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Experimental Study on Solar Air Heater with Continuous Arc Type Roughness and Thermal Storage

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ABSTRACT

In the present work, Aluminium wire of 20 mm diameter in the form of continuous arc type geometry has been used as artificial roughness underside the absorber plate. Two set ups were used: first set up was rough solar air heater with roughened absorber plate (RH) and other was solar air heater with smooth absorber plate (SH). It was found that when the solar radiation starts decreasing, the outlet air temperature of RH was still higher than ambient and inlet temperature because of the thermal storage system. Outlet air temperature of SH was maximum (75°C) at 1:00 pm and minimum (38°C) at 7:00 pm. Outlet air temperature of RH was maximum (67°C) at 1:00 pm and minimum (44°C) at 7:00 pm. Up to about 4:00 pm, the outlet air temperature of SH was recorded higher as compared to RH. Afterwards, the outlet air temperature of RH was recorded higher than that of SH. After 4:00 pm, the average elevated outlet air temperature of RH was found to be 4.7°C higher than that of SH. These data indicated the smooth functioning of RH as compared to SH.

***Keywords*--** artificial roughness, solar air heater, thermal storage

I. INTRODUCTION

Solar energy is a renewable source of energy which emits energy in the form of radiation. The utilisation of radiation is further converted into various forms of energy. Solar energy is eco- friendly and easily available in the nature. One of the applications of utilisation of solar energy is solar air heater in which absorber plate absorbs the solar radiation in the form of heat and supplies to the standard fluid air. Absorber plate is coated with black colour of black board paint, due to this it absorb of heat increases. The heated air is used for various application e.g. crop drying, grains, fruits, vegetable etc. Thermal efficiency of smooth solar air heater duct is less as compare to artificially roughened solar air heater because of laminar sub-layer which hinders the heat transfer between the absorber plate and air is less. Hence an artificial roughness is provided on the absorber plate to break the laminar sub-layer and improve its thermal efficiency.

Skullonga et al. [1] conducted experiments on solar air heater channel with wavy groove with pair of trapezoidal-winglets (TW) as artificial roughness with Reynolds number in the range of 4500-22000. The trapezoidal winglets (TW) include relative winglet-pitches (P_R) and relative winglet height or blockage ratios (B_R) at an attack angle (α) = 45°, whereas the wavy rectangular - groove include relative groove-pitch lengths (P_R). It was found that use of wavy groove increases the heat transfer as compare to smooth duct channel. The trapezoidal winglet provides higher heat transfer but groove yields provide low pressure drop. At relative groove-pitch lengths (PR) =1, the compound device with BR=0.28 offers the highest heat transfer and friction factor while the one with BR=0.24 gives the maximum thermal performance.

Sawhney et al. [2] explored the performance of a solar air heater roughened with wavy - up winglet vortex generator provided on the absorber plate with Reynolds number (Re) in the range of 4000-17300, no. of waves (Ø) = 3,5,7 and relative longitudinal pitch (P/H) = 3, 4, 5 and 6 respectively, angle of attack (α) = 60°. The results between the staggered and inline arrangement inferred that inline arrangement produce the higher Nusselt number (Nu). The maximum Nusselt number increase was found to be 223% over the flat plate using P/H = 3, with five wave winglets at Re = 4000 with an increased in friction factor by 10.3 times. Thermohy draulic performance was 2.09.

Kumar et al. [3] carried out study or air heater with discretized broken V- shape baffle provided on the absorber plate. The roughened baffle of solar air heater has a width to height ratio (W/H) = 10, relative baffle gap distance (D_d/L_v) varied between 0.26 -0.83 and relative baffle gap width (g_w/H_b) varied between = 00.5-1.5, respectively. Experiments were carried out in the range of Reynolds number (Re) from 3000 - 21000 with the range of relative baffle height H_b/H = 0.25-0.80, range of relative baffle pitch P_b/H = 0.5-2.5; and range of angle of attack (α) = 30°-70°. For Nu_{rs} the maximum increase of 4.47 times of that of without channel has been obtained. The absolute maximum value of thermal hydraulic performance parameter has been found to be greater corresponding to 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 of 60°. The maximum value of the thermal hydraulic performance parameter was observed to be 3.14.

Sahu and Prasad [4] investigated the thermal and thermohy draulic performance of solar collector for heating air having circular wire rib roughness in the form of arc shape. A mathematical model incorporating the operating and system parameters was developed and the results were computed using MATLAB. At rib height-to-duct hydraulic diameter ratio = 0.0422 and flow-attack-angle = 0.3333 the values of maximum thermal and effective efficiencies were recorded as 79.84% and 75.24% respectively. Optimization of different parameters of wire roughness for optimum thermohydraulic efficiency of solar air heater duct was also carried out.

