Heat Transfer and Friction Factor Study for Triangular Duct Solar Air Heater Having Discrete V-Shaped Ribs

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Abstract—Solar energy is a good option among renewable energy resources due to its easy availability and abundance. The simplest and most efficient way to utilize solar energy is to convert it into thermal energy and this can be done with the help of solar collectors. The thermal performance of such collectors is poor due to less heat transfer from the collector surface to air. In this work, experimental investigations of single pass solar air heater having triangular duct and provided with roughness element on the underside of the absorber plate. V-shaped ribs are used for investigation having three different values of relative roughness pitch (p/e) ranges from 4-16 for a fixed value of angle of attack (α), relative roughness height (e/D_h) and a relative gap distance (d/x) values are 60°, 0.044 and 0.60 respectively. Result shows that considerable augmentation in heat transfer has been obtained by providing roughness.

Keywords—Artificial roughness, Solar Air heater, Triangular duct, V-Shaped Ribs.

I. INTRODUCTION

ENERGY plays a very crucial role in everyone`s life either it is the matter of economic growth or the growth of industrialization [1]. Conventional energy resources are limited and their reserves are threatened due to huge demand for energy throughout the world. There is a need of switching over to non-conventional energy resource like solar energy, wind energy, tidal energy etc. which are non-exhaustible types of energy sources and produces less or no pollution. The energy resources may also be classified as non-renewable and renewable energy resources. Among all the alternative of renewable energy resources, the sun is of domineering in nature. The solar radiation striking the earth surface is absorbed by earth and used for further energy generation. Solar energy is one of the most important alternatives for energy generation in future because the total energy received from sun is around 35000 times the total energy used by human beings [2]. The average intensity of solar radiation in India works out to be approximately 2000 kWh/m²as compared to world average of 2200 kWh/m² [3]. The major drawback with this resource is its low intensity and it is erratic in nature. The solar intensity reaching the earth is typically about 1 kW/m² however; availability varies with location and time [2]. In spite of these limitations, solar energy appears to be the most promising same among all the renewable energy resources.

To harness solar energy it is convenient to use solar collectors. These solar collectors can be categorized as water heating and air heating collectors. The heat transfer coefficient of air is less hence, the efficient of solar air heater is low. There are several methods to increase heat transfer from the heat surface. The most important effect produced by the presence of a rib on flow pattern, generation of two flow separation regions, one on each side of the rib. The vortices so generated are responsible for the turbulence and hence the enhancement in heat transfers as well as in the friction losses takes place. The possibility of further enhancing the wall heat transfer by using V-shaped ribs was based on the observation of the creation of secondary flow cell due to angling of the rib resulting in a region of higher heat transfer near the leading end. By splitting the long angled rib into a V - shape to form two leading ends and a single trailing end (apex of *V*), a much larger (about double) region of high heat transfer was produced. It was infect the formation of two secondary flows cells instead of one as in the case of transverse rib that results in higher overall heat transfer in the case of V-shaped ribs. Momin et al. [4] have investigated the effect of v-shaped ribs on heat transfer and fluid flow characteristics. In this investigation Reynolds number ranges from 2500-18000, relative roughness height ranges from 0.02 -0.034 and angle of attack ranges from 30-90° and relative roughness pitch was fixed of 10. It has been observed that both friction factor and Nusselt number increases with Reynolds number but increase of Nusselt number was less as compared to friction factor. It has been found that when angle of attack was 60°and relative roughness height of 0.034 then corresponding to this values the Nusselt number increases 1.14 times as compared to inclined ribs and 2.30 times increases when compared with smooth plates in rectangular channels. Leung et al. [5] have studied the effect of artificial roughness on heat transfer enhancement in case of triangular duct. They found the best thermal performance is achieved with an apex angle of 60° and surface roughness of 11 μm has the highest ability to enhance forced convection.

