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Plate temperature distribution and heat transfer analysis of an artificially roughened Solar air heater

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Abstract - *If the intensity of radiation observed to be higher on absorber$_r$ plate of solar air heater shows an effective value of heat transfer rate from the plate by the carrier fluid, air, enhances thermal performance of solar air heaters. The paper deals with the experimental results of enhancing the heat transfer rate by means of providing transversely placed circular ribs as artificial roughness$_s$ on the air flow side of the absorber$_r$ plate. The non-dimensional parameters$_s$ having relative roughness$_s$ height$_t$ (e/D) and relative roughness$_s$ pitch (P/e) at constant value of mass flow rate chosen as a design parameter and its effect on heat transfer and temperature distribution on the absorber$_r$ surface has been analysed. From the above analysis it is observed that as the e/D value increases the mean fluid temperature increases thus increases the heat transfer rate of the flowing fluid and attain its maximum value at e/D of 0.01740.*

Key Words*: *Solar air heater, Relative roughness$_s$ pitch (p/e), relative roughness$_s$ height$_t$ (e/D)

1. INTRODUCTION

The rapid depletion of fossil fuel resources has necessitated an urgent search for alternative sources of energy. Every country draws its energy needs from a variety of sources. These sources can be categorized broadly as commercial sources and non-commercial sources. Of the many alternatives, solar energy stands out as the brightest long-range promise towards meeting the continually increasing demand for energy. Solar energy is available freely, omnipresent and an indigenous source of energy provides a clean and pollution free atmosphere. The simplest and the most efficient way to utilize solar energy is to convert it into thermal energy for heating applications by using solar collectors. Several investigators have investigated to enhance the heat transfer in solar air heater by using extended surface, packed bed and by providing artificial roughness$_s$ on the absorber$_r$ plate. Sharma et al. [1] studied the double pass solar air heater (DPSAH) consisted of rectangular duct provided with artificial roughness$_s$ on both side of the absorber$_r$ plate has been experimentally investigated. Experiment is carried out over the range of Reynolds Number from 4900 to 12000, and relative roughness$_s$ height$_t$ (e/Dh) varies from 0.022 to 0.044.Bhardwaj et al. [2] state that the thermo hydraulic performance of artificially roughened equilateral triangular solar air heater duct has been investigated and the comparison of the same has been presented with that of a conventional smooth solar air heater duct**.** Tao lieu et al. [3] state that the thermal performance of cross-corrugated and v-groove solar air collectors has been compared under a wide range of configuration and operating conditions. Lanjewar et al. [4] state that an experimental investigation has been carried out to study heat transfer, friction characteristics and thermo hydraulic performance of roughened absorber$_r$ plate in solar air heater by using W-shape rib roughness$_s$, the roughened wall being heated while the remaining three walls insulated. Elradi et al. [5] Correlated transient heat transfer and pressure drop have been developed for air flowing through the porous media, which packed a double-pass solar air heater. Various porous media are arranged in different porosities to increase heat transfer, area density and the total heat transfer rate. Bashria et al. [6] investigate the effect of mass flow rate, flow channel depth and collector length on the system thermal performance and pressure drop through the collector, on V-groove absorber$_r$ at single and double flow mode. Gupta et al. [7] did the investigation on inclined ribs of different parameters$_s$ like relative roughness$_s$ height$_t$, attack angle and Reynolds number on solar air heater system and its effect on heat transfer and friction factor observed having circular rib roughness$_s$ on the absorber$_r$ plate. Momin et al. [8] used V-Shaped ribs for the investigation and observed that rate of increase of Nusselt$_t$ number is found to be lower than rate of increase of friction factor with an increase in Reynolds number. number is found to be lower than rate of increase of friction factor with an increase in Reynolds number. Han and park [9] conducted experimental study using transverse circular ribs which were found to be considerable enhancement in heat transfer coefficient$_t$ between the absorber$_r$ plate and the flowing fluid. It is stated that artificial roughness$_s$ applied on the absorber$_r$ plate is the most acclaimed method to improve thermal performance of solar air heaters at the cost of low to moderate friction penalty. The application of artificial roughness$_s$ in the form of fine wires and staggered ribs of different shapes has been recommended to enhance the heat transfer coefficient$_t$ by several investigators. In a similar type of study done using the liquid crystal thermography (LCT) by Kumar and layek [10] having transverse circular rib for attaining its optimal Nusselt$_t$ number and friction characteristics. Kumar et al. [11] conducted the experimental work on three sided artificial roughness on solar air heater and its effect on heat transfer for different value of relative roughness pitch and relative roughness height has been studied. Roughness$_s$ elements have been used to improve the heat transfer coefficient$_t$ by creating turbulence in the flow. However, it would also result in an increase in friction losses and hence greater power requirements for pumping air through the duct. In order to keep the friction losses at a low level, the turbulence must be created only in the region very close to the duct surface, i.e. in the laminar sub layer. Our objective is to investigate the effect discrete shaped roughness$_s$ on the absorber$_r$ plate of solar air heater, on the heat transfer coefficient$_t$ and friction factor and to compare it with smooth absorber$_r$ plate to know the actual increase in performance of flat plate solar air collector by using this particular artificial roughness$_s$ on absorber$_r$ plate.Fig.1 depict the schematic sketch diagram of circular rib roughness$_s$ on the absorber$_r$ surface.

