Thermal Performance Enhancement of Inclined Rib Roughness Solar Air Heater

Gurpreet Singh and Satwant Singh

Lala Lajpat Rai Institute of Engineering and Technology, Moga (Punjab) –142001

Abstract : Artificial roughness applied on the absorber plate is the most efficient method to improve thermal performance of solar air heaters. An experimental investigation has been carried out on solar air heater roughened with circular inclined rib. The range of parameters for this study has been decided on the basis of practical considerations of the system and operating conditions of solar air heaters. The experimental investigation encompassed the Reynolds number (Re) range from 2564 to 6206; relative roughness pitch (P/e) of 8, angle of attack (α) of 45° and relative roughness height (e/Dh) is 0.047.

Keywords: Artificial Roughness, Solar air heaters, heat transfer, Roughness Geometry, thermal efficiency, Reynolds number.

I INTRODUCTION

Energy is a basic need for human being; it is a prime agent in the generation and economic development. Energy resources may be classified in two ways conventional and non-conventional energy resources. It can be used in different forms. Most of the energy comes from fossil fuels and the world fossil fuels reserves are limited. The rapid depletion of fossil fuel resources has necessitated an urgent search for alternative sources of energy of the many alternatives; solar energy stands out as the brightest long range promise towards meeting the continually increasing demand for energy. Solar energy is available freely, omnipresent and an indigenous source of energy provides a clean and pollution free atmosphere. The simplest and the most efficient way to utilize solar energy are to convert it into thermal energy for heating applications by using solar collectors. Solar air heaters, because of their inherent simplicity are cheap and most widely used collector devices. The efficiency of flat plate solar air heaters has been found to be low because of low heat transfer coefficient between the absorber plate and the flowing air, which increases the absorber plate temperatures, leading to higher heat losses to the environment. Hence, different modifications are suggested and applied to improve the heat transfer coefficient between the absorber plate and air. One of the methods is installation of turbulence promoters in the form of artificial roughness on the underside of the absorber plate. Such artificial roughness produces the turbulence and breaks the laminar sub layer due to this more heat transfer archived.

There are many applications of solar air heaters that are used at low and moderate temperatures. Some of these are timber seasoning, crop drying, space heating, chicken brooding and curing / drying of concrete / clay building components. Han et al. [1] seen the effect of artificial roughness on heat transfer and friction factor for two opposite roughened surfaces.

Verma and Prasad [2] studied the effect of protruding wires on friction factor, heat transfer coefficient and plate efficiency factor of a solar air heater , Prasad and Saini [3] studied the effect of roughness and flow parameters such as relative roughness height (e/D) and relative roughness pitch (p/e) on heat transfer and friction factor. Sahu et al.[4] experimentally investigated the heat transfer coefficient by using 900 broken transverse ribs on absorber plate of a solar air heater, Gupta et al. [5] experimentally investigated the effect of relative roughness height (e/d), Aharwal et al.[6] carried out result of inclination of rib with respect to flow direction and Reynolds number (Re) onthe thermo hydraulic performance of a roughened solar air heater for transitionally rough flow region. Lanjewar et al. [7] studied a very narrow channel (AR = 8:1) with W-shaped, discrete W- shaped, v-shaped, angled ribs. Singh et al.[8] carried out the result of thermo-hydraulic performance due to flow attack angle in V-down rib with gap in the rectangular duct of solar air heater. Experimentally they found that the highest heat transfer enhancement and the highest friction losses done by Wshaped and discrete W- shaped roughness. In view of above literature the present experimental work conducted the range of parameters of Reynolds number 2000-14000, relative roughness height 0.036, relative roughness pitch 8-12, angle of attack 600 and duct aspect ratio 8. Singh et al. [9] conducted an experimental study on solar air heater roughened with circular transverse rib in actual atmospheric condition. In present study, the experimental investigation of thermal performance for artificial roughened duct solar air heater has been reported.