Leung et al. [6] have conducted an experimental investigation to study the heat transfer characteristic of machined surfaces. The triangular duct used in this experiment was artificially roughened by placing equally distance square ribs at orthogonal to the mean air flow. It was found out that forced convection was enhanced by the roughened surfaces. However, heat transfer enhancement was proportional to rib size. Maximum heat transfer was obtained by using smallest ribs among those tested (i.e. 6.35 mm). They also concluded that the influence of rib size on the forced convection is non-linear and they also suggested that an optimal surface roughness for maximum heat transfer performance exist if it

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exceeds 3μm. Gaurav and Varun [7] have investigated the thermo-hydraulic performance of artificially roughened equilateral triangular solar air heater duct and the comparison of the same has been presented with that of a conventional smooth solar air heater duct. The range of relative roughness height (e/D_h) is from 0.021 to 0.043, value of angle of attack (α) and relative roughness pitch (p/e) has been 30° and 8 respectively. The range of Reynolds number is from 5600 to 28000 and aspect ratio of the duct is 1.15. It has been found that the thermo hydraulic performance of artificially roughened triangular solar air heater duct is always more than that of the smooth absorber plate in the range of Reynolds number investigated.

II. EXPERIMENTAL SET-UP AND PROCEDURE

A schematic of experimental set up is shown in Fig. 1 and experimental setup has been designed and fabricated to study the effect of artificial roughness on heat transfer and friction factor. The experimental set up consists of a single pass triangular channel, plenum, electric heater, pressure measuring devices, temperature measuring devices and blower. The experimental setup consists of a triangular channel which has been designed and fabricated from wood. The dimensions of the triangular channel are 2010 mm × 180 mm × 48 mm. The entry and exit length are kept equal. Consequently, the flow can be assumed to be fully developed turbulent flow in the entire length of the test section. It is necessary for the development of fully developed turbulent flow, the entry length and exit length should be equal to or greater than 10 times the hydraulic diameter [1]. Test section is of 100 mm and 505 mm each is provided for entry and exit section of the duct.

1. Entry Section   5. Voltmeter   9. Selector Switch   13. U-Tube Manometer
2. Test Section   6. Variable Transformer 10. Milli voltmeter   14. Control Valves
3. Exit Section   7. Micro manometer   11. GI Pipe   15. Centrifugal Blower
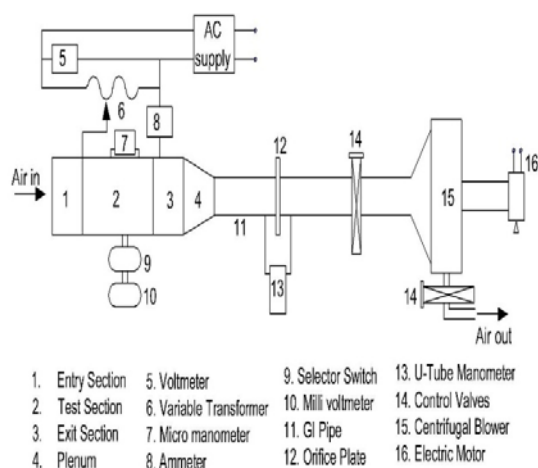4. Plenum   8. Ammeter   12. Orifice Plate   16. Electric Motor

Fig. 1 Schematic diagram of experimental set up

The atmospheric air is sucked by means of a blower having capacity of 3 HP through the inlet portion of the single pass triangular channel. The air moves to outlet of triangular channel through triangular duct. The exit section of channel is connected to a galvanised iron pipe via rectangular mixing chamber called plenum. The mass flow rate of air has been measured with the help of a calibrated orifice plate provided in the GI pipe. The pressure drop across the orifice plate has been measured with the help of a U-tube manometer. The test section is of galvanised iron which acts as an absorber plate. The roughness is created on the upper and lower part of the absorber plate with the help of ribs. A heater is used to provide the constant heat flux to absorber plate and the temperatures of the heated absorber plate and air are measured by the help of copper-constantan thermocouples and a digital milli-voltmeter. The pressure drop across the test section has been measured with the help of a micro-manometer. Two control valves are provided to control the mass flow rate of the air at the exit and entrance of the blower.