Li et al. [5] focussed on proving a solution for the low thermo-physical properties of air using different absorber surface of air heater. Four types of air solar collectors: sinusoidal corrugated plate, protrusion plate, sinusoidal corrugated and protrusion plate and a base flat-plate collector are presented. The data showed that heat transfer coefficient and pressure drop and the performance factor *PF* increase with shape of absorbers surface. The efficiency of the collector improves with increasing mass flow rates. With the increase of surface roughness, both the heat transfer and pressure loss increases. The corrugated absorber surface has a comparatively larger heat exchange area, thus, the heat transfer was higher. The protrusion absorber plate surface produces swirl and secondary flows, which cause the convection coefficient of the heat transfer to increase.

Kumar A. [6] analyzed the performance of a solar air heater duct provided with artificial roughness in the form of thin circular wire in V-shaped, Multi v-shaped ribs and Multi v-shaped ribs with gap geometries using CFD. Renormalization k-epsilon model based results was found in good agreement and ,thus, this model is used to predict heat transfer and friction factor in the duct. The maximum enhancement in heat transfer and friction factor was observed in the Multi v-shaped ribs with gap. The enhancement in heat transfer is found to be increased to 1.7, 4.7, 5.6 times that of the heat transfer with that of the heat transfer of smooth surface for V-shaped, Multi v-shaped and Multi v-shaped with gap ribs roughened solar air heater.

Ravi and Saini [7] carried out an experimental study on double pass solar air heater (DPSAH) duct employed with absorber plate attached with discrete multi V- shaped and staggered rib pattern with Reynolds number (Re) = 2000 - 20000 and relative staggered rib size (r/e) = 1 - 2.5, relative staggered rib position (P_o/P) = 0.2, angle of attack (α) = 60°, relative gap distance (G_d/L_v) = 0.70, relative pitch ratio (p/e) = 10, relative roughness height (e/D) = 0.043 and relative gap width (g/e) = 1.0. Heat transfer rate has found to be increased significantly through a double pass channel of a solar air heater. Increase in pressure drop was also considerable in comparison to the single pass flow. Roughness parameters were found to be the strong function of Nusselt number and friction factor. Nusselt number and friction factor are found to be maximum at r/e = 2.5 and the maximum value of Nusselt number ratio and friction factor ratio for double pass and single pass channel have been found as 3.4 and 2.5, respectively.

An investigation of artificial roughness geometry of expanded metal mesh type in the absorber plate of solar air heater duct was carried out by Gupta and Kaushik [8]. The performance evaluation in terms of energy augmentation ratio (*EAR*), effective energy augmentation ratio (*EEAR*) and exergy augmentation ratio (*EXAR*) were carried out. It is found that the augmentation ratios decrease at faster rate with *Re* in the order of *EAR*, *EEAR* and *EXAR*. *EXAR* decreases with *Re*, and becomes less than unity and may be even negative when exergy of pump work required exceeds the exergy of heat energy collected by roughened solar air heater. Therefore, *EXAR* provides the meaningful criteria for performance evaluation. The *EXAR* is more than unity for larger flow cross section area of solar air heater duct along with low *Re* range and higher intensity of solar radiation. The *EXAR* increases with roughness height for low range of *Re*. The long way length *l/e* of expanded metal mesh may be desirable in the range 40–55°C with an angle of attack of 60° for higher *EXAR*.

II. EXPERIMENTAL SETUP

Figure 1 shows the experimental set ups. In the experiment, two set ups were arranged parallel to each other. First set up was rough solar air heater with roughened absorber plate (RH) and other was solar air heater with smooth absorber plate (SH). RH and SH, both have same dimensions of 1900mm×900 mm×50 mm. In RH, oil box is used whose dimension was 1540mm×540mm×50mm. The oil is used as thermal storage system. Aluminium wire of 20 mm diameter in the form of continuous arc type geometry has been used as artificial roughness underside the absorber plate. Both duct made up ply wood having thickness of 12 mm. It was studied that after sun set how many hour hot air is produced by the SH. Diameter of entry section and exit section had same diameter, 100 mm for both the heaters. Mild steel rod it provided support to the oil box. Oil box was made up of Galvanised iron sheet having thickness of 0.5 mm. RH and SH consists of three sections: inlet section, middle section outlet section. Artificial roughness was provided under side of the absorber plate. Black colour coating was done by the black board paint on the upper surface of the absorber plate, thus, it absorbs high intensity of radiation. The experiments were performed at Radharaman Institute of Research and Technology, Bhopal, India having East longitudinal 77.36° North latitude 23.16°. The absorber plates was placed facing south at a slope angle of 23° with horizontal due to latitude of the city.

