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Thermo-Hydraulic Performance Evaluation Using W-Discrete Rib in Solar Air Heater

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Abstract

Background/Objective: This paper have more emphasis towards augmentation of solar air duct thermal efficiency. Flow of heat restricted by sub-layer of laminar flow is the major criterion to reduce the thermal efficiency of solar air duct. **Methods/Statistical analysis:** For breaking laminar sub-layer artificial roughness with pattern of W-Discrete geometry has been developed. With all consideration of different previous geometries as a pattern of artificial roughness W-Discrete ribs have best thermo-hydraulic performance. During experimental investigation different parameter taken are Reynolds number of 14000-4000, duct aspect ratio of 8, angle of attack of 45^{o} and relative roughness height of 0.03375. **Findings:** Maximum increment of Nusselt number along with friction factor found in order of 2.79 and 1.98 as compare to smooth plate. Increase in heat transfer enhancement rate is obtained to be 2.35 times for W-discrete up and 2.60 times for W-discrete down rib pattern. Simultaneously with the consideration of smooth plate data results have been evaluated. **Application/Improvements:** Now a day's various solar collection and conversion systems are used like air heaters for crop drying, solar air conditioning and industrial applications. Solar collector is most important component that accounts for major portion of system cost comprising and utilization as a whole.

Keywords: Thermo-Hydraulic Interpretation, W-Discrete Rib, Solar Air Duct

1. Introduction

India has ideal condition for the utilization of sun light. Conversion of thermal energy into heat makes basis of solar air heater. It has been noticed that thermal efficiency of solar air heater corresponds to smooth duct is low that is due to lower value of coefficient of heat transfer between the flowing fluid and absorber plate. In solar air heater generation of laminar sub-layer obstruct the transfer of heat to the flowing air and it makes adverse effect on transfer of heat and thermal performance of solar air duct. The rate heat transfer can be enhanced by developing turbulence to disturb laminar sub-layer of flowing fluid over plate. The development of turbulence must be close to the laminar sub layer to evade extensive friction deprivation. Friction deprivation is possible by maintaining the roughness altitude within the permissible limit and not to exceed beyond the limit. The artificial roughness break laminar sub-layer but simultaneously friction factor is also increased. Therefore heat transfer rate and pumping power these are two major factors necessary before designing rib roughness geometry. Several investigators worked on continuous ribs that can be further modified by discretization near about the reattachment zone. Discretization help to further create turbulence to break boundary layer development.

2. Studies in Solar Air Heater

[1]Investigated on solar air duct with natural ventilation in Single Sided Ventilated Room (SSVR). [2]Studied on wire mesh solar air heater. [3]Worked on investigation on solar air duct packed bed with low porosity system has been done. [4]Studied on W-continuous pattern with repeated ribs in rectangular roughened duct assembly.[5]Studied on rib groove duct. [6]Worked analysis of light weight cryogenic tank for space vehicles and their effect on heat transfer. [7]Studied on water silver nano-fluid in a rectangular two-

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dimensional micro channel. [8]Worked on effect of solar irradiance fall on the parabolic dish applications. [9]Studied on heat transfer applications of synthesis of silver nano-fluid with the help of novel one pot method. [10]Worked on heat exchanger of copper-nickel multi tube assembly along with corrugated copper fins. [11]Studied on heat convey rate of viscous liquid with hydro-magnetic oscillatory flow along with a vertical pervious plate in a revolving medium. [12]Investigated on rectangular plate type heat pipe to find the enhanced heat transfer rate. [13]Worked on nano-fluid flowing through a straight tube with constant heat flux and their effect on convective heat convey of CuO. [14]Studied on cylinder block shape geometries to analyse heat transfer characteristic and temperature distribution. [15]Worked on (PBPD) Performance Based Plastic Design in order to find yield mechanism and target drift levels and drift due to flexural yielding of the column. [16]Worked on transverse pattern of continuous ribs and also studied performance of combination of transverse and inclined ribs. [17]Continuous inclined pattern of rib. [18]Worked on continuous cross wire pattern. [19]Perform experimental investigation on continuous chamfered ribs. [20]Studied on continuous pattern of V-ribs. [21]Worked on continuous pattern of W-ribs. [22]Investigated on multiple patterns of continuous V-ribs. [23]Worked on groove used with transverse ribs element. [24]Investigated on geometry of groove used with chamfered ribs element. [25]Worked on arc shaped rib geometry. [26]Studied on arc geometry in double form. [27]Investigate on V-discontinuous and V-discrete rib. [28]Studied on gap provision on inclined ribs pattern. [29]Investigated on V-down rib containing gap. The literature shows V-ribs discretization has not been done hence the present study has been taken up to study thermo-hydraulic performance of W-discrete roughness. Further effect of rib orientation has also been studied.