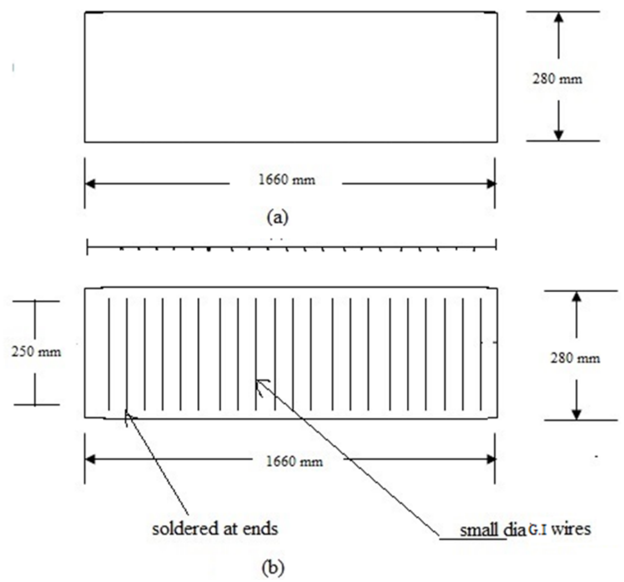

Fig.1 (a), (b) Smooth and typically roughened absorber$_r$ plates respectively

Nomenclature

Cp	Specific heat capacity (J/kgK)
e	Small diameter of wire
D	Hydraulic diameter
f	Friction factor
W	Duct width
k	Thermal conductivity (W/mK)
Nu	Nusselt$_t$ number
m	Mass flow rate (kg/s)
P	Pitch of the wire
Pr	Prandtl number
Q	Heat transfer rate (W)
Re	Reynolds number

2. SYSTEM DEVELOPMENT AND PROCEDURE

The system is designed and manufactured according to ASHRAE standards and is specially designed for rectangular pipes with only one artificial roughening of the surface. In order to generate heat transfer, fluid flow, thermal and hydraulic performance data on artificially rough solar air heater pipes, and such a system was developed. Figures 2 and 3 shows the experimental setup, and the arrows show the flow direction of the air sucked in by the system (blower). The thermometer has been inserted into ten different points in the rectangular air duct, namely the inlet, middle and outlet of the solar air heater and it will read the temperature at different positions of the solar air heater. U-tube manometers have been used to measure the pressure drop across the carrier liquid pipeline, and calculate the Reynolds number and mass flow based on this pressure drop flow rate. Digital radiometers have been used to measure global radiation and direct radiation.