III. INSTRUMENTATION

Calibrated copper–constantan (T-type) thermo-couples were used for air and absorber plate temperature measurements. Twelve thermocouples were mounted on the top side of the absorber plate. The temperature measured by each thermocouple was then averaged to obtain the average temperature of the absorber plate. Two thermocouples each were provided at the inlet and outlet of the test section, and then the temperatures indicated by them were averaged to determine the mean temperature of the air flowing through the duct for the estimation of different properties of air. The air flow rate in the duct was measured using a concentric orifice plate with 45° bevelled edges, which was designed, fabricated and fitted in the 81 mm diameter pipe carrying air from mixing chamber to the blower. The orifice plate was calibrated against a pitot tube, and the value of the coefficient of discharge (C_d) was determined as 0.61 and it was used to measure the mass flow rate of the air. A micro-manometer having a resolution of 0.001 mm was used to measure the pressure drop across the test section. Before starting the experimentation it is necessary to check that there should be no leakage. If there is any leakage do the proper arrangement to stop that leakage. Check all the instruments properly. The experimental runs were conducted under quasi-steady state to collect the relevant data for heat transfer and friction factor.

IV. DATA REDUCTION

The raw experimental data have been reduced to obtain the average plate temperature, average air temperature, mass flow rate and Reynolds number. These data were then used to determine the heat transfer coefficient, Nusselt number and friction factor.

The mean plate temperature T_p is calculated by the average of the temperatures recorded at various locations on the absorber plate and is given as;

$$T_p = \frac{T_3 + T_4 + T_5 + T_6 + T_7 + T_8 + T_9 + T_{10} + T_{11} + T_{12} + T_{13} + T_{14}}{12}$$

The bulk mean air temperature, T_f is the arithmetic mean of the measured values of air temperature at the entry and exit to the test section,

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$$T_f = \frac{T_1 + T_2}{2}$$

Pressure drop (ΔP_d) measured across the test section length is used to find out the friction factor using Darcy-Wiesbach equation:

$$f = \frac{2(\Delta P_d)D_h}{4\rho L V^2}$$

The heat transfer coefficient and Nusselt number is calculated from the relationship given below,

$$h = \frac{Q_u}{A_p(T_P - T_f)} \quad \text{and} \quad Nu = \frac{hD_h}{k}$$

V. RESULT AND DISCUSSION

A. Effect of Reynolds Number (Re) on heat transfer

The values of Nusselt number for different orientation of roughness geometry in single pass solar air heater were computed on the basis of experimental data for different roughness and operating parameters and plotted as a function of Reynolds number.
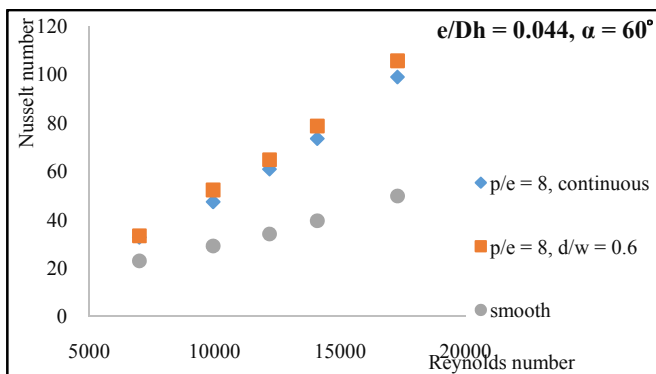

Fig. 2 Variation of Nusselt number with Reynolds number

The Nusselt number increases monotonously with an increase in Reynolds number i.e. Nusselt number varies directly with Reynolds number due to increase in swirl intensity caused by increase in turbulent kinetic energy and turbulent dissipation rate with the increase in Reynolds number. But the maximum value of the Nusselt number occur at relative roughness height value of (e/D_h) 0.043, relative roughness pitch (p/e) value of 8 and angle of attack (α) value of 60° respectively. Fig. 2 shows the variation of Nusselt number with Reynolds number for smooth plate and absorber plate having continuous and discrete ribs. Fig. 2 shows that maximum enhancement in discrete type of roughness as compared to smooth and continuous v-shaped roughness. This is due to the fact that the air flowing through the gap creates turbulence at the downstream side of the gap. The variation in Nusselt number due to gap is influenced by velocity of air through the gap and the area disturbed by this airflow downstream of the gap [8].

