Thermal Performance of Inclined and Transverse Wire Solar Air Heater

Dr. Rajeev Ranjan[1], Dr. Prakash Kumar[2]
[1]Associate Professor, [2]Associate Professor
[1] Department of Mechanical Engineering, RKDF University Ranchi,
Email: rajeev3278@gmail.com
[2] Department of Computer Engineering, RKDF University Ranchi,

Abstract:

This paper presents an analytical investigation on the been carried out to study the heat transfer and friction characteristics by using a combination of inclined as well as transverse wire on the absorber plate of a solar air heater. The Analytical investigation encompassed the Reynolds number (Re) ranges from 3000 to 14000, relative roughness pitch (p/e) 10–30 and relative roughness height (e/D) 0.0135-0.0225. The effect of these parameters on the heat transfer coefficient and friction factor has been discussed in the present paper and correlations for Nusselt number and friction factor has been developed within the reasonable limits. A procedure to compute the thermal efficiency based on heat transfer processes in the system is also given and the effect of these parameters on thermal efficiency has been discussed .transverse wire has been used to enhance heat transfer coefficient. By providing artificial roughness it has been concluded that there is an improvement of heat transfer coefficients which results increase in pumping power, pressure drop and high value of thermal performance.

Introduction:

Solar collector is a basic device which captures the solar radiation and converts into useful heat energy. Solar air heat collector due to its simple design, construction and low cost, it is widely used to collect solar energy. It has applications from seasoning of timber to drying of seeds tor preservation. Solar collector consists of an absorber plate, wooden box, back plate, glass cover and insulator. Major drawback of solar air heater is low efficiency due to low heat transfer coefficient which leads to poor performance. Convective heat transfer is low between air and absorber plate due to formation of laminar sub-layer. Heat transfer coefficient can be enhanced by breaking the sub-layer by creating turbulence in air flow. Turbulence can be created by introducing artificial roughness on collector surface however it increases the friction losses and therefore required more power for pumping air through collector. To keep frictional losses as low as possible it is required to create turbulence only near the surface without disturbing already existing turbulent flow.

The concept of surface roughness in solar air heater was first introduced by Prasad and Mullick. Saini (1988) they studied the effect of transverse rib roughness in solar collector on heat transfer it was based on the approach considered by Han 1984, the maximum nusselt number was reported to be 2.38 times over the conventional duct.

The correlation used to predict the average nusselt number is given as:

$$\overline{Nu} = \frac{\bar{f}/2}{1+\sqrt{\left(\frac{\bar{f}}{2}\right)}\left[4.5(e^{+})^{0.28} pr^{0.57} - 0.95\left(\frac{p}{e}\right)^{0.53}\right]} \mathrm{RePr} \qquad (1)$$

Top side artificially roughened solar heater was studied by Prasad and Saini 1991 for optimizing Thermo-Hydraulic performance, they uses various values of relative roughness pitch $\left(p/e\right)$,relative roughness height $\left(e/D\right)$ and Reynolds number (Re) they arrived at the conclusion that the value of roughness Reynolds number , $e^{+} \approx 24$ gives the optimal value of Thermo-Hydraulic performance (i.e. minimum pumping power and maximum heat transfer).

Gupta et al 1993 investigated the performance of solar air heater using transverse wire rib on the top surface .they kept relative roughness pitch value constant ($p/e = 10$) and studied it for different aspect ratio and relative roughness height, flow Reynolds number used was 3000 - 18000. Based on their study they concluded following correlations:

For $e^{+} < 35$

$$Nu_r = 0.000824 \left(\frac{e}{D}\right)^{-0.178} \left(\frac{W}{H}\right)^{0.288} (Re)^{1.62} \qquad (2)$$

For $e^{+} \geq 35$

$$Nu_r = 0.00307 \left(\frac{e}{D}\right)^{0.469} \left(\frac{W}{H}\right)^{0.245} (Re)^{0.812} \qquad (3)$$

Karwa et al. developed correlations for friction factor and heat transfer coefficient in transition flow for top roughened solar collector duct. Verma and Prasad 2000 developed correlations for heat transfer coefficient for top side artificially roughened solar heater duct in fully developed turbulent flow which is given as :

