type solar air heater (SAH). The experiments have been performed by varying the parameters, pitch ratio (PR), hole number (N) and Reynolds number (Re) in a range of between 3000 and 7500 under solar radiation heat flux (I). A significant enhancement in heat transfer on SAHs with CRTs was observed. The higher heat transfer augmentation with CRTs inserted inside the tube in SAHs have been obtained for $PR = 2$ and $N = 2$. The best experimental results were found with $\sim 229\%$ heat transfer enhancement, ~ 5.8 times friction factor compared to a conventional plain tube and the thermal performance factor (η) was computed as ~ 1.83 .

Alam et al. [6] studied the effect of non-circular perforation holes in term of circularity of V-shaped blockages type roughness in a rectangular duct of air heater. Five different hole shapes ranging from circular to square to rectangular in the circularity range of 1–0.6 have been used with varying relative pitch of 4–12, relative blockage height of 0.4–1.0, open area ratio of 5–25% and angle of attack of 30–75° and Reynolds number of flow was varied between 2000 and 20,000. A perfectly circular hole performs poorly as compared to a non-circular hole of considerable non-circularity ($\psi = 0.69$). An enhancement of Nusselt number value in the ratio of 1.13 was found when circular perforation holes are replaced by rectangular holes of circularity of 0.69.

Shui-lian et al. [7] studied a solar air collector with hemispherical protrusion/ dimple on the absorber plate. The analysis was performed on the basis of optics and thermodynamics. The optical path shinning on the dimple and protrusion artificial roughness was simulated by using TRACEPRO software. The optical path of hemispherical and the spherical cap dimple were also simulated. The hemispherical dimple was found to be best in term of the optics. The maximum value of Nusselt number has been found corresponds to relative pitch (p/e) of 5.

Saxena et al. [8] improved the heat transfer rate and efficiency of a solar air heater using “granular carbon” as heat absorbing media inside the solar heater. The thermal performance evaluation of solar heater has been carried out on four different configurations by operating it on natural and forced convection. A good stability in temperature of absorber plate, output air velocity, outlet temperature, and thermal efficiency was found in the improvised solar air heater in comparison to conventional one. This improved air heater was also found economical by eliminating a blower of high power consumption which minimizes the system’s operating and maintaining cost.

Kumar et al. [9] investigated the performance of a rectangular duct having multi V-shaped rib with gap roughness on absorber plate. For Nusselt number (Nu), the maximum enhancement of the order of 6.74 times of the corresponding value of the smooth duct has been obtained. The friction factor (f) has also been seen to increase by 6.37 times of that of the smooth duct. The rib parameters corresponding to maximum increase in Nu and f were $Gd/Lv = 0.69$, $g/e = 1.0$, $e/D = 0.043$, $P/e = 8$, $W/w = 6$ and $\alpha = 60^\circ$.

In the present study a solar air heater has been designed with multi V-shaped rib with gap underneath the absorber plate. A thermal storage system with oil was incorporated which releases heat at the time of low solar radiation. The performance of this modified solar air heater is investigated and compared with that of conventional solar air heater.

2. Experimental Details

2.1. Experimental set-up

In the experimental investigation, two solar air heaters were planned and designed that have constructed in equal dimensions and same materials were used. First one was the conventional solar air heater with flat smooth absorber plate (SH) and another one was the modified solar air heater in which roughness as the multi V-shaped rib with gap and oil box as the thermal storage have attached with flat absorber plate (RH). The photo of the experimental set-ups is shown in figure 1. Both the set-ups consists of a rectangular wooden duct having outer dimensions of 1900mm \times 1000mm \times 135mm, including 50mm insulation (plywood and glass wool) on side wall and bottom. The duct is divided into two part: lower half (D1) having a height of 25mm in which flow of air take place and upper half (D2) having a oil box which is used for thermal storage. The bottom of the duct air channel is called base plate and the upper surface is called absorber plate. The upper surface of D2 is

covered by the glass for the absorption of solar energy. The D2 is painted with black paint for the optimized absorption capacity of absorber plates. A 0.5mm thick Galvanized Iron (G.I.) sheet was used for the making of plates and oil box. Below the absorber plate, RH 2mm aluminum wire are used for providing artificial roughness that breaks the boundary layer and to increase the heat transfer rate. A 5 kW blower was used for providing required amount of air flow. The experiments were performed at the Radharaman Institute of Research and Technology Bhopal India which is located in 77.5° East longitude and 23.3° North latitude. The absorbing plates were facing south and a slope angle of 23° with respect to the horizontal line.



