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Performance analysis of a solar air heater having multiple arc with gap type artificial roughness and thermal storage

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Abstract- *One of the most efficient ways to improve efficiency of a solar air heater is by using artificial roughness under the absorber plate of duct. Roughness in the form of multiple arc having gap is a simple and easy process of enhancing heat transfer rate in an air heater. In this research paper the duct was roughened by multiple arc having gap under the absorbing plate. The experimental data was analysed on the basis of various parameters like temperature and radiation. The setup was inclined at 23˚C in accordance with geographical feature of the place where experiment was done. The angle of attack (α) was 60˚ and Reynolds number was 9000. Under the same environmental condition performance was analysed for smooth and artificially roughened duct. The reading was observed between 9:30 am to 7:00 pm. The maximum temperature difference between outlet air temperature of roughened surface and smooth surface was recorded as 9ºC at 5:00 pm. The maximum radiation was 1072 W/m^2, maximum ambient temperature, inlet temperature, duct temperature, oil temperature and outlet temperature was recorded as 45, 53, 64, 92 and 76ºC, respectively for the roughened surface. The maximum values of inlet temperature, duct temperature and outlet temperature of smooth surface was 53, 73 and 86ºC, respectively. Due to the use of an oil box in MH the system was heated up by 2.5 hours extra after fall in solar radiation.*

Keywords: *Artificial roughness, solar air heater, thermal heat transfer, thermal storage*

Introduction

Anil Kumar [1] investigated on artificial roughness on the underside of heat transfer surface in the form of projections to make turbulence near the surface wall to hinder the formation of laminar sub-layer to increase the heat transfer rate. In his investigation a solar air heater having artificial roughness in the form of thin circular wire in V-shaped, Multi v-shaped ribs and Multi v-shaped ribs with gap geometries was analyzed. The changes in heat transfer, friction factor and performance increment was investigated for V-shaped, Multi v-shaped ribs, Multi v-shaped ribs with gap. Increment in heat transfer was calculated to be 1.7, 4.7, 5.6 times that of the heat transfer of rough surface to the heat transfer of smooth surface of a solar air heater.

Garcia et al. [2] analyzed in their research that the pattern geometry of an artificial roughness inhabit a good effect on the heat transfer augmentation of a solar air heater duct. In the same way it also increases the performance parameters of the system by providing disturbance to break the formation of laminar sub layer. According to his study for Reynolds number below 200 smooth tubes are suitable while for Reynolds numbers between 200 and 2000 wire coils are more effective. For Reynolds number more than 2000, dimple and corrugated tubes are favourable over the wire coils due to lower pressure drop chances for similar heat transfer coefficient levels.Reynolds numbers above 2000 gives high heat transfer in deformed tubes than the wire coil: at Re = 10000 and Pr = 200, Nu_a/Nu_s = 2.9 for mechanically deformed tubes and Nu_a/Nu_s = 2.4 for the wire coil.

Yadav et al. [3] carried out an experiment to study heat transfer and friction factor of air flow having artificial roughness in the form of angular arc.The thermal and friction factors are calculated by duct aspect ratio (W/H), hydraulic diameter (D), relative roughness pitch (P/e), relative roughness height (e/D), arc angle (a) and Reynolds number (Re). The parameters for the experiment was Reynolds number varies between 3600 to 18,100, P/e in the range of 12 to 24, e/D between 0.015 to 0.03 and arc angle of ranges from 45° to 75°. The maximum value of heat transfer and friction factor is noted as 2.89 and 2.93 times as compared with respect to the smooth duct.

Pandey et al. [4] experimental study was based on heat transfer and friction factor in duct of rectangular shape having artificial roughness of pattern multiple-arc shaped with gap. The parameters on which his experiment was based was as per Reynolds number (Re) ranges 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 (4 values), 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 found to be 5.85 and 4.96 of roughened duct as compared with smooth duct.