II EXPERIMENTAL SETUP AND PROCEDURE

Experimental apparatus

In solar air heaters, the three walls of rectangular duct are smooth and insulated while only one wall i.e. absorber is explored to solar radiation. It is reported that, by using the roughness underside the absorber plate results in higher heat transfer enhancement than smooth plate. The basic experimental setup consists of duct, G.I. pipe, orifice plate, flow valve, flexible pipe, blower, etc. The ambient air is sucked by blower the rib-roughened rectangular duct. An experimental setup has been designed and fabricated for determining the thermal efficiency of roughened duct. The schematic diagram of experimental setup and direct photograph of the experimental setup are shown in Figures 1 and 2 respectively. The detailed constructional features of individual components are as under; the cross-section of the rectangular duct is shown in figure 1. The duct has 2200 mm length; 520 mm width and 25 mm depth made up of galvanized iron sheet and kept inclined at angle of 45° to the horizontal. The absorber plate is 1 mm thick galvanized iron (GI) sheet. The length of GI sheet is 1900 mm. The two sides of duct are covered with wood having 45mm thickness and bottom is insulated with 76 mm thick glass wool. The side of G.I sheet (absorber plate) is painted with dull black color to increases the absorber efficiency. A 4 mm thick glass cover is fixed above the absorber plate and wooden box is fitted like duct to place thermometer at the outlet of duct. A blower, control valve, orifice plate and other devices such as thermometer measures temperature, manometer for pressure measurement. Blower sucks the air through duct and pipe and control valve regulate and change the flow of air.

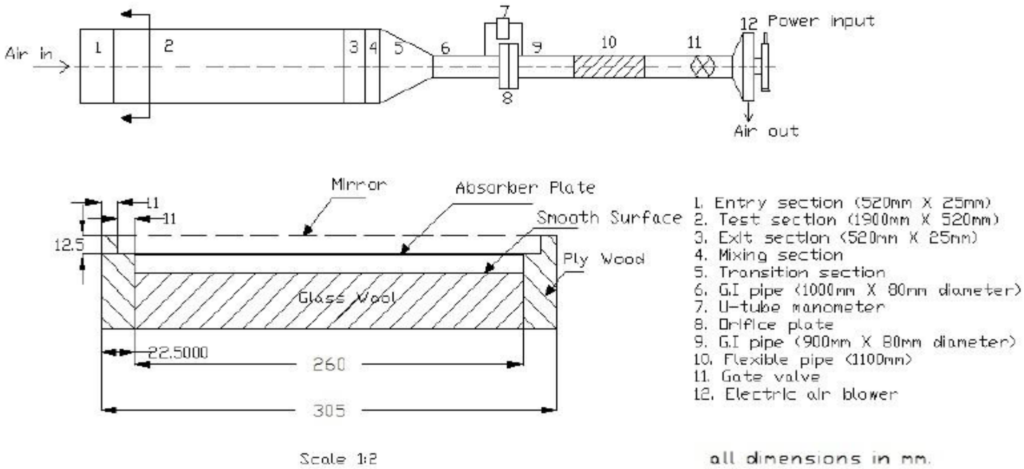


Figure 1 Schematic diagram of experimental setup.

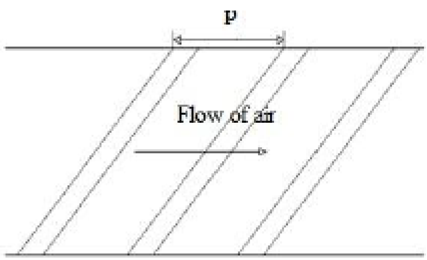
Figure 2 Direct photograph of the experimental setup.

Geometry of roughened surface and range of parameters

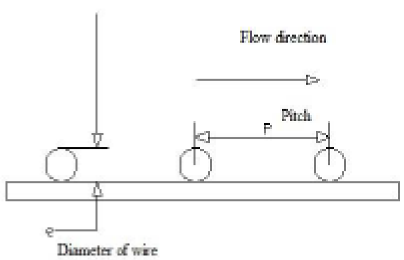
The general geometry of artificial rib roughness and direct photograph of absorber plate with inclined ribs are shown in figure 3 and figure 4 respectively. The roughness, inclined circular rib was produced on GI sheet over a length of 1900 mm and width of 520 mm (Aluminum wires were used to create artificial roughness on the underside of the absorber plat). The rib roughness geometry can be described by the values of rib height (e), rib pitch (P) These parameters have been expressed in the form of dimensionless roughness parameters, viz., relative roughness pitch (P/e), angle of 45° attack (α) and relative roughness height (e/Dh). The range of parameters for this study have been decided on the basis of practical considerations of the system and operating conditions of solar air heaters and is given in Table 1.

Table 1: Values of flow and roughness parameters.

Sl. No.	**Parameter**	**Range**
1	Air flow rate	0.01-0.027 kg/s-m^2; (Re= 2564 - 6206).
2	Relative roughness pitch (P/e)	8
3	Angle of attack (α)	45°
4	Relative roughness height (e/ D_h)	0.047



a) Plain view



b) Enlarged view

Figure 3: Geometry of inclined rib.