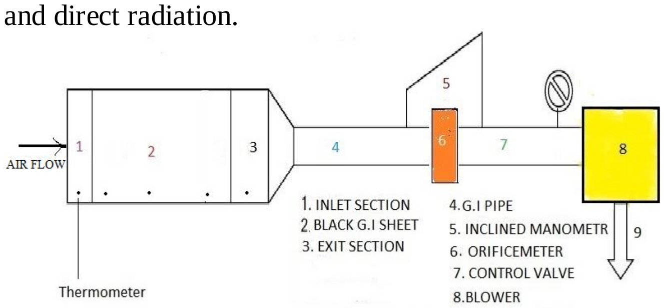

Fig.2 Schematic diagram of solar air duct

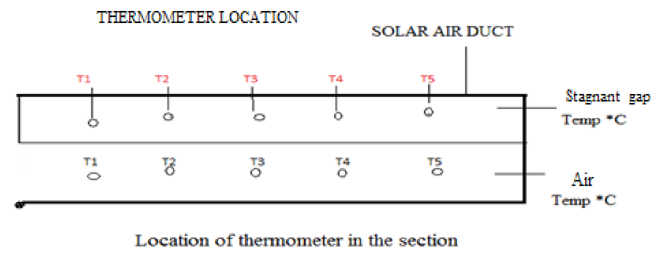

Fig.3 Location of thermometer in solar air duct

The experimental schematic diagram set-up consists of an entry section$_n$, an exit section$_n$, a flow meter and a centrifugal blower. The duct is of size 1680mm x 280 mmX60mm (dimension of inner cross- section$_n$) and is constructed from wooden panels. There is an orifice$_e$ plate assembly which is connected between duct and blower. Duct length is 168cm and width is 28cm.Thikness of 6cm is divided into two parts, one of height$_t$ 4cm and another of 2cm. the side walls were 25mm×25mm wooden pieces. The heated plate is a 1 mm thick GI plate with integral rib-roughness$_s$ formed on its rear side and this forms the top broad wall of the duct. The mass flow rate of air is measured by means of a calibrated orifice$_e$ meter connected with an inclined manometer, and the flow is controlled by the control valves provided in the lines. The orifice$_e$ plate has been designed for the flow measurement in the pipe as per the recommendation. The orifice$_e$ plate is fitted between the flanges, so aligned that it remains concentric with the pipe. Hg (0-100) thermometers are used to measure the temperature at different places. Thermometer have been used to measure the local temperature of the absorber$_r$ plates as well as the duct air temperature. Intensity of global solar radiation was measured with precision digital pyrometer with global radiation sensor. Which is installed by CWET (Center for Wind Energy Technology) an autonomous research and development institution under the ministry of new and renewable energy.

e/D_1=0.009571

e/D_2=0.0140

e/D_3=0.01740

Fig.4 Photograph of Roughened absorber$_r$ plate

The artificial roughness$_s$ has been provided on the bottom side of the plate. The pitch of the roughness$_s$ has been selected as per diameter of the wire that is height$_t$ of roughness$_s$ from the theoretically and experimentally optimized results. This experiment is performed by taking typical value of e/D_1=0.009571, e/D_2=0.014, e/D_3=0.01740. It is well ensured that the roughness$_s$ is varied with the absorber$_r$ plate and its effect on the heat transfer has been calculated. The different configuration of the artificially roughened absorber$_r$ plate as shown in Fig.4.

3. RESULTS AND DISCUSSION

It is observed that artificial roughness$_s$ is a good technique to improve thermal performance of solar air heaters. The result with respect to the enhancement of performance and the effect of roughness$_s$ and flow parameters$_s$ on the Nusselt$_t$ number, Reynolds number and temperature rise of air has been discussed.

3.1 Effect of parameters$_s$ on solar collector performance

The following discusses the influence of various flow and roughness parameters on the heat transfer characteristics of air flow in rectangular pipes with different relative roughness in this study. Under similar flow and geometry conditions, the results are also compared with the results of smooth pipes to observe the increase in heat transfer coefficient. The results are shown in Figure 5, and the data are presented in the form of Nusselt figures to clearly show the influence of parameters and heat transfer enhancement. Figure 5 shows that the value of the Nusselt number increases with the increase of the Reynolds number, because it is just the ratio of the conduction resistance of the heat flow to the convection resistance, and as the Reynolds number increases, the thickness of the boundary layer decreases, so The convection resistance decreases, which in turn increases the Nusselt number.

3.2 Nusselt$_t$ Vs. Reynolds number

Fig. 5 shows the experimental values of average Nusselt$_t$ no plotted as a function of Reynolds number for various sets of roughness$_s$ and roughness$_s$ height$_t$ values. Corresponding values of experimental Nusselt$_t$ number in a smooth duct have also been plotted in these Fig. 5.

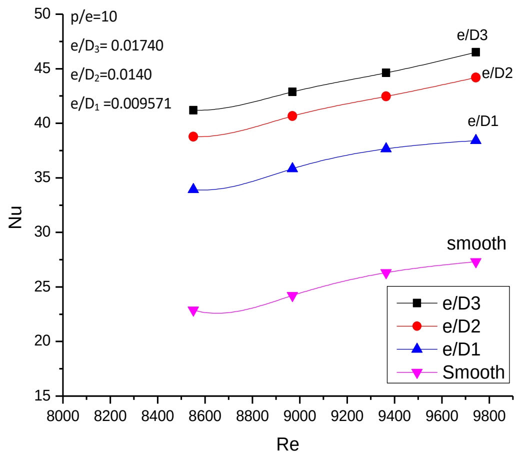

Fig. 5 Performance characteristics for Nu vs. Reynolds number

3.3 Absorber$_r$ plate temp distribution w.r.t length of duct for (p/e = 10) i.e. constant

Fig. 6 to 8. shows the temperature distribution of fluid (air) along the duct length for the roughened solar air heaters. The absorber$_r$ plate temp distribution for both the air heater along the flow ducts has been shown in Fig. 6 to 8.