Fig.1 Photo of experimental set-ups

2.2. Thermal storage system

In roughened solar air heater absorber plate was attached with oil box having a size of 1540 mm × 540 mm × 50 mm and it is also made by galvanized iron sheet. The distance between upper surface of oil box and toughened glass is 5 mm. Refined oil is used for thermal storage in oil box because it has good specific gravity, absorptive and easily available compared to other.

2.3 Artificial roughness

Artificial roughness was produced on the inner surface of absorber plate by pasting aluminum wires having a diameter of 2mm in the shape of multiple V - shaped with gap rib. Araldite was used for pasting of artificial roughness.

2.4. Instrumentations

2.4.1. The J-Type Thermocouples were used to measure the temperatures of the duct at different places. Following thermocouples were used in the duct: three are used for air temperature; six are used for surface temperature in both set-ups and one in the oil box. For the recording of temperature multi-channel temperature indicator was used. Another thermometer was used for measuring the ambient temperature.

2.4.2 Measurement of radiation intensity

The intensity of solar radiation was measured by digital pyranometer (Solar Power meter, make TENMARS, model- TM-207). The data can be recorded by. It recorded the intensity of solar radiation in W/m^2 .

2.4.3. Air flow measurement

The volume flow rate of air was measured by the volumetric flow meter and it is also known as anemometer (make- Lutron AM 4210). Speed of air flow is controlled by speed controller valve. This instrument measures the velocity of turbulent flow of air in m/s.

2.4.4. Pressure drop measurement

The pressure loss was measured by U – Tube Manometer which measures the static pressure and dynamic pressure of air. Two manometers are used for static pressure in inlet and outlet and one is used for dynamic pressure at the inlet. This pressure head was recorded in mm.

2.5. Experimental procedure

Experiments were performed from 09:30 am to 07:00 pm at the campus of Radharaman Institute of Research and Technology, Bhopal, MP, India. Prior to the experiment, it was confirmed that all instruments were working properly, there were no leakages at the interconnection and insulation material was proper. One blower of 7.5 hp was used for providing the air in the set ups. The outlet of the blower is divided into three parts: one each for the two set ups and one for the bypass. Pipe connections were done by PVC pipes of 10 cm diameter. The blower was switched on and flow through the blower was adjusted with the help of valves and anemometer to get the Reynolds number of 11000. After half an hour, the readings were taken at every half hour. Following data were recorded:

- Solar Intensity (W/m^2)
- Air Temperature ($^{\circ}\text{C}$)
- Plate Surface Temperature ($^{\circ}\text{C}$)
- Oil Temperature ($^{\circ}\text{C}$)
- Pressure (mm)