Fig. 1. Experimental set ups

III. INSTRUMENTATION

3.1 Measurement of surface temperature

J-Type thermocouple wires were used to measure the temperatures of the absorber plate at different positions. One end of thermocouple wire placed on the absorber plate and other end is connected to the display meter. Extension wire was used to supply AC to the digital meter, and hence readings were displayed on the digital meter.

3.2 Ambient air temperature measurement

An alcohol thermometer was used for measuring the ambient temperature.

3.3 Measurement of radiation intensity

During the experiment to measure the solar radiation, digital pyranometer was used whose model number was Tenmars TM207. The readings were taken in W/m^2.

3.4 Airflow measurement

During the experiment flow rate of air was measured with the help of a digital anemometer (make: Lutron, model no was AM4210).

3.5 Air flow controller

The flow of air was controlled by valve fitted on the blower. For further control of air PVC valve was used fitted into the flexible pipe. At the time of experiment flow of air was control manually.

IV. EXPERIMENTAL PROCEDURE

Firstly the starter switch was switched on and the blower motor got started. It was insured that the leakage was prevented from every part of the system. The mass flow rate of air was controlled by valve provided in blower. The flow of air also control by the PVC valve fitted on the pipe. This helped in getting exact amount of air flow needed for the system. The air flow rate was fixed at Reynolds number there after readings were taken by using various instruments. There were different positions on solar air heater where temperature was measured during the experiments. The experiments were performed from 10:00 am to 07:00 pm and readings of following parameters were taken.

a) Oil temperature
b) Glass temperature
c) Upper surface temperature
d) Inner surface temperature
e) Rectangular duct air temperature
f) Ambient temperature
g) Radiation

