Experimental Investigation for Enhancement of Heat Transfer in Two Pass Solar Air Heater Duct using Multi V-Shaped With Gap Roughness Geometry

Ravendra Kumar Ray[1] Dr. A. R. Jaurker[2]
[1]Researcher [2]Professor & Head
[1,2]Department of Mechanical Engineering
[1,2]Jabalpur Engineering College Jabalpur, India

Abstract— The important factors of increasing the efficiency of solar air heater are reducing the heat losses and increasing the heat transfer rate between the absorber plate and working medium air. An experimental work is design and developed to achieve the above goal by providing the double pass instead of single pass in conventional solar air heater. The heat transfer rate is increased by providing the artificial roughness on heat transfer surface. This paper present an experimental study to investigate the effect of roughness and flow parameter on heat transfer using multi v-shape rib with gap geometry. The experimental investigation encompassed the Reynolds number (Re) range from 2000 to 15,000, relative width ratio (W/w) of 3, relative gap distance (Gd/Lv) of 0.24-0.80, relative gap width (g/e) of 0.5-1.5, relative roughness height (e/D) of 0.043, relative roughness pitch (P/e) of 10, angle of attack (α) of 60°. Result is compared to smooth duct under similar flow condition and found that the maximum enhancement is observed at a relative gap distance of 0.69 for relative gap width of 1.0, relative roughness pitch of 10, angle of attack of 60°and relative roughness height of 0.043.

Key words: Double pass solar air heater, Relative gap distance, Nusselt number, Friction factor

I. Introduction

Solar air heaters are considered to be compact and less complicated as compared to solar water heaters. In Solar air heaters the incoming solar radiation is absorb and converting into thermal energy at absorbing surface and transferring the energy to a fluid flowing through the collector. Thermal efficiency of solar air heater is poor because of low rate of heat transfer capability between absorber plate and air flowing in the duct. In order to make a solar air heater more effective solar by enhancing the heat transfer rate from absorber plate to air flowing in the duct of solar air heater. One of the methods for enhancement of convective heat transfer is by creating turbulence at heat transfer surface with the help of provides d artificial roughness on absorber plate. Artificial roughness in the form of ribs and wire. Ribs provided artificial roughness break laminar sub layer and create local wall turbulence due to flow separation and reattachment between the consecutive ribs. As a result thermal resistance reduces and heat transfer rate and friction loss increased. In order to reduce the friction loss with the help of application of artificial roughness, turbulence should be created in the region very close to heat transferring surface i.e. in laminar sub layer. Therefore, height of the roughness element should be kept small in comparison with duct dimensions.

Prasad and Saini (1998) investigated the effect of relative roughness pitch (P/e) and relative roughness height (e/D) on Nusselt number and friction factor using transverse ribs geometry. It was observed that maximum heat transfer occurred in the vicinity of reattachment points.

Gupta et al. (1993) investigated the effect of relative roughness height, angle of attack, Reynolds number (Re) on Nusselt number and friction factor using inclined circular ribs. The maximum heat transfer and friction factor was found at angle of attack (α) 60° and 70°. In both inclined and transverse ribs inclined ribs get better performance. Momin at al. (2002) investigated the effect of v shape ribs on heat transfer and fluid flow characteristics. The maximum enhancement of Nusselt number and friction factor has been found 2.30 and 2.83 as compared to smooth plate. Jaurker at al. (2006) investigated heat transfer and friction factor using rib-grooved roughness geometry and the result is compared to the smooth duct, Nusselt number up to 2.7 times while the friction factor rises up to 3.6 times in the range of parameters investigated. Aharwal at al. (2008) experimentally studied the effect of width and position of the gap in an inclined ribs having square section on heat transfer and friction factor of a rectangular duct .it was found inclined ribs with gap arrangement show higher enhancement heat transfer as compared to continuous inclined ribs. Saini and Saini (2008) studied the effect of arc shaped ribs on the heat transfer coefficient and friction factor of rectangular ducts.