3. Experimental Set-up and Procedure Details

The fabrication of experimental set-up along with their designed has been shown in Figure 1. The experimental setup made up of inlet portion, test portion, exit portion and mixing chamber as per[30]. The experimental setup consists of a duct of length 2040 mm. The size of inlet section maintained at 177 mm, test section 1500 mm and exit section at 353 mm. The space among the baffles maintained at 87 mm. The air exhausted from the outlet of solar air heater used to be mixed by using baffle plate to maintain bulk mean temperature. The fabrication of electric heater done by using looping of heating wire in combination of parallel and series arrangement on asbestos sheet. An electric heater of dimension same as that of the size of absorber plate is used to maintain constant heat flux on entire surface of artificial roughened sheet up to 1500 W/m^2. A variable transformer has been provided for continuous power supply or it may be varied if needed.

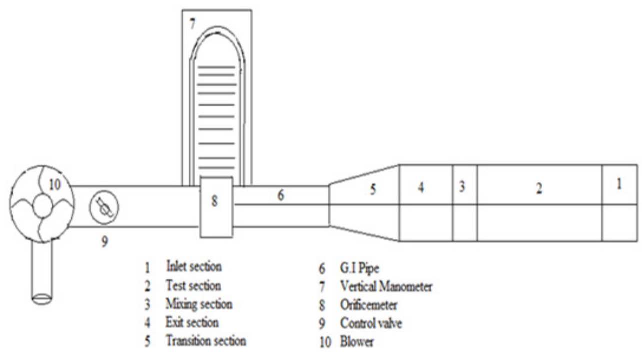

Figure 1. Experimental schematic diagram setup.

A control valve is used beside the orifice plate to change the Reynolds number according to the requirement. A vertical manometer is placed in between exit section of the duct and blower. Heat flux with uniform supply of 900 W/m^2 is provided on roughened plate. For minimizing losses of heat a glass wool is put at the back side of heater and also a piece of wood of 12 mm thick is provided at the top of heater to prevent heat leakage from top surface. AC power variac is used to control the supply of heat to the roughened plate. The top or upper surface of artificial roughened plate is painted black. The outlet of wooden duct is attached, with a trapezoidal section and a round section transition pieces to G.I pipe of 76 mm inside diameter with assembly of orifice plate. The orifice assembly has a diameter of throat of 38 mm. At the end of pipes a blower is connected. G.I pipes are used to connect blower with the help of flexible pipes. Roughened plate with W-discrete roughness geometry of angle of attack of 45^o is shown in Figure 2. At the bottom of 1 mm thickness (20 SWG) GI sheet, roughness is created with the help of copper wire and heating flux was applied on the upper side. Mass flow rate was calculated with the help of calibrated orifice meter. This orifice meter attached with vertical manometer and flowing air was controlled with the help of control valve used in line. Calibrated thermocouples were used in order to calculate inlet and outlet temperature with better precision. The specification of thermocouple is copper-constantan 0.3 mm (24 SWG) and it is implemented to measure the temperature of flowing air through the duct and also the roughened absorber plate temperature at various locations. The selected value of relative roughness pitch is 10, as per parameter shows in the literature survey.