Promvonge et al. [5] carried out their research on effects of combined ribs and delta-winglet type vortex generators (DWs) for analyzing heat transfer and friction factor of a solar air heater in a turbulent flow forced convection. Various parameters of research of a rectangular duct are: aspect ratio,AR=10 and height, H=30 mm. The Reynolds number on which the research was performed between ranges 5000 to 22000. The rib description was taken as single rib height, e/H=0.2 and ribpitch, Pl/H=1.33. There were 3 angles of attack (α) 30°, 45° and 60° respectively for better results. According to their results it is cleared that thermal behavior and friction factor are higher for combination of delta-winglet and rib with respect to single delta-winglet or a single rib. At angle of attack (α=60°) increase in Nusselt number and friction factor was recorded highest while at angle of attack α=30° thermal performance was at its best. The value of Nu/Nu_o was in the range of 2.3 to 2.6 while f/f_o ranges between 4.7 to 10.1 depends on angle of attack.
Skullong et al. [6] experimental study deals with wavy-rib and groove turbulators having turbulent flow characteristics in solar air heater. Reynolds number was taken between 4000 and 21000 by controlling the air flow.The placement of triangular shape wavy ribs was done on the grooved channel walls in order to get recirculation flow. The angle of attack was taken as 45°. Three types of rib arrangement was investigated, rib-groove on the upper wall only, inline rib-groove, and staggered ribinlinegroove.Combine rib groove on inner and outer wall are efficient than the smooth channel with or without rib. Groove alone has low thermal efficiency as compared to combination of rib groove. The value of Nu/Nu_o lies between 4.4-7.69 depending upon rib arrangement and Reynolds number. Application of combine rib groove on absorber plate enhances the heat transfer upto 49-52% with respect to alone groove.

Bopche and Tandale [7] studied heat transfer coefficient and friction factor by using artificial roughness of inverted U shape on the absorber plate. The part of the duct which was roughened was heated in uniform manner while other three parts were well insulated.The research parameters were as Reynolds number range in between 3800 to 18000; e/Dh = 0.0186 to 0.03986 (Dh = 37.63 mm ande = 0.7 to 1.5 mm) while p/e = 6.67 to 57.14 (p = 10 to40 mm). The angle of attack (α) was taken at 90º during the whole research. At uniform condition the thermal characteristics and friction factor were analyzed. Enhancement in heat transfer as compared with smooth duct was recorded as 2.82 & 3.72 respectively.

Tamna et.al [8] performed experiments on heat transfer enhancement on V-baffle vortex generator on air heater absorber plate. The air flowed through the duct had given a uniform heat onto the absorber plate. The Reynolds was taken in between 4000-21000. The angle of attack was at 45° with respect to the direction of flow. The main purpose to use V-baffle vortex generator in the channel is to increase turbulence. The ratio of f/f0 = 12.5–129.6 and Nu/Nu0 = 3.91–7.53 were concluded in the experiment.

Alam et.al [9] by their experiments illustrated the effect of non-circular perforation holes in term of circularity of V-shaped blockages attached on the absorber plate. Five different hole shapes viz. circular, square and 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 30–75ºC and Reynolds number of flow was varied between 2000 and 20,000. A perfect circular hole performs inferior as compared to a non-circular hole of considerable non-circularity (w = 0.69). An improvement of 1.13 times in Nusselt number was observed when circular perforation holes are replaced by rectangular holes of circularity of 0.69.

Gawande et al. [10] carried out an experiment for enhancement in heat transfer by using artificial roughness in the form of repeated ribs on beneath of the absorber plate. The use of forced convection was done having reverse L-shape ribs and on this the experiment was proceeded.Parameters on which his experiment was base are as: relative roughness pitch ranges in 7.14-17.86, Reynolds number was taken in between 3800-18000, heat flux was $1000W/m^2$ and relative roughness height was (e/D) 0.042. Reverse L shape artificial roughness helps to increase the heat transfer coefficient with respect to the variables like relative roughness pitch (P/e) and Reynolds number (Re).The analysis was done on CFD simulation on ANSYS software.The numerical analysis was having higher accuracy than that with experimental analysis. Relation between Nusselt number and friction factor was established. The maximum rise in Nusselt number was concluded to be 2.827 times as compared with the smooth duct. The maximum increment in friction factor was 3.424 times than the smooth duct.