3. Results and Discussion

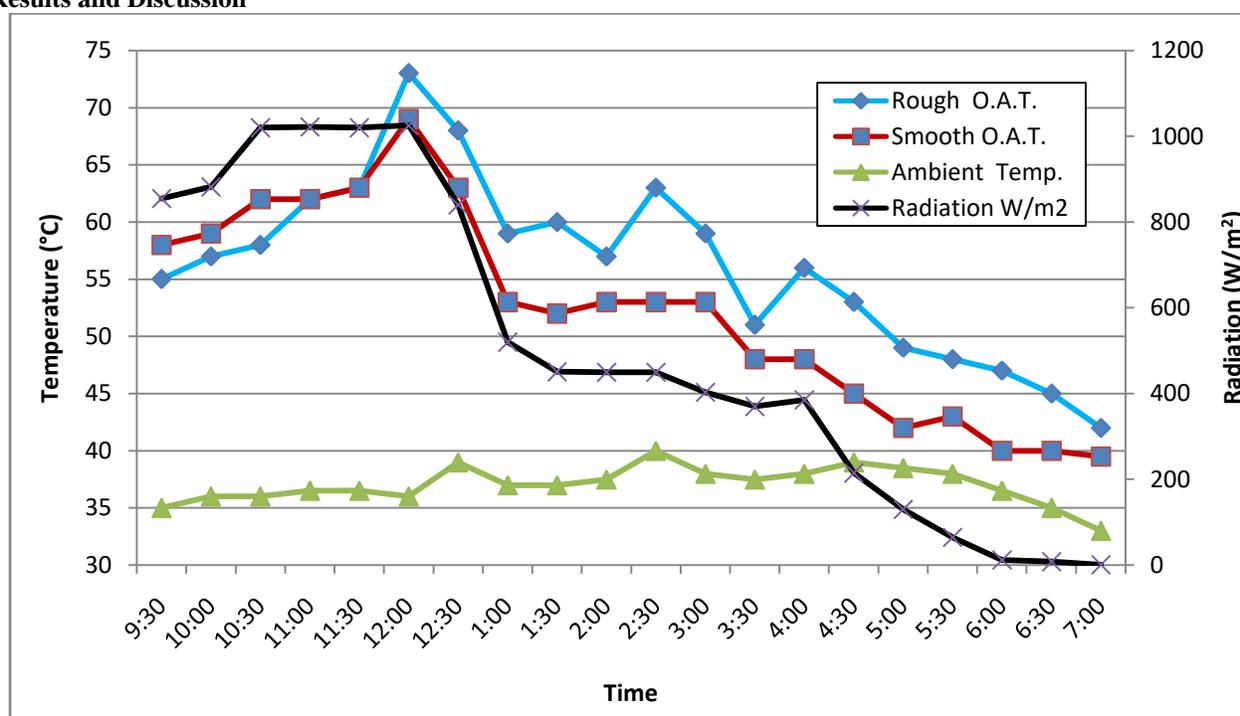


Figure. 2. Comparison of temperatures with time and radiation

Figure 2 shows the comparison of outlet temperature between smooth and rough surface. Initially, outlet air temperature of RH was lower than outlet air temperature of SH up to 11:00 am. After 11:00 am outlet air temperature of RH was found to be higher than outlet air temperature of SH until the end of the experiment i.e. 7:00 pm. The maximum outlet air temperature of RH was 73°C and that of SH was 69°C . The maximum difference between these outlets temperatures was recorded as 10°C at 2:30 pm. The Performance of RH was extended up to two hours after the sun set.