B. Effect of Relative Roughness Pitch (p/e) on heat transfer

Fig. 3 shows the effect of Reynolds number on Nusselt number for various relative roughness pitch (p/e) values varies from 4-16 and for a fixed value of angle of attack (α) and a fixed value of relative roughness height (e/D_h) of 60° and 0.044 respectively. The graph has been plotted to compare the Nusselt number for a single pass solar air duct having V-shape rib roughness element on the absorber plate for different values of relative roughness pitch (p/e). Fig. 3 shows that Nusselt number increases with the increase in Reynolds number for different values of relative roughness pitch (p/e). From Fig. 3 it is clear that the maximum value of Nusselt number has been found corresponding to relative roughness pitch of 8. As the value of relative roughness pitch (p/e) goes on increasing the number of reattachment points on the surface get decreased due to which less heat transfer take place as reported by [9]. So, the maximum heat transfer occurs when reattachment points are maximum on surface, hence maximum heat transfer occurs at relative roughness pitch (p/e) value of 8. The flow gets separated while being upstream of a rib but does not get reattached if the relative roughness pitch (p/e) is less than 8. Fig. 4 shows the variation of Nusselt number as a function of relative roughness pitch (p/e) for different values of Reynolds number and for fixed value of relative roughness height (e/D_h) and angle of attack (α).
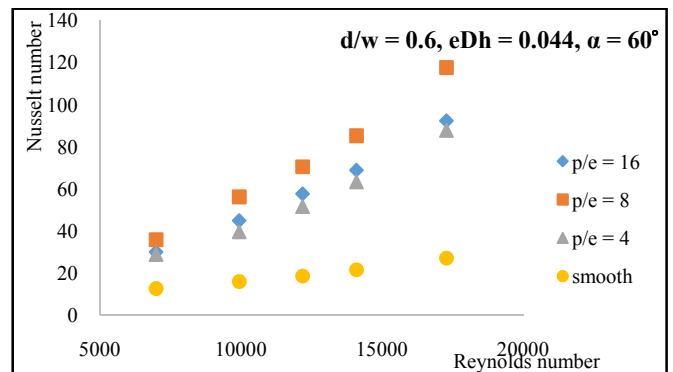

Fig. 3 Variation of the Nusselt number with the Reynolds number for different values of p/e and for fixed e/D_h = 0.044 and α = 60°

C. Effect of Reynolds Number on friction Factor

The friction factor (f) obtained from the experimentation have been plotted as a function of Reynolds number having different orientation of roughness geometry. The friction factor decreases with the increase in the Reynolds number. But the maximum value of the friction factor occurs at relative roughness height (e/D_h) of 0.044, relative roughness pitch (p/e) of 8 and angle of attack (α) of 60° respectively. Discussion of effect of various roughness parameters and operating parameter on heat transfer is given above. Fig. 4 shows the effect of Reynolds number on friction factor for smooth plate and absorber plate having continuous and discrete ribs.

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D. Effect of Relative Roughness Pitch (p/e) on Friction Factor

Fig. 5 shows the effect of relative roughness pitch (*p/e*) values varies from 4-16 on friction factor with Reynolds number for a fixed value of angle of attack (α) and relative roughness height (*e/D_h*) of 60° and 0.044 respectively. The maximum value of friction factor occurs at relative roughness pitch (*p/e*) of 8.
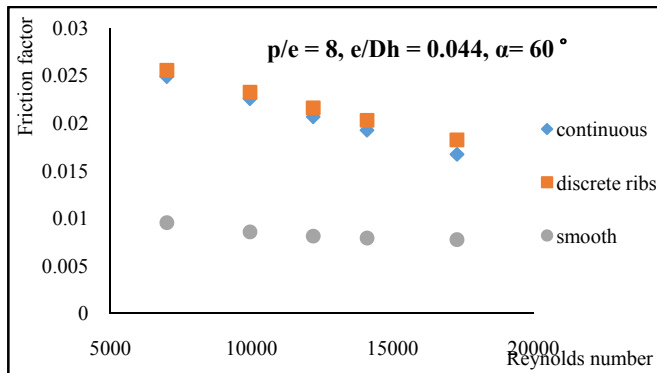