This paper deals with the use of multiple arc having gap as roughness geometry on the underside of absorbing plate. There is also a use of an oil box for enhancing heat transfer even after sunset to make some extra use of heating time. The performance of conventional solar air heater (CH) was compared with this modified solar air heater (MH).

2. Experimental Program

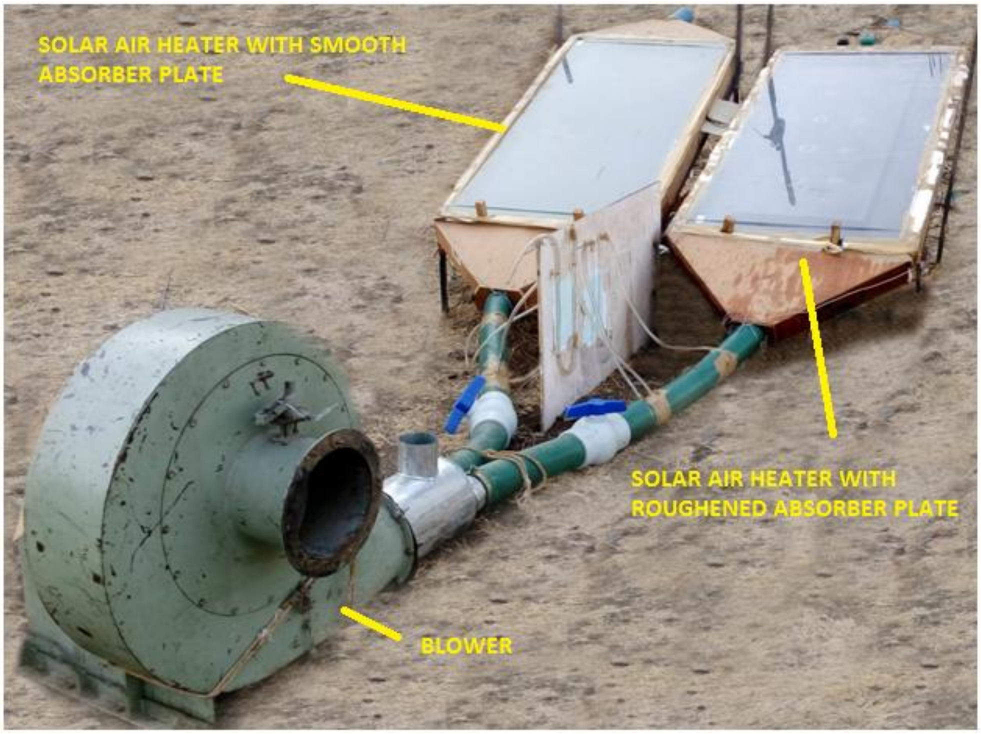

Figure 1. Experimental setup of a solar air heater having inclination of 23º

The experiments were carried out on a well equipped setup in order to attain higher effectiveness of heat transfer. There were two set up one for smooth duct, named as conventional solar air heater (CH) and the other one for artificially roughened duct, named as modified solar air heater (MH). The roughness was provided by means of aluminum wire by giving its shape in multiple arc having gap. The modified duct also had an oil box fitted with the duct. The oil box was used as a thermal storage for providing sufficient amount of heat in absence of solar radiation. A view of the setup is shown in the figure 1. The system was inclined at 23˚ because of latitude of Bhopal. The duct shape was rectangular having cross-section of 1900×900 mm^2. The duct was made up of galvanized iron sheet and the base box was of plywood. To prevent heat loss glass wool was used as an insulating material. There were 8 iron rods whose function was based on the process of conduction. The system works on the principle of forced convection. For this a 3-phase blower was used for air supply. Flow of air was controlled by valve fixed in the blower itself. But for further control PVC valve was used fitted in the flexible pipe. Flexible pipe was used for the flexibility of duct, so that we can move our system as per the demand of condition. The reading was taken from 9:30 am to 7:00 pm. There were various parameters which were measured during the experiment such as temperature, solar radiation, pressure (inlet and outlet), velocity of air at both inlet and outlet etc. The Experiment was carried out at Radharaman Institute of Research and Technology campus in Bhopal city of India.

