Experimental study of effect of Reynolds number and Nusselt Number on the performance of flat-plate solar Air Heater having artificial roughened (Rhombus shape) absorber plates

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

Keywords— Solar air heater; Centrifugal Blower; Artificial roughness.

I. INTRODUCTION

The use of artificial roughness on a surface is an effective technique to enhance heat transfer 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 thermo hydraulic optimization of the roughness and flow parameters for Reynolds number (R_e) range of 5000-20,000, relative roughness pitch (P/e) range of 10-40 and relative roughness height (e/D_h) range of 0.01-0.03.

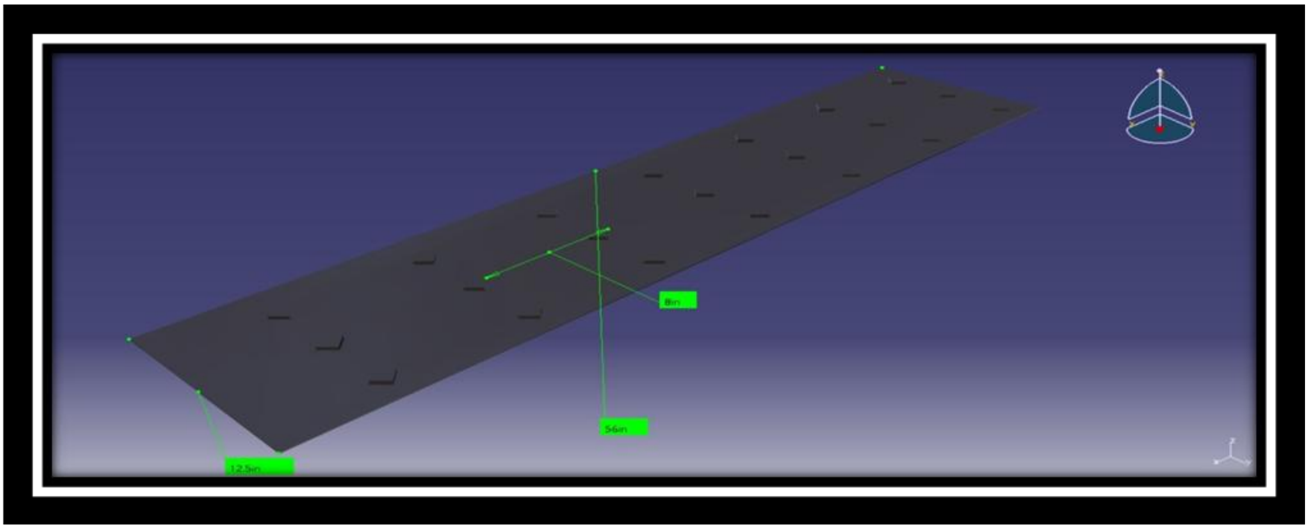
The optimal thermohydraulic performance was reported to be 71%. Karwa et al. (1999) has been experimentally investigated the effect of repeated rectangular cross-section ribs on heat transfer for duct aspect ratio (W/H) range of 7.19-7.75, P/e value of 10, e/D_h range of 0.0467-0.050 and R_e range of 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/D_h, inclination of rib with respect to flow direction and Reynolds number (R_e) 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 heat transfer.

1.1 Roughness parameters

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). 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 Table1. For studying the effect of P/e on heat transfer roughened plates were experimentally investigated at various mass flow rates.



(A) DIAGRAM OF THE ABSORBER PLATE

(B) PICTORIAL VIEW OF THE ABSORBER PLATE

FIG. 1. (A) DIAGRAM OF THE ABSORBER PLATE. (B) PICTORIAL VIEW OF THE ABSORBER PLATE

TABLE 1
VALUES OF FLOW AND ROUGHNESS PARAMETER

S.No.	Parameters	Range
1	Aspect ratio (W/H)	1
2	Relative roughness pitch (P/e)	40-60
3	Reynolds number	5100-27000

Nomenclature

A	area of absorber plate (m^2)
D	equivalentdiameter of the air passage (m)
e	height of roughness element
e^+	roughness Reynolds number
e/D	relative roughness height
f_r	friction factor for roughened duct
f_s	friction factor for smooth duct
h	convective heat transfer coefficient (W/m^2 k)
H	height of duct (m)
I	intensity of solar radiation (W/m^2)
m	mass flow rate of air (kg/s)
$\overline{Nu}$	Nusselt number for roughened absorber plate
Nu_s	Nusselt number for smooth absorber plate
P_r	prandtl number

p	roughness pitch (m)
p/e	relative pitch roughness
R_e	Reynolds number
t_f	average fluid temperature (K)
t_i	air inlet temperature (K)
t_o	air outlet temperature (K)
t_p	average plate temperature (K)
W	width of duct (m)