For $e^+ \leq 24$

$$Nu_r = 0.08596 \left(\frac{e}{D}\right)^{0.072} \left(\frac{p}{e}\right)^{-0.054} (Re)^{0.728} \tag{4}$$

For $e^+ > 24$

$$Nu_r = 0.02954 \left(\frac{e}{D}\right)^{0.021} \left(\frac{p}{e}\right)^{-0.016} (Re)^{0.802} \tag{5}$$

Various investigators with their roughness geometry and dimensional parameters are tabulated below:

Investigator	Roughness geometry	parameter
Prasad and Mallick	Transverse wire rib	$e/D = 0.0190$; $P/e = 12.7$
Gupta	Inclined wire rib	$e/D = 0.0230$; $P/e = 10$
Momin	v- shaped rin	$e/D = 0.0230$; $P/e = 10$
Karwa	Chamfered rib	$e/D = 0.0441$; $P/e = 4.85$
Jaurker	Rib – grooved	$e/D = 0.0363$; $P/e = 6$
Bhagoria	Transverse wedge	$e/D = 0.0330$; $P/e = 7.57$
Saini and Saini	Arc shaped rib	$e/D = 0.0422$; $P/e = 10$
Karmare and Tikekar	Metal grit rib	$e/D = 0.0440$; $P/e = 17.5$
Pawar	Wedged shaped rib groove	$e/D = 0.0330$; $P/e = 8$
Aharwal	$60°$ inclined square rib with gap	$e/D = 0.0370$; $P/e = 8$

Sharp edge roughness element increases heat transfer coefficient more than smooth or roundness shaped roughness but it increases friction losses even more than the roundness shaped roughness. The net effect of sharpness of roughening element is investigated by Sparrow and Hossfeld, 1984 and it was reported that round shaped roughness geometry is more suitable than sharp edge roughness.

Studies of Sharma and Varun, 2010, while comparing the performance of different types of geometry of roughness element in solar air heater duct, shows that small diameter protrusion wire are better for flow Reynolds number up to 10000.

The value of collector efficiency factor, F' given by equation (Bliss, 1959), is given as:

$$F' = \frac{h}{h+U_L} \tag{6}$$

F'can be enhanced by increasing the value of heat transfer coefficient, h , between the absorber plate and flowing air over it . The increase in the value of h further decrease the value of heat loss coefficient which also increases the value of F' .

It is general practice to provide roughness only on one surface (top surface) of solar air heater duct so, only the top surface forms the absorber plate and the side plates are insulated which are not the part of absorber. Glass cover is also provided on the top side to receive solar radiation. The side wall of the solar air heater duct may form the part of absorber plate having artificial roughness and side glass to receive solar radiation. Considering that the rectangular solar air heater duct has two sides absorber plate and two sides (bottom plate and one side wall) insulated, the present work has been focused at to analyze for fluid flow and heat transfer for fully developed turbulent flow in solar duct roughened artificially using small diameter wires on two sides (top side and one side wall). The analytical values of the roughness and the heat transfer parameter has been found out with the reference to the results of Prasad and Saini 1998; Prasad , 2013;B.N. Prasad et al. 2014 available for one side and three side roughened solar air heater , to see the effect of roughness on heat transfer enhancement in the present solar air heater.

Analysis:

The following analysis is purely based on the approach used by (Prasad et. Al, 1984) who analysed for the fluid flow in rectangular duct having three side artificial roughness and (Prasad and saini 1988) who analysed for one side roughened rectangular solar air heater duct. Both of these ducts have identical dimensions and cross sectional area of W × B with the assumption of

W >> B.

Friction factor for fully developed turbulent flow in a four side smooth duct, is given by the relation, $f_s = \frac{\tau_s}{\frac{1}{2}\rho v_s^2}$ (7)

Similarly, the friction factor for fully developed turbulent flow in a four side rough duct, is given by the relation, $f_r = \frac{\tau_r}{\frac{1}{2}\rho v_r^2}$ (8)

Average friction factor for fully developed turbulent flow for a duct having two side smooth and two side rough wall is given by the relation, $\bar{f_r} = \frac{\bar{\tau}_r}{\frac{1}{2}\rho \bar{v}_r^2}$ (9)

If τ_{2r} is the shear stress on the rough surfaces of four sided duct having two roughened walls and two smooth wall , and τ_{2s} is shear stress on two smooth wall surfaces .τ_s is the shear stress in the duct having all four wall rough and $\tau_r$is the shear stress in the duct having all four wall smooth.