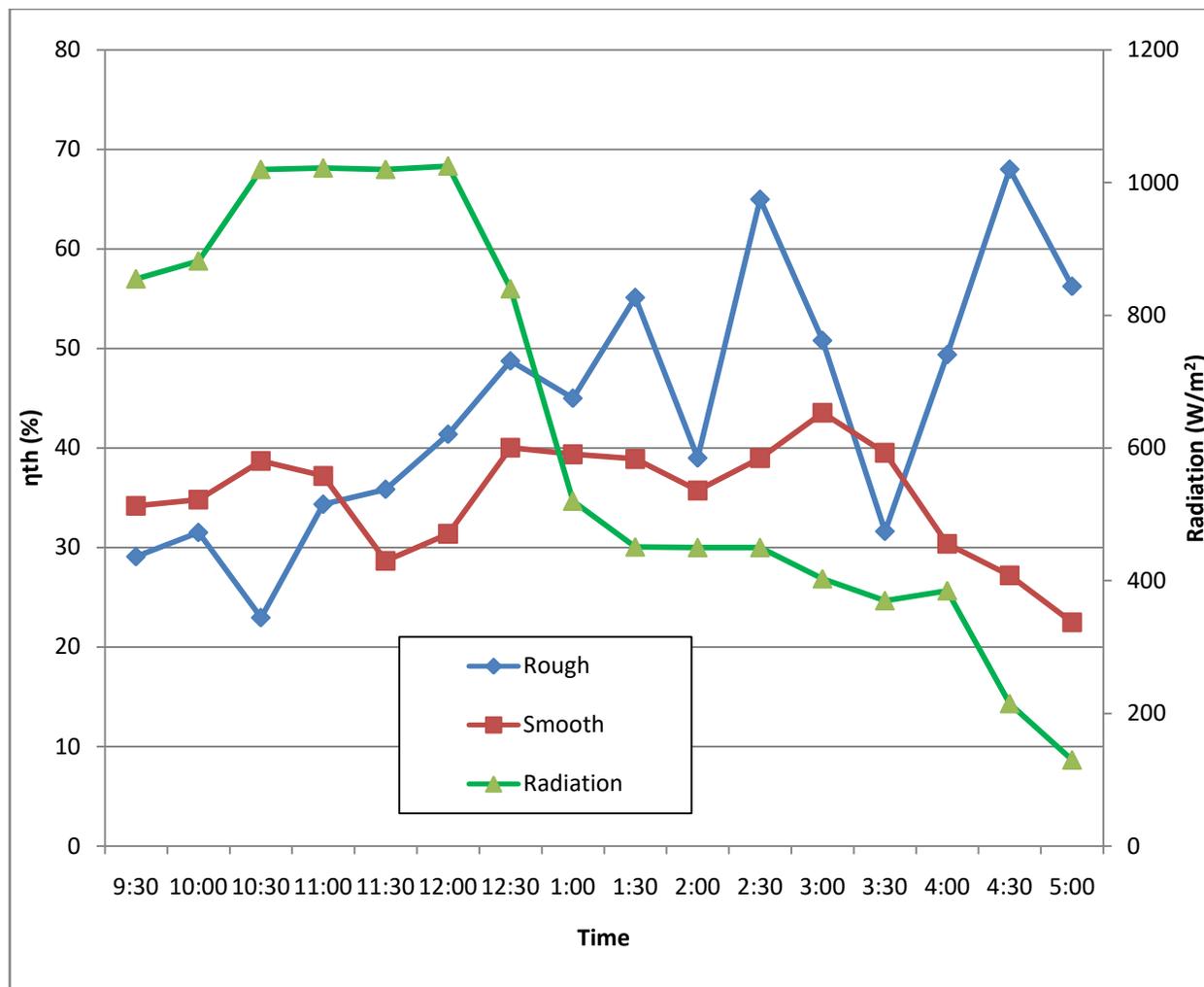


Figure 3. Variation of thermal efficiency with time and radiation

Figure 3 shows the comparison of thermal efficiency at various locations with time and radiation in both set-ups. The thermal efficiency of RH was low up to 11:00 am and after that higher than SH almost at every place. The Maximum thermal efficiency of RH was 68% and SH was 40%. So the increase in maximum thermal efficiency was 28%. After 5:00 pm radiation reached below 100 W/m^2 and then the calculation of efficiency was not considered.

4. Conclusions

The heat transfer coefficient between absorber plate and the air is low, which lowers the efficiency of a solar air heater. By providing artificial roughness, the efficiency of the solar air heater increases. Artificial roughness disturbs the viscous sub layer which increases the intensity of turbulence in the duct and causes increase in heat transfer from the roughened surface. In the present work, a solar air heater has been designed with multi V-shaped rib with gap below the absorber plate. A thermal storage system with oil was incorporated which releases heat at the time of low solar radiation. The performance of this modified solar air heater is investigated and compared with that of conventional solar air heater. Experiments were performed from 09:30 am to 07:00 pm at Reynolds number of 11000. After performing experiments, following conclusions are drawn:

- Initially, outlet air temperature of RH was lower than outlet air temperature of SH up to 11:00 am. After 11:00 am outlet air temperature of RH was found to be higher than outlet air temperature of SH till the end of the experiment i.e. 7:00 pm. The maximum outlet air temperature of RH was 73°C and that of SH was 69°C . The maximum difference between these outlets temperatures was recorded as 10°C at 2:30 pm. The Performance of RH was extended up to two hours after the sun set.
- Thermal efficiency of RH was low up to 11:00 am and after that higher than SH almost at every moment. Maximum thermal efficiency of RH was 68% and SH was 40%. So, the increase in maximum thermal efficiency was 28%. After 5:00 pm radiation reached below 100 W/m^2 and then calculation of efficiency was not considered.

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