(a)

(b)

Figure 4: A few photographs of absorber plates roughened with inclined rib.

Experimental Procedure

Before starting the experiment, all the components of the experimental setup were checked for proper operation. It was ensured that all the thermometers gave the same output at ambient temperature. The blower is then switched ON, and all the joints were checked for air leakage using soap bubble technique.

b) Enlarged view

The gate valve is adjusted to give the desired flow rate through the test section. The duct was placed directed to in the atmosphere conditions with south facing. The test runs to collect the relevant heat transfer data were conducted under steady state conditions. Five values of flow rate were used for both smooth and roughened test. After each change of flow rate, the system was allowed to attend steady state before the data were recorded. During the test runs, all data have been recorded and checked out the difference between inlet and outlet temperatures. As well as also checked radiation intensity of the sun light. The reading was taken at every 30 min at a same flow rate for 9 a.m. to 3 p.m. For each experimental run, the following observations were recorded:

1. Inlet air temperature of collector
2. Outlet temperature of collector
3. Solar Radiation intensity
4. Pressure drop across orifice plate

Collection of data

Experimental data for roughened plates has been collected for five different air flow rates. In addition, data for smooth rectangular duct was also collected under similar operating conditions for the purpose of comparison and for evaluation of the accuracy of measurement on the present setup.

Relative roughness pitch: 8

Angle of attack: 45°

Relative roughness height: 0.047

For the typical run, Table shows the recorded values of temperature of air at inlet and outlet of test section for flow rate of 0.014 kg/sec-m^2 (Re =3214). Four thermometers (T_1, T_2, T_3 and T_4) were used to measure the inlet and outlet temperature at equal interval of time. Solar radiation meter was used to measure the solar radiation intensity. Pressure drop was measured with the help of U-tube manometer.

Data reduction

(a) Mean temperature of air at inlet and outlet of the duct.

The mean temperature of air outlet (T_o) by weighted average method and the temperature at inlet of duct is direct measured as ambient temperature (T_a).

T_a= ambient temperature (°C)

$T_o = \frac{T_1+T_2+T_3}{3}$= is called mean temperature at outlet of the duct.

(b) Mass flow rate of air

Mass flow rate of air has been determined from using the following relationship:

$$m = Q \times \rho$$

Where, $m$mass flow rate of air and ρ is the air density and Q is discharge.

Mass flow rate of air was taken according to area of the absorber plate and the ranges were between 0.011 to 0.027 $kg/sec - m^2$

$Q = C_d \frac{A_1 \times A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh_a}$Where, Q is a coefficient of discharge.

A_1, area of platem^2

A_2, area of orificem^2.

C_d, coefficient of discharge assuming 0.62

$$h_a = h_m \left(\frac{\rho_m}{\rho_a} - 1\right)$$

Where,h_m, manometric height of fluid

ρ_m, Density of manometric fluid (water 1000kg/m^2)

ρ_a, density of air kg/m^3

(c) Velocity of air through duct

The velocity of air is obtained from the calculated values of mass flow rate of air and flow area as,

$$V = \frac{m}{\rho_{air} WH}$$

Where,

m = Mass flow rate, kg / sec

ρ_{air} = Density of air in kg/m^3

H = Height of the duct in m

W = Width of the duct, m

(d) Equivalent hydraulic diameter

The hydraulic diameter of the rectangular section of the duct is determined from the relationship as given here:

$$D_h = \frac{4 \times \text{aera of flow}}{\text{wettedparameter}} = \frac{4(WH)}{2(W+H)}$$

(e) Reynolds number (Re)

The Reynolds number of air flow in the duct is calculated from the following relationship:

$$Re = \frac{VD_h}{v}$$

(f) Useful gain

$$a = (mc_p \Delta T)$$

(g) Thermal efficiency (η_{th})

$$\eta_{th} = \frac{\text{useful gain (a)}}{\text{Radiation(b)} \times \text{Area of absorber plate}}$$

III RESULT AND DISCUSSION

The major objective of the present study is to determine the thermal efficiency of solar air heater artificially roughened with circular inclined rib and the average thermal efficiencies are presented and discussed as a function of airflow rate.

Smooth duct: Figure 4 shows the variation in average thermal efficiency with respect to Reynolds number. It is clearly seen that with increase in Reynolds number from 2564 to 6206, the average thermal efficiency increases from 36% to 62%. It has also been observed that the thermal efficiency increases with increase in Reynolds number.