The following equivalence between the total shear forces of the duct system can be established

[(W+B)τ_{2r} + (W+B)τ_{2S}]L $\cong$ [(W+B)τ_r + (W+B)τ_S] L

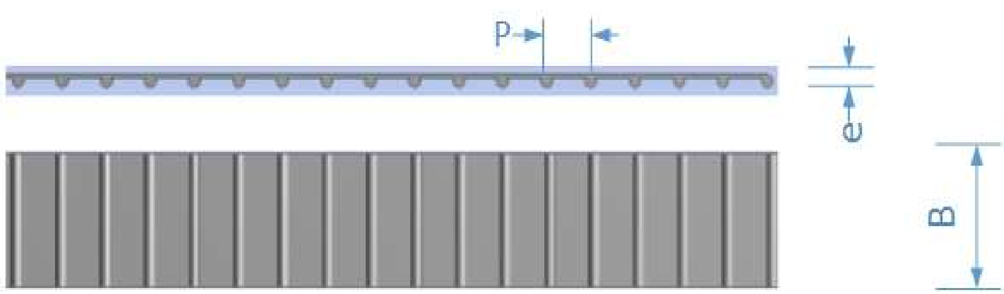

Fig.1. side absorber plate

Results and discussion:

Fig. 2 represents the effect of roughness pitch on the average friction factor for constant relative roughness value of e/D = 0.0135 at varying values of Reynolds number, while the fig. 3 shows the effect of relative roughness height on friction at for constant value of roughness pitch p/e

=10 , for varying values of Reynolds number. Both figure also shows the investigation made by Prasad et.al. 2014 for three side artificially roughened solar air heater duct.