In the present work, experimental investigation on the performance of rectangular duct, having the absorber plate with artificial roughness in the form of Multi v-shaped ribs provided with gap in both limbs of V. providing a gap in all the limbs of multi- v shape geometry the maximum enhancement of thermo-hydraulic performance as compared to simple single v-ribs arrangement.

The variations of Nusselt number and friction factor as a function of roughness parameters including gap distance and gap width have been evaluated to examine the thermo-hydraulic performance of the system to ascertain the benefit of this selected roughness geometry.

II. Experimental Setup and Procedure

Experimental duct consists of a wooden channel that includes an entry section, text section, exit section, transition section, a flow measuring orifice-meter and a centrifugal blower with a control valve. Entrance and exit duct have been provided at the inlet and outlet of the test collectors to stabilize the air flow. These are made from plywood of thickness 18.0 mm and having the same cross section as that of test section. The length of entry and exit section has been taken as 400 mm and 200 mm respectively. This has been decided based on the recommendation of ASHRAE Standard 92-77 (1997). A G.I. plate of length 1500 mm and width 200 mm is used as an absorber plate and the lower surface of the plate is provided with artificial roughness in the form of multi v-shape ribs with gap. The roughness elements used in the roughened plate are G. I. wires of 16 gauges. In the upper surface of the plate the Eight Calibrated thermocouples (K-type) is attached for temperature measurement. An electric heater is fabricated by nichrome wire of 25 SWG of size 1500 X 200 was used to provide a uniform heat flux up to a maximum of 1000 W/m^2 to the absorber plate. The power supply to the heater plate assembly was controlled through an AC varia.

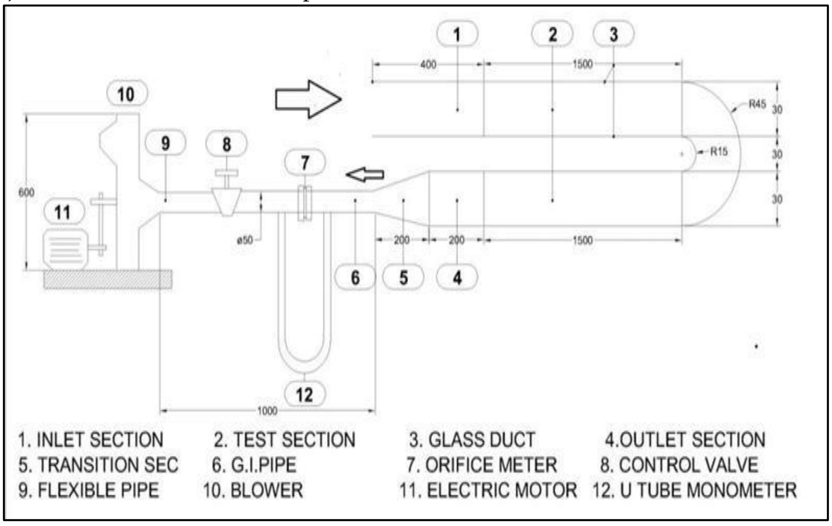

Fig.1. Schematic diagram of experimental set up.

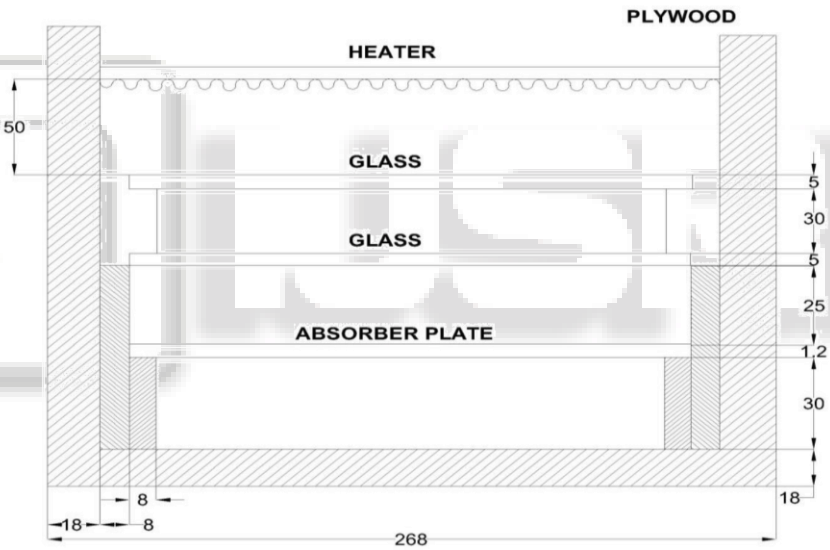

Fig. 2: Cross Sectional View of duct (all dimensions are in mm)