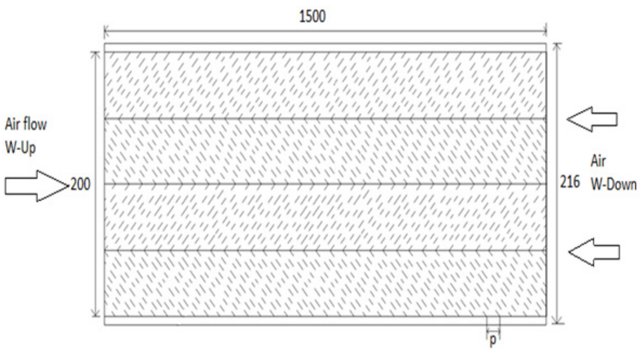

Figure 2. W-discrete ribs.

For every plate 6 reading were taken for different flow rate having Reynolds number range in between 4000 to 14500. All experimental parts and working component of the setup and various corresponding instruments have been inspected for proper working and evaluation process. Validity test as per norms has been done on smooth absorber plate. The smooth plate testing is done with similar operating and geometric condition of duct arrangement and all the result saved for the comparison analysis. For measuring the exit air temperature five thermo-couples are placed in exit section. The plate and air temperature is measured after the steady state condition is reached. Following measurements are taken

- Temperature of entrance air.
- Temperature of the exit air.
- Plate temperature.
- Pressure drop during the flow passing through the test section.
- Mass flow rate of air.

4. Result and Discussion

Validity test:
Modified Dittus Boelter and Modified Blaisius equation are the best way to compare smooth duct data to the data obtained from these equations. Modified Blausius equation used for friction factor and for the calculation of Nusselt number the modified Dittus-Boelter equation were implemented.

The comparison analysis of predicted and experimentally performed value of Nusselt number along with friction factor has been shown in Figure. 3 and Figure. 4. As compare to predicted value the average deviation of friction factor is 5.76% and also as compare to predict value the average deviation Nusselt number is 7.96 %.

The Figure 5. shows the variation of Reynolds number on Nusselt number for W-discrete up and W-discrete down rib orientation for angle of attack of 45°. Figure 6. shows variation of Reynolds number on friction factor for different rib orientation.

As seen from Figure 5. Nusselt increases with increase in Reynolds number due to progressive breaking of laminar sub-layer. Also as seen from Figure 6. friction factor decreases as with the increase of Reynolds number pressure drop in duct increases.

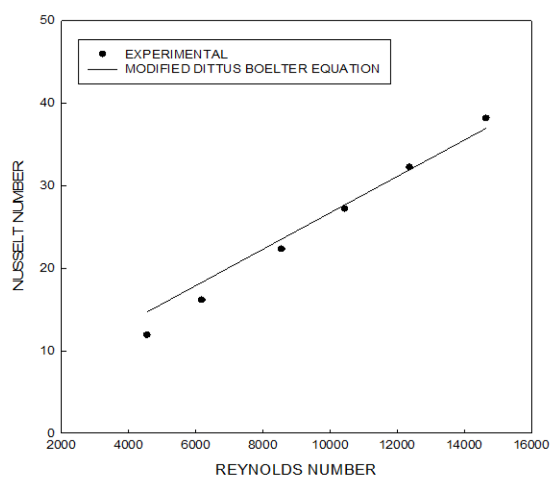

Figure 3. Comparative study between predicted and experimental data of Nusselt number corresponding to smooth duct.

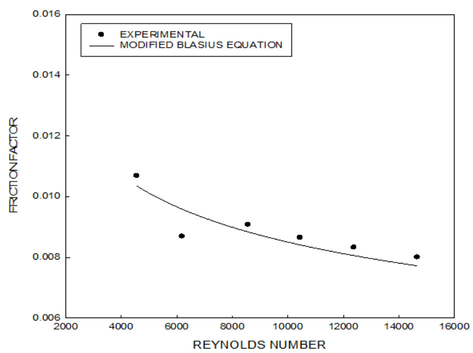

Figure 4. Comparative study between predicted and experimental data of friction factor corresponding to smooth duct.