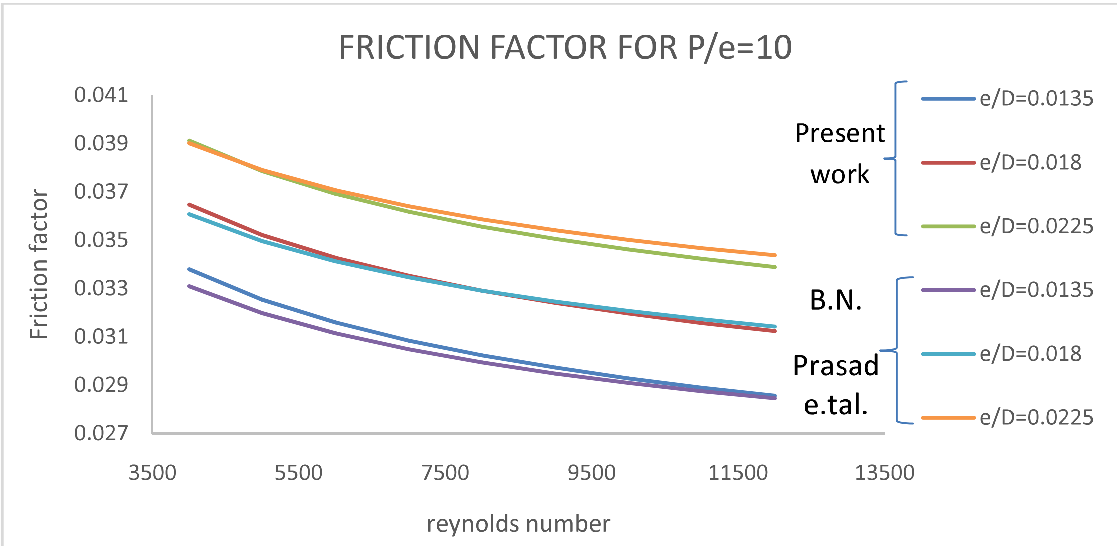

Fig. 2. Effect of roughness pitch on the average friction factor

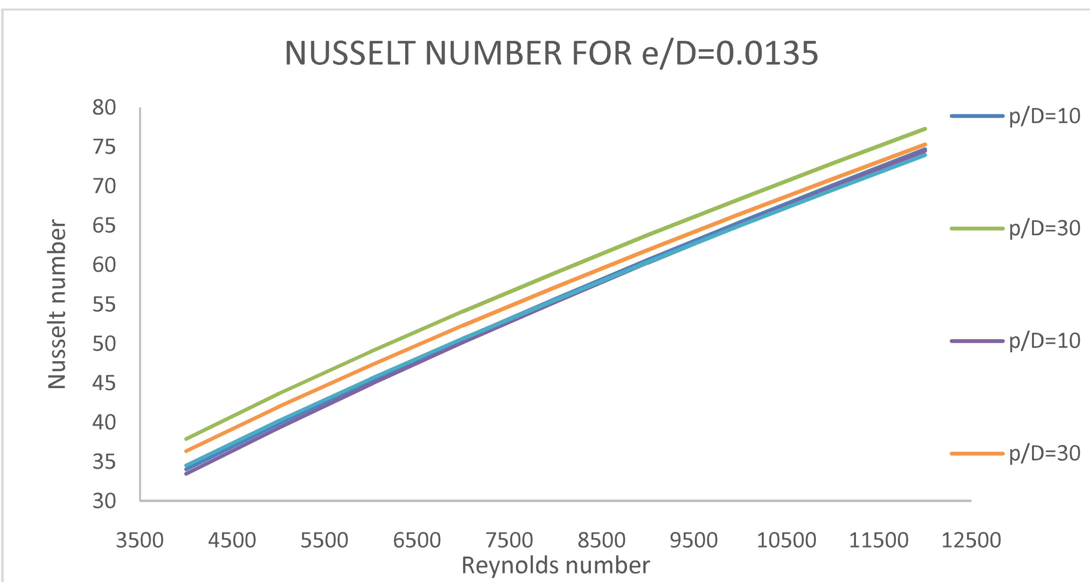

Fig.3 Effect of relative roughness pitch on average nusselt

Fig.3 shows the effect of relative roughness pitch on average nusselt $\overline{Nu_r}$ number for constant values of relative roughness heightof e/D=0.0135 at varying values of Reynolds number while the variation of average nusselt number with relative roughness height for constant relative roughness pitch of p/e=10 at various Reynolds number. Nusselt number increases with increase in relative roughness pitch for constant values relative roughness height whereas for constant values value of relative roughness pitch enhancement in nusselt number is not recognizable at lower Reynolds number. In both of the cases nusselt number increases with increase in Reynolds number. nusselt number for two side roughened duct is slightly higher than three side roughened duct for higher values of relative roughness pitch whereas nusselt number is higher for three side roughened duct for higher values of relative roughness height.

Conclusions:

On the basis of the results obtained and discussion the following conclusion can be drown:-

- ❖ Heat transfer and fluid flow analysis of rectangular solar air heater duct having two side (one top and one side wall) artificially roughened surface with two side glass cover.
- ❖ Correlations for Average friction factor and heat transfer co-efficient have been developed in terms of geometrical parameters.
- ❖ Average nusselt number and Average friction factor for different values of relative roughness height, relative roughness pitch and Reynolds number are calculated.
- ❖ Maximum 7.4 % decrease in friction factor is recorded as compared to three side roughened duct.
- ❖ In this study it is found out that substantial increase in thermal efficiency in solar air heater having roughness elements as a combination of inclined and transverse wire on the two side absorber plate. The efficiency increases with increasing air flow rate though for higher air flow rate. In this solar air heater it is found out that solar irradiation is also a factor to effect the solar efficiency. The maximum nusselt number found 77.32 for a relative pitch p/e=10, roughness pitch of e/D= 0.0225 at Reynolds number Re = 12000

References:

- ➢ *M.K. Paswan and S.P. Sharma – 2009 – Thermal performance of wire mess roughened solar air heater. Ariser . International Journal of energy volume – 5 No.- 1 Page No.- 31 to 40*