3.4 Absorber$_r$ plate temp distribution w.r.t length of duct for e/D$_1$

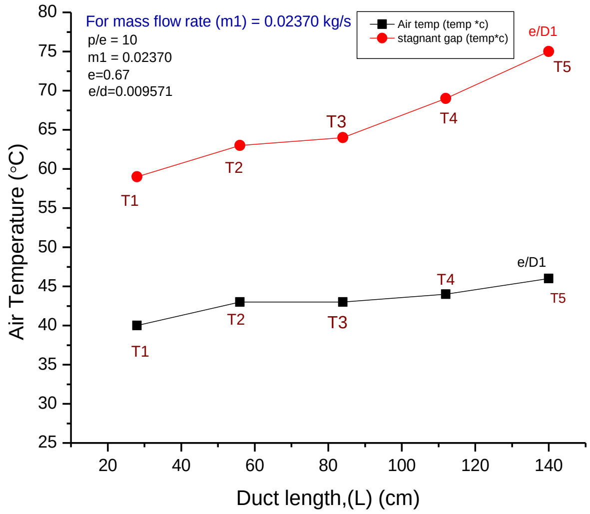

Fig 6 Solar air temperature along duct length

3.5 Absorber$_r$ plate temp distribution w.r.t length of duct for e/D$_2$

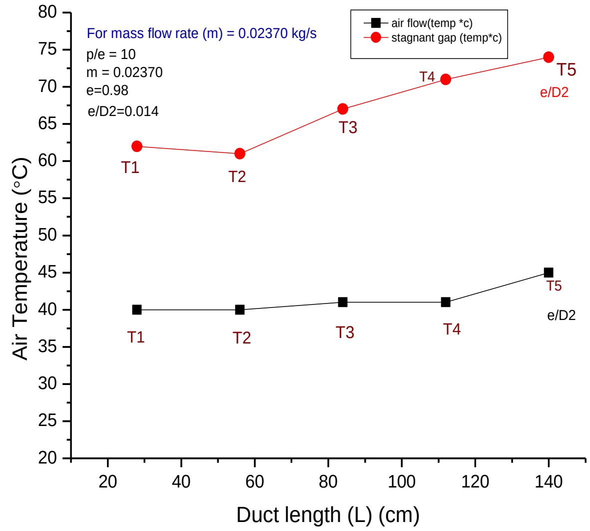

Fig 7 Solar air temperature along duct length

3.6 Absorber$_r$ plate temp distribution w.r.t length of duct for e/D$_3$

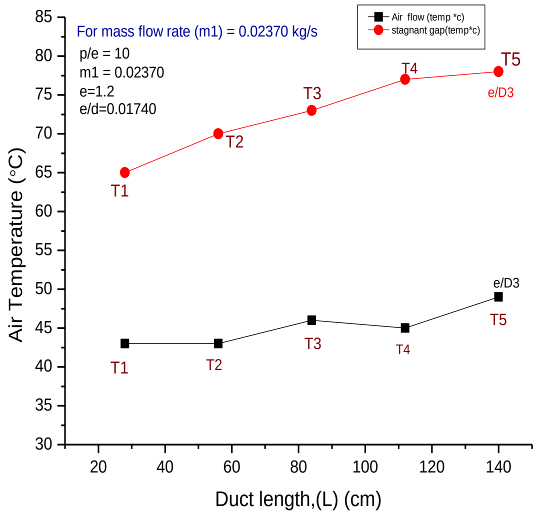

Fig 8 Solar air temperature along duct length

The range of values of relative roughness$_s$ height$_t$ corresponding to optimal conditions is a function of Reynolds no and the relative roughness$_s$ pitch.as shown in table 1.

Table 1 Range of roughness$_s$ and flow parameters$_s$

e/D	m(kg/s)	Re	p/e	e
0.014	0.023706	8551	10	0.98
0.014	0.024866	8951	10	0.98
0.014	0.025964	9358	10	0.98
0.01740	0.023706	8551	10	1.2
0.01740	0.024866	8951	10	1.2
0.01740	0.025964	9358	10	1.2
0.009571	0.023706	8551	10	0.67
0.009571	0.024866	8951	10	0.67
0.009571	0.025964	9358	10	0.67

4. CONCLUSIONS

The following conclusions have been derived based on the results and discussions:

- The Nusselt$_t$ number of the roughened solar air heaters increases with the increasing the flow Reynolds number for different value of relative roughness$_s$ height$_t$ (e/D) at constant value of relative roughness$_s$ pitch and observed to be optimum at (e/D) of 0.0174.
- Artificially roughened solar air heaters have enhanced rate of heat transfer as compared to the smooth solar air heaters under the same operating conditions of mass flow rate and intensity of solar radiation.

- The performance of solar air heaters is a strong function of absorber plate temperature, higher the plate temperature resulting higher the heat transfer rate.
- The rate of enhancement of heat transfer rate of roughened solar air heaters depends upon the values of flow Reynolds number (Re), relative roughness$_s$ pitch (p/e) and relative roughness$_s$ height$_t$ (e/D).
- Roughness$_s$ in the form of transvers circular ribs were mainly suggested by different investigators to achieve better thermal performance.

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