2.1 Instrumentation

a) Temperature measurement

For measuring temperature at various places J-type thermocouple wire was used. Temperature at inlet and exit sections was measured. A total of 12 thermocouple wires were used in the roughened duct where as 9 thermocouple wires for smooth duct. For measuring the values digital temperature recorder was used and thus temperatures at various sections were observed.

b) Radiation measurement

Radiation intensity was measured with the help of digital solar power meter having sensor for sensing radiation. The radiation was measured at 23º which is same as angle on which the system works.

c) Air flow measurement

The flow of air was measured by using anemometer of digital type. The velocity was recorded both at inlet and outlet for better efficiency of solar air heater. Air flow controlling was done with the help of valve attached with the blower itself. Another valve made up of PVC was attached with flexible pipe for better results.

2.2 Experimental Procedure

There were various parameters related with this experiment and was recorded as per need, which are as follows.

a) Ambient temperature
b) Inlet temperature
c) Duct air temperature
d) Outlet air temperature
e) Solar radiation Intensity

In the beginning of the experiment all possible leakage factor were examined properly. After proper checkup blower was started from which air flowed into the pipe which was inserted into the duct. And from the duct air came out after consuming heat with itself. In this way a solar air heater works.

3. Results and Discussion

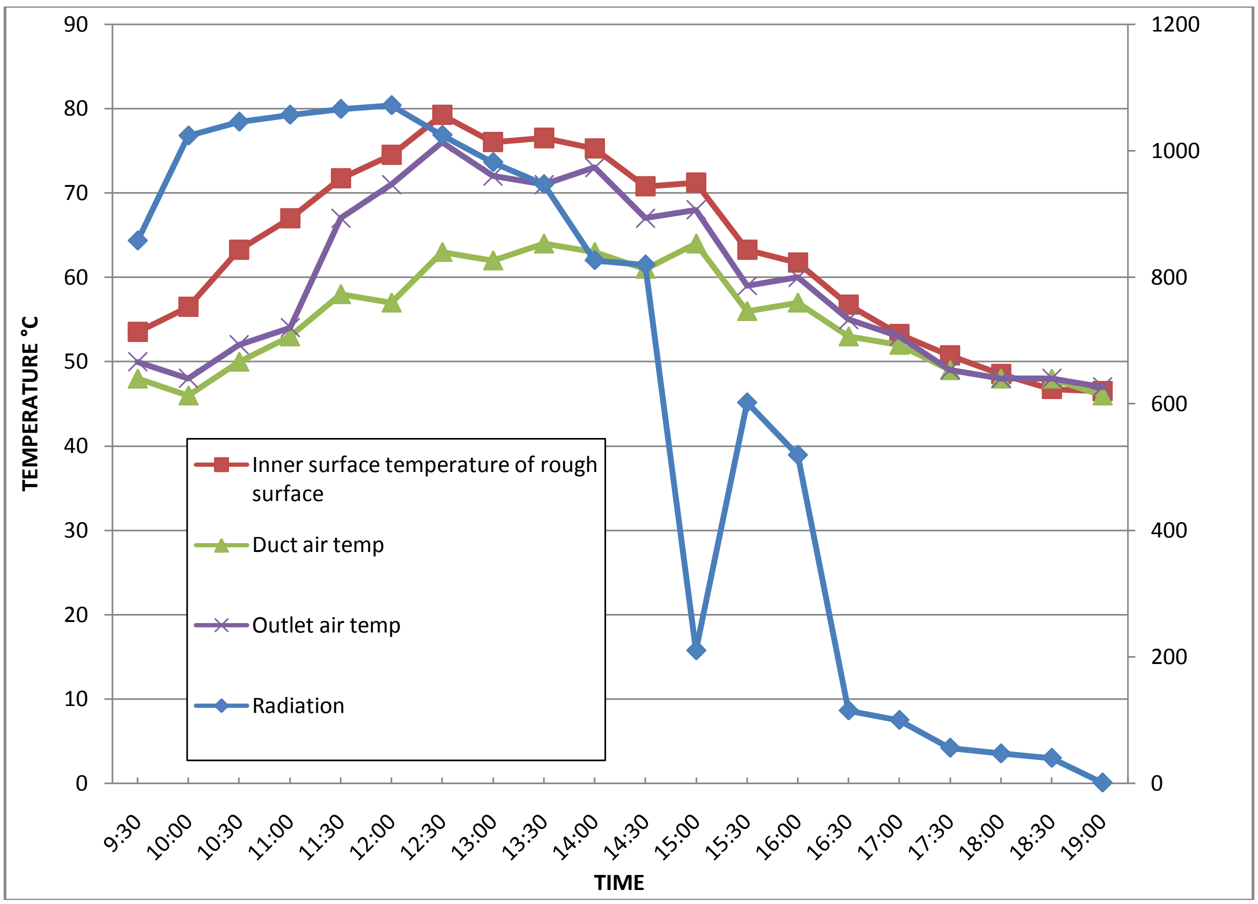

Figure 2. Variation of temperature with time and radiation for rough surface

Figure 2. shows the variation of temperature with time and radiation for rough surface. With the help of graphical representation it is clear that the inner surface temperature of rough surface is the highest amongst all other temperatures. The observations of these parameters were taken in between 9:30 am to 7:00 pm. The outlet temperature curve is slightly above duct temperature curve at all the points. The maximum inner surface temperature was recorded at 12:30 pm and was 79°C. In same way the maximum duct air temperature was 64°C at 1:30 pm. The maximum outlet was 76°C at 12:30 pm. The

radiation was at its peak at 12:00 noon. The graph shown above helps in getting exact information of inner surface temperature, duct air temperature and outlet air temperature of roughened duct having artificial roughness.