Air is sucked through a rectangular duct with the help of a blower driven by a 3-phase, 440 V, 2.3 kW and 1420 r.p.m. and a gate valve has been used to control the amount of air in the duct. The duct was covered with thermocole to minimize the losses to the surroundings. Other end of the duct is connected to a circular pipe via a rectangular to circular transition section. Airflow rate in the duct was measured by orifice meter. Pressure drop across the orifice meter was measured by an inclined U-tube manometer with mercury as manometric fluid. Data were noted under steady state condition which is assumed to have reached when the plate and air temperatures showed negligible variation for around 10 min duration. When the experiment is started with the set up at ambient temperature, it takes about 1.5–2 hour to reach quasi steady state condition.

Temperatures on absorber plate at different location are measured with the help of k -type thermocouple. A digital multi - meter is used to indicate the output of the thermocouples through the selector switch. The position of the thermocouple is shown in fig.3-

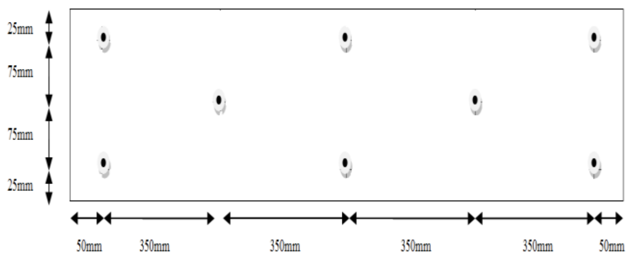

Fig.3. Position of thermocouple

A. Roughness Geometry

The rib roughness can be described by the value of the duct (W), width of the single v shape rib (w), rib hight (e), rib pitch (p), gap distance (Gd), length of single v shape rib

(L_v), gap width (g), angle of attack (α), relative gap distance (Gd/L_v), relative roughness width (g/e).the roughness geometry is shown in fig.4

B. Range of parameter

Sr. no.	Parameter	value
1	Relative roughness pitch (p/e)	10
2	Relative roughness width (W/w)	3
3	Relative roughness hight (e/D)	0.043
4	Reynolds number (Re)	2000-15000
5	Angle of attack (α)	60°
6	Relative gap distance (G_d/L_v)	0.20-0.80
7	Relative gap width (g/e)	0.5-1.5

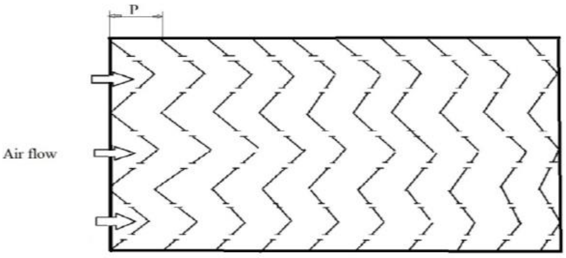

Fig. 4: Roughness Geometry

C. Data Reduction

The experimental data for plate and air temperature at various locations in the duct was recorded under steady state condition for given heat flux and mass flow rate of air. Following equation has been used for the determination of heat transfer coefficient (h), Nusselt number (Nu), Reynolds number (Re), and Friction factor (f).

