W-Discrete Rib for Enhancing the Thermal Performance of Solar Air Heater

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Abstract - *For the maximum efficiency of solar air heater it is necessary to enhance convective heat transfer coefficient with the help of artificial roughness in the form of repeated ribs. Experimental investigation on W-shaped ribs deals with the enhancement of Nusselt number which can be further enhanced beyond that of W-shaped ribs geometry while keeping minimum penalty of friction factor. W-discrete ribs with high-aspect-ratio rectangular duct give high performance heat transfer rate as compare to previous investigations. By using W-discrete ribs enhancement of heat transfer rate with respect to relative roughness height (e/D_h) is shown in this paper. The investigation is based on the following flow parameters that is Reynolds number (Re) from 4000 – 14500, relative roughness length (B/S) as 6, relative roughness pitch (p/e) as 10, relative roughness height (e/D) as 0.033753- 0.02250, angle of attack (α) range of 60°. The duct has aspect ratio (AR) of 8.*

Key Words: Relative roughness height, Solar air duct, Thermal efficiency

1. INTRODUCTION

A lot of active and passive techniques have been applied to enhance the thermal efficiency of solar air heater with minimum power consumption of fan and blower. For the enhancement of convective heat transfer coefficient and for minimum friction factor flow structure variation are achieved with the help of roughened wire orientation and geometry, pitch and relative roughness height. Angle of attack (α), relative roughness pitch (p/e) and relative roughness height (e/D) these are the important parameter necessary for finding the heat transfer rate. An experimental investigation is performed to know about heat transfer, thermo hydraulic performance and friction factor of W-discrete ribs in the form of artificial roughness of solar air heater. A strict procedure is followed while testing with one roughened wall heated and keeping another three insulated. Under similar flow and thermal boundary condition the heat transfer coefficient and friction factor is found and thermo hydraulic performance of duct is presented. Han et. al. [1] studied rib pattern in V-down and V-up pattern on two opposite wall. Heating condition maintained at all four wall heated and he concluded that with parameter of W/H =1 , Re= $1.5 \times 10^4 - 9 \times 10^4$, $e/D_h = 0.0625$, P/e = 10 , α = 45° & 60° V-up pattern give better performance than V-down pattern. Karwa [2] worked on transverse, incline, V-continuous, V-discrete rib in both V-up and V-down pattern on one broad wall. Roughened wall heated by taking the parameter of

W/H = 7.19-7.75, Re = 2800-1.5x10^4, e/D_h = 0.0467-0.05, p/e = 10, α = 60° & 90° and conclusion is with B/S = 3, v-down discrete ribs give the best thermo hydraulic performance. Lau et al. [3] worked on ribs in v-pattern on two opposite walls heated condition is all four wall heated with parameter i.e W/H = 1, Re = 1×10^4- 7×10^4, e/D_h = 0.0625, p/e = 10,20, α = 45°, 60° & 90° and finally get concluded that 60° v-up ribs with p/e = 10 gives the best thermal performance. Momin et al. [4] roughness were circular section wire in v-up pattern on one broad wall heated while other three insulated. Parameter taken as W/H = 10.15, Re = 2500 - 1.7x10^4, e/D_h=0.028, p/e = 7.5 - 20, α = 45° and finally concluded that p/e = 10 ribs provided the best performance. Han and Zhang et al. [5] used continuous and discrete ribs in V-up pattern on two opposite walls and all four walls heated and parameter taken as W/H = 1, Re = 1.5×10^4 – 9×10^4, e/D_h = 0.0625, p/e = 10, α = 45°, 60° & 90° and have got result of 60 ° v-up ribs with p/e = 10 gives the best thermal performance. Taslim et al. [6] worked on square section ribs glued into two opposite walls in staggered fashion (Discrete and inclined in v-pattern) and heating condition is liquid crystal thermography by using parameter like W/H = 1, Re = 5000-3× 10^4 , e/D_h = 0.083,0.125,0.167 , P/e = 10 , α= 45° & 90° and concluded 45° V-down broken ribs are better than 90° but inferior to V-shaped continuous ribs

2. EXPERIMENTAL SETUP

This setup consists of a inlet section, a test section, an exit section, a flow meter, centrifugal blower and wooden table. The size of duct is 2042 mm x 200mm x 20mm (dimension of inner cross-section) and is constructed from wooden panel of 25 mm thickness. The length of test section is 1500mm (33.75 D_h).