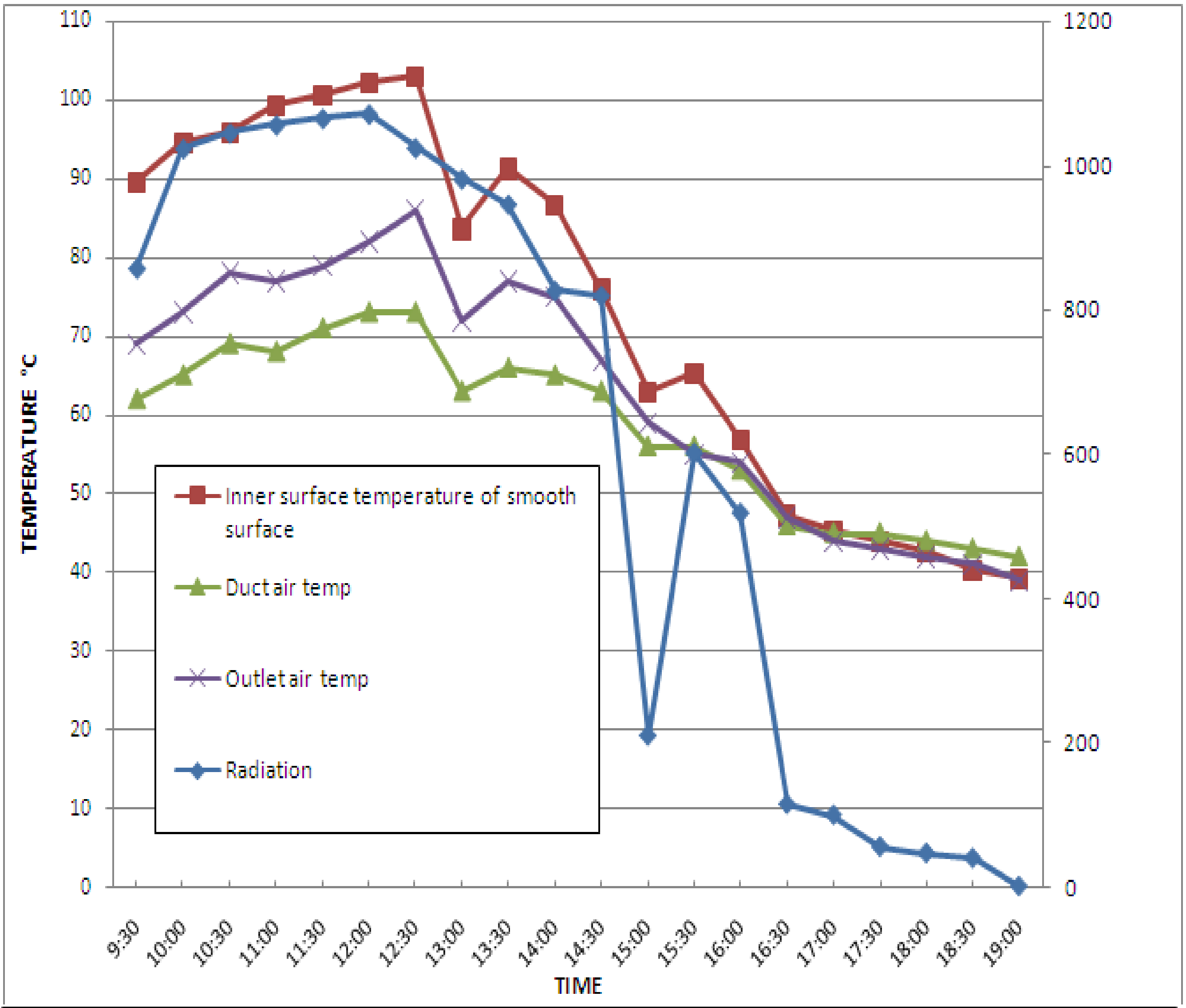

Figure 3. Variation of temperature with time and radiation for smooth surface

Figure 3. shows the variation of temperature with time and radiation for smooth surface. The inner surface temperature was maximum at 12:30 pm and was 103°C. But around 1:00 pm the inner surface temperature decreases due to hindrance made by clouds. But after departure of clouds the reading starts coming as usual. The duct temperature was the lowest amongst all other shown in the graph. The peak temperature of duct and outlet was recorded as 73°C and 82°C at 12:30 pm respectively. Above graph shown provides the accurate time and temperature variance data for a smooth surface.