$$h = \frac{Q_a}{A_p(T_p - T_f)} \quad (1)$$

$$Q = mC_p(T_o - T_i) \quad (2)$$

Where,
Qair = heat input to air in KJ,
Tp = temperature of plate, °C
Tf = temperature of fluid, °C
Cp = specific heat of air, KJ/kg-K
To = temperature at exit, °C
Ti = temperature at entry, °C
Mass flow rate (m) has been determine from the pressure drop measurement across the orifice plate-

$$m = C_d \times A_o[2 \times \rho(\Delta p)_o/(1 - \beta^4)]^{0.5} \quad (3)$$

Where, c_d is the discharge coefficient
Heat transfer coefficient has been used to determine the Nusselt number using the equation

$$Nu = \frac{h.D_h}{k} \quad (4)$$

Where,
h = heat transfer coefficient, W/m^{2}k
D_h = hydraulic diameter, m
K = thermal conductivity of air, W/mk
The friction factor calculated by-

$$f = \frac{2.(\Delta P)_d .D}{4 .\rho.L.V^2} \quad (5)$$

The value of Reynolds number calculated by-

$$Re = \frac{\rho V D_h}{\mu} \quad (6)$$

Where,
V = velocity of air (m/s)
D_h = hydraulic diameter (m)
P = density of air (kg/m3)
μ = viscosity of air (m2/s)

Thermal efficiency calculated by-

$$\eta = \frac{GC_p(T_o - T_i)}{I} \quad (7)$$

$$G = \frac{m}{A_p} \quad (8)$$

Where,
G = mass velocity, kg/s-m
A_p = area of the plate, m^2
I = heat flux, W/m^2

D. Validation of experimental data

The data obtained from the experiment compared with the theoretical value. The values of Nusselt number determine from the experimental data for smooth duct have been compared with value obtained from the Dittus-Boelter equation.
The Dittus-Boelter equation is –

$$Nu_s = 0.023Re^{0.8}Pr^{0.4} \quad (9)$$

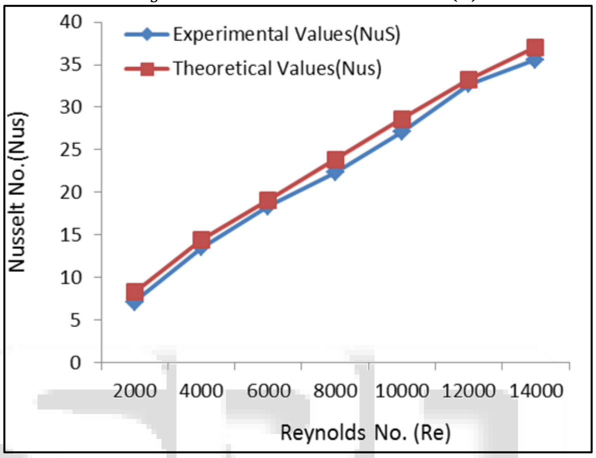

Fig. 5: Comparison of Nusselt number with experimental value and theoretical value of smooth surface.

III. RESULTS

Using the data obtained from experiments, the heat transfer, friction factor and the thermal performance characteristics of duct are shown in a graph. In each graph comparison between roughened duct and smooth duct is made to determine the enhancement in heat transfer. These graphs show the variation in the parameter.

Fig.6 shows that the effect relative gap distance on the Nusselt number for a fixed relative gap width (g/e) 1.0. It shows the Nusselt number increase with increase in relative gap distance and attains the maximum at a relative gap distance of 0.69 and thereafter it decreases with increases in relative gap distance.

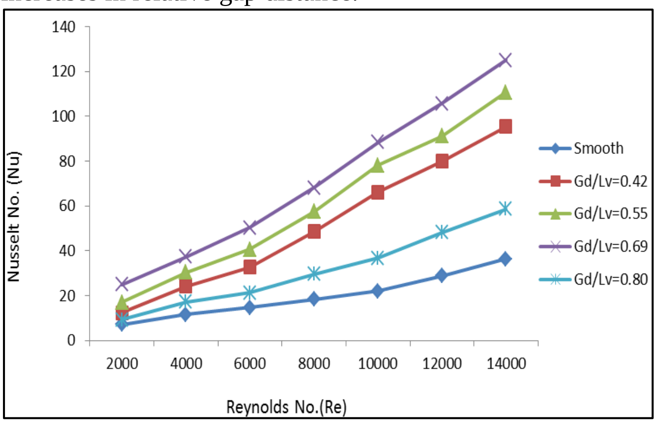

Fig. 6: Effect of relative gap distance on Nusselt number.