V. RESULTS AND DISCUSSION

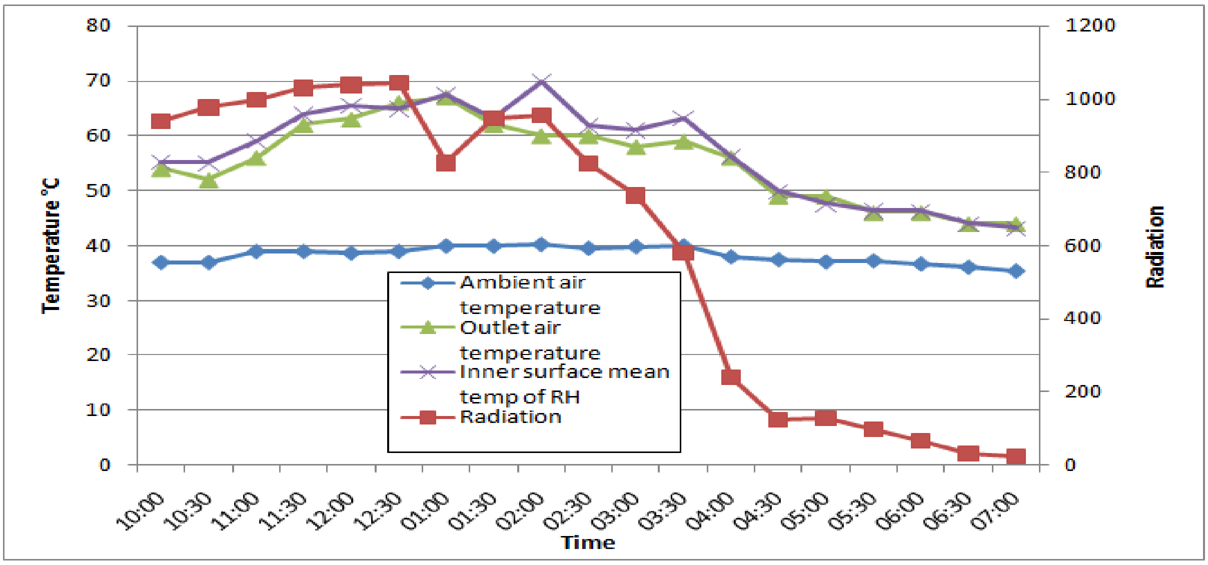

Fig. 2. Variation of temperature at various locations in RH with time

Variation of temperature at various locations in RH with time is shown in figure 2. The outlet air temperature starts increasing from 10:00 and reaches a maximum value of 67°C at 1:00 pm. As the radiation starts decreasing the outlet air temperature also started decreasing and reaches a minimum value of was 44°C at 7:00 pm. When the solar radiation starts decreasing, the outlet air temperature was still higher than ambient and inlet temperature because the thermal storage system stated releasing heat at that time. The ambient air temperature is always less than that of outlet air temperature and inner surface mean temperature of RH. Maximum inner surface mean temperature was 69.8°C at 2:00 pm and minimum was 43.2°C at 7:00 pm. The maximum temperature difference between outlet air temperature and inner surface mean temperature was 2.8°C and minimum 0.8°C. The maximum value of radiation was 1045 W/m^2 at 12:30 pm. Outlet air temperature and inner surface mean temperature was same 44°C at 6:30 pm. Maximum ambient air temperature was 40.3°C at 2:00 pm and minimum 35.4°C at 7:00 pm.

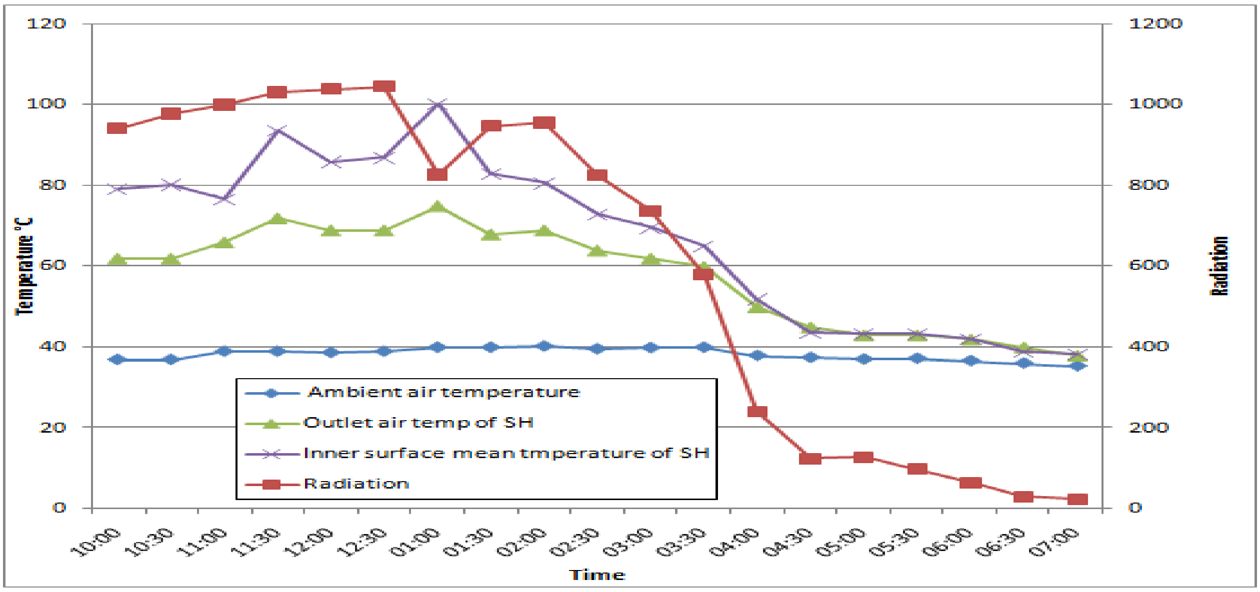

Fig. 3. Variation of temperature at various locations in SH with time

Variation of temperature at various locations in SH with time is shown in figure 3. Inner mean surface temperature was maximum 100.33°C at 1:00 pm and minimum 38.33°C at 7:00 pm. Outlet air temperature of SH was maximum 75°C at 1:00 pm and minimum 38°C at 7:00 pm. Maximum temperature difference between inner surface temperature and outlet air temperature of SH was 25.33°C at 1:00 pm. Minimum temperature difference between inner mean surface temperature and outlet air temperature of SH was 0.33°C at 7:00 pm.