II. EXPERIMENTAL SETUP AND PROCEDURE

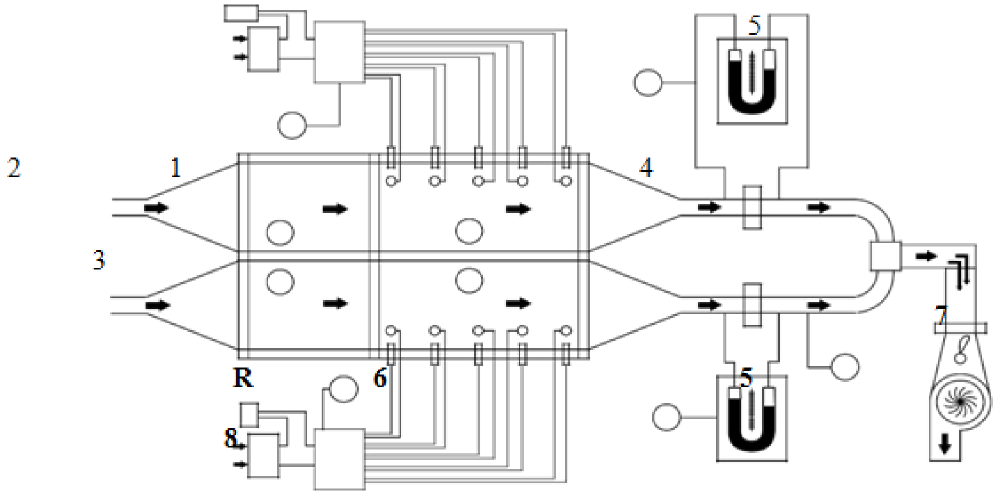


FIG. 2.1 SHOWS THE SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SET-UP USED.

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
R	reference junction (icebath)

Major components of this set-up are:

a) Flow Straighteners.
b) Test section i.e. plane and roughened collectors
c) Out let headers and pipe fittings.
d) Flow meters provided with U-tube manometers
e) Thermocouples with selector switches.
f) Centrifugal blower.
g) 5 h.p. 3-phase electric motor.

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 30 numbers of test runs, raw experimental data were collected for 3 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 2 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 heat transfer.

Fig. 3(a) and Fig. 3(b) shows the data of Solar Intensity and Time, and Temperature and Time respectively. Fig. 3(c) represents the heat transfer results in the form of Nusselt number for roughened and smooth absorber plates. The analytical and experimental values of Nusselt number for roughened and smooth absorber plates has been compared. The analytical value of Nusselt number is calculated by using the equation given by Prasad and Saini (1988) as:

$$Nu_s = 0.14Pr^{0.5}R_e \quad (1)$$

$$\overline{Nu} = (\bar{f}/2)RePr/\left[1+\sqrt{(\bar{f}/2)}\{4.5(e^+)^{.28}Pr^{0.57}\}-0.95\left(\frac{p}{e}\right)^{0.53}\right] \quad (2)$$

Where $\bar{f} = (f_s + f_r)/2$

The experimental value of the heat transfer coefficient for roughened and smooth absorber plates have been calculated by using the relation:

$$mc_p(t_o-t_i) = hA(t_p-t_f) \quad (3)$$

Nusselt number is calculated for roughened and smooth absorber plates with the help of equation (4) by using the relation

$$Nu = hD/k \quad (5)$$

The experimental and analytical values of Nusselt number for roughened and smooth absorber plates is represented in Figure 3.(c) for a given value of e/D, equal to 0.0493 at different values of P/e of 40, 50 and 60.

