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Thermal analysis of three sides artificially roughened solar air heaters

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Abstract

Artificial roughness have been provided under side of the absorber plate for improve in the friction factor, heat transfer and pumping power as compared to smooth one. Analysis and experimental investigation for fully developed turbulent flow of artificially roughened solar air heaters have been established to have a better performance as compared to smooth one under the similar operating conditions [1, 2]. Three sides glass covers with three sides artificially roughened solar air heater has been analyzed and investigated [3, 4], which result in enhancement of friction factor and heat transfer than existing one side artificially roughened ones. Three sides glass covers with three sides artificially roughened and existing one side artificially roughened collectors have been analyzed and optimized for maximum friction factor and heat transfer and minimum pumping power [5-7]. This paper represents an experimental investigation for the thermal analysis of three sides glass covers with three sides artificially roughened solar air heaters under actual outdoor conditions and compare well with smooth ones, also having three sides glass covers.

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Keywords: Friction factor, Heat transfer coefficient, Flow Reynolds number, Relative roughness height, Relative roughness pitch.

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1. Introduction

Friction factor and heat transfer for tubes, artificially roughened collectors and annuli have been studied earlier by [8-11]. For enhancement of thermal performance, various solar air heaters have been developed and designed by the researchers over the years.

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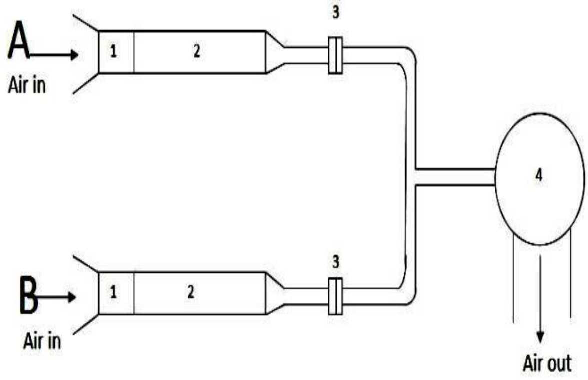
For solar air heaters it has been concluded that the low range of heat transfer coefficient between the absorber plate and flowing air, which increase the absorber plate temperature and resulting higher value of heat losses and lower value of thermal efficiency. Inclination of 60^0 to artificial roughness using continuous ribs on the absorber plate, which results at higher relative roughness and low flow rate yields a better performance [12]. Transverse ribs have been used to enhance heat transfer coefficient [13]. Wire mesh roughness, wedge shape ribs, V-shape ribs, arc shape roughness, dimple shape roughness, combined inclined and transverse ribs, multi V-rib roughness, w-shaped ribs [14-22], are the works on investigations and analysis, have been found qualitatively and quantitatively enhancement of heat transfer coefficient. By providing artificial roughness it has been concluded that there is an improvement of heat transfer coefficient, which results increase in pumping power, pressure drop and also higher value of thermal performance. This paper represents the experimental investigation for three sides glass covers with three sides roughened collectors under the actual outdoor conditions at different range of roughness and flow parameters and also compare well with smooth ones having three sides glass covers.

Nomenclature

A_C	collector area, m^2	k	thermal conductivity of air, W/m K
B	solar air heater duct height, *m*	$\dot{m}$	mass flow rate of air, kg/s
Cp	specific heat of air at constant pressure, J/kg K	Nu	Nusselt number
D	hydraulic diameter of solar air heater duct, *m*	$\overline{Nu_r}$	average Nusselt number
e	roughness height, *m*	Nu_S	Nusselt number for smooth duct
e^+	roughness Reynolds number[4], $e^+ = {}^{e}/_{D}\sqrt{\frac{f_r}{2}}\,Re$	Nu_F	Heat transfer enhancement factor
e/D	relative roughness height	p	pitch of roughness element, *m*
f	friction factor	p/e	relative roughness pitch
f_S	friction factor for smooth duct	Re	flow Reynolds number
f_r	friction factor for four sided rough duct	T_0	outlet temperature of air, ^0C
$\bar{f_r}$	average friction factor	T_i	inlet temperature of air, ^0C
f_F	friction enhancement factor	$\bar{T}_P$	average plate temperature, ^0C
f_F	friction enhancement factor	$\bar{T}_f$	average air temperature, ^0C
H	convective heat transfer coefficient, W/m^2K	W	width of solar air heater duct, m
		SWG	standard wire gauge