Fig.7 shows that the effect relative gap distance on the heat transfer coefficient for a fixed relative gap width (g/e) 1.0. It increases with increases in relative gap distance and found the maximum at a relative gap distance of 0.69.

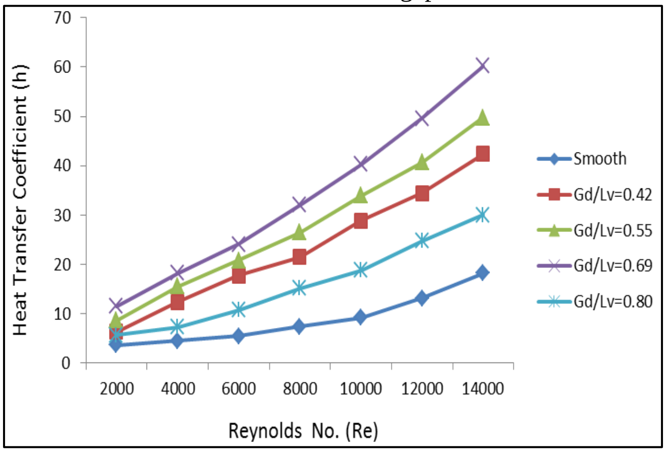

Fig. 7: Effect of relative gap distance on Heat transfer coefficient.

Fig.8 Show variation on thermal efficiency with Reynolds number. The maximum efficiency is found at a relative gap on 0.69 with a relative gap width 1.0 and relative roughness pitch 10.

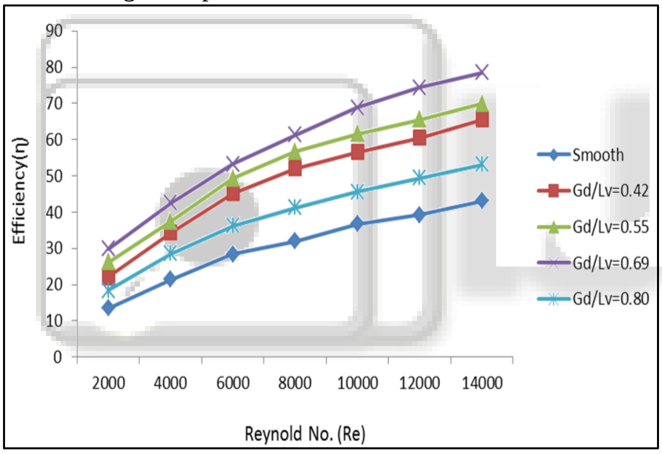

Fig. 8: Variation of Thermal Efficiency with Reynolds number

IV. Conclusion

The following conclusion can be drawn from the experimental work-

1) Introduction of artificial roughness on under side of the absorber plate enhances Nusselt Number and Heat transfer coefficient compare to smooth duct.
2) Providing gap in multi v-shaped rib result in increasing in heat transfer coefficient of air flow duct.
3) The maximum value of Nusselt number and friction factor are observed in multi v-shaped with a relative gap distance of 0.69 and relative gap width of 1.0.
4) Thermal efficiency roughed plates has been compared with the smooth duct and the maximum the efficiency show in roughed plate at a relative gap distance of 0.69 and relative gap width of 1.0.
5) Multi v-rib with gap also shows maximum thermo hydraulic performance as compared to inclined rib with gap, and multi v-rib without gap.