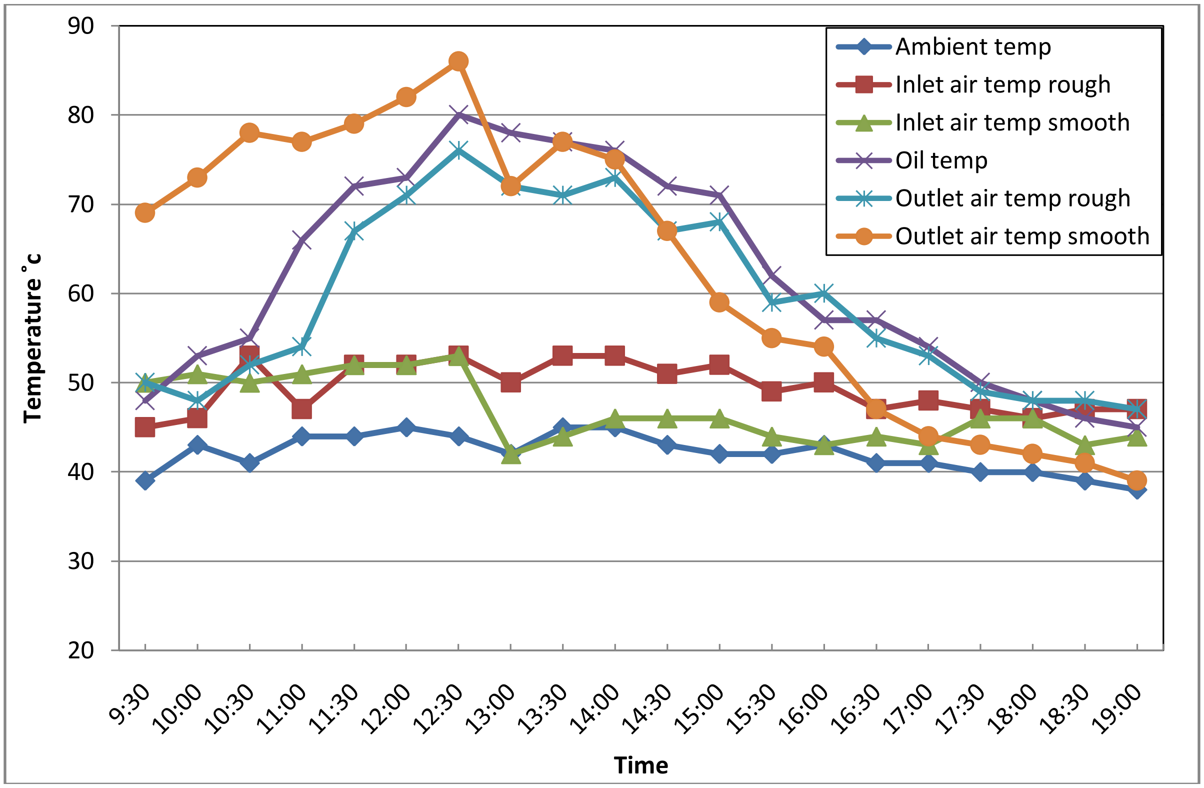

Figure 4. Comparison of various temperatures of CH and MH with time and radiation

Figure 4 shows the variation of ambient temperature, inlet and outlet temperature of smooth and roughened duct and oil temperature with time and radiation. The reading was recorded in between 9:30 am to 7:00 pm. As per the graph it is clearly depicted that outlet air temperature of smooth surface till 2:00 pm is higher than outlet temperature of roughened duct. But after 2:00pm the solar radiation starts decreasing and then after the outlet temperature of roughened duct increases due to use of oil. Soya oil was used as the thermal storage which provides heat after the sunset. The temperature of oil was higher, at almost every moment, than that of outlet temperature in MH. The solar radiation after 4:00 pm was quite low and after that role of oil gets started. We use heat of oil for some 2.5 extra hours, which increases the thermal efficiency of the system.

4. Conclusions

Solar air heater has varieties of applications due to which it is frequently used in various industries. Its design and construction is quite simple which makes its use easier. In textile industries, for drying building materials, for drying crops, for timber seasoning, for brooding chicken etc. are some use of solar air heater. In this paper solar air heater is experimented at Reynolds number of 9000 having artificial roughness pattern of multiple arc shape with gap. The performance was analysed between smooth duct and roughened duct. The roughened also had an oil box having vegetable oil to gain a higher heat transfer rate. Due to use of oil we get 2.5 hours extra heat even after absence of solar radiation. Thus the efficiency of roughened duct in comparison to smooth duct is higher. Thus, it is concluded that the performance of roughened duct at different parameters like duct air temperature, outlet air temperature etc. at same environment condition is higher than that of smooth duct.

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