- ***M.K.Paswan 2014 "****Experimental analysis of renewable energy as solar air heater with artificial roughness" vol-4 issue 1, Page-125-134*
- *Bhagoria, J.S., 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.*
- *M.K.Paswan ,R.Ranjan, K.Jharia,A CFD based Performance Analysis of Heat Transfer Enhancement in solar air heater Provided with transverse semi circular ribs. International Journal of Innovative Research in science , Engineering and Technology, Volume- 4, Issue-6, June 2015,4528-4537, ISSN-2319-8753*
- *Bhushan, B., Singh, R., 2012. Thermal and thermo-hydraulic performance of roughened solar air heater having protruded absorber plate. Int. J. Sol. Energy 86 (11), 3388–3396.*
- *M.K.Paswan et al.,2016.****Experimental Study of Effect of Friction Factor on Flat-Plate Solar AirHeater having Roughened (Rhombus Shape) Absorber Plate****,vol-2, issue -5 Page-272-277.*
- *Bliss, R.W., 1959. Derivation of several plate efficiency factors useful in design of flat plate solar heat collectors. Sol. Energy 3, 55–64.*
- *Chamoli, S., Chauhan, R., Thakur, N.S., Saini, J.S., 2012a. A review of the performance of double pass solar air heater. Int. J. Renew. Sustain. Energy Rev. 16 (10), 481–492.*
- *Chamoli, S., Thakur, N.S., Saini, J.S., 2012b. A review of turbulence promoters used in solar thermal system. Int. J. Renew. Sustain. Energy Rev. 16 (5), 3154–3175.*
- *Dalle Donne, M., Meyer, L., 1977. Turbulent convective heat transfer from rough surfaces with two dimensional rectangular ribs. Int. J. Heat Mass Trans. 20, 583–620.*
- *Dipprey, D.F., Sabersky, R.H., 1963. Heat and momentum transfer in smooth and rough tubes at various Prandtl number. Int. J. Heat Mass Trans. 6, 329–353.*
- *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.*
- *Han, J.C., 1984. Heat transfer and friction in channels with two opposite rib-roughened walls. Trans. ASME J. Heat Trans. 106, 774–781.*
- *Hans, V.S., Saini, R.P., Saini, J.S., 2009. Performance of artificially roughened solar air heater-A review. Renew. Sustain. Energy Rev. 13, 1854–1869.*

- *Hans, V.S., Saini, R.P., Saini, J.S., 2010. Heat transfer and friction factor correlations for a solar air heater duct roughened artificially with multiple V-ribs. Sol. Energy 84, 898–911.*
- *Jaurker, A.R., Saini, J.S., Gandhi, B.K., 2006. Heat transfer and friction characteristics of rectangular solar air heater duct using rib-grooved artificial roughness. Sol. Energy 80, 895–907.*
- *Karwa, R., 2003. Experimental studies of augmented heat transfer and friction in asymmetrically heated rectangular ducts with ribs on the heated wall in transverse, inclined, V-continuous and V-discrete pattern. Int. Commun. Heat Mass Trans. 30, 241–250.*
- *Karwa, R., Chitoshiya, G., 2013. Performance study of solar air heater having V-down discrete ribs on absorber plate. Int. J. Energy 55, 939–955.*
- *Karwa, R., Solanki, S.C., Saini, J.S., 1999. Heat transfer coefficient and friction factor correlation for the transitional flow regimes in rib-roughened rectangular duct. Int. J. Heat Mass Trans. 42, 1597–1615.*
- *Karwa, A., Saini, R.P., Saini, J.S., 2013. Development of correlation for Nusselt number and friction factor for solar air heater with roughened duct having multi v-shaped with gap rib and artificial roughness. Int. J. Renew. Energy Res. 58, 151–163.*
- *Lanjewar, A.M., Bhagoria, J.L., Sarviya, R.M., 2012. Thermo hydraulic performance of solar air collector using W-shaped artificial roughness. J. Environ. Res. Dev. 6 (3A), 874–878.*
- *Layek, A., Saini, J.S., Solanki, S.C., 2009. Effect of chamfering on heat transfer and friction characteristics of solar air heater having absorber plate roughened with compound turbulators. Renew. Energy 34, 1292–1298.*
- *Patil, A.K., Saini, J.S., Kumar, K., 2012. A comprehensive review on roughness geometries and investigation techniques used in artificially solar air heaters. Int. J. Renew. Energy Res. 2, 1–15.*

****