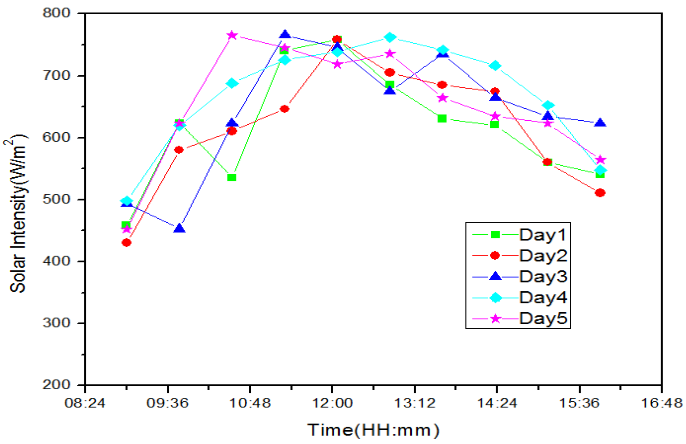


FIGURE 3(A)

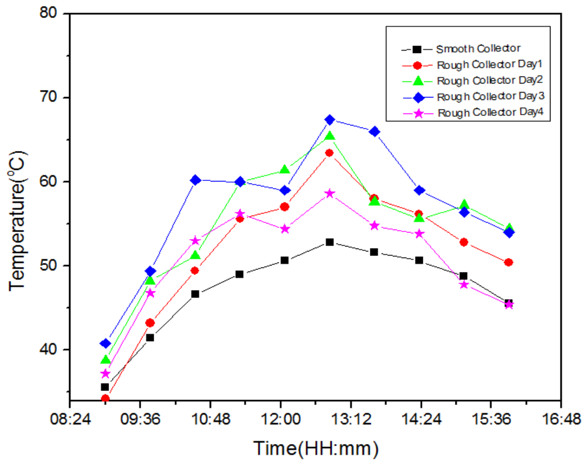


FIGURE 3(B)

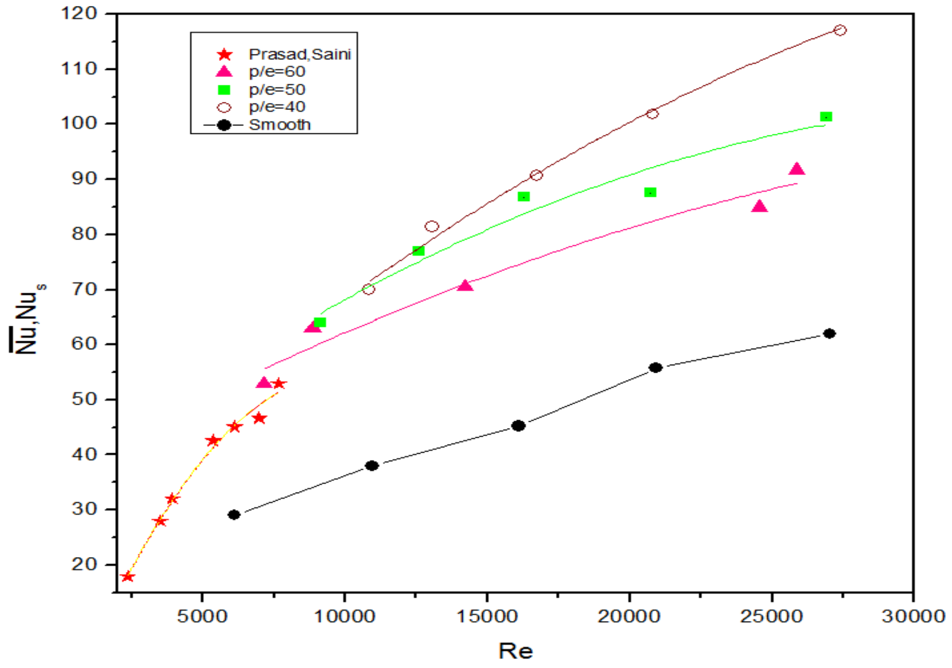


FIGURE 3(C)

Fig.3 (c) has been drawn to analysis the effect of the roughness parameter p/e on Nusselt number in roughened as well as smooth absorber plate at the same value of Reynolds number. In this figure the effect of roughness parameter p/e on heat transfer is shown for a given value of e/D. It is clear from the figure that the value of Nusselt number increases with decrease in the value of roughened parameter p/e.

The value of Nusselt number also increases as the values of Reynolds number increases and also at the faster rate than that in smooth absorber plate. It can be also seen that the experimental and analytical results on heat transfer is have been found to be compare good. It is found for a particular value of Reynolds number at 10000, the values of Nusselt numbers are 75,82 and 98 for p/e of 60, 50 and 40 respectively in roughened absorber plate whereas 55 for smooth absorber plate.

In figure present result is compare with prasad and saini but for higher values of Reynolds number. Within the tested range of investigation, the value of the Enhancement factor ($\overline{Nu}/Nu_s$) is found to be in the range of 1.5 to 2.1 for Reynolds number of range 5100 to 18000.But after that it decreases.