Nomenclature

- A_p area of absorber plate, m^2
- A_o cross section area of orifice, m^2
- C_d coefficient of discharge of orifice
- C_p specific heat of air at constant pressure, J/kg K
- D hydraulic diameter of duct, m
- e rib height, m
- e/D relative roughness height
- f_s friction factor of smooth duct
- f friction factor of roughened duct
- G_d gap distance, m
- G_d/L_v relative gap distance
- g gap width, m
- g/e relative gap width
- H depth of duct, m
- h convective heat transfer coefficient, W/m^2 K
- k thermal conductivity of air, W/m K
- L_v length of single v shaped rib, m
- L test section length for pressure drop measurement,
- m mass flow rate, kg/s
- Nu Nusselt number of roughened duct
- Nu_s Nusselt number of smooth duct
- $(\Delta P)_O$ difference of manometric fluid level in U-tube manometer,
- $(\Delta P)_d$ difference of water column level in U-tube manometer, m
- P pitch of the rib, m
- P/e relative roughness pitch
- Qu useful heat gain rate, W
- Tf mean temperature of air, K
- Ti inlet temperature of air, K
- To outlet temperature of air, K
- Tp average plate temperature, K
- V velocity of air, m/s
- W width of duct, m
- w width of single v-shaped rib, m
- W/w relative roughness width ratio

Greek symbol

- α rib angle of attack, degree
- β ratio of orifice diameter to pipe diameter
- ή thermo-hydraulic performance parameter
- ρ density of air, kg/m^3
- ρ_m density of manometric fluid, kg/m^3

References

[1] M.K Gupta, S.C. Kaushik, Performance evaluation of solar air heater having expanded metal mesh as artificial roughness on absorber plate 48 (2009) 1007–1016.
[2] Anil P. Singh, Varun, Siddhartha, Effect of artificial roughness on heat transfer and friction Characteristics having multiple arc shaped roughness element on the absorber plate 105 (2014) 479–493.
[3] Rajendra Karwa, S.C. Solanki, J.S Saini Thermo-hydraulic performance of solar air heaters having integral chamfered rib roughness on absorber plates 26 (2001) 161–176.
[4] J.L Bhagoria, J.S Saini, Solanki SC. Heat transfer coefficient and friction factor correlations for

rectangular solar air heater duct having transverse wedge shaped rib roughness on the absorber plate. Renew Energy 25 (2002) 341–369.

[5] A.R Jaurker, J.S Saini, B.K Gandhi Heat transfer and friction characteristics of rectangular solar air heater duct using rib-grooved artificial roughness 80 (2006) 895-907.

[6] B.N Prasad, J.S Saini, Effect of artificial roughness on heat transfer and friction factor in a solar air heater. Solar Energy 41 (1988) 555–560.

[7] J.C. Han, Heat transfer and friction characteristics in rectangular channels with rib turbulators, ASME J. Heat Transfer 110 (1988) 321–328.

[8] J.C. Han, Y.M. Zhang, C.P. Lee, Augmented heat transfer in square channels with parallel, crossed and V-shaped angled ribs, ASME J. Heat Transfer 113 (1991) 590– 596.

[9] S.C. Lau, R.D. McMillin, J.C. Han, Heat transfer characteristics of turbulent flow in asquare channel with angled discrete ribs, ASME J. Turbo machinery 113 (1991) 367–374.

[10] T.M. Liou, J.J. Hwang, Effect of ridge shapes on turbulent heat transfer and friction in a rectangular channel, Int. J. Heat Mass Transfer 36 (1993) 931–940.

[11] Abdul-Malik, J.S. Saini, S.C. Solanki, Heat transfer and friction in solar air heater duct with V-shaped rib roughness on absorber plate International Journal of Heat and Mass Transfer 45 (2002) 3383–3396.

[12] Arvind Kumar, J.L. Bhagoria, R.M. Sarviya, Heat transfer and friction correlations for artificially roughened solar air heater duct with discrete W-shaped ribs 50 (2009) 2106–2117.

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

[14] D. Gupta, Investigations on fluid flow and heat transfer in solar air heaters with roughened absorbers, Ph.D. Thesis. University of Roorkee, India, June 1993.

[15] R.P. Saini, J.S. Saini, Heat transfer and friction factor correlations for artificially roughened ducts with expanded metal mesh as roughness element, Int. J. Heat Mass Transfer 40 (1997) 973–986.

[16] A. Lanjewar, J.L. Bhagoria, R.M. Sarviya Experimental study of augmented heat transfer and friction in solar air heater with different orientations of W-Rib roughness 35 (2011) 986–995.