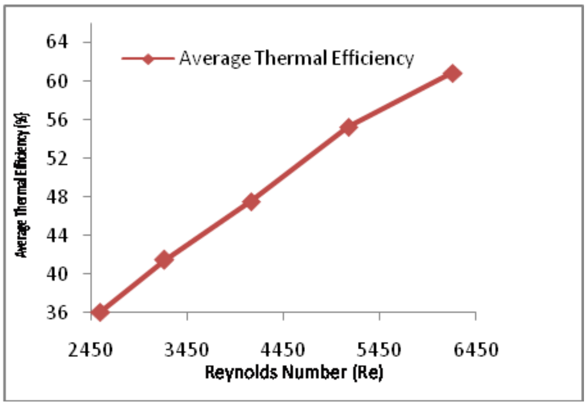


Figure 4 Variation in average thermal efficiency with respect to Reynolds number for smooth duct.

Roughened duct: Figure 5 shows the variation in average thermal efficiency with respect to Reynolds number for roughened duct.

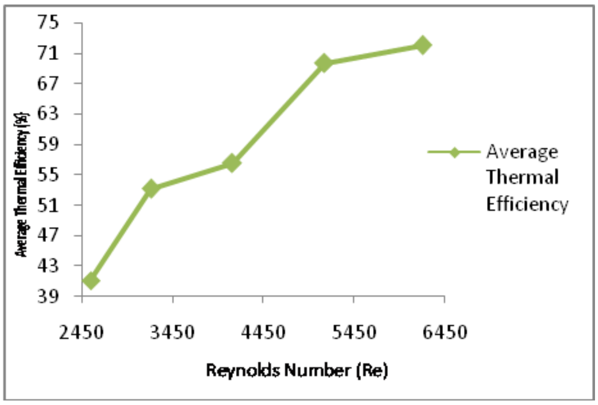


Figure 5 Variation in average thermal efficiency with respect to Reynolds number for roughened duct.

The value of thermal efficiency lies between 40% to 72% in case of roughened solar air heater. It has been observed that by increasing the Reynolds number, the thermal efficiency also increased. This is due to increase in turbulence in the flow with the increase in Reynolds number and hence higher heat transfer rate from absorber plate to the flowing air, results in higher thermal efficiency at higher Reynolds number.

Comparison

Figure 6 shows the comparison of average thermal efficiency at different Reynolds number between the smooth and roughened duct. It has been concluded that the average thermal efficiency in roughened duct is more as compare to smooth duct. The variation in thermal efficiency varies from 36% to 60% in case of smooth duct whereas the value of thermal efficiency increases from 41% to 72% in roughened duct for different Reynolds numbers.

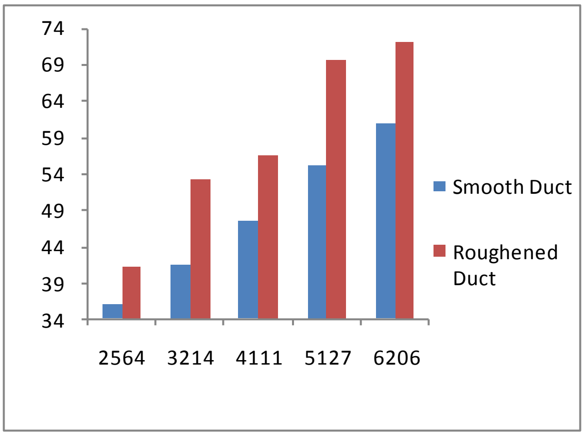


Figure 6 Comparison of average thermal efficiency with respect to Reynolds number between smooth and roughened.

The thermal efficiency of roughened solar air heater is higher than the smooth solar air heater due to the breakage of laminar sub-layer by the artificial rib roughened that makes the flow to turbulent. By breaking the sub layer, higher value of heat transfer from absorber plate to the flow of air. Further it has been observed that there was increase in average thermal efficiency with increase in Reynolds number.

IV CONCLUSIONS

The following conclusions are drawn from the present study:

1. As the value of Reynolds number increases from 2564 to 6206, the thermal efficiency also increases 41 % to 72% due to increase in rate of heat transfer from absorber plate to air.

2. Application of inclined rib on the underside of absorber plate of solar air heater enhances the rate of heat transfer as compared to that in conventional solar air heater

3. Comparison between conventional and roughened solar air heater shows that average thermal efficiency increases from 5 to 15% as the Reynolds number increases from 2564 to 6206.

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