2. Experimental study

Fig. 1 represents the two rectangular collectors of similar size, smooth one and three sides roughened collector, whereas, Fig. 1(a) represent the photograph of measuring instruments. Both the ducts are having three sides glass covers. The total length of the ducts consists of entry sections for flow stabilization and test sections. Mass flow rate was varied by controlling the blower speed by means of a 3-phase auto-variac. G.I. wires of 20, 22 and 24 SWG were used as artificial roughness in transverse direction for three sides artificially roughened collector. Flange-tap orifice-meters in both the ducts (roughened and smooth) used for measuring the flow rates. Multi-tube manometers were used to measure the pressure drop, while thermocouples measured the air and plate temperatures. A pyranometer was used for measuring the intensity of solar radiation. Top side absorber plate having artificial roughness shown in fig. 1(b), whereas, fig. 1(c) shows the side walls of the absorber plate with artificial roughness.



A-Three sides smooth with three sides glass covers, B-Three sides glass covers with three sides artificially roughened, 1-Entry section, 2-Test section, 3-Orifice meter, 4-Blower

Fig. 1 Block diagram of experimental set-up

Fig. 1(a) Photograph of measuring instruments

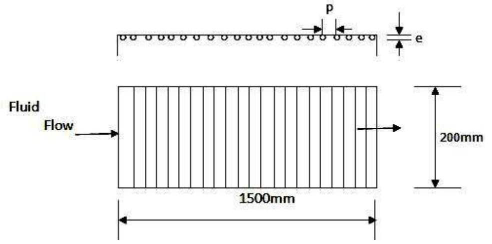


Fig. 1(b) Top absorber plate for three sides artificially roughened one

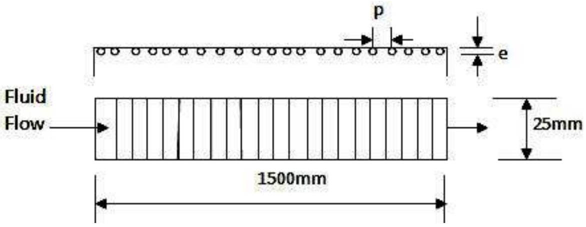


Fig. 1(c) Side view of three sides artificially roughened one (two nos.)

3. Results and discussions

The data were collected simultaneously for both three sides smooth solar air heater and three sides artificially roughened ducts. Table-1 shows the range of flow parameters and roughness investigated. Figs. 2 and 3 represent the improvement of heat transfer for three sides glass covers with three sides roughened collectors and the smooth ones. The experimental values of heat transfer coefficient for three sides glass covers with three sides artificially roughened collectors and the smooth ones have been found out from Eq. (1) as under:

$$\dot{m}C_p(T_0 - T_i) = hA_C(\bar{T}_p - \bar{T}_f) \tag{1}$$

For smooth and roughened collectors, the above equation has been used to find out the range of Nusselt number by using the equation:

$$Nu = \frac{hD}{K} \tag{2}$$

Table 1 Range of flow parameters and roughness

Sl. No	Parameters	Range of parameters
1.	Mass flow rate (Kg/s)	$8.36 \times 10^{-3} – 3.74 \times 10^{-2}$
2.	Reynolds number, Re	4000 – 20000
3.	Roughness height	0.6 mm – 1.1 mm
4.	Roughness pitch	6 mm – 30 mm
5.	Relative roughness pitch, p/e	10 – 30
6.	Relative roughness height, e/D	0.0135 – 0.0247

Figs. 2 and 3 show the range of Nusselt number for three sides glass covers with three sides artificially roughened collector and three sides smooth one with the effect of the roughness parameters p/e and e/D respectively. Fig. 2 shows the influence of p/e on heat transfer for a fixed value of e/D, equal to 0.0247. It has been found from this figure that at the decreasing values of relative roughness pitch, p/e and increasing values of the flow Reynolds number, Re, the values of Nusselt number increase, but at a quicker way than that in the smooth collector. It has been observed that for a flow Reynolds number of 9806, the corresponds to the values of Nusselt number are 58, 62 and 66 in three sides roughened collector for p/e equal to 20, 15 and 10, whereas, it is 32 in the smooth collector. Fig. 3 shows the influence of e/D on heat transfer for a fixed value of p/e, equal to 10. It has been concluded from this figure that the values of Nusselt number increase with the increasing value of e/D, with enlarging values of flow Reynolds number, also at a rapid speed than that in smooth ones. It has been recorded that for a flow Reynolds number of 9806, the corresponds to the values of Nusselt number in three sides roughened collector are 56, 61and 64 for the corresponding values of e/D, equal to 0.0135, 0.0225 and 0.0247 at a fixed value of p/e, equal to 10, while, it is 30 for smooth collector.