Fig. 4 Variation of Frictional factor with Reynolds number for discrete V-down ribbed duct, continuous V-down ribbed duct and smooth duct
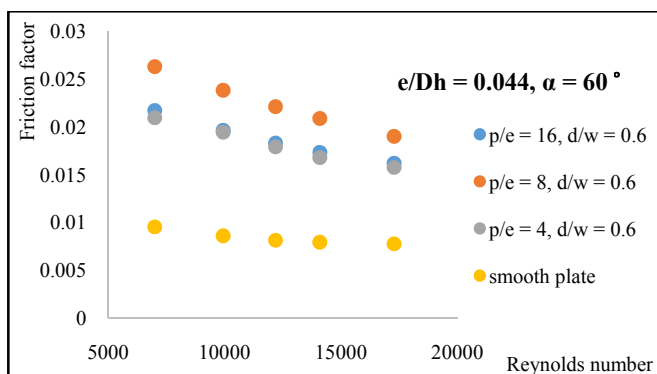

Fig. 5 Variation of friction factor with the Reynolds number for different values of p/e and for fixed e/Dh =0.044 and α =60°

V. Conclusions

In this experimental investigation heat transfer and friction characteristics of discrete v-shaped shaped in triangular duct has been studied. The heat transfer coefficient and the friction factor get enhanced by providing the artificial roughness on low side of the absorber plate in the triangular single pass solar air heater duct. The maximum heat transfer and the friction factor occur at the relative roughness pitch (*p/e*) of 8 and relative angle of attack (*α*) of 60° for the fixed value of relative roughness height (*e/D_h*) of 0.044 and relative gap position of (*d/w*) of 0.6.

References

[1] Incropera, F. and Dewitt, P.D., *Introduction to heat transfer*, 3rd edition, New York: John Wiley and sons Inc., (1996).
[2] Ministry of New and Renewable Energy (MNRE), Government of India, http://www.mnre.gov.in (accessed on Aug 2014)
[3] Goswami, D. Y., Krieth, Frank, and Kreider, Jan F., *Principles of Solar Engineering, Philadelphia*: Taylor & Francis, 2000.
[4] Momin, Saini J.S., Solanki S.C., "Heat Transfer and Friction in Solar Air Heater Duct with V Shaped Rib Roughness on Absorber Plate", International Journal of Heat and Mass Transfer, 2002, vol.45, pp.3383-3396.
[5] Leung, C.W., Chen, S., Wong, T.T. and Probert, S.D., *Forced convection and pressure drop in a horizontal triangular-sectional duct with V-grooved (i.e. orthogonal to the mean flow) inner surfaces*, Applied Energy 66 (2000), 199-211.
[6] Leung, C.W., Wong, T.T., and Kang, H.J., *Forced convection of turbulent flow in triangular ducts with different angles and surface roughness*, Heat and Mass Transfer 34 (1998), 63-68.
[7] Gaurav Bharadwaj, Varun, *Thermo hydraulic performance of an equilateral triangular duct with artificial roughness used in solar air heater*. International Journal of Mechanical and Industrial Engineering (IJMIE), 2012, Vol-2, ISSN No. 2231 –6477.
[8] Singh S., Chander S., Saini J.S., *Heat transfer and friction factor correlations of solarair heater ducts artificially roughened with discrete V-down ribs*, Energy 36 (2011), 5053-64.
[9] Verma S.K. and Prasad B.N., *Investigation for the optimal Thermo hydraulic performance of artificially roughened solar air heaters*, Renewable Energy 20 (2000) 19-36.

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