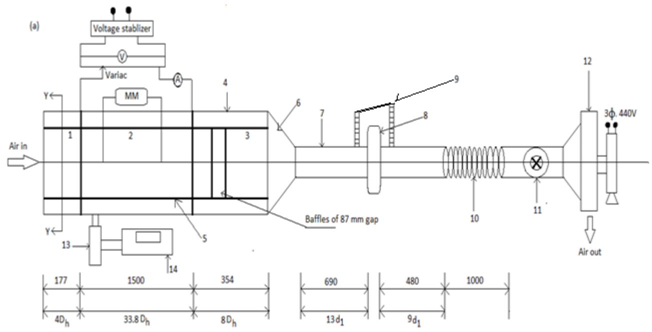

Fig. 1 Experimental Set-up

The length of entry and exit section is 192 mm (7.2 D_h) and 350 mm ($12D_h$) respectively as show in Fig. 1. For the roughened duct a short entrance length (L/D_h = 7.2) was chosen because fully develop flow is established in a short length 2-3 hydraulic diameter.5√WH and 2.5 √WH are the entry and exit length. For the turbulent flow regime, ASHRAE standard recommends. In this setup calibrated copper – constantan 0.3 mm (24 SWG) thermocouple were used to measure the heated plate temperature and the air temperature at different location.

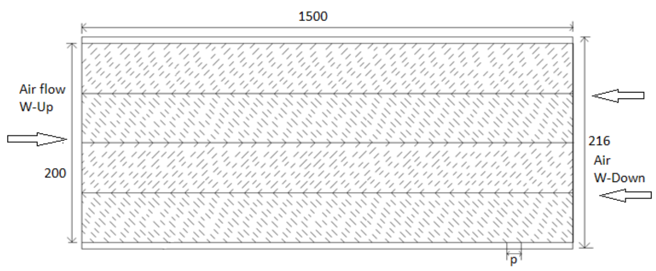

Fig. 2 W-discrete roughness plate geometry

For the reading of the thermocouples on the heated wall a digital micro voltmeter is used. Micro-manometer is used to measure the pressure drop across test section. The heated plate is a 1mm thick GI plate and below 25 mm wood with insulation. Smooth faced 8 mm thick plywood used at entry and exit section of the duct to cover it. An insulation of 25 mm thick polystyrene foam with different thermal conductivity of 0.037 is used outside of entry setup from the inlet to the orifice plate. An electric heater is used for heating purposes. The specification of this heater is 1500 x 216 mm made of parallel and series loops of heating wire. A mica sheet of 1 mm is placed between GI sheet (absorber plate) and electric heater. 0 to 1000 W /m^2 flux may be varied by a variac across it to change the heat flux. For mixing the hot air baffles are provided in the exit section with dimension of 116 mm, three equally spaced with the length of 87 mm. For calculating mass flow rate an orifice meter with vertical manometer will be used and the flow is controlled by the control valve putted across the line.The various parameters used while experimental testing of roughened plate is shown in the Table - 1.

Table -1: Roughness Parameters

S.No.	Parameter	Value
1	Relative roughness height (e/D_h)	0.03375
2	Relative roughness pitch (p/e)	10
3	Roughness height (e)	1.5mm
4	Reynolds Number (Re)	4000-14500
5	Heat Flux (I)	900 w/m^2
6	Hydraulic Diameter (D_h)	0.04444 m
7	Test Length	1500 mm
8	Channel Aspect ratio (W/H)	8
9	Angle of attack	60^o

3. DATA REDUCTION

Following equations have been used for the evaluation of relevant parameters.

$$Q = m \times c_p \times (t_o - t_i)$$

$$H = q / [A_c \times (t_p - t_f)]$$

$$Nu_r = (h \times D_h)/ h$$

$$f_r = D_h \times \Delta p / (2 \times L \times V^2 \times \rho)$$

4. RESULT AND DISCUSSION

4.1 Variation of Nusselt Number and friction factor for other values of relative Roughness height shown in Fig. 3 and Fig. 4. . It is seen here that Nusselt number increases with increase in Reynolds. As Reynolds number increases thickness of boundary layer decreases and hence convective resistance decreases which in turn increases the Nusselt number. It is also proposed that the friction factor is a strong function of Reynolds number for smooth and roughened plate surface. The value of friction factor drop proportionally as the Reynolds number increases due to the extinction of viscous sub-layer with increase in Reynolds number.

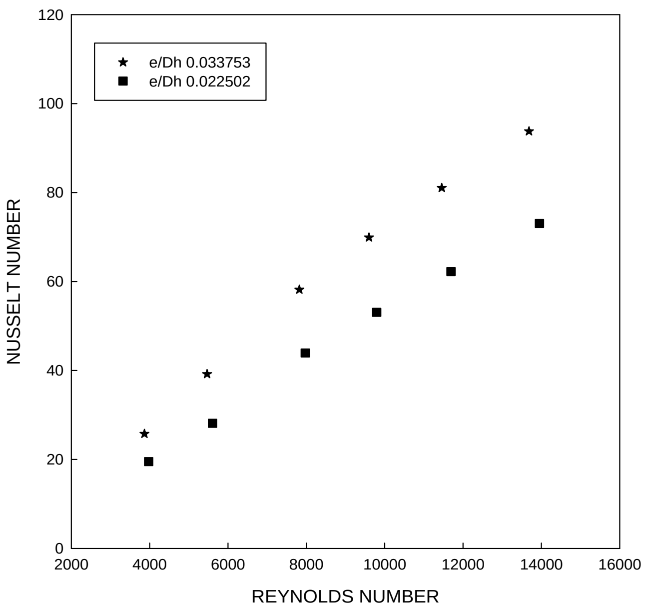

Fig. 3 Effect of Reynolds number on Nusselt number for angle of attack of flow of 60º and relative roughness height ratio of 6 for W-discrete down ribs for different relative roughness height.