IV. CONCLUSION

The effect of roughened geometry on heat transfer leads the following conclusions:

1. Heat transfer for flat plate solar air heater is represented in the form of Nusselt number.
2. Solar air heater having artificial roughened absorber plate have high rate of heat transfer than that of smooth solar air heater.
3. The rate of enhancement of heat transfer of roughened flat plate solar air heater strongly depends on Reynolds number and relative roughness pitch (p/e).It is worthy to note here that the best Enhancement Factor is found in the range of 12500 to 18000 Reynolds number.
4. At higher Reynolds number i.e. above 18000 the Enhancement Factor decreases considerably.

REFERENCES

[1] Aharwal, K.R., Gandhi, B.K., Saini, J.S., 2008. Experimental investigation on heat transfer enhancement due to a gap in an inclined continuous rib arrangement in a rectangular duct of solar air heaters. Renew. Energy 33, 585-596.

[2] Aharwal, K.R., Gandhi, Bhupendra K., Saini, J.S., 2009. Heat transfer and friction characteristics of solar air heater ducts having integral inclined discrete ribs on absorber plate. Int. J. Heat Mass Transfer. 52, 5970-5977.

[3] Altemani, C.A.C., Sparrow, EM, 1980. Turbulent heat transfer and fluid flow in an unsymmetrically heated triangular duct.

[4] Behura, Arun K., Prasad, B.N., and Prasad, L., 2016. Heat transfer, friction factor and thermal performance of three sides artificially roughened solar air heaters. Sol. Energy, 130, Feb, pp.46-59.

[5] Bemier, M.A., Plett, E.G., 1988. Thermal performance representation and testing of solar air collector. Trans. ASME, 110, 74-81.

[6] Bhagoria, J.L., Saini, J.S., Solanki, S.C., 2002. Heat transfer coefficient and friction factor correlation for rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate. Renew. Energy 25, 341-369.

[7] Bhushan, B., Singh, R., 2010. A review on methodology of artificial roughness used in duct of solar air heaters. Energy 35, 202-212.

[8] Edwards, F.J., Sheriff, N., 1961. The heat transfer and friction factor characteristics for forced convection flow over a particular type of rough surface. In: Int. Developments in Heat Transf. Proc. Heat Trans. Conf. ASME, pp. 415-425.

[9] Emerson, W.H., 1966. Heat transfer in duct in regions of separated flow. Proc. Third Int. Heat Transd. 1, 267-275.

[10] Esen, H., Ozgen, F., Esen, M., Sengur, A., 2009. Modeling of a new solar air heater through least squares support vector machines. Expert Systems with Applications 36, 10673-10682.

[11] Gawande, V.B., Dhoble, A.S., Zodpe, D.B., 2014. Effect of roughness geometries on heat transfer enhancement in solar thermal systems. A review. Renew. Sustain. Energy Review. 32, 347-378.

[12] Gillet, W.B., Aranoviteh, E., Moon, J.E., 1983. Solar collector testing in the European community. Int. J. Sol. Energy 1, 317-341.

[13] Gupta, D., Solanki, S.C., Saini, J.S., 1993. Heat and fluid flow in rectangular solar air heater ducts having transverse rib roughness on absorber plate. Sol. Energy 51, 31-37.

[14] Prasad, K., mullick, S.C., 1983, Heat transfer characteristics of a solar air heater used for dry purpose, Applied Energy 13, 83-85.

[15] Prasad, B.N., Saini,J.S., 1988.Effect of artificial roughness on heat transfer and fiction factor in a solar air heater. Sol. Energy 41, 555-560.

[16] Saini, R.P., Saini, J.S., 1997. Heat transfer and friction factor correlations for artificially roughened duct with expanded metal mesh as roughness element .Int.J. Heat Mass transf. 40, 973-986.

[17] Saini,S.K ., Saini,R.P., 2008 . Development of correlations for Nusselt number and friction factor for solar air heater with roughened duct having arc-shaped wire as artificial roughness.Sol.Energy 82, 1118-1130.

[18] Saini, R.P., Verma,J., 2008. Heat transfer and friction correlation for a duct having dimple shape artificial roughness for solar air heater .Energy 33, 1227-1287. Sol. Energy 81, 1340-1350.

[19] Sukhatme, S.P., 2008. Solar Energy. Principles of thermal collection and storage TATA MC-GROW HILL, New Delhi.

[20] Varun, Saini, R.P., Singal, S.K.,2007. A review on roughness geometry used in solar air heaters.