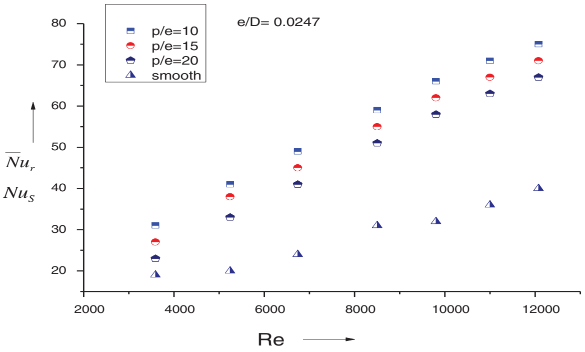


Fig. 2 Influence of p/e on heat transfer in three sides artificially roughened and smooth collector

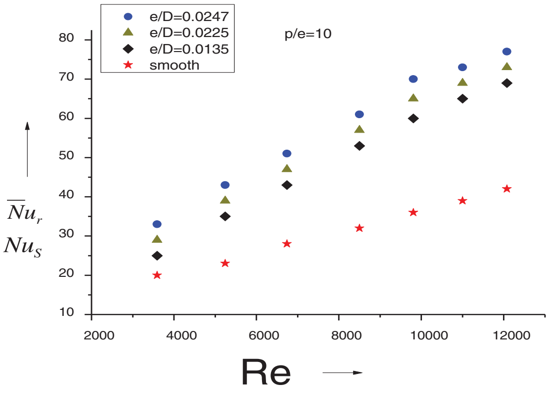


Fig. 3 Influence of e/D on heat transfer in three sides artificially roughened and smooth collector

Figs. 4 and 5 represent results with respect to friction factor for three sides glass covers with three sides roughened and the smooth one for fixed value of p/e and e/D, respectively. The values of f_s has been taken from Moody chart to find out for values of $\bar{f}_r$ by using Eq. (3) of [4], written under as:

$$\bar{f}_r = \frac{(W+2B)\left[\frac{2}{\left\{0.95\left(\frac{p}{e}\right)^{0.53}+2.5\ln\left(\frac{D}{2e}\right)-3.75\right\}^2}\right]+Wf_s}{2(W+B)} \tag{3}$$

Fig. 4 represents the influence of p/e on friction factor for a fixed value of e/D, equal to 0.0247. It has been found from the figure that the values of friction factor increase with reduction in the value of the relative roughness pitch p/e, decrease with increasing values of the flow Reynolds number, Re for three sides glass covers with three sides roughened collector and the smooth ones. Similarly, Fig. 5 shows the influence of e/D on friction factor for a fixed value of p/e, equal to 10. It is quite clear from the figure that the values of friction factor enlarge with the enlarging in the value of relative roughness height, e/D and the values of friction factor decrease with enlarging values of flow Reynolds number, Re for three sides glass covers with three sides artificially roughened collector and the smooth ones.

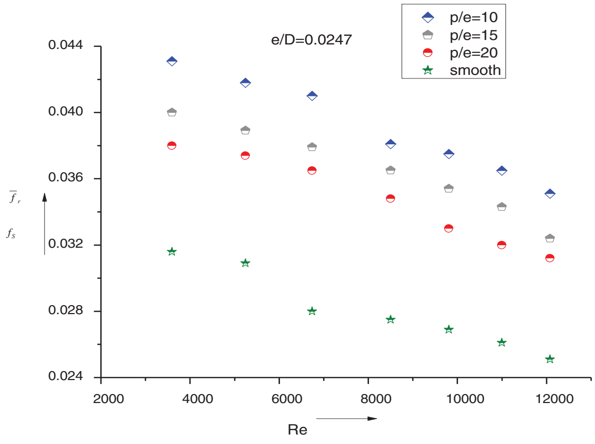


Fig. 4 Influence of p/e on friction factor in three sides artificially roughened and smooth collector