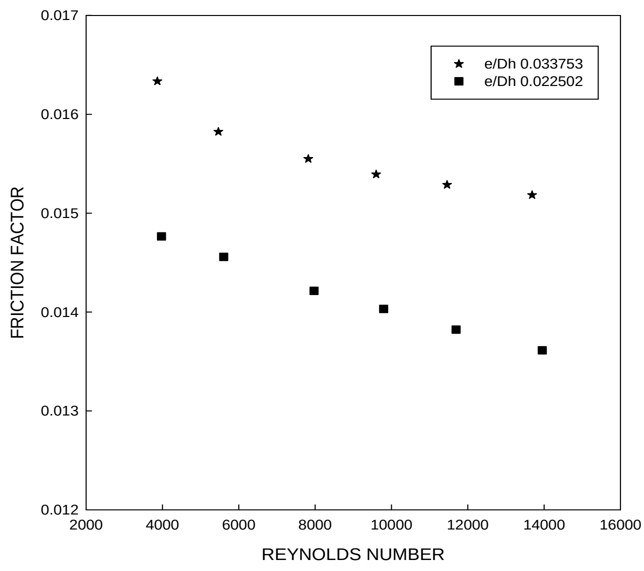

Fig. 4 Effect of Reynolds number on friction factor for angle of attack of flow of 60º and relative roughness length ratio of 6 for W-discrete down rib for different relative roughness height.

It is seen from Fig. 3 and Fig.4 that increase in relative roughness height results in an increase in heat transfer coefficient and also friction factor. Maximum enhancement of Nusselt number has been found to be...,... and...times that for smooth duct for relative roughness height of ...,... and ...respectively for angle of attack of 60º.

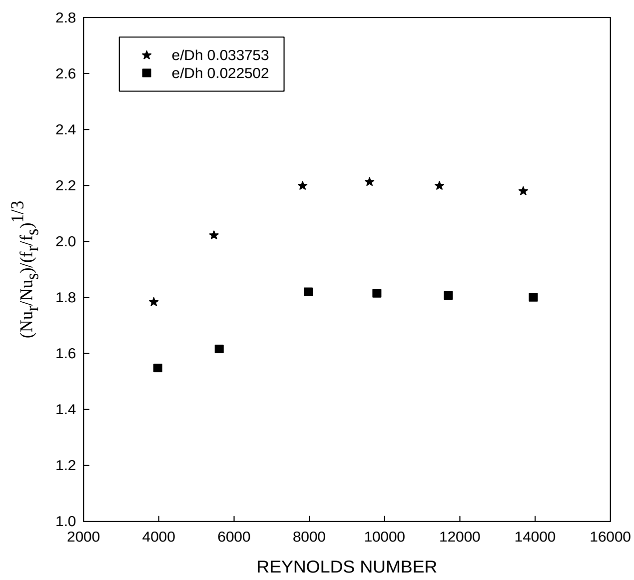

Fig. 5 Effect of Reynolds number on Thermo-hydraulic parameter for angle of attack of flow of 60º and relative roughness length ratio of 6 for W-discrete down ribs for different relative roughness height

4.3 THERMO-HYDRAULIC PERFORMANCE

Thermal performance of solar air heater improves as the flow rate is increased. Enhancement in heat transfer is accompanied with friction penalty due to corresponding increase in friction factor. At higher mass flow rate net energy gain may be less due to greater energy expenditure required to propel air through the collector. Hence it is essential to determine maximum enhancement of heat transfer with minimum friction penalty. This requirement is fulfilled by considering het transfer and friction characteristic simultaneously and defined parameters $(Nu_r / Nu_s) / (f_r/f_s)^{1/3}$ to determine thermo-hydraulic performance. Fig. 5 shows variations of thermo-hydraulic performance with Reynolds number. It is seen that thermo-hydraulic performance improves with increase in relative roughness height. Hence higher rib height is preferable for better performance.

5. CONCLUSIONS

1 As Reynolds number increases Nusselt number increase

2 As Reynolds number increase friction factor decreases.

3 As relative roughness height increases, Nusselt also number increases.

4 As relative roughness height increase, friction factor also increase.

5 As relative roughness height increase, thermo hydraulic performance also increases.

Nomenclature

A Area of cross-section, m^2

C_p Specific Heat of air at constant pressure

D_h Equivalent diameter of duct, D = 4WH /2(W+H)

α Rib angle of attack (°)

p/e Relative roughness pitch, dimensionless

p Rib pitch, m

e Rib height, m

B/S Relative gap width

f Friction factor

H Depth of duct

L Duct length, m

m Mass flow rate, kg/s

Nu Nusselt number

Re Reynolds number

e/D_h Relative roughness height

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