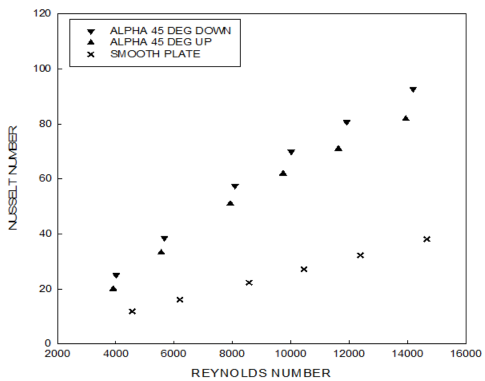

Figure 5. Variation of Reynolds number on Nusselt number with W-Discrete down and W-discrete Up ribs for angle of attack of flow of 45° and relative roughness height of 0.03375.

Maximum increase in Nusselt number is 2.36 times for W-discrete up and 2.60 times for W-discrete down as compare to smooth duct. Maximum increase in friction factor is 1.79 times for W-discrete up and 1.73 times for W-discrete down as compare to smooth duct.

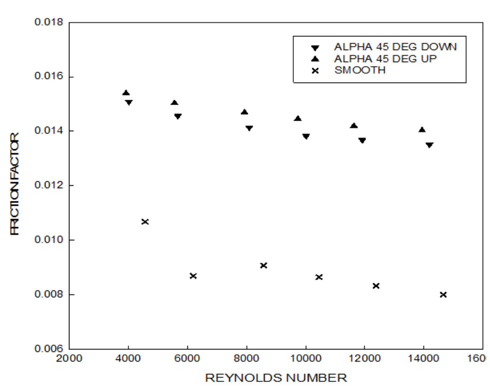

Figure 6. Variation of Reynolds number on friction factor for W-Discrete down and W-discrete Up ribs for angle of attack of flow of 45° and relative roughness height of 0.03375.

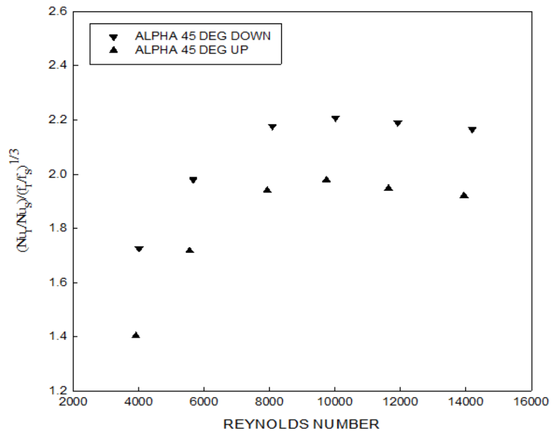

Figure 7. Variation of Reynolds number on Thermo-hydraulic performance parameter for relative roughness height of 0.00375 and for given angle of attack of flow for W-Down and W-Up discrete ribs.

5. Thermo-Hydraulic Performance

For the augmentation of heat transfer rate artificial roughness endorse important action but simultaneously friction factor also act as restricting medium for flowing fluid. For optimising performance selection of proper roughness geometry is major criterion. Duct performance depends upon the combined effect of Nusselt number along with friction factor characteristic simultaneously. [31]Given the concept of thermo-hydraulic performance parameter defined as $(Nu_r/Nu_s)/(f_r/f_s)^{1/3}$ where Nu_r and Nu_s show Nusselt number of roughened and smooth plate respectively. The Figure 7. shows thermo-hydraulic parameter along with Reynolds number with e/D_h of 0.00375 and for angle of attack of 45°. Investigation shows that W-discrete down ribs perform better inspite of W-discrete up module with consideration of thermo-hydraulic performance.

6. Conclusion

Heat transfer rate is higher in W-discrete down orientation as against W-discrete-up orientation. Also friction factor of W-discrete-up is greater than W-discrete down orientations. Thermo-hydraulic performance evaluated with consideration of heat transfer augmentation and pressure drop reimbursement. Investigation reveals that W-discrete down rib has better performance than W-discrete up orientation.

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