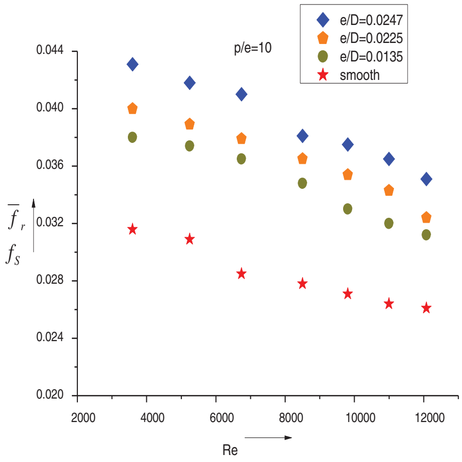


Fig. 5 Influence of e/D on friction factor in three sides artificially roughened and smooth collector

Inclusion of artificial roughness invariably increases friction factor, leading to more pumping power. The rate of heat transfer improvement due to inclusion of artificial roughness and that of friction factor have not been found to be the same. The heat transfer enhancement factor, Nu_F and friction enhancement factor, f_F, defined by Eqs. 4 and 5 respectively have been considered to represent the thermo hydraulic results as shown in Fig. 6, for fixed value of e/D equal to 0.0247 and changing values of relative roughness pitch and flow Reynolds number. Fig. 6 shows the results of heat transfer enhancement factor, Nu_F, and friction enhancement factor, f_F, with increasing values of Reynolds number for a given value of e/D, equal to 0.0247 at different values of p/e.

$$Nu_F = \frac{\overline{Nu}_r - Nu_s}{Nu_s} \tag{4}$$

$$f_F = \frac{\bar{f}_r - f_s}{f_s} \tag{5}$$

It has been concluded could be seen from this figure that the values of both heat transfer enhancement factor and friction loss factor increase with the improving of flow Reynolds number. Fig. 6 also shows that for a fixed value of e/D the rate of increment of f_F is higher than that of Nu_F at varying values of p/e. In the range of the parameters investigated, the value of heat transfer increment factor is in the range of 0.378 to 0.487, while, it is in the range of 0.384 to 0.491 for that of friction factor. At greater values of Reynolds number, the rate of improvement of heat transfer enhancement factor appears to be monotonous. It can therefore, be concluded that performance of such solar air heater could be better at lesser values of Reynolds number.

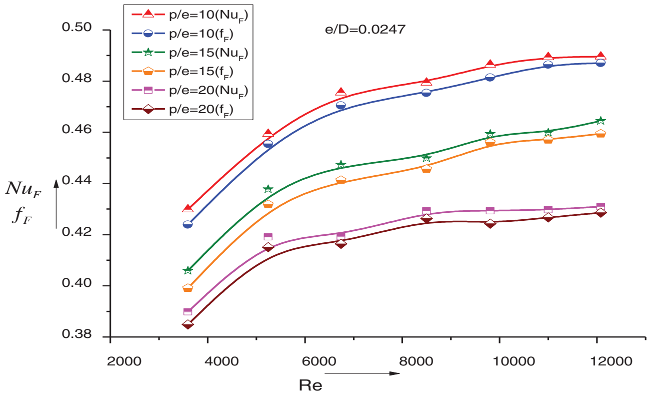


Fig. 6 Influence of Heat transfer enhancement factor and friction loss factor

4. Conclusions

Based on the experimental results and subsequent analysis, the following conclusions are drawn:

A) Three sides glass covers with three sides artificially roughened solar air heaters have improved rate of heat transfer as compared to the smooth ones at the same operating conditions of mass flow rate.

B) Heat transfer rate of three sides roughened solar air heaters improves with the increasing values of flow Reynolds number and relative roughness height for a fixed value of relative roughness pitch.

C) It has been found that the range of values of Reynolds Number from 5000-13000, results better thermal performance in three sides glass covers with three sides artificially roughened solar air heater as compared to one side artificially roughened solar air heater and also three sides smooth solar air heaters.

D) Three sides glass covers with three sides artificially roughened solar air heater have been established better thermal performance due to the more surface area, high turbulent flow and more heat transfer coefficient as compared to existing one side artificially roughened and also smooth collectors.

E) Heat transfer rate of three sides roughened collectors improves with the improving values of flow Reynolds number and relative roughness pitch for a fixed value of relative roughness height.

F) The values of Nusselt number for three sides glass covers with three sides artificially roughened and smooth collector have been established to be in the range of 31.24-75.62 and 20-40 respectively, for the varying values of parameters investigated.

G) Heat transfer increament factor have been established to lie in between 0.378 to 0.487 in the varying values of parameters investigated.

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