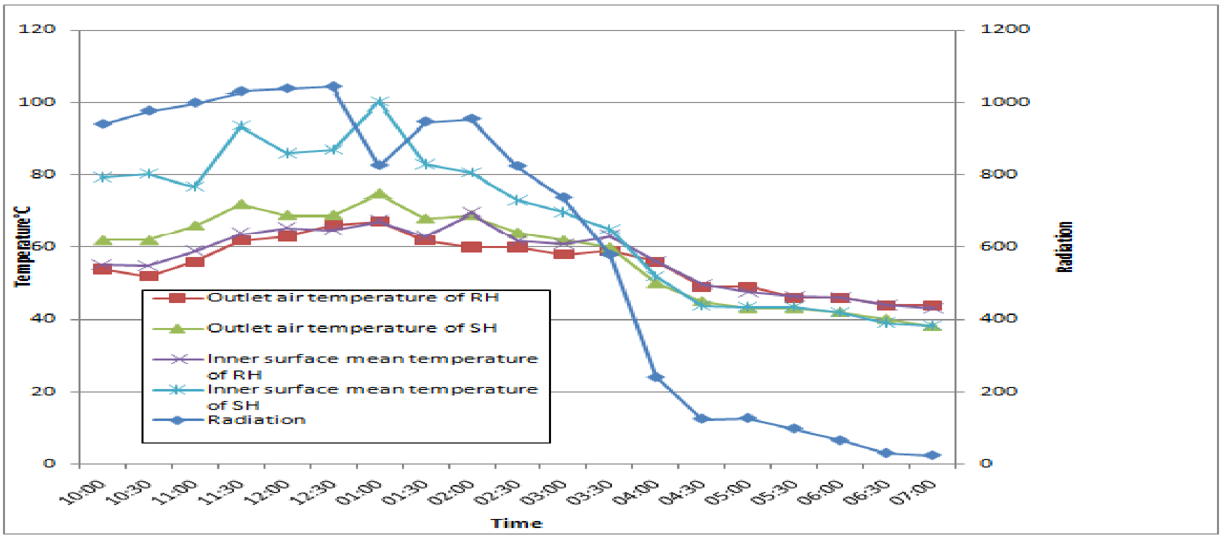

Fig. 4. Comparison of various temperatures of RH and SH with time and radiation

Figure 4 shows the comparison of various temperatures of RH and SH with time and radiation. Up to about 4:00 pm, the outlet air temperature of SH was recorded higher as compared to RH. Afterwards, the outlet air temperature of RH was recorded higher than that of SH. After 4:00 pm, the average elevated outlet air temperature of RH was found to be 4.7°C higher than that of SH. Similar trend was also found in the inner surface temperature of both the stills. The standard deviation of the outlet air temperature of RH was found to be ±7.4 whereas it was ±12.4 for SH. These data indicate the smooth functioning of RH as compared to SH. Similar trend was also found in the inner surface temperature.

VI. CONCLUSION

Solar air heater found various applications in agriculture and industrial sectors, space heating for warehouse, drying of crops to protect it from rodents mildew etc. Artificial roughness underside the absorber plate of a solar air heater breaks the laminar sub layer and increases the heat transfer. In the present work, Aluminium wire of 20 mm diameter in the form of continuous arc type geometry has been used as artificial roughness underside the absorber plate. In the experiment, two set ups were arranged parallel to each other. First set up was rough solar air heater with roughened absorber plate (RH) and other was solar air heater with smooth absorber plate (SH). The experiments were performed from 10:00 am to 07:00 pm and following conclusions are drawn.

1. The outlet air temperature of RH starts increasing from 10:00 and reaches a maximum value of 67°C at 1:00 pm. As the radiation starts decreasing the outlet air temperature also started decreasing and reaches a minimum value of was 44°C at 7:00 pm. When the solar radiation starts decreasing, the outlet air temperature was still higher than ambient and inlet temperature because the thermal storage system stated releasing heat at that time. Maximum inner surface mean temperature of RH was 69.8°C at 2:00 pm and minimum was 43.2°C at 7:00 pm. The maximum value of radiation was 1045 W/m^2 at 12:30 pm. Outlet air temperature and inner surface mean temperature was same 44°C at 6:30 pm.
2. Inner mean surface temperature of SH was maximum 100.33°C at 1:00 pm and minimum 38.33°C at 7:00 pm. Outlet air temperature was maximum 75°C at 1:00 pm and minimum 38°C at 7:00 pm. Maximum temperature difference between inner surface temperature and outlet air temperature of SH was 25.33°C at 1:00 pm. Minimum temperature difference between inner mean surface temperature and outlet air temperature of SH was 0.33°C at 7:00 pm.
3. Up to about 4:00 pm, the outlet air temperature of SH was recorded higher as compared to RH. Afterwards, the outlet air temperature of RH was recorded higher than that of SH. After 4:00 pm, the average elevated outlet air temperature of RH was found to be 4.7°C higher than that of SH. The standard deviation of the outlet air temperature of RH was found to be ±7.4 whereas it was ±12.4 for SH. These data indicate the smooth functioning of RH as compared to SH.

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