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Experimental study of Collector heat removal factor and Collector efficiency factor of flat-plate solar Air Heater having roughened (Rhombus shape) absorber plate

[1] Pankaj Kumar,[2]Dr. S.C.Roy,[3]Dr.M.K.Paswan
[1(]Assistant Professor),(Professor), Department of Mechanical Engg., B.I.T. Sindri
[3]Professor, Department of Mechanical Engg., N.I.T. Jamshedpur
[1]deoghar100@gmail.com

Abstract- **An experimental investigation has been carried out for a range of system an operating parameters in order to analyze effect of artificial roughness on Collector heat removal factor and Collector efficiency factor in flat plate solar air heater having rhombus shape (sheet metal) as roughness geometry. Duct has an aspect ratio W/H of 7, relative roughness pitch (p/e) range of 40 to 60 relative roughness height (e/D) range of 0.071 to 0.119 and Reynolds Number (Re) range from to 5100 to 28000. A considerable increase in Collector heat removal factor and Collector efficiency factor has been observed.**

Index terms- **experimental investigation, operating parameters and Collector efficiency factor.**

I. Introduction

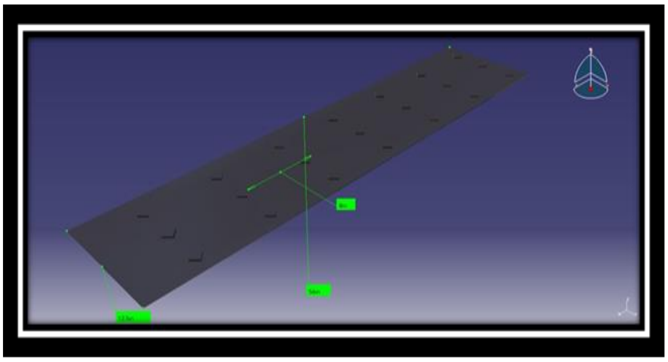
Solar energy can play vital role in clean and sustainable energy sources. Solar collectors have an important place among applications of solar energy system. Solar collectors are classified as liquid collectors and gas collectors. Liquid collectors uses water whereas gas collectors uses air as flowing fluids. Since air has very low value of thermal conductivity, the efficiency of solar air collectors are low. Therefore, various techniques are used to improve the thermal performance of solar air heater. One of the method is to use artificial roughness.

The use of artificial roughness on a surface is an effective technique to enhance thermal performance to fluid flowing in a duct. This roughness can be provided by sand blasting, fixing wires, wire mesh or by providing roughness in the form of ribs, dimples, protrusion etc. reported by Dippery and Sabersky (1963), Sheriff and Gumley (1966), Saini and Saini (1997), Saini and Verma (2008), Hans et al. (2009) and Bhushan and singh (2011). Several investigations have been carried out to study the effect of artificial roughness on heat transfer used in compact heat exchanger by Elyyan et al. (2008) and Webb (1994) and in solar air heater by Momin et al. (2000), Varun et al. (2008), Singh et al. (2011), Lanjewar et al. (2011), Jauker et al. (2006) and Layek et al. (2007).The roughness destroy the laminar sublayer and create turbulence in the flow. The turbulence leads to increase in pumping power which is required for flow of air in the duct. Therefore roughness is created in such a region which is near to the absorber plate i.e. laminar sublayer only.

The roughness was first used in solar air heater and resulted in better heat transfer in comparison to that in conventional solar air heater by Prasad and Mullic (1985). Prasad and Saini (1988) studied the effect of roughness and flow parameters on heat transfer for transverse ribs. It was observed that maximum heat transfer occurred near to the reattachment points. The maximum enhancement in Nusselt number was reported to be 2.38 times over smooth duct. Verma and Prasad (2000) has been carried out experimental study for thermohydraulic optimization of the roughness and flow parameters for Reynolds number (Re) range of 5000-20,000, relative roughness pitch (P/e) range of 10-40 and relative roughness height (e/Dh) range of 0.01-0.03. The optimal thermohydraulic performance was reported to be 71%. Karwa et al. (1999) has been experimentally investigated the effect of repeated rectangular cross-section ribs on heat transfer for duct aspect ratio (W/H) range of 7.19-7.75, P/e value of 10, e/Dh range of 0.0467-0.050 and Re range of 2800-15,000. The enhancement in the Stanton number was reported to be 65-90% Gupta et al. (1997) experimentally investigated the effect of e/Dh, inclination of rib with respect to flow direction and Reynolds number (Re) on the thermohydraulic performance of roughened solar air heater. The detailed studies on roughness geometries used in solar air heater ducts are also available in Varun et al. (2007), Hans et al. (2009) and Bhushan and Singh (2010).

The application of artificial roughness in the form of rhombus shape on absorber plate is attractive roughness geometry for solar air heater due to its less complicated manufacturing process. In this paper experimental data has been collected by performing experiment to see the effect of roughness parameters (rhombus shape) on thermal performance.

A. roughness parameters



1) Diagram of the absorber plate

2) Pictorial view of the absorber plate

Fig. 1. (a) Diagram of the absorber plate.
(b) Pictorial view of the absorber plate

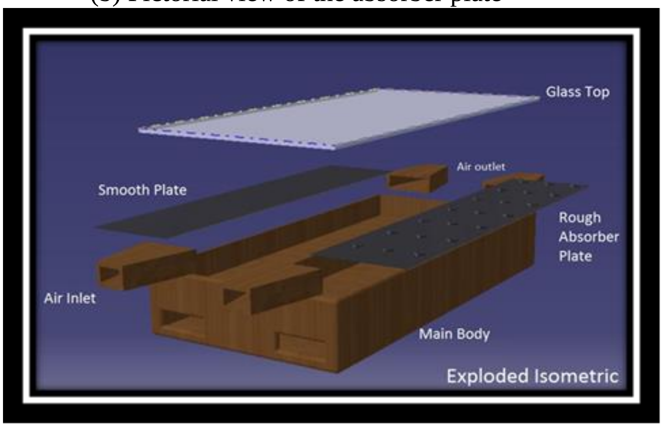


Fig. 1.2 Isometric view of experimental set-up

Rhombus shape (sheet metal) roughness elements have been generated on the absorber plate to create roughness in the duct. A schematic and pictorial view of roughness geometry is shown in fig. 1(a) and (b). The roughness parameters in non-dimensional form have been expressed as, relative roughness pitch (P/e). Fig. 1.2 shows the isometric view of experimental set-up. The rhombus shape of roughness was produced on the underside of the absorber plate. The range of roughness parameters and operating parameters is given in Table 1. For studying the effect of P/e and e/D on Collector heat removal factor and Collector efficiency factor roughened plates were experimentally investigated at various mass flow rates.

Nomenclature

Ac	area of absorber plate (m2)
Cp	specific heat at constant pressure (Jkg-1 0K)
D	equivalent diameter of the air passage (m)
e/D	relative roughness height
FR	collector heat removal factor
FR UL	slope of the thermal performance curve
FR (τ α)	intercept of thermal performance curve
I	intensity of solar radiation (W/m2)
	mass flow rate of air (kg/s)
p/e	relative roughness pitch
Re	Reynolds number
tf	average fluid temperature (K)
ti	air inlet temperature (K)
to	air outlet temperature (K)
tp	average plate temperature (K)
UL	overall heat loss coefficient (Wm-2 0K-1)
W	width of duct (m)
τ α	transmittance-absorptance product
he	effective heat transfer coefficient (Wm-2 0K)
hr	radiative heat transfer coefficient (Wm-2 0K)
B	height of duct (m)
W	width of duct (m)
Subscripts	
r	rough collector
s	smooth collector

II. EXPERIMENTAL SETUP AND PROCEDURE

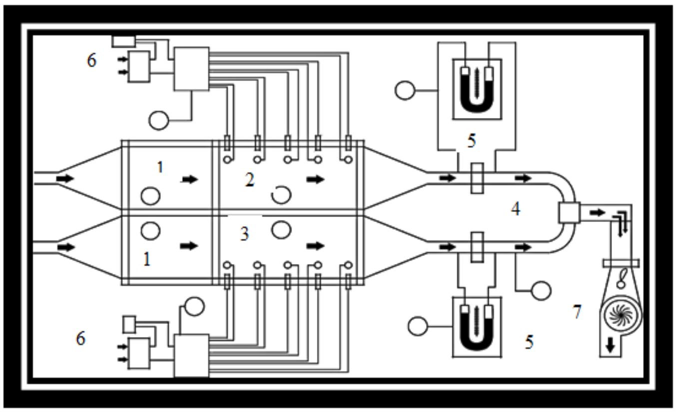


Fig. 2.1 shows the schematic diagram of the experimental set-up used. Major components of this set-up are:

1 flow straighteners
2 plane solar air heater
3 roughened solar air heater
4 outlet headers & pipe fittings
5 manometers
6 selector switches
7 centrifugal blower
8 auto transformer

Two- dimensional, fully developed flow was obtained by sucking atmospheric air through flow straighteners by means of blower. The air thus passes through the test section i.e. solar air heaters; one with rhombus shape roughened and the other plane (Flat-Plate) collector, and flow meters before exhausting into the atmosphere. Thermocouples were used to measure absorber and air temperature at different location in the solar air heaters as flow progresses. The output of the thermocouple fed to digital micro voltmeter displays directly the temperature values. Mass flow rate of air through these collector ducts were measured by two orifice meters provided with U-tube manometers. For each experimental run, initially all the instruments, viz. manometer, milli-voltmeter, U-tube manometer, Blower and electric circuit were checked for their correctness and all joints were carefully checked to avoid any air leakage. Data was recorded under quasi-study state (when there is no appreciable change in temperature for 10-15 min) conditions for the air temperature at different points on the duct and temperature of absorber plate at 05 different locations. Data were taken at the regular interval of 1hour and accordingly the pressure drop across orifice meter has been measured with the help of U-tube manometer.

III. Results and Discussion

The total 25 numbers of test runs, raw experimental data were collected for 5 set of roughened solar air heater as well as smooth one. For a particular test run, mass flow rate in the roughened and smooth collector remained the same. Table 1 represents the roughness and flow parameters investigated. The raw experimental data were reduced to work out for the values of the results with respect to thermal performance.

The solar air heaters, operating without recycling of air, the following equations have formed the basis of representation of collector heat removal factor (FR) and collector efficiency factor (F'):

The collector heat removal factor FR is given by the relation:

$$F_R = \frac{\dot{m}C_p}{U_l A_c}\left[1 - exp\left(-\frac{F' U_l A_c}{\dot{m}C_p}\right)\right] \qquad (3.1)$$

The collector efficiency factor, F' is given by the relation:

$$F' = \left[1 + \frac{U_l}{h_e}\right]^{-1} \qquad (3.2)$$

$$\text{Where, } h_e = \left[h_{fp} + \frac{h_r h_{fp}}{h_r + h_{fp}}\right] \qquad (3.3)$$

$$h_r = \frac{4\sigma T_{av}^3}{\left(\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_b} - 1\right)} \qquad (3.4)$$

$$h_{fp} = \frac{Nu\ k}{D} \qquad (3.5)$$

$$U_l = U_t + U_b$$

A_c = Area of collector plate,

D = Hydraulic diameter = $\frac{4(WXB)}{2(W+B)}$

$$\varepsilon_p = \varepsilon_b = 0.95$$

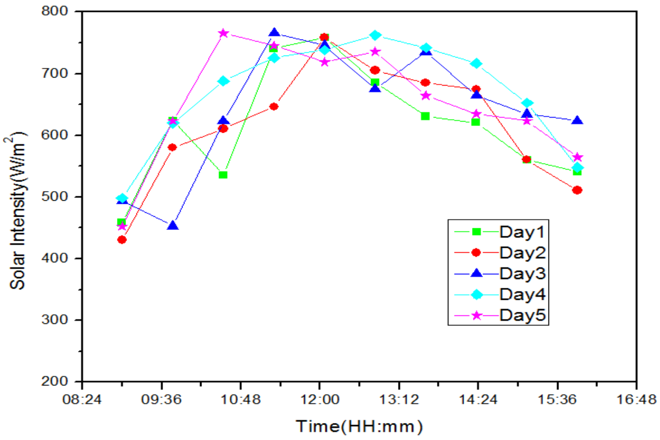


Figure 3(a)

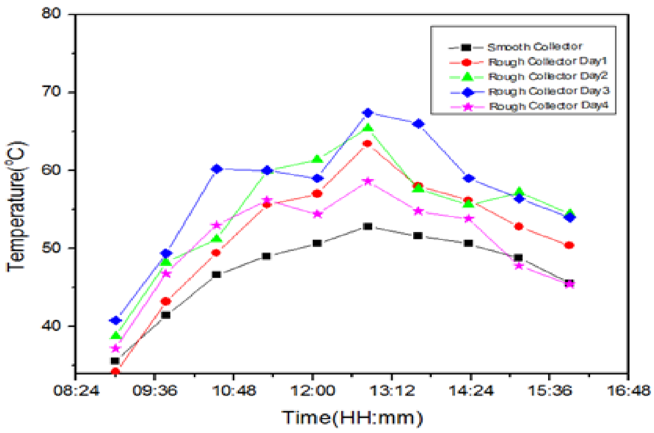


Figure 3(b)

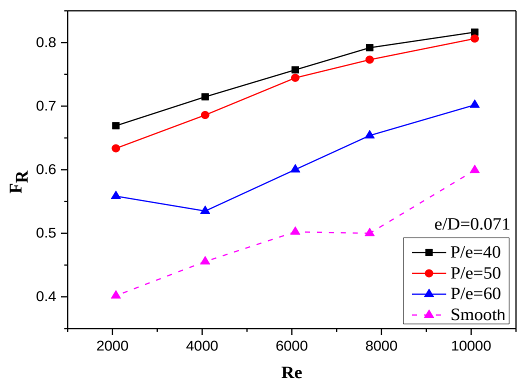


Figure 3(c)

Effect of P/e on collector heat removal factor (FR) in roughened solar air heater

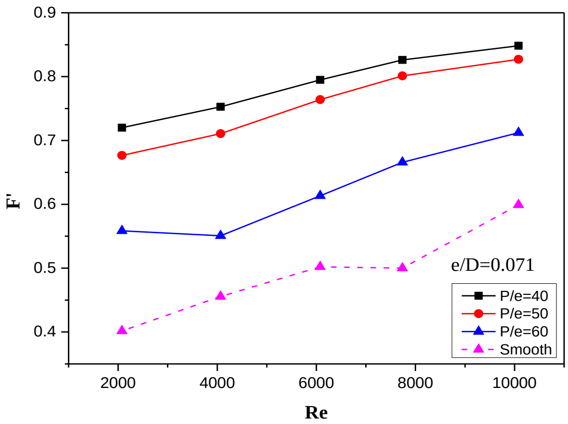


Figure 3(d)

Effect of P/e on collector efficiency factor (F') in roughened solar air heater

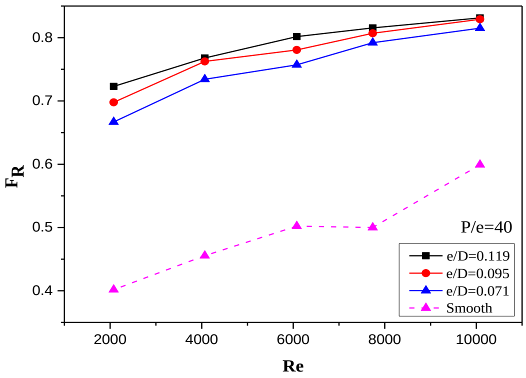


Figure 3(e)

Effect of e/D on collector heat removal factor (FR) in roughened solar air heater.

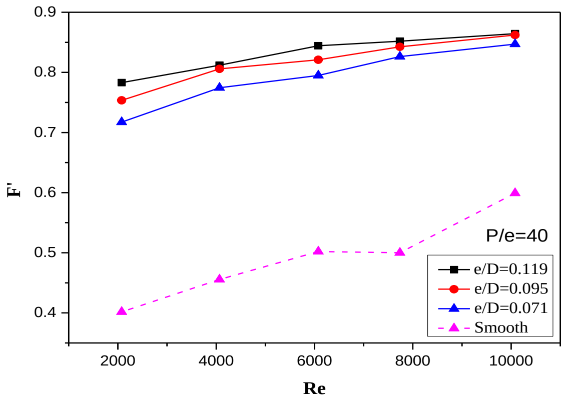


Figure 3(f)

Effect of e/D on collector efficiency factor in roughened solar air heater

Fig. 3(a) and Fig. 3(b) shows the data of Solar Intensity and Time, and Temperature and Time respectively. Fig. 3(c) and Fig. 3(d) represents typically the collector heat removal factor (FR) and collector efficiency factor (F') of the roughened collectors for relative roughness pitch (P/e) equals to 40, 50 and 60 for a particular value of relative roughness height (e/D) equals to 0.071 and also for smooth collectors at various Reynolds number. Similarly, Fig. 3(e) and Fig. 3(f) represents typically the collector heat removal factor (FR) and collector efficiency factor (F')of the roughened collectors for relative roughness height (e/D) equals to 0.071, 0.095 and 0.119 for a particular value of relative roughness pitch (P/e) equals to 40 and also for smooth collectors at various Reynolds number.

The values of both these factors, collector heat removal factor (FR) and collector efficiency factor (F'), have found to be higher in the roughened collectors compare to those of the smooth ones. Both of these factors have been found to increase with decrease in the value of relative roughness pitch (P/e) and increase in the value of the flow Reynolds number for a given values of relative roughness height (e/D).The value of collector efficiency factor (F') of roughened solar air heater have been found to be higher by a factor 1.57, 1.51 and 1.23 in comparison to that of smooth one, while collector heat removal factor (FR) has been found to be higher by a factor 1.53, 1.49 and 1.25 in comparison to that of smooth one for relative roughness pitch of 40, 50 and 60 respectively.

At a value of relative roughness pitch (P/e) equals to 40, the value of collector heat removal factor (FR) for roughened collector have been found to be higher by a factor of 1.54, 1.59 and 1.62 for relative roughness height (e/D), equal to 0.071, 0.095 and 0.119 respectively as compare to those in the smooth collectors for the same flow Reynolds number, while the values of collector efficiency factor (F') for roughened collector have been found to be higher by a factor of 1.57, 1.63 and 1.66 respectively as compare to those of smooth collectors.

CONCLUSIONS

The effect of roughened geometry on thermal performance leads the following conclusions:

1. The value of collector heat removal factor (FR) and collector efficiency factor (F') both, of roughened solar air heaters is enhanced as compare to the smooth solar air heaters.
2. The rate of enhancement of collector heat removal factor (FR) and collector efficiency factor (F') of roughened flat plate solar air heater strongly depends on relative roughness height (e/D) and relative roughness pitch (p/e).
3. The collector heat removal factor (FR) and collector efficiency factor (F') of solar air heater increases with decrease in the value of relative roughness pitch (p/e) and with increase in the values of relative roughness height (e/D).
4. It is worthy to note here that the increase in collector heat removal factor (FR) and collector efficiency factor (F')is more in case of relative roughness height (e/D) than in case of relative roughness